TRENCHLESS RENEWAL of Culverts and Storm Sewers

ASCE Manuals and Reports on Engineering Practice No. 120

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Trenchless Renewal of Culverts and Storm Sewers

Prepared by
the Pipeline Infrastructure Committee of
the Pipeline Division of
the American Society of Civil Engineers

Edited by
Lynn Osborn

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PREFACE

The Task Force for Trenchless Renewal of Culverts and Storm Sewers of the ASCE Committee on Pipeline Infrastructure (PINS) of the ASCE Pipeline Division is proud to present this Manual of Practice. The manual describes culvert and storm sewer renewal technologies used by engineers and transportation professionals in renewing culverts and drainage structures under roads, railroads, airport runways, streets, and similar structures. For the purpose of this manual, culverts and storm sewers are defined as having a diameter or equivalent diameter range of 12 in. (305 mm) to 144 in. (3,658 mm), with at least one open end. The manual covers topics such as safety, cleaning and inspection, condition assessment and evaluation, description of trenchless renewal methods, and life-cycle considerations. The PINS Committee, under the leadership of Larry Catalano, P.E., is responsible for the efforts leading to this publication. The committee thanks contributors, task force members, and blue ribbon reviewers, whose names follow, for their support, time, and effort. The efforts of Dr. Mohammad Najafi, Director of the Center for Underground Infrastructure Research and Education (CUIRE) at the University of Texas at Arlington, and Diego Calderón, a UTA–CUIRE research assistant, are greatly appreciated.

Lynn Osborn, Chair
ASCE Trenchless Renewal of Culverts
and Storm Sewers Task Committee

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CONTRIBUTORS

Lynn Osborn, Insituform Technologies, *Task Committee Chair and Editor*
Mohammad Najafi, The University of Texas at Arlington, *Task Committee Vice-Chair and Co-Editor*
Larry Catalano, City of Aurora, Colorado, *PINS Committee Chair*
Dan Carroll, City of Aurora, Colorado
Melissa Allen, St Louis Metropolitan Sewer District
Deepak Bhattachar, Insituform Technologies
Greg Baryluk, Advanced Drainage Systems Inc.
Rick Turkopp, Hobas Pipe USA
Larry Petroff, Performance Pipe
Zack Zhao, Ultraliner Inc.
Michael Yen, Sekisui SPR
Chip Johnson, Sprayroq, Inc.
Bill Shook, AP/M Permaform
Erez Allouche, Louisiana Tech University

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GRADUATE STUDENT ASSISTANT

Diego Calderón, Center for Underground Infrastructure Research and Education (CUIRE), The University of Texas at Arlington

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INTRODUCTION

Many good textbooks and manuals describe renewal techniques for sanitary sewers, and many of the described techniques are suitable for the renewal of culverts and storm sewers. However, the literature is lacking in detailed guidance for those in search of information on renewal techniques specifically for culverts and storm sewers. The purpose of this book is to provide a resource for engineers, transportation and government agencies, consultants, and others who are not familiar with or need a refresher course on culvert or storm sewer renewal.

The ASCE task committee that prepared this manual spent a lot of time discussing what the book should include. Although it is about the renewal of culverts and storm sewers, the more the task committee discussed the content, the more we realized that the book should focus on culverts and not storm sewers. Many storm sewer systems consist of pipes, manholes, and structures with pipe sizes in the 8–96-in. (203.2–2,438.4-mm) range. Renewal of storm sewer systems in these pipe ranges is similar to sanitary sewer renewal. Several manuals, textbooks, and publications currently available discuss these renewal techniques. A listing of these related documents can be found at the end of this chapter. Therefore, the task committee agreed that this book need not cover this territory again. In general, this manual covers culverts crossing under transportation systems, such as roads, highways, airports, railroads, and canals.

However, there are some gray areas. For example, what about a culvert passing under a school or playground? Renewal of this culvert would be the same as if this culvert passed under a highway if there is at least one open end for that culvert. As a result of lengthy discussions, the task committee decided to limit the scope of this book as described in the following section.

1.1 SCOPE OF THE MANUAL

The task committee developed a mission statement: "The purpose of this manual of practice is to address trenchless renewal of culverts and storm sewers with a diameter or equivalent diameter range between 12 in. (305 mm) and 144 in. (3,658 mm). The culverts and storm sewers must have at least one open end with any renewal proceeding from the open end to the first structure from the open end."

This scope allows the inclusion of storm sewers that have one open entrance or open discharge. Any renewal processes described are applicable from the open end to the first structure. From the first structure on, the storm sewer system becomes an enclosed system, and renewal processes for enclosed systems are defined in other publications, such as Najafi (2005).

Some of the renewal processes described in this book have technical envelopes that go outside of this scope. For example, some spray-on techniques have no practical upper size limit. For some processes, it does not matter whether the culvert or storm sewer is open-ended. For all products and processes, technical envelopes and capabilities are covered in detail in Chapter 5 on renewal methods.

The most common types of culvert materials are concrete, plastic, and metal. Concrete culverts are available in almost any size, including the size range specified in the scope of this book, and many shapes. Typical shapes are round, rectangular, arch, and elliptical. Plastic culverts are round and are generally manufactured from high-density polyethylene (HDPE) or polyvinyl chloride (PVC) and are available in either smooth or profile wall designs. Metal culverts are also available in many sizes and shapes, including round, box, arch, and elliptical. Although the most common type is corrugated steel (metal) pipe, corrugated aluminum pipe can also be used.

Practically any material available for pipes or conduits has been used for culvert construction. However, for a broad range of applications and for a large number of culverts, concrete, plastic, and steel continue to be the most widely used and cost-effective. Culverts consist of an entrance, a barrel, and an outlet. For noncircular shapes, size is described by culvert rise and span. For circular culverts, size is expressed as culvert diameter. Figure 1-1 illustrates components of a culvert.

The major subjects discussed in this book are the following:

safety,
cleaning and inspection,
evaluation and condition assessment,
renewal methods,

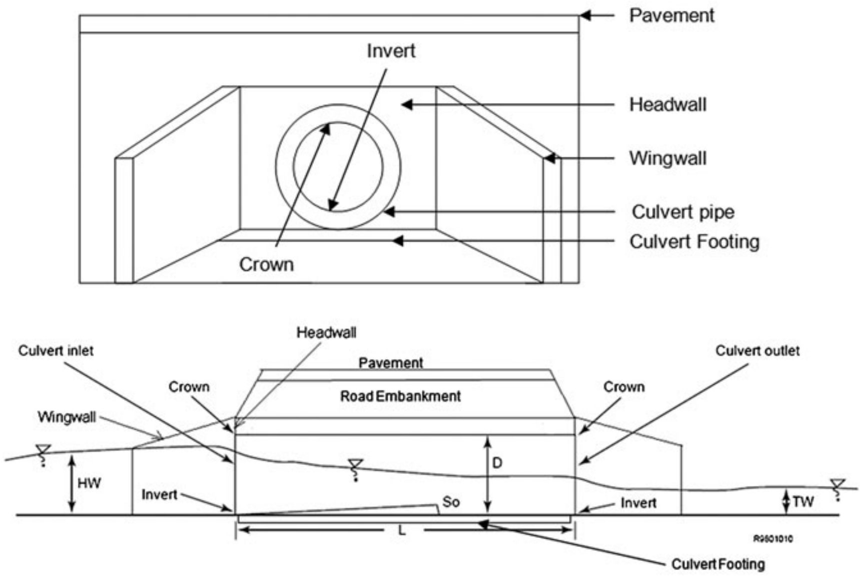

Figure 1-1. Culvert Components. HW: headwater elevation; TW: tailwater elevation; L: barrel length; So: slope of culvert; D: diameter of culvert barrel.

quality assurance and quality control, and
life-cycle considerations.

Many of these subjects are described in general, followed by supporting references, where the reader can find more detailed information. For example, this book does not include a detailed defect classification and scoring system to determine culvert renewal priorities. However, culvert evaluation and assessment are described, and references are provided where more detailed information can be found. Chapter 5 presents renewal methods; it is where the most important information and the most detailed discussions can be found.

1.2 RELATED DOCUMENTS[1]

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[1] These important documents provide supplementary information to this manual. They are not necessarily cited in the text.

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1.3 GLOSSARY AND DEFINITIONS

Annular grout: Material for grouting the annular space between the existing pipeline and the new lining pipe.

Annulus: Free space between the existing pipe and the lining pipe.

Bentonite: Colloidal clay sold under various trade names that forms a slick slurry or gel when water is added; also known as driller's mud.

Carrier pipe: See Product pipe.

Channel: A prepared flow route within the bench of a culvert that conveys the incoming flow to the downstream pipe.

CIPP: Cured-in-place pipe; a renewal technique whereby a flexible resin-impregnated tube is installed into an existing pipe and then cured to a hard finish, usually assuming the shape of the existing pipe.

Close-fit: Description of a lining system in which the new pipe makes close contact with the existing defective pipe at nominal or minimum diameter. An annulus may occur in sections where the diameter of the defective pipe is in excess of nominal or minimum diameter.

Continuous pipe: A single contiguous pipe lining or joined sections to form a continuous lining.

Conventional trenching: See Open-cut method.

Corrosion: The destruction of a material or its properties because of a reaction with its surroundings.

Cracks: Fracture lines visible around the circumference, along the length of a pipe, or both.

Crown: Top of the pipe in the cross section.

Cured-in-place pipe: See CIPP.

Dimension ratio: A pipe's outside diameter divided by its wall thickness.

Driller's mud: See Bentonite.

Efflorescence: "The formation of the whitish powder or crust on the surface of encrusting bodies, as salts, etc." (Webster's 1998).

Exit pit: See Reception pit.

Fold and form lining: Method of culvert renewal in which a liner is folded to reduce its cross section before insertion and reverts to its original shape by the application of pressure, heat, or both.

Grout: (1) Material, usually cement- or polymer-based, used to fill the annulus between the existing pipe and the lining; also used to fill voids outside the existing culvert. (2) A material, such as cement slurry, sand, or pea gravel, that is placed into voids.

Grouting: See Grout.

High-density polyethylene (HDPE): See Polyethylene.

Joints: The means of connecting sectional lengths of a pipeline system into a continuous line using various types of jointing materials. The number of joints depends on the pipe section lengths used in the specific culvert or storm sewer.

No-dig: See Trenchless technology.

Open-cut method: The conventional method by which access is gained to the required level underground for the installation, repair, or replacement of a pipe, conduit, or cable by excavation. The excavation is then backfilled and the surface is restored.

pH: A measure of the acidity or alkalinity of a solution. A value of seven is neutral; lower numbers indicate more acidity; higher numbers, more alkalinity.

Polyester resin: The most common form of thermosetting resin used in cured-in-place pipe (CIPP) technology. Polyester resin is formed by the reaction of organic acids and alcohols. The resulting resin is then dissolved in an active monomer, such as styrene.

Polyethylene (PE): A ductile, durable, virtually inert thermoplastic composed of polymers of ethylene. It is normally a translucent, tough solid.

In pipe-grade resins, ethylene–hexene copolymers are usually specified with carbon black pigment for weatherability.

Product pipe: Utility pipe for conveyance for water, gas, sewage, and other products. Also called carrier pipe; permanent pipeline for operational use.

Receiving pit: See Reception pit.

Reception pit: Excavation into which trenchless technology equipment is driven and recovered after the installation of the casing, product pipe, conduit, or cable. Also known as Exit pit.

Rehabilitation: See Renewal.

Renewal: All aspects of upgrading with a new design life for the performance of existing pipeline systems. Includes rehabilitation, and renovation.

Renovation: See Renewal.

Replacement: Removing an existing pipe and installing a new pipe of same or larger diameter in its place.

Resin: An organic polymer, solid or liquid; usually thermoplastic or thermosetting.

Resin impregnation (wet-out): A process used in the cured-in-place pipe installation process where a plastic-coated fabric tube is uniformly saturated with a liquid thermosetting resin while air is removed from the coated tube by means of vacuum or pressure.

Sewer: An underground pipe or conduit for transporting stormwater, wastewater, or both.

Sliplining: (1) General term used to describe methods of lining with continuous or discrete pipes. (2) Insertion of a new pipe by pulling or pushing it into the existing pipe and grouting the annular space. The pipe used may be continuous or a string of discrete pipes. The latter is also referred to as segmental sliplining.

Spalling: A chip, fragment, or flake from a piece of culvert material. (*American Heritage Dictionary of the English Language* 2006).

Spiral lining: A technique in which a ribbed plastic strip is spirally wound by a winding machine to form a liner, which is inserted into a defective culvert. The annular space may be grouted or the spiral liner may be expanded to reduce the annulus and form a close-fit liner. In larger diameters, the strips are sometimes formed into panels and installed by hand. Grouting the annular space after installation is recommended.

Spoil: Earth, rock, and other materials displaced by a tunnel, pipe, or casing and removed as the tunnel, pipe, or casing is installed.

Thermoplastic: A polymer material, such as polyethylene, that repeatedly softens when heated and hardens and re-forms when cooled. Thermoplastics are generally easier to recycle than their thermoset counterparts.

Thermoset: A polymer material, such as a polyester resin pipe, that does not melt when reheated. Thermoset polymers can be formed initially into almost any desired shape, but they cannot be reformed at a later time.

Trenching: See Open-cut method.

Trenchless technology: Also called No-dig; the variety of techniques for underground pipeline and utility construction and replacement, rehabilitation, renovation, collectively called renewal, repair, inspection, and leak detection, with a minimum of excavation at the ground surface.

Upsizing: Any method, such as pipe replacement or pipe bursting, that increases the cross-sectional area of an existing pipeline by replacing it with a larger-diameter pipe (ASCE 2007).

Voids: (1) Holes external to the pipe in the surrounding soil or material. (2) A term generally applied to paints to describe holidays, holes, and skips in the film. (3) Shrinkage in castings or welds.

1.4 ACRONYMS

ACI	American Concrete Institute
ACPA	American Concrete Pipe Association
ASA	American Shotcrete Association
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
CCTV	Closed-Circuit Television
CIPP	Cured-in-Place Pipe
CLSM–CDF	Controlled Low-Strength Material–Controlled Density Fill
CMP	Corrugated Metal Pipe
CUIRE	Center for Underground Infrastructure Research and Education
DVD	Digital Versatile (or Video) Disc
FHWA	Federal Highway Administration
FRTR	Fiberglass Reinforced Thermosetting Resin
GIPP	Grout-in-Place Pipe
HDD	Horizontal Directional Drilling
HDPE	High-Density Polyethylene
I.D.	Inside Diameter
ICRI	International Concrete Repair Institute
LCCA	Life-Cycle Cost Analysis
MSDS	Material Safety Data Sheet
MUTCD	Manual on Uniform Traffic Control Devices
NACE	National Association of Corrosion Engineers

NASSCO	National Association of Sewer Service Companies
NCHRP	National Cooperative Highway Research Program
NIOSH	National Institute for Occupational Safety and Health
NSF	National Science Foundation
O.D.	Outside Diameter
ODOT	Ohio Department of Transportation
OSHA	Occupational Safety and Health Administration
PACP	Pipeline Assessment Certification Program
PE	Polyethylene
PINS	Pipeline Infrastructure Committee
PPI	Plastic Pipe Institute
PVC	Polyvinyl Chloride
SSPC	Society for Protective Coatings
UV	Ultraviolet
VHF	Very High Frequency
VOCs	Volatile Organic Compounds
WRC	Water Research Center

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2

SAFETY CONSIDERATIONS

2.1 INTRODUCTION

Worker safety is of prime importance when inspecting, repairing, replacing, and renewing culverts and storm sewers. Culvert and storm sewer inspections and improvements must always be conducted with due consideration for the safety of the inspectors, workers, and the public. Najafi and Salem (2008) thoroughly discuss culvert and storm sewer inspection techniques. Access and entry to these potentially dangerous environments requires strict compliance to all applicable local, state, and federal standards. Successfully performing inspection and work without injury or death is the primary concern of all parties providing services in a hazardous environment.

Workers must be cognizant of the hazards that are present around and within culverts and storm sewers, as well as the methods and equipment necessary to work safely within such environments. Traffic control always must be considered where culvert work impedes traffic, results in distractions to the motorists, or subjects workers to traffic hazards. A detailed safety plan must be in place before the workers enter any culvert or storm sewer.

The following sections illustrate and discuss the main hazards associated with the inspection and renewal activities for culverts and storm sewers. In particular, those activities related to manholes and other confined spaces should be incorporated into any safety program.

2.2 POTENTIAL HAZARDS

The many hazards to which workers can be exposed while performing operations in culverts and storm sewers include

- confined spaces,
- traffic,
- equipment and materials,
- atmospheric conditions,
- entrapment or engulfment,
- falling objects,
- mechanical and electrical hazards,
- ladders and scaffolding,
- lighting and noise,
- animals and pests,
- trenching and excavation,
- restricted communication,
- flash flooding, and
- restricted visibility.

2.3 PROJECT SAFETY ASSESSMENT

Each of the hazards that may be encountered by workers should be identified before entering the culvert or storm sewer and evaluated to prepare and implement control measures and monitoring procedures.

2.3.1 Confined Spaces

Occupational Safety and Health Administration (OSHA) regulations direct how certain activities must be performed to ensure the safety of the workers. OSHA (1999) concerns work within confined spaces, and this term has been interpreted to include the interior of culverts and storm sewers.

A confined space is defined as one that is large enough for a person to enter and perform assigned work, yet has limited or restricted means of entry or exit and is not intended for continuous occupancy. Before entering a confined space, the air within the space must be tested in a prescribed manner with approved equipment to determine its safety for entry and work. Various states have more distinctly defined confined space regulations. Before entering any culvert, the state's applicable OSHA rules, in addition to any other local regulations, must be checked for compliance. This is not only a legal concern but, more importantly, it affects the inspectors' safety. Although federal and state regulations exist to ensure that safety is observed in all operations, many practical safety considerations exist and must be followed as well. For more information, refer to the OSHA Web site for permit requirements for confined spaces, available at http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9797.

2.3.2 Traffic

Traffic can present the most immediate and frequent danger to workers, whether opening one manhole lid for a quick inspection or performing major renewal work. Worksites must be evaluated and secured with necessary signage, safety cones, barricades, or other traffic control mechanisms, including visible protective clothing to ensure worker protection from traffic hazards. Most governmental agencies and departments of transportation require traffic plan preparation for inspection and construction activities within rights-of-way or locations that affect the flow of traffic. Most agencies reference the current edition of the *Manual on Uniform Traffic Control Devices*. Chapter 6 of that manual, entitled "Temporary Traffic Control," details the normal requirements essential for safely completing renewal activities in traffic areas and is available at http://mutcd.fhwa.dot.gov/pdfs/2003r1r2/ch6a_e.pdf.

2.3.3 Equipment and Materials

Workers should be educated and trained to properly use and handle all equipment and materials anticipated for use during inspection or a renewal project. In addition to general safety hazards of manhole cover opening and confined space entry and work within the culvert or storm sewer, workers must understand any hazards associated with the use of tools and equipment within the manholes or pipes. Materials and equipment should be evaluated for flammability, oxygen displacement, potential spill, contamination, and other hazards. Safety equipment must be inspected for wear and calibrated for use on a regular basis as recommended by the manufacturer and in accordance with local, state, and federal regulations. A safety communication plan must be established to alert personnel to potential material and tool hazards, and what to do if a hazardous situation occurs. An appropriate safety plan must identify restrictions for safe use of equipment and materials within culverts and storm sewers.

In the United States, OSHA requires that Material Safety Data Sheets (MSDSs) be available to employees for substances in the workplace specifically if the substances are potentially harmful. Also, most fire and emergency planning officials require that MSDSs be maintained on sites where the substances are stored and used. MSDSs include information such as toxicity, health effects, first aid, reactivity, storage, disposal, protective equipment, and spill handling procedures. Each worker should review the MSDSs for all substances present on the worksite.

2.3.4 Personal Protection

Protective clothing, hard hats, gloves, boots, and eye protection are usually required to protect workers from injury and must be provided to all workers, and their use must be enforced. Personal hygiene practices must be followed. Prohibition of smoking, drinking, and other potentially hazardous practices must be instituted as necessary and applicable.

2.3.5 Physical Hazards

Workers should be instructed in the identification of potential physical hazards related to their work tasks and equipped with procedures and control measures to reduce or eliminate the potential for injury.

2.3.6 Trenching and Shoring

Pit excavations, trenching and shoring may be involved in the renewal of culverts and storm sewers. OSHA regulates workplace activities involving trenching and shoring because excavating is recognized as one the most hazardous construction operations. Chapter 2 of OSHA's *Technical Manual*, titled "Excavations," (OSHA 2002) defines hazard recognition in trenching and describes requirements for shoring; it is available at http://www.osha.gov/. This manual contains an overview of all excavation safety issues.

OSHA has also prepared a booklet on excavations to provide an overview of the excavation and trenching standards, safety issues, safety planning, protective systems, and OSHA's services and assistance programs. OSHA (2002) is available at http://www.osha.gov/Publications/osha2226.pdf.

For more information regarding safety requirements, please refer to the following Web sites:

Construction Safety Council home page: http://www.buildsafe.org/
Electronic Library of Construction Occupational Safety and Health (eLCOSH): http://www.cdc.gov/elcosh/
Federal Highway Administration Manual on Uniform Traffic Control Devices: http://mutcd.fhwa.dot.gov/pdfs/2003r1r2/ch6a_e.pdf
National Institute for Occupational Safety and Health (NIOSH) site on construction safety: http://www.cdc.gov/niosh/topics/constructionsafety/
National Work Zone Safety Information Clearinghouse: http://www.workzonesafety.org/
OSHA home page: http://www.osha.gov/

3

CLEANING AND INSPECTION

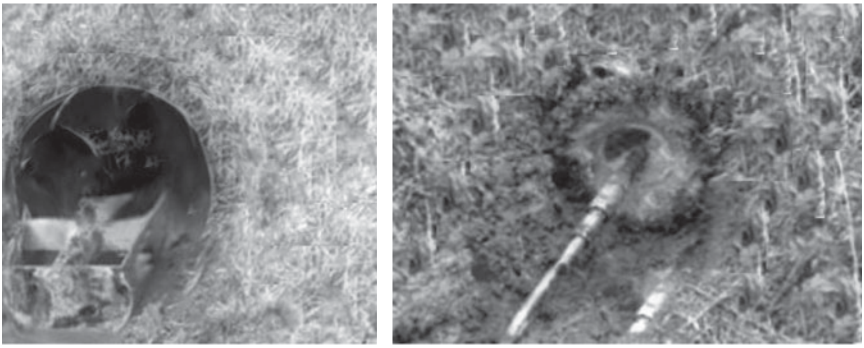
3.1 CLEANING

Routine cleaning and maintenance is imperative to prolong the service life of a culvert. Culverts or storm sewers that become clogged with sedimentation and debris (Fig. 3-1) or develop defects that allow infiltration deteriorate faster and exhibit adverse performance in the form of drainage backups, sinkholes, and damage to paved surfaces or other structures, including road embankments. To remove obstructions such as solids, silt buildup, roots, rocks, trash, debris, and mineral deposits, cleaning equipment often must be used.

Different renewal methods require different degrees of cleaning and surface preparation. For renewal methods that do not require bonding to the existing culvert wall, high-pressure water jetting, which can be combined with vacuum equipment or flushing with water, can often clean the culvert or storm sewer. This process can also be used in combination with other methods, such as rodding or the use of bucket machines. Large pipes are often cleaned manually with hand tools and high-pressure water with wheelbarrows or front-end loaders to remove debris. For renewal methods that require bonding to the existing culvert wall, these same techniques can be used for rough debris removal. However, more aggressive surface preparation techniques may be required to achieve a bond between the renewal material and the interior of the pipe wall. For further cleaning requirements, refer to the individual product descriptions in Chapter 5.

For culverts or storm sewers that are particularly difficult to clean or completely full of debris, a horizontal directional drilling (HDD) machine can be used to loosen and remove debris. In this method, controlled pullback and thrust speeds are used in combination with different attachments, such as a cutter tool, which is designed to loosen and remove

Figure 3-1. Example of Obstruction in a Culvert.



(a) (b)

Figure 3-2. (a) Pull Bucket and (b) Brush.

heavy material in the culvert. Other attachments used with HDD machines are push buckets or pull buckets (Fig. 3-2a). To fine-clean the culvert, a brush attachment can be used (Fig. 3-2b).

Removing heavy siltation and debris may necessitate excavating the adjacent upstream and downstream channels to the original flow line. This excavation results in more spoils to manage. There also must be means of collecting removed debris and then properly disposing of the collected material. Governmental regulations need to be considered when disposing of the solids and, specifically, contaminated materials.

3.2 INSPECTION

Inspections are performed to verify the condition of the culverts or storm sewers and to make decisions on the necessary maintenance, repair, renewal, or replacement works. The Ohio Department of Transportation's *Culvert Management Manual* (ODOT 2003) identifies five types of culvert and storm sewer inspections, namely, inventory inspection, routine inspection, damage inspection, interim inspection, and storm sewer inspection.

1. *Inventory inspection* is the first inspection of the culvert once it has been constructed. Inventory inspection is also applied whenever there has been a change in the configuration of the structure.
2. *Routine inspection* is performed according to a regular schedule. The main objectives of a routine inspection include identifying the physical and functional condition of the culvert and identifying future problems that may occur.
3. *Damage inspections* are performed on an unscheduled basis because of damaging floods or storms. The objectives of this type of inspection include assessing necessary repair work and identifying the necessity of load restrictions or traffic closures.
4. *Interim inspections* are performed at the discretion of the individual or department responsible for culvert inspections, according to the agency's inspection protocols. It can be performed by any qualified person who has knowledge about culverts.
5. *Storm sewer inspections* are the application of inventory and routine inspections to storm sewers.

The frequency of inspections is listed in the ODOT *Culvert Management Manual* (2003), and in Table 3-1.

Various culvert inspection techniques have been developed over the past decade. Depending on the size of the culvert, it may be possible for the inspector to enter and perform the inspection, but in this case the inspection data may not be well documented and may be subjective, and record keeping may be arbitrary. Moreover, this situation may pose safety risks for the inspector. The following techniques and equipment can be used whenever the size of the culvert or storm sewer does not allow the inspector to enter the pipe or when it is not safe to perform worker-entry inspections. For a complete review of pipeline cleaning and inspection techniques, refer to Najafi (2005).

3.2.1 Closed-Circuit Television Inspections

Closed-circuit television (CCTV) inspection is the most widely used inspection technique for sewer and storm drainage inspection. CCTV

Table 3-1. Frequency of Culvert Inspections

Description	Frequency of Inspection	Type of Inspection
Diameter or span equal to or more than 12 in. (305 mm) and equal to or less than 120 in. (3,048 mm)	Every 5 years	Routine
Storm sewers, diameter equal to or greater than 36 in. (914 mm)	Every 5 years	Routine, storm sewer
Culverts and storm sewers with known defects	Determined by culvert inspection reviewer or bridge engineer	Damage, interim

inspection uses a television camera together with a video or digital monitor, videocassette or DVD recorder, and other recording devices. CCTV inspection uses a camera mounted on a robot or tractor that enters a culvert or storm sewer system. The camera generally looks forward as the robot system moves along the culvert longitudinal axis. This setup allows the operator to examine and evaluate the entire length. Some CCTV systems have pan, tilt, and zoom camera attachments to the tractor, which can find defects hidden behind connections and other obstructions. Sonar or ultrasound systems are often attached to the robots, which can examine the portions of the culvert below the waterline. The faults and defects identified through CCTV inspections include longitudinal and circumferential cracks, collapsed sections, displaced bricks, broken pipes, defective and displaced joints, evidence of abrasion or corrosion, siltation, encrustation, root penetration, loss of mortar, deformation, and infiltration.

3.2.2 Laser-Based Scanning Systems

Laser-based scanning systems can be used to evaluate both the shapes and the types of defects the culvert or storm sewer contains. These systems are restricted to the part of the pipe above the waterline, but they can make accurate inspections of sewer conditions. An additional advantage of this technique is that the information from the laser scans is readily recorded and analyzed by computer, substantially reducing operator errors. This method is more effective than CCTV because finer defects can

Figure 3-3. A Laser-Based Scanning System.

be detected and the errors of operator fatigue, which can lead to lack of accuracy in a CCTV assessment, are reduced (Fig. 3-3).

3.2.3 Sonar–Ultrasonic Inspections

Ultrasonic inspection is performed using a beam of very high frequency (VHF) coherent sound energy. The frequency is many orders of magnitude higher than a human being can hear. This method is best where the flow depth is greater than 75 percent of the diameter. Sound waves travel into the object being inspected and reflect. The technique can detect pits, voids, and crack orientations that are more difficult to detect than with other methods. The ultrasonic wave reflects most easily when it crosses an interface between two materials that are perpendicular to the wave. The ultrasonic beams work well to examine the sewer pipe below the waterline and therefore complement CCTV systems, which are confined to examining pipe surfaces above the waterline.

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4

EVALUATION AND CONDITION ASSESSMENT

4.1 INTRODUCTION

To determine whether a culvert or storm sewer needs to be renewed, an inspection needs to be conducted and the findings recorded. The first step in such a program is to establish a standard set of guidelines for evaluation and assessment of existing pipe. The following sections describe sample guidelines. Furthermore, inspectors need to be trained in the use of these guidelines and how to identify defects within an existing culvert or storm sewer system. Lastly, a regular program of evaluation and assessment needs to be established to make the process of making the renewal decision a success. Regular inspection is consistent with the goals and objectives of asset management programs that are being developed by various agencies to manage and optimize the use of assets. The frequency of inspections can vary based on site conditions specific to the pipe, its size, components, and location, as well as other factors, such as environmental and hydraulic parameters. Additional information on inspection frequency and culvert asset management can be found in Najafi and Salem (2008), as well as other references listed in the references of this manual.

4.2 PERFORMANCE MEASURES

A uniform and consistent set of performance measures should be used to evaluate pipe through a process of rating parameters that are collected in the field. For the pipe, these ratings are focused on barrel performance, which can be quantified by assigning a numeric rating on a scale of 0 to

9. A rating of 9 implies an essentially new pipe, whereas a rating of 0 indicates a complete failure, with the roadway closed. The rating tables are extensions of those initially developed by the Federal Highway Administration (FHWA 1986) in its *Culvert Inspection Manual* and later developed for the Utah Department of Transportation for assessment. These tables can be found in the report titled *Management of Utah Highway Culverts* (Beaver and McGrath 2005).

For the purpose of this publication, the barrel ratings are provided as guidance and are not intended to be considered standards. These maintenance ratings can fall into three broad groups that also use a scale of 0 to 9, with no action required for 6–9; need to inform supervisor with repair or maintenance required within one year for 3–5; and immediate action required and road closure should be considered for 0–2.

Observing surface conditions immediately above the culvert may provide an indication of culvert performance problems that may not be otherwise detectable. For example, inspection of a pipe under dry conditions may not indicate joint leakage, but roadway settlement or cracking over this same culvert provides a strong indicator that leakage and infiltration of fines is occurring.

4.3 BARREL PERFORMANCE

The culvert pipe, also called the barrel, is the main structural element of a culvert. It provides support for the roadway or ground surface above, while providing a path for storm water to safely pass. In the following sections, performance measures are presented and discussed separately for each pipe material.

4.3.1 Metal

Metal culverts are flexible, which means that their performance is often evaluated by monitoring deflection. Corrosion and abrasion are the main issues for durability of these materials. Table 4-1 presents rating guidelines and performance measures for typical corrugated metal culverts. The ratings were consolidated from tables in FHWA (1986) for corrugated metal material and round or vertical elongated corrugated metal pipe barrels. The FHWA manual provides tables for other corrugated metal shapes with numeric ratings for various deflection limitations. Inspectors should note levels of corrosion and abrasion. Protective coatings should be examined for abrasion damage, tearing, cracking, and removal. The inspector should document the extent and location of surface deterioration problems. When heavy corrosion is found, inspectors should perform pH testing and electrical resistivity measurements, both pH and

Table 4-1. Rating Guidelines for Round and Vertical Elongated Corrugated Metal Pipe Barrels

Rating	Shape[a]	Seams and Joints	Metal
9	New[b]	Tight; no openings	Near original condition
8	Good; smooth curvature in barrel; horizontal diameter within 10% of design	Tight; no openings	Superficial rust; no pitting
7	Generally good; top half of pipe smooth but minor flattening of bottom; horizontal diameter within 10% of design	Minor cracking at a few boltholes; minor joint or seam openings; potential for backfill infiltration	Moderate rust; slight pitting
6	Fair; top half has smooth curvature, but bottom half has flattened significantly; horizontal diameter within 10% of design	Minor cracking at bolts is prevalent in one seam in lower half of pipe; evidence of backfill infiltration through seams or joints	Fairly heavy rust; moderate pitting; slight thinning
5	Generally fair; significant distortion at isolated locations in top half and extreme flattening of invert; horizontal diameter 10–15% greater than design	Moderate cracking at boltholes along one seam near bottom of pipe; deflection of pipe caused by backfill	Extensive heavy rust; deep pitting; moderate thinning
4	Marginal significant distortion throughout length of pipe; lower third may be kinked; horizontal diameter 10–15% greater than design	Moderate cracking at boltholes on one seam near top of pipe; deflection caused by loss of backfill through open joints	Pronounced thinning with some deflection; penetration when struck with pick hammer

Table 4-1. *Continued*

Rating	Shape[a]	Seams and Joints	Metal
3	Poor shape; extreme deflection at isolated locations; flattening of crown, crown radius 20–30 ft (6.1–9.1 m); horizontal diameter in excess of 15% greater than design	3-in. (76-mm) long crack at boltholes on one seam	Extensive heavy rust; deep pitting; scattered perforations
2	Critical; extreme distortion and deflection throughout pipe; flattening of crown, crown radius more than 30 ft (9.1 m); horizontal diameter more than 20% greater than design	Plate cracked from bolt to bolt on one seam	Extensive perforation caused by rust
1	Partially collapsed; crown in reverse curve	Failed; closed to traffic	Invert completely deteriorated
0	Closed to traffic	Totally failed	Partial or complete collapse

[a] See FHWA 1986 for other barrel shapes.
[b] New culvert may be deflected. If so, quantify deflection.
Source: FHWA 1986.

resistivity of surrounding soils, and pH of the incoming storm water. Inspectors should also consider obtaining core samples from the pipe wall.

4.3.2 Plastic

Plastic pipes are flexible culverts and should be inspected for many of the same features as metal pipe with regard to monitoring deflection. Plastic pipes are often made up of relatively thin elements, which make them susceptible to local buckling. Additionally, properties of plastics are time-dependent, and cracking can occur over time. Suggested performance measures are provided in Table 4-2.

Table 4-2. Rating Guidelines for Plastic Pipe Barrels

Rating	Shape and Alignment	Joints
9	New[a] or like-new condition; pipe is clean, straight, and deflected 5% or less	New; tight with no defects apparent
8	Good, smooth curvature in barrel; no settlement or misalignment; vertical diameter within 5% of original i.d.; no buckling of pipe surface	Tight with no defects apparent
7	Generally good; minor misalignment at joints; no settlement; generally smooth curvature with minor flat spots or bulges; vertical diameter between 5% and 7.5% of original i.d.; no buckling of pipe surface	Minor openings; possible infiltration or exfiltration of water with no soil particles
6	Fair; minor misalignment and settlement at isolated locations; generalized flat spots or isolated areas of buckling in the liner; vertical diameter between 7.5% and 10% of original i.d.	Minor backfill infiltration caused by slight opening at joints
5	Generally fair; minor misalignment or settlement throughout pipe; possible piping; significant distortion at isolated locations and extreme flattening of invert; generalized liner buckling; vertical diameter between 10% and 12.5% of original i.d.	Open and allowing backfill to infiltrate; possible gasket displacement
4	Marginal; significant settlement and misalignment of pipe; evidence of piping; end section or headwall dislocated; significant distortion throughout length of pipe; corrugations may show some buckling; some circumferential cracking that does not allow soil entry; vertical diameter between 12.5% and 15% of original i.d.	Differential movement and separation of joints; significant infiltration or exfiltration at joints; deflection caused by loss of backfill through open joints

Table 4-2. *Continued*

Rating	Shape and Alignment	Joints
3	Poor; significant ponding of water caused by sagging or vertical misalignment; poor shape with extreme deflection at isolated locations; general areas of flattening; circumferential cracking that does not allow soil entry; flattened crown; vertical diameter between 15% and 17.5% of original i.d.	Significant openings; dislocated joints in several locations, exposing fill materials; infiltration or exfiltration, causing misalignment and deflection of pipe and roadway settlement
2	Critical; reverse curvature; excessive piping and loss of alignment; vertical diameter differs from original i.d. by more than 17.5%; minor roadway subsidence	Closed to traffic
1	Partial collapse; holes in road surface	Totally failed; closed to traffic
0	Pipe collapsed; road closed to traffic	Totally failed; closed to traffic

[a] New culvert may be deflected. Quantify deflection.

4.3.3 Concrete

Concrete culverts are classified as rigid because they are not designed to deform appreciably under load. Thus, deflection cannot be casually measured with sufficient accuracy to assist engineers in assessing the structural state of the pipe. Suggested performance parameters are presented in Table 4-3. Inspections should note cracking, alignment, joints, and walls of the structure. General signs of wall distress, such as differential movement, efflorescence, spalling, or rust stains, should be noted.

Table 4-3. Rating Guidelines for Concrete Pipe Barrels

Rating	Alignment	Joints	Concrete
9	New condition		
8	Good; no settlement or misalignment	Tight; no defects apparent	No cracking, spalling, or scaling present; surface in good condition
7	Generally good; minor misalignment at joints; no settlement	Minor openings; possible infiltration or exfiltration	Minor hairline cracking at isolated locations; slight spalling or scaling present on invert or crown
6	Fair; minor misalignment and settlement at isolated locations	Minor backfill infiltration caused by slight opening at joints; minor cracking or spalling at joints, allowing exfiltration	Extensive hairline cracks, some with minor delaminations or spalling; invert scaling less than 0.25 in. (6.4 mm) deep; small spalls present
5	Generally fair; minor misalignment or settlement throughout pipe; possible piping	Open and allowing backfill to infiltrate; significant cracking; significant joint spalling	Cracks open more than 0.12 in. (3.0 mm); moderate delamination and spalling, exposing reinforcement at isolated locations; large areas of invert with surface scaling or spalls greater than 0.25 in. (6.4 mm) deep
4	Marginal; significant settlement and misalignment of pipe; evidence of piping; section dislocated; about to drop off	Differential movement and separation of joints; significant infiltration or exfiltration at joints	Cracks open more than 0.12 in. (3.0 mm) with efflorescence and spalling at numerous locations; spalls have exposed reinforcement bars, which are heavily corroded; extensive surface scaling on invert greater than 0.5 in. (12.7 mm)

Table 4-3. *Continued*

Rating	Alignment	Joints	Concrete
3	Poor; significant ponding of water caused by sagging or misalignment of pipes; end section dropoff has occurred	Significant openings, dislocated joints in several locations, exposing fill materials; infiltration or exfiltration, causing misalignment of pipe and settlement or depressions in roadway	Extensive cracking, spalling, and minor radial shear failure; invert scaling has exposed reinforcing steel
2	Critical; culvert not functioning because of alignment problems throughout	Closed to traffic	Severe radial shear failure has occurred in culvert wall; invert concrete completely deteriorated in isolated locations
1	Partial collapse	Closed to traffic	Partially collapsed
0	Total failure of culvert and fill	Closed to traffic	Total failure

4.4 ADDITIONAL REFERENCES

As mentioned previously, FHWA (1986) provides additional information on culvert pipe inspection and assessment procedures. NCHRP (2002) provides a synopsis of the state of the practice of culvert pipe assessment. State departments of transportation that are listed in that report as having guidelines to assess culvert pipe conditions include California, Connecticut, Maine, Maryland, Minnesota, New York, North Carolina, Pennsylvania, Utah, and Vermont. The specific programs for these individual states can also be referenced and used for evaluation and assessment information.

The Pipeline Assessment Certification Program (PACP) of the National Association of Sewer Service Companies (NASSCO) is widely gaining acceptance as the standard sewer inspection and assessment software in North America. PACP was originally developed with the intent of inspecting sanitary sewers, combined sewers, culverts, and storm sewers. However, as more information has been gained on inspecting culverts and storm sewers, it is clear that changes to PACP are required. Future modifications to PACP will be made as more culvert inspections are scheduled and completed.

4.5 LIFE-CYCLE COST CONSIDERATIONS

4.5.1 Introduction

The objective of this section is to summarize the concepts of life-cycle costs related to culverts and storm sewers. This section should serve as a handy tool for any engineer, department of transportation, or inspector in determining the overall costs and making the decision on choosing the culvert or storm sewer renewal material. As the concept of infrastructure asset management was introduced in 1999, importance was given to durability and economic studies, rather than just design studies. Lower installation or construction costs are not always the best approach in determining the most economical culvert system. To determine the most economical product, one can use the asset management approach, which is explained in this chapter. Also, American Society for Testing and Materials (ASTM) international standards procedures and formulas in calculating the life-cycle cost of the culverts are discussed with an example for ease of understanding.

4.5.2 Culvert Asset Management

As defined by FHWA (1986), culvert asset management is the science of tracking, operating, managing, and updating culverts cost-effectively. It combines engineering principles with economic theories and sound business practices to facilitate a logical approach to decision making. It is used to develop short- and long-term planning. The culvert asset management concepts as related to culvert life-cycle cost considerations are the following:

- Take design factors (e.g., structural, hydrological, and environmental) into account when selecting culvert materials.
- Regularly track and inspect the culverts to access their condition from time to time and avoid sudden failure, which would contribute to additional social costs.

- Store the inspection results, along with the design data, for future reference.
- Do not use first cost as the only criterion in culvert selection.
- Always have an alternate material or system that best integrates engineering, economic, and political considerations.

The chosen culvert material shall be based on

- construction and maintenance costs,
- risk of failure or property damage,
- current and future population demand,
- environmental or esthetic considerations,
- land use and zoning requirements, and
- traffic safety.

4.5.3 Life-Cycle Cost Analysis

The lowest initial or construction cost does not always yield the most economical system. The various factors affecting cost-effectiveness must be examined, and the principles of economics must be used throughout the culvert life-cycle cost analysis (LCCA). Some of these factors are

- project design life,
- material service life,
- initial cost,
- interest rates,
- inflation rates,
- maintenance cost,
- rehabilitation cost,
- replacement cost, and
- salvage value.

4.5.3.1 Project Design Life. All culvert and storm sewer construction or renewal projects have a project design life, which is simply the number of years the project is expected to serve its intended function. NCHRP (1978) recommends that up to 50 years of relatively maintenance-free performance should be required for culverts on secondary road facilities and up to 100 years for primary and interstate highways and all storm and sanitary sewers.

4.5.3.2 Material Service Life. Material service life is defined as the number of years of service a material system or structure provides before rehabilitation or replacement is required. U.S. Army Corps of Engineers (1998) summarized their findings on the correlation between culvert material and service life. They stated that designers should use a minimum of 100 years in designing any culvert for LCCA. Most of their findings indicated that the service lives of concrete pipes are between 70 and 100 years. Corrugated metal pipes (CMP) usually fail because of corrosion and abrasion and, because of this, may not have a service life of 50 years. Aluminum pipes may fail because of soil-side corrosion, so designers should not expect the service life cycle of aluminum culverts to be more than 50 years. Because the performance history of plastic pipes is limited, designers should not use the service life of plastic culverts as more than 50 years unless supporting evidence is available.

4.5.3.3 Initial Cost. Initial cost is the original cost incurred in planning, designing, and constructing a project, including the direct cost of materials and labor, mobilization, excavation, backfill, dewatering, surface restoration, traffic control, bypass, and general administrative and project management costs.

4.5.3.4 Inflation and Interest Rates. The difference between interest and inflation rates for projects involving state or local funding should be determined using the municipal bond rate average. Projects involving federal funding should be determined by the U.S. Treasury bill rate average, and those involving private funding should be determined by the prime lending rate. From historical data, it is understood that the interest rate over a period of time is always greater than the inflation rate by 1% or 2%. Therefore, the inflation/interest factor (F) is always less than 1.

4.5.3.5 Maintenance, Renewal, and Replacement Cost. These are the future costs involved in repair, renewal, or total replacement of the culvert or storm sewer because of failure or lack of performance. The inflation/interest factor to the "nth" power is used as a multiplier to adjust future maintenance, renewal, and replacement costs and discount them back to the present constant dollar value. The n term is the number of years at which the costs are incurred.

4.5.3.6 Salvage Value. If a culvert material or structure has a service life greater than the project design life, it has a future salvage current dollar value, which should be discounted back to a present constant dollar value using the inflation/interest factor (F) and subtracted from the original cost.

4.5.3.7 Life-Cycle Cost Analysis—Methodology. ASTM C1131 (2007) adopts a five-step procedure generally described as follows:

- **Step 1**: Identify objectives, alternatives, and other constraints.
- **Step 2**: Establish basic criteria like project design life, material or system service life, initial cost, maintenance cost, rehabilitation or replacement costs, and salvage value.

- **Step 3**: Gather data.
- **Step 4**: Compute life-cycle analysis for each culvert material or system.
- **Step 5**: Evaluate results.

4.5.3.8 Life-Cycle Analysis Computation. ASTM C1131 (2007) contains a formula to compute the life cycle of buried pipelines. The formula, also reprinted in ACPA (2007), is as follows:

$$\text{LCA} = C - S + (M + N + R)$$

where LCA = life-cycle cost,
C = initial cost,
S = salvage value,
M = maintenance cost,
N = renewal cost, and
R = replacement cost.

Using straight-line depreciation, the salvage value (S) is defined as

$$S = C(F)^{n_p}\left(\frac{n_S}{n}\right)$$

where S = salvage value,
C = present constant dollar value,
F = inflation/interest factor = $(1 + I)/(1 + i)$,
I = inflation rate,
i = nominal discount rate,
n_p = project design life,
n_s = number of years service life exceeds design life, and
n = service life.

The present value of maintenance costs can be determined by applying the inflation/interest factor to each cost occurrence and summing all values.

$$M = C_m\left[\frac{1\text{-}(F)^{n_p}}{\frac{1}{F} - 1}\right]$$

where M = maintenance cost,
C_m = annual maintenance cost,
F = inflation/interest factor, and
n_p = project design life.

Renewal costs can be calculated using the formula

$$N = C_N F^n$$

where N = renewal cost,
C_N = constant dollar cost for renewal project,
F = inflation/interest factor, and
n = service life.

A similar calculation can be made for replacement costs if the service life is less than the project design life,

$$R = C_R F^n$$

where R = replacement cost,
C_R = constant dollar cost for replacement,
F = inflation/interest factor, and
n = service life.

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5

RENEWAL METHODS

5.1 INTRODUCTION

This chapter presents an overview of different methods that can be used for culvert and storm sewer renewal. For each method, product main characteristics, method description, construction requirements and quality assurance and quality control, and post-installation asset management requirements are described.

5.2 CURED-IN-PLACE-PIPE

5.2.1 Introduction and Background

Cured-in-place-pipe (CIPP) was the first truly trenchless full pipeline renewal process. Invented in 1970, the first commercial project was completed in the United Kingdom in 1971, and it was introduced into the United States in 1976. As of 2009, it is estimated that more than 35,000 miles (56,325 km) of CIPP have been installed worldwide.

5.2.2 Product Main Characteristics

There are many different kinds of CIPP products and processes. However, CIPP generally involves manufacturing a fabric tube of the length and diameter of the host pipeline. The wall thickness of the fabric tube is designed depending on the installation process, applied loads, and physical properties of the finished CIPP laminate. The fabric tube is saturated with a liquid thermosetting resin, inserted into the host pipeline,

Figure 5-1. CIPP Finished Product.

and inflated with air or water pressure. The resin is then cured by one of several methods (hot water, hot air, steam, UV light, or at ambient temperature), resulting in a new, tight-fitting plastic pipe within the host pipe. Once the ends are trimmed and any side connections are opened, the renewed host pipeline is returned to service. Figure 5-1 illustrates culvert renewal with CIPP.

Although CIPP is used for storm sewers, water lines, and industrial and other process piping, historically it has principally been used for sanitary sewer renewal. CIPP is routinely used for manhole-to-manhole installations in sanitary sewers. Whereas excavation is typically not required for small to medium-size sanitary sewers, larger sewers (48 in. or 1,219 mm equivalent diameter or larger) may require removal of a portion of the manhole or excavating a pit or shaft. Using CIPP for sanitary sewer renewal is well described in the literature (Najafi 2005), and that information is not repeated in this discussion.

A large majority of CIPP installed as of 2008 has used the hydraulic pressure of water to install the CIPP tube and heated water to cure heat-initiated resin. During the hot water cure cycle, small amounts of organic chemicals, such as styrene, can leach into the cure water. This hot water cure process is quite acceptable in sanitary sewers because the waste process water, once cooled, can safely be discharged to the sanitary sewer system. However, this waste process water, in many cases, should not be discharged to the environment. For a discussion of the use of styrenated resins with CIPP, see NASSCO (2008).

If water is used to install and cure CIPP for culverts or storm sewers, the waste process water often must either be pumped to an adjacent sanitary sewer system or hauled to a suitable disposal site. Depending on the

Table 5-1. Technical Envelope of CIPP for Culverts and Storm Sewers

Issue	English	International
Equivalent diameter	12–108 in.	305–2,743 mm
Installed length		
Small diameter	(12–18 in.) 1,000 ft	(305–457 mm) 305 m
Medium diameter	(21–36 in.) 2,000 ft	(533–914 mm) 610 m
Large diameter	(42–108 in.) site-dependent	(1,067–2,743 mm) site-dependent
Wall thickness	2-in. maximum	51-mm maximum
Effluent temperature	Up to 140 °F	Up to 60 °C
Manning *n*	0.010[a]	
Design life	50–100 years	
Structural solution	Yes	
Negotiate bends	Yes (case-by-case basis)	
Host pipe material	Any	
Host pipe shape	Most common shapes	
Resin	Polyester	

[a] For relatively smooth host pipe. See Table 5-6 for mature sewer design values.

project location and logistics, this process can be cost-prohibitive. Many rural culverts are long distances from water sources and suitable cure water disposal sites. As a result, water must be hauled to the jobsite, used during the installation, and then collected and hauled away from the jobsite to a suitable disposal location. These additional costs can render a project not cost-effective. Therefore, CIPP installations and cure methods that do not use large amounts of water are better suited for the renewal of many culverts and storm sewers. Table 5-1 lists the current CIPP technical envelope for culverts and storm sewers.

A culvert with an inverted crown may not be a good candidate for CIPP renewal. Metal culverts with heavily corroded or missing bottom portions are common. In these cases, any sharp edges should be trimmed and bottom voids filled and smoothed before installing the CIPP. The technical envelope in Table 5-1 is for general guidance only. Because of variable site conditions, specific decisions can be made only on a case-by-case basis.

5.2.3 Method Description

Three types of installation processes are discussed below. Each type uses pressurized air to install the CIPP tube, and steam, hot air, UV light, or simply ambient temperature to cure the resin once the CIPP tube is in place. A large number of CIPP products, processes, and installers are available in the North American market, and each is slightly different, with varying technical envelopes. However, CIPP products and processes are currently available for storm sewers and culverts up to an equivalent diameter of 108 in. (2,743 mm). Of course, CIPP is available for sewers smaller than 12-in. (305-mm) diameter, but that size range is outside the scope of this manual. The standard CIPP installation method of water inversion and water cure can also be used for culverts and storm sewers. However, discharge or disposal of the cure water must be properly handled by the installing contractor.

5.2.3.1 Invert with Air. Once the host pipeline has been cleaned and prepared, the CIPP tube is saturated with liquid thermosetting resin, a polyester resin for culverts and storm sewers. This process is commonly called the wet-out process and typically occurs in a factory setting, but it can also take place at the jobsite if the wet-out tube is too large or heavy to transport. Once the wet-out tube is on the jobsite, the installation process can begin (Fig. 5-2).

Although there are many different combinations of CIPP tube types and installation equipment available, in almost all cases the beginning of the CIPP tube is turned inside out and attached to some type of inversion device. Air pressure is added to a sealed chamber, causing more of the CIPP tube to turn inside out or to invert. As the inversion process progresses, the inverting face of the CIPP moves through the host pipeline. When the tube is half inverted or halfway into the host pipeline, the last of the wet-out tube moves into the inversion device. Depending on the type of installation being performed, at this time a rope may be attached

Figure 5-2. CIPP Inverted with Air.

to the end of the CIPP tube. In addition, hoses may also be attached to deliver air and steam throughout the CIPP tube once it is fully inverted.

As the inversion continues, tension is maintained on the previously attached rope, often called a hold-back rope, to control inversion rate, and the inverting face continues to move to the termination point. This rope and any previously attached hoses eventually travel through the entire length of the host pipeline.

With the inversion process, resin-saturated felt is pressed out against the host pipe. Because of this phenomenon, care must be taken to prevent liquid resin from flowing into the receiving stream or downstream storm sewer.

Most air-inverted CIPP tubes are cured with steam. In this case, steam is either discharged into the attached hoses or directly into the CIPP tube. Once the CIPP has been heated and cured, it is cooled with air. Once cool, the ends are trimmed, any side connections are reinstated, and the culvert or storm sewer is placed back into service.

Wall thickness design and installation of CIPP using the inversion process is described in ASTM F1216 (2009). Wall thickness for each project can be tailored to the existing design parameters and condition of the existing culvert or storm sewer.

5.2.3.2 Pull-In and Invert-Through Method. Two CIPP tubes are required for this method. Once the host pipeline has been cleaned and prepared, the CIPP tubes are saturated with liquid thermosetting polyester resin or wet-out. This method typically occurs in a plant setting, not on the project site. Typically, the bulk of the finished wall thickness, and thus, resin is placed in the tube that is pulled in (Tube A). The inverted tube (Tube B) may include a thin layer of fabric to be wet-out or it can simply be a bladder material with no fabric, requiring no wet-out.

First, Tube A is pulled into place. Tube B is then inverted with air through Tube A. Inversion of Tube B is as described in Section 5.2.3.1. This process inflates Tube A and holds it in place tight against the host pipeline. Steam is then introduced to cure the resin. If Tube B included a fabric material that was wet-out, Tube A and Tube B cure together, forming one laminate. If Tube B is simply a bladder material with no wet-out fabric, it is typically extracted and discarded. With this method, the resin is contained between an outer and inner membrane or coating during the cure process, thus minimizing the chance that any liquid resin will escape into the environment.

For example, consider using this method for an 84-in. (2,134-mm) culvert. Assuming a wall thickness design of 1.41 in. (36 mm), a typical scenario would be a 1.30-in. (33-mm) thick Tube A and 0.12-in. (3-mm) thick Tube B, both trucked to the jobsite. The 1.30-in. (33-mm) Tube A is first pulled into the culvert, the 0.12-in. (3-mm) Tube B is then inverted

Figure 5-3. Pull-In and Invert Through Method.

through Tube A, and then the two tubes are cured together, achieving the desired thickness (Fig. 5-3).

This method is advantageous for locations that are difficult to access. Tube A can be lowered in with a crane and pulled in with a cable and winch. Air-inverting the 0.12-in. (3-mm) thick Tube B is much easier and does not require the large set-up area when compared to inverting a 1.42-in. (36-mm) tube.

Once cured and cooled, the ends are trimmed, any side connections are reinstated, and the storm sewer or culvert is placed back into service.

Wall thickness design and installation of CIPP using the pull-in and invert-through process is described in ASTM F1743 (2008).

5.2.3.3 Pull-In and Inflate. Once the host pipe has been cleaned and prepared, the resin-saturated CIPP tube is pulled into the host pipe. Once the pull-in process is completed, the CIPP tube is inflated with air. For this process to work, the CIPP tube must have a coating or bladder on the inside that allows the tube to be inflated. The CIPP tube must also have a coating on the outside to allow the tube to be impregnated with resin and also to protect the saturated tube during the pull-in process. Because the resin is contained between outer and inner membranes or coatings during the installation process, the chance that any liquid resin will escape into the environment is minimized.

Once the CIPP tube is pulled in and inflated with air, it can be cured with UV light, steam, or hot air. Once cooled, the ends are trimmed, any side connections are reinstated, and the culvert or storm sewer is placed back into service. Wall thickness design and installation of CIPP using the pull-in and inflate process is described in ASTM F1743 (2008).

5.2.4 Construction Requirements and Quality Assurance and Quality Control

The contractor installing the CIPP should take quality assurance measures during the installation process to ensure that quality controls listed in the contract documents are met. This process is more easily accomplished if the contractor has a permanent quality program in place.

The testing requirements to determine if the installed CIPP meets the performance requirements of the contract documents are typically listed in the technical specifications. Also, the basic testing requirements outlined in ASTM F1216 (2009), ASTM F1743 (2008), and ASTM D5813 (2008) are applicable to storm sewers and culverts. These requirements include the following:

- **Workmanship:** This requirement includes a visual inspection for dry spots, lifts, delaminations, and other defects. This inspection is by closed-circuit television for small pipes or a walk-through on larger culverts or storm sewers.
- **Flexural properties:** Flexural strength and flexural modulus, in accordance with ASTM D790 (2007), are determined from a CIPP sample collected at the jobsite. These values should meet or exceed the values specified.
- **Wall thickness:** The in-place wall thickness should meet or exceed the specified minimum wall thickness, including any tolerances.
- **Chemical resistance:** Although chemical resistance properties are not as important in a culvert or storm sewer as compared to a sanitary sewer, the materials installed should meet the requirements of the chemical resistance test described in ASTM F1216 (2009).
- **Tensile strength:** Tensile strength testing is not required for CIPP used to renew storm sewers, culverts, or sanitary sewers. Tensile testing is required only for pressure CIPP.

Conformance to performance-based requirements is a true indication of the installed CIPP's ability to perform satisfactorily over the expected design life of the project. Strict means and methods specifications can be restrictive and exclusive because there are several types of CIPP installation methods and numerous CIPP installers in the marketplace. Inspector training for CIPP is now available through NASSCO (for more information, visit http://nassco.org) and may also be available through educational institutions.

5.2.5 Asset Management Requirements

5.2.5.1 Inspection Requirements. Although CIPP has a minimum 50-year design life, it is recommended that the CIPP be inspected periodically in accordance with the owner's asset management plan to ensure that there is no excessive accumulation of debris or possible damage from floods.

5.2.5.2 Maintenance Requirements. If cleaning is required, small pipes can typically be cleaned with a high-pressure jet. Larger pipes may require worker-entry methods or mechanical equipment. As with any plastic pipe, care should be taken not to damage the CIPP during the cleaning operation. In case of required repairs, an experienced CIPP contractor should be contacted.

5.3 APPLIED SHOTCRETE

5.3.1 Introduction and Background

Shotcrete is the application of concrete or mortar conveyed through a hose and pneumatically projected at high velocity onto a surface. Shotcrete refers to the wet process, whereas the dry mix process is called gunite. With gunite, the dry mix is pumped through a hose to the nozzle, where the bulk of the water is added. Shotcrete and gunite applications can provide structural strength and, in some cases, improved corrosion resistance with certain mix designs. Najafi (2005) contains a more full discussion.

5.3.2 Product Main Characteristics

Because pressure-applied concrete requires an operator at the point of application, it can be used in storm sewers and culverts 42 in. (1,067 mm) and larger. As long as the surface can be accessed, there is no practical upper limit in size. The concrete can be troweled after application to produce a smooth surface.

Depending on the thickness and the quantity and type of reinforcement used, shotcrete can be designed as a structural solution. Any connecting piping is easily handled by tapering or feathering the spray at the junction. Because the product is sprayed on, any cross section, as well as variations in cross section, can be readily accommodated. Shotcrete is often a low-cost solution and can have increased corrosion resistance compared to standard concrete. However, installation is relatively slow and requires safe conditions for worker entry. Depending on the applied thickness, there can be a significant pipeline cross section reduction. Product quality depends on operator skill and surface preparation. Although more corrosion-resistant mixes can be used, corrosion can be an issue with low-pH effluents.

5.3.3 Method Description

Generally, steel mesh or bars are used for reinforcing. Reinforcement is typically attached to the existing pipe wall with anchors before applying the concrete. Reinforcing increases structural strength and creates a new reinforced concrete pipe within the existing pipe. To ensure full penetration and encapsulation of the reinforcement, the design of the concrete mix is important.

In a typical project, the culvert or storm sewer is cleaned to remove debris, encrustation, and protrusions. Any significant sources of infiltration should be plugged to prevent material washout. Pipeline flows can be routed through the renewal area in hoses, or precast concrete slabs can be used to divert flow under the work surface. The surface of the existing structure should be cleaned to maximize adhesion. Once the reinforcement is installed, concrete is discharged through a hand-held nozzle and sprayed onto the existing pipe wall. Depending on the surface finish desired, the newly sprayed concrete can be troweled. Once the concrete has set and any rebound material and construction materials and equipment have been cleared, the pipe is returned to service.

5.3.4 Construction Requirements and Quality Assurance and Quality Control

The finished product should be visually inspected for workmanship, either through worker entry or closed-circuit television. Cores of the sprayed material can be collected on a sample panel and tested for compressive strength. Periodically during application, material thickness should be measured. Special gauge pins can be installed for this purpose.

5.3.5 Asset Management Requirements

5.3.5.1 Inspection Requirements. The shotcrete installation should be inspected periodically in accordance with the owner's asset management plan to ensure that there is no excessive accumulation of debris, cracking, excessive corrosion, or exposed reinforcing steel.

5.3.5.2 Maintenance Requirements. Cleaning operations can be conducted in a similar manner to cleaning any concrete pipe.

5.4 SPINCAST SHOTCRETE

5.4.1 Introduction and Background

Spincast is an automated process of applying shotcrete by casting the shotcrete against the existing wall. Structural reinforcement and trenchless renewal of buried pipe and structures with air-placed concrete is a well-accepted procedure. Shotcrete has an excellent history of lining pipes, including culverts and storm sewers because of the flexibility of its design. The characteristics of the concrete lining, such as strength, density, thickness, and corrosion resistance, can be engineered to address the deficiencies in the existing pipe and thereby provide a cost-effective, long-term solution to failing culverts.

5.4.2 Product Main Characteristics

The principal causes of failure of culverts can be eliminated with structural shotcrete lining. It is one continuous length of concrete pipe without joints to leak or create weak points. It is abrasion resistant. It is a new and fully structural pipe within the old culvert. Flows can be improved with its smooth, uniform surface rather than corrugations. It is dense to prevent future leaks or damage from freeze–thaw. It is not likely to be damaged by future mechanical cleanings to remove debris from storm events.

Thickness of the liner and quality of the concrete provide the greatest flexibility for design considerations. Experience and empirical design formulas provide the best strength-to-thickness ratio for any particular pipe diameter, shape, bury depth, and flow. Design formulas and standards are readily available (ACI 1995, 2005; Austin and Robins 1995). The degree of loss of soil support and residual strength of the existing pipe are prime considerations. Concrete may be designed with embedded reinforcement, high durability, and abrasion resistance; and, the new, uniform, circular lining can improve flow characteristics over corrugations.

The chief limitation has been smaller diameters, which prevent worker entry; however, with the advancement of remote spincasting, diameters as small as 12 in. (305 mm) can be lined. Access points can be a limiting factor for pumping distances that exceed 500 ft (152 m). Shape is not a limiting factor because shotcrete works equally well on circular and noncircular and box culverts.

Because the design of the concrete is critical to the long-term performance of the shotcrete lining, it is highly recommended that factory-blended and packaged materials be used. Hand mixing of sand, cement, and additives at the site is problematic and unlikely to produce consistent performance of the finished material.

Like other remedial lining methods, a preinspection is required to determine severe leaks, access, and structural condition. Debris must be removed and the surface cleaned of any loose or deleterious matter. Pristine cleanliness is not required because concrete adheres well to both metal and concrete culvert pipe, and the shotcrete lining is designed as a structural liner that can be fully independent of the host pipe.

5.4.3 Method Description

First, the culvert or storm sewer is cleaned and active leaks are stopped. Shotcrete of the specified design mix is pumped and hand-sprayed or spuncast onto the interior of the pipe, commencing at one end or from the middle and moving backward toward the pumping source. The thickness is easily verified with a wet gauge. A curing compound is spray-applied as soon as the concrete sets sufficiently to allow placement without damaging the new surface. Lining is performed when flows are not occurring, or flows are diverted.

5.4.4 Construction Requirements and Quality Assurance and Quality Control

Specifications for thickness, strength, density, abrasion resistance, and corrosion are determined by the design engineer to meet the specific depth, diameter, shape, dynamic traffic loads, groundwater pressure, and condition of the existing culvert.

Quality assurance and quality control issues are critical to any field-produced lining. Concrete materials have prescribed ASTM test methods for each required characteristic taken from field-mixed materials. Thickness is easily verified in the field, and visual inspection of the interior surface is recommended.

Once the host pipe is cleaned and prepared, shotcrete lining can be accomplished quickly. Production rates vary with conditions and number of setups. For example, 60-in. (1,524-mm) diameter pipe with access at 250-ft (76-m) intervals would typically have two sections fully lined in one day, for a total of 500 ft (152 m).

5.4.5 Asset Management Requirements

Visual inspections at 30 days and at the end of the first year are recommended. Thereafter, inspections may be limited to those required for debris management only (Fig. 5-4).

5.4.6 Invert Lining of Corrugated Metal Culvert Pipe

One of the most effective ways to rehabilitate corroded and severely deteriorated inverts of corrugated metal pipe (CMP) is by paving with reinforced concrete or shotcrete. If abrasion is present, the aggregate source should be of harder material than the streambed load and have a high durability index. Consideration should be given for using a high-strength concrete mix with a compressive strength of 6,000 psi (41 MPa) or higher.

The abrasion resistance of cementitious materials is affected by both compressive strength and hardness of the aggregate. There is a correlation between decreasing the water–cement ratio and increasing compressive strength and abrasion resistance. Therefore, where abrasion is a

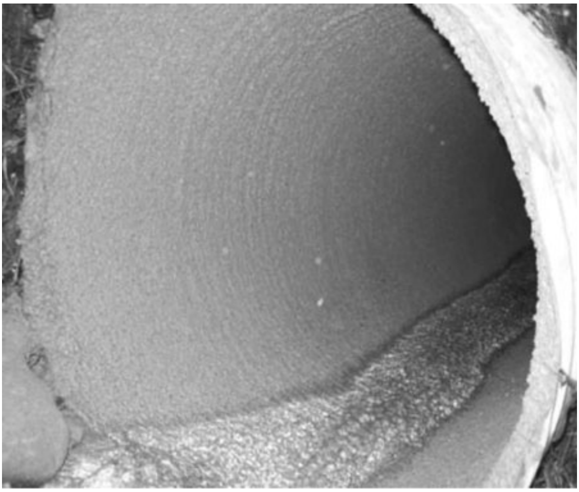


Figure 5-4. Finished Shotcrete Culvert Inspection.

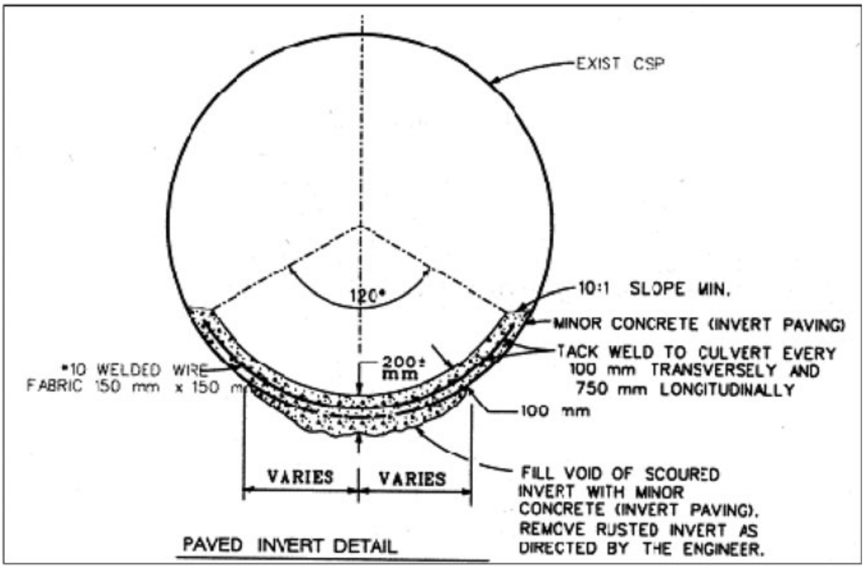


Figure 5-5. Shotcrete Lining of Corrugated Metal Pipes.

significant factor, the lowest practicable water–cement ratio and the hardest available aggregate should be used.

A typical design detail for invert paving is shown in Fig. 5-5 for situations with minimal loss of the invert (some perforations, but not complete invert loss) that do not require an extensive structural

Figure 5-6. Metal Culvert with Paved Concrete Invert.

connection between the invert paving and the CMP. Paving thickness ranges from 3 in. to 6 in. (76–152 mm), depending on the abrasiveness of the site, and paving limits typically vary from 90 to 120 deg for the internal angle.

For situations where there is significant loss of the pipe invert, it is necessary to tie the concrete to the more structurally sound portions of the pipe wall to transfer compressive thrust of the culvert walls into the invert slab through mechanical connections.

During cleaning and preparing the host pipe for lining, if there are just a few strands of steel remaining, it is preferable to keep as much of the remaining pipe material in the invert as possible, regardless of its condition. If necessary, small openings can be cut in the invert to expose void pockets beneath the culvert. Filling voids with slurry restores lost bedding material beneath the culvert. Welded wire fabric is installed to control cracking in the concrete invert paving. To provide a bond between the concrete and the culvert wall and as a mechanism to transfer thrust into the slab, angle iron or welding studs can be welded to the pipe wall. When mechanical connections are used, paving limits may vary up to 180 deg for the internal angle (Fig. 5-6).

5.5 SLIPLINING WITH THERMOPLASTIC PIPE

5.5.1 Introduction and Background

Thermoplastic pipe is used for the conveyance of storm water in both closed and open-ended systems. Because of its main characteristics listed below, the use of thermoplastic pipe has also become an effective and efficient alternative for the renewal of culverts and storm sewers.

Table 5-2. PVC and HDPE Standards

Sliplining Method	Product	Standard
Segmental	PVC corrugated wall pipe	ASTM F949 (2006)
	PVC profile wall pipe	ASTM F794 (2003)
	PVC closed-profile wall pipe	ASTM F1803 (2006)
	HDPE annular, corrugated-profile wall pipe	ASTM F2306 (2008)
	HDPE profile wall pipe	ASTM F894 (2007)
Continuous	Fusible PVC	AWWA C900 (2007), AWWA C905 (2008)
	Butt-fused HDPE	ASTM F714 (2008)

5.5.2 Product Main Characteristics

Thermoplastic pipe is manufactured in set lengths, which vary depending on the material type. Thermoplastic pipe can be manufactured with leak-resistant joints, which are necessary for a slipline application. From a performance standpoint, thermoplastic pipe provides durability benefits in the area of resistance to corrosion and abrasion. Lastly, from an installation standpoint, thermoplastic pipe is lightweight, making it easy to handle in the field. Table 5-2 lists common PVC and HDPE standards for slipline pipe.

5.5.3 Method Description

Before an existing culvert is sliplined, it is important to inspect the pipeline and remove any debris or obstructions that may interfere with the installation process. Failure to do this may result in a damaged slipline product. Existing flow should be eliminated, diverted, or kept to a minimum during the renewal process. Excessive flow not only interferes with the sliplining and grouting procedure but can also create safety issues during the installation process.

5.5.3.1 Insertion Forces. Once the culvert is clear, the slipline material may be pushed or pulled through the open end. It is important to determine the maximum insertion force that can be applied to the liner pipe. This determination prevents the pipe wall profile from buckling in the axial direction under excessive insertion loading.

In cases where the new culvert is two or more sizes smaller than the existing culvert, it is possible to construct mechanisms to transport the new material along the existing culvert without sliding across the invert. Although ideal for construction, many times there is insufficient room to allow this technique. Figure 5-7 shows an inserted pipe.

Figure 5-7. Inserted Pipe.

Figure 5-8. Grouted Pipe.

5.5.3.2 Grouting Procedures. When relining a culvert using sliplining techniques, it is recommended that the void space between the existing culvert and the new material be filled with a grout material (Fig. 5-8). The grout material is often a controlled low-strength material-controlled density fill (CLSM–CDF). Also, a low-density cellular concrete (LDCC) or cellular grout with 100–150 psi (0.7–1.0 MPa) compressive strength at 28 days can be used. The proper grout material helps provide uniform support on the sides of the pipe, maintains a consistent soil density, provides lateral support for the pipe, eliminates point loads, and minimizes effects of hydrostatic pressure if applicable. In cases where the existing invert has deteriorated or is completely destroyed, the grout material fills any fractures or holes in the existing culvert.

To ensure proper alignment and prevent joint separation, the sliplining pipe should be anchored against flotation when placing the grout material. Grouting in lifts is recommended to help minimize effects from flotation. Each lift should be allowed to set up between pours. Contractors may have other techniques to prevent flotation, such as the use of dead weight inside the pipe. Grouting in lifts is not always required when using an LDCC or cellular grout. The buoyancy calculations should include the density of the grout to be used to determine the blocking requirements. Regardless of the method used, it is also important to avoid applying point loads to the pipe.

It is important not to use excessive grout pressure to avoid buckling caused by fluid pressure or total pressure. In most circumstances, the sliplined joint, not the wall strength, is the limiting factor for maximum allowable grouting pressure. During the grouting operation, gauges should be used to monitor the grout pressure exerted on the pipe system. In addition to grouting pressure, hydrostatic head pressure may increase the expected pressure on the slipline pipe. Additional pressure may be a result of the slope or diameter of the pipe, elevation changes between the pipe and the gauge, and other conditions that should be considered during the design. Whereas slipline grout is often gravity-fed, the sum of all pressures exerted on the slipline pipe should not exceed the recommended maximum pressure for the application.

5.5.3.3 Joint Considerations. Because of the application method of the grout, leak-resistant pipe is recommended for sliplining applications. Including a factor of safety, the recommended maximum grouting pressure for leak-resistant pipe products is 5 psi (34 kPa). A maximum of one degree of joint misalignment can be accommodated. The annulus at the open ends should be bulkheaded to prevent the grout material from leaking out.

5.5.4 Construction Requirements and Quality Assurance and Quality Control

5.5.4.1 Access. The host pipe should be open on both ends or, at the very least, have one open end. If access can only be made through a manhole, thermoplastic pipe products may not be acceptable because they cannot be bent sufficiently. Open-ended applications are more appropriate for thermoplastic pipe products, provided they do not require the pipe to be bent to enter the host pipe.

5.5.4.2 Structural Requirements. Failing culverts in need of relining may eventually deteriorate into a conduit with no structural integrity. For this reason, it is important to reline with a new conduit capable of handling the existing loads and assuming no load reduction from the host pipe. Loading for highway and pavement tunnels, if applicable, should be based on a continuous load-carrying structure for the height of cover under HS-25 loading (AASHTO 2009). Voids between the surrounding soil and the host pipe must be grouted to ensure structural integrity and resistance to thermal effects, as well as to minimize effects of groundwater pressure.

5.5.4.3 Diameter of the Host Pipe. The greater of either the outside diameter of the thermoplastic slipline pipe or coupler, if applicable, should be compared to the inside diameter of the host pipe. This comparison may be accomplished by attempting to pull a short section of the assembled pipe and coupler through the host pipe as a trial run. The host pipe should be free from sediment and debris so as not to interfere with the installation of the liner pipe. Sliplining installations may be subject to thermal length changes. One should design to allow for these changes during installation. To allow for proper grout placement and clearance, the reline pipe should have a minimum outside diameter no greater than 90% of the inside diameter of the host pipe. The maximum outside diameters of corrugated high-density polyethylene thermoplastic pipe are shown in Table 5-3. However, a large selection of other products is available for sliplining applications. Figure 5-9 shows a CMP culvert sliplined with solid-wall HDPE.

Table 5-3. Sliplining Product Dimensions

Nominal Inside Diameter in. (mm)	Maximum Outside Diameter in. (mm)
4 (100)	4.8 (122)
6 (150)	7.0 (178)
8 (200)	9.5 (241)
10 (250)	12.0 (305)
12 (300)	14.5 (367)
15 (375)	17.8 (452)
18 (450)	21.5 (546)
24 (600)	28.4 (721)
30 (750)	35.6 (904)
36 (900)	41.4 (1,052)
42 (1,050)	48.0 (1,219)
48 (1,200)	55.0 (1,397)
54 (1,350)	61.0 (1,549)
60 (1,500)	67.3 (1,709)

Figure 5-9. Sliplining Finished Product.

5.5.4.4 Length of Installation. Limitations on sliplining length vary by product type. Pushing the pipe through the host pipe may damage the pipe ends as they butt up against each other. Typical insertion distance limits are product-specific and range from 100 ft (30.5 m) to up to several hundred feet. Some items that need to be considered when evaluating sliplining lengths are anticipated frictional forces and the strength of the product that is required to offset these forces. The anticipated frictional forces depend on the condition of the host pipe. Using skids or casing spacers, especially in a corrugated host pipe, helps minimize resistance between the two surfaces. Skids can be as simple as 2 × 4 boards placed near the invert. A push-and-pull technique keeps stress on the joints to a minimum. Contact the pipe manufacturer for information regarding safe slipline installation lengths.

5.5.4.5 Quality Assurance and Quality Control. Thermoplastic pipe used for sliplining must conform to the requirements of the applicable ASTM standard for that product.

5.5.5 Asset Management Requirements

There are no special maintenance requirements for thermoplastic slipline pipe. It is recommended that the sliplined pipe be inspected in accordance with the guidelines outlined in Chapter 3. Any accumulated debris should be removed so that the flow capacity of the sliplined culvert is not reduced. Furthermore, the sliplined pipe should continue to be evaluated and its condition assessed, as outlined in Chapter 4.

5.6 FOLDED THERMOPLASTIC PIPELINERS

5.6.1 Introduction and Background

Folded thermoplastic polyvinyl chloride (PVC) pipeliners are used to rehabilitate small (30 in. (762 mm) and under) culverts. All folded thermoplastic pipeliners share the following common characteristics:

- Cross-sectional area is temporarily altered to enable insertion.
- The pipeliner is pulled through one access point to the next.
- After insertion, pipeliners are expanded, heated, and thermoformed to fit tightly inside the old pipe.

Folded thermoplastic PVC pipeliners were first installed in 1988. More than 5,000 mi (8,047 km) of folded thermoplastic pipeliners have been installed in the wastewater, storm water, and other water sectors. A typical folded thermoplastic pipeliner is shown in Fig. 5-10.

5.6.2 Product Main Characteristics

5.6.2.1 Standards. PVC folded pipeliners comply with the ASTM D1784 (2008) material standard. Two PVC pipeliner product standards are currently available in the market. Pipeliners complying with the ASTM F1871 (2002) product standard are constructed in accordance with the ASTM F1867 (2006) installation standard. Those complying with the ASTM F1504 (2002) product standard are constructed in accordance with the comparable ASTM F1947 (2004) installation standard.

Folded thermoplastic pipeliners are structurally designed according to the ASTM F1216 (2009) design appendix. The design life is generally established as 50 years, but a 100-year performance life is reasonably achievable with adequate conservatism in design choices.

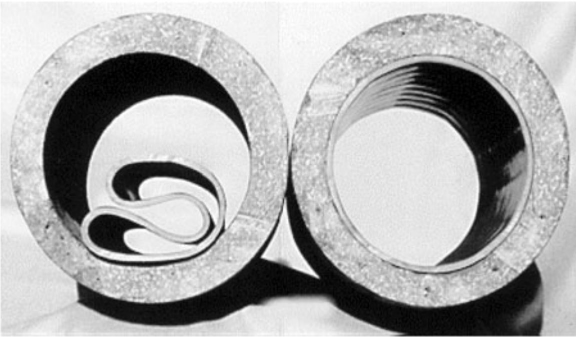


Figure 5-10. Folded Thermoplastic Pipeliner.

5.6.2.2 Technical Envelope. Folded thermoplastic pipeliners are supplied with the product capabilities listed in Table 5-4.

5.6.2.3 Flow Impact. The flow capacity of a deteriorated culvert can be significantly reduced by the deterioration of the invert and by the resulting debris collected. The culvert preparation and precleaning process frequently restores most of the original design flow capacity. Thermoplastic PVC pipeliners are highly resistant to corrosion and abrasion and are not subject to comparable flow deterioration over time.

PVC materials have a material Manning coefficient of approximately 0.009, although the effective Manning coefficient is expected to be higher because of conformance to the host pipe geometry. The enhanced surface smoothness after lining can significantly increase the flow speed, thus reducing future debris deposition. Although the pipeliner slightly reduces the culvert inside diameter, the renewal results in no loss of flow capacity. Even though it is generally not the primary reason for culvert lining, the increased flow rate resulting from lining can be significant. As a result, project engineers should be cautious to consider the prospects of downstream scouring after lining and to include additional outlet modifications as needed.

5.6.3 Method Description

5.6.3.1 Preparation. Before pipeliner installation, the culvert or storm sewer needs to be properly cleaned and prepared, with a final cleaning and inspection to be completed while the pipeliner is preheating. Proper cleaning should include derooting, if applicable, repairs to missing or damaged inverts, and removal of debris or deposits in the culvert. If roots, deposits, or rocks in the invert are lined over, the pipeliner conforms to the irregularities. Missing inverts should generally be repaired; the pipeliner can be expected to "belly" into any unfilled voids in the invert, thereby increasing the likelihood of future siltation in the lined culvert.

5.6.3.2 Insertion. Water flow must be stopped or diverted before pipelining. Once all site preparations have been completed, the preheated pipeliner is pulled through the existing pipe by means of a winch cable extending to a distant access point.

5.6.3.3 Processing. After pipeliner insertion, a flow-through plug is inserted into the pipeliner at the boiler end, and steam is sent through the pipeliner to relax it from the axial forces of the insertion pull. Once the pipeliner has dimensionally stabilized, the pipeliner is cut to length, and hydrophilic gasket end seals are positioned if they are to be used. The pipeliner is then plugged at both ends. Steam is then reintroduced to

Table 5-4. Technical Envelope of Folded Thermoplastic Pipeliners

	PVC 1	PVC 2		PVC 3
Parameter	ASTM F1871 (2002)	ASTM F1871 (2002)	ASTM F1504 (2002)	ASTM F1504 (2002)
Available sizes	6–12 in. (152–305 mm)	3–30 in. (76–762 mm)	3–15 in. (76–381 mm)	6–16 in. (152–406 mm)
Routine size	6–12 in. (152–305 mm)	6–24 in. (152–610 mm)	6–15 in. (152–381 mm)	8–12 in. (203–305 mm)
Available dimension ratio	32.5–26	60–26	41–32.5	34
Maximum length at maximum size	500 ft (152 m)	650 ft (198 m)	800 ft (244 m)	250 ft (76 m)
Bends	>60°	90°	90°	90°

Note: Maximum length for all types is 1,500 ft (457.2 m).

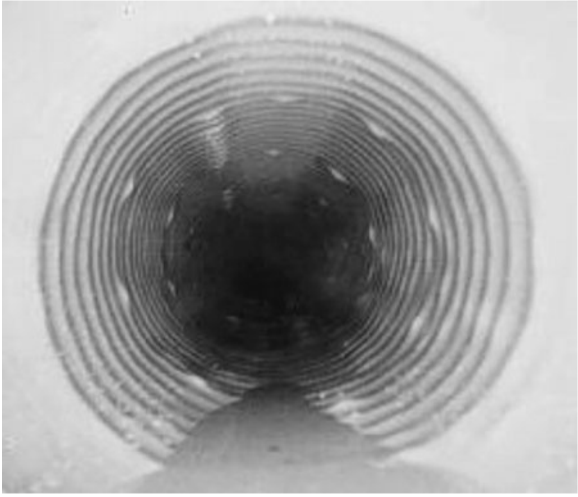


Figure 5-11. A Lined Corrugated Pipe.

process the pipeliner. The equipment at the distant access point (B station) includes a ball valve that is partially closed to create backpressure inside the pipeliner. As the pressure rises inside the pipeliner, the pipeliner begins to round and then expand so as to thermoform the pipeliner tightly against the pipe. The pipeliner conforms to the exact geometry of the host pipe. If a corrugated pipe is lined, the pipeliner will likewise become corrugated (Fig. 5-11).

5.6.3.4 Cooling. Once the pipeliner has “belled” past the diameter of the host pipe in the downstream access point, steam is discontinued, but the pressure is raised, with an increase of airflow to keep the pipeliner tight against the host pipe. Cooling the pipeliner under pressure substantially precludes shrinkage from thermal contraction. As the pipeliner cools, a chiller is used to refrigerate the air to more fully cool the pipeliner. The cooler the pipeliner is at the time of depressurization, the tighter the pipeliner fits. When the pipeliner is below at least 100 °F (38 °C), the flow-through plugs can be removed.

5.6.3.5 Finishing. Immediately after the pipeliner processing and cool down are complete, the construction crews should view the full length of the pipeliner using CCTV to confirm proper installation. Ends should not be trimmed until a full-length inspection has been completed. Before trimming the ends, if necessary, a pipeliner can be reprocessed or, if seriously damaged or failed, reheated, collapsed, and removed. After cooling and initial postinstallation inspection, the ends are trimmed to length (Fig. 5-12).

Figure 5-12. Culvert Renewed with a Thermoplastic Pipeliner.

5.6.4 Construction Requirements and Quality Assurance and Quality Control

5.6.4.1 Construction Requirements. Access must be available at both ends of the culvert or storm sewer to string a winch cable. Trucks generally need road access within 300 yards of one pipe end to reach with a steam hose. The pipeliner and smaller equipment, such as winches, can generally gain off-road access to remote culvert ends. The downstream equipment has even been floated on barges to simplify lining of culverts that empty into waterways. The installation of folded thermoplastic pipeliners is generally not precluded by steep slopes or narrow catch basins; such site conditions do not alter any of the design properties of a folded thermoplastic pipeliner (Fig. 5-13).

5.6.4.2 Quality Assurance and Quality Control. Folded thermoplastic pipeliners are premanufactured. The required quality control protocols of the ASTM product standards verify the pipeliner's compliance with wall thickness, material modulus, corrosion resistance, and other long-term structural design requirements within the controlled environment of the manufacturing facilities. The field installation process, including variable field conditions and crew decisions, does not influence the structural design compliance of a folded thermoplastic pipeliner. Compound suppliers, manufacturers, and technology providers perform essential roles in the quality assurance and quality control of folded thermoplastic pipeliners.

The compound supplier is responsible for testing every blended lot of compound for either the flexural modulus and flexural strength or the

Figure 5-13. Lining a Culvert.

tensile modulus and tensile strength, according to the referenced ASTM standards.

The technology supplier's production request to the manufacturer should include specific information about the project. The manufacturer, to comply with the applicable specifications and standards, is generally required to clearly mark the pipeliner in standard format at 5-ft (1.5-m) intervals or less. The information about operators and shifts is also recorded for quality assurance and record tracking.

Quality assurance and quality control personnel at the manufacturing facility are required to measure the wall thickness of the pipeliner at the end of each reel, observe the internal and external cosmetics of the pipeliner, record additional comments if necessary, and determine the overall pass or fail of each reel according to established standards.

Samples should be collected from the beginning and end of every reel produced. From a portion of these samples, the following tests should be run, to comply with the applicable specifications and standards:

- impact resistance (ASTM D256 (2006) and ASTM D2444 (2005));
- flattening to 60% (ASTM D2412 (2008));
- pipe stiffness at 5% deflection (ASTM D2412 (2008));
- acetone immersion (ASTM D2152 (2003));
- heat reversion (ASTM F1057 (2005));
- tensile strength (ASTM D638 (2008));
- flexural modulus (ASTM D790 (2007));
- overall (pass or fail); and
- signature of the quality assurance/quality control inspector.

Figure 5-14. Reels of Folded Thermoplastic Pipeliners.

5.6.4.3 Shipping and Handling. Folded thermoplastic pipeliners are coiled on reels or coiled and shipped on pallets and then transferred to reels at the jobsite. The folded thermoplastic pipeliners are shelf-stable and can be shipped and stored in bulk. There are no caustic, toxic, or noxious chemicals, resulting in no extra regulations regarding permitting or handling. No special protective equipment is required when handling a folded thermoplastic pipeliner during transit and setup. Although folded thermoplastic pipeliners can routinely survive the brunt of shipping and handling abuse, on-site inspection of the pipeliner as received should be completed to ascertain any shipping damage that may have occurred, such as nails through the pipeliner, structurally collapsed reels, broken reels, and excessive abrasion of the pipeliner. Typical reels used are shown in Fig. 5-14.

5.6.4.4 Environmental Considerations. Folded thermoplastic pipeliners are generally safe for use in environmentally sensitive areas and have routinely been approved by environmental agencies for such applications. Folded thermoplastic pipeliner materials do not contain any fillers, plasticizers, lead, cadmium, phthalates, or styrene. Certain folded thermoplastic pipeliner material formulations contain no volatile organic compounds (VOCs) and have been approved by the National Science Foundation (NSF) for potable water use (consult different vendors for details). During a PVC pipeliner installation, the pipeliner is softened with high temperatures to be pulled through and subsequently thermoformed to the host pipe. No chemical reaction occurs during the entire installation process of a folded thermoplastic pipeliner. The folded thermoplastic pipeliner is heated using steam, which is safe to be released to the environment without any treatment and without risk of chemical pollution or of significant thermal pollution to receiving waters.

5.6.5 Asset Management Requirements

The quality assurance and quality control at the manufacturing facility, which is comparable to the requirements for direct burial plastic pipe, ensures the consistency of the pipeliner's design properties, such as the material modulus, the wall thickness, and the corrosion resistance. The field installation practice does not change these critical design properties. Only the geometry and wall thickness vary as the pipeliner conforms to varying diameters of the host pipe, and the product design standards ensure conservative allowance for such inherent and mostly predictable geometric variability.

If a section greater in length than eight times the diameter has to be excavated and exposed as a part of future operation and maintenance requirements, consideration should be given to replacing that section with a direct burial pipe point repair, or else maintenance crews should take additional precautions during backfilling to ensure that the pipeliner is not overdeflected. Pipeliners are not designed to handle backfilling pressures and loads from consolidating soils generated by traditional direct burial construction practices. Shorter lengths of exposed pipeliners are adequately stiffened by the soil support around the unexposed portion of the pipeliner; thus, "localized" direct burial loads can be handled with adequate precompaction above the springline of the pipeliner.

The material consistency and familiarity of folded thermoplastic pipeliners provide additional life-cycle cost savings. Maintenance personnel are generally highly familiar with the inspection, operation, and maintenance of PVC and HDPE piping materials, including how to clean them without damage. If excavation is required, a host pipe can be readily removed without damaging a folded thermoplastic pipeliner. Commonly inventoried saddles, compression fittings, and repair sleeves can be used with folded thermoplastic pipeliners with minimal adaptations and with no special training required. Because the dimensions of a folded thermoplastic pipeliner are not standard but rather conform to the irregular inside diameter of the host pipe, it is advisable to use a 50-year urethane between the pipeliner and standard saddles and sleeves to ensure a leak-proof seal.

5.7 HDPE GROUT-IN-PLACE PIPELINERS

5.7.1 Introduction and Background

The grout-in-place pipeliner (GIPP) technology, which uses anchored HDPE panels, was developed in Germany in the early 1990s. Since 1992, HDPE GIPP has been widely used, with more than 1 million ft installed worldwide. The essential component of the HDPE GIPP renewal

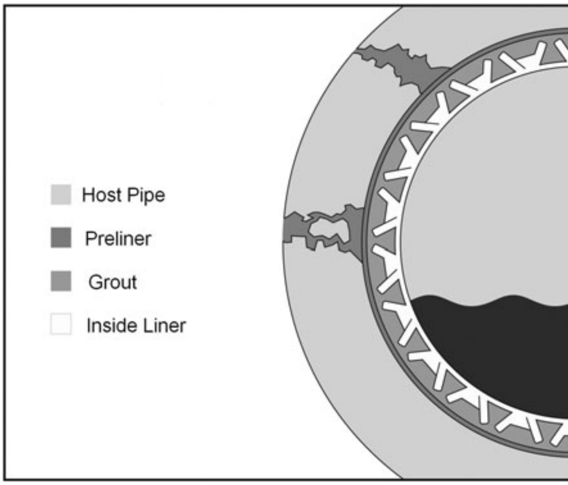


Figure 5-15. Grout-in-Place Pipeliner.

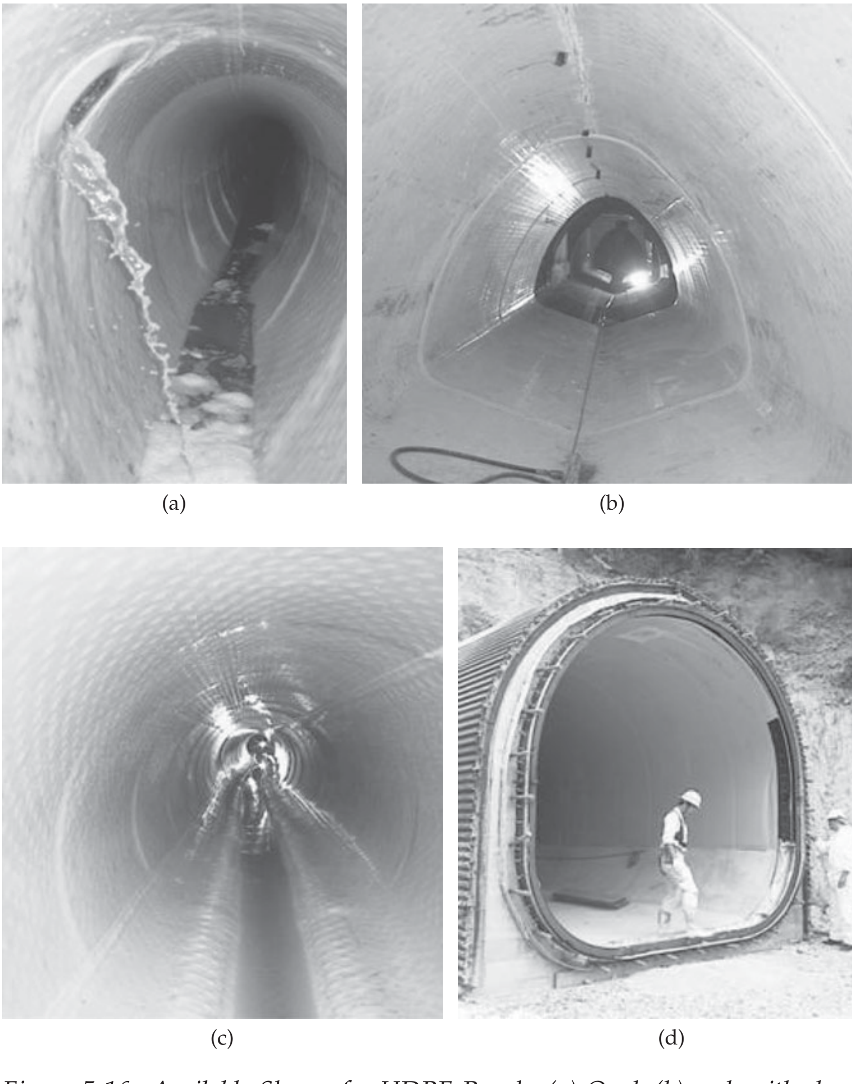
technique is the HDPE panel with V-shaped embedment anchors. The annular void created by the anchors is filled with high-strength grout. The grout fixes the HDPE panels permanently in place. The grout and the embedded HDPE anchors function as a composite structure and provide the load-bearing capacity (Fig. 5-15).

5.7.2 Product Main Characteristics

5.7.2.1 Materials. The HDPE panels are made of high-density ethylene–octane copolymer resin. Depending on the specific jobsite condition, a preliner typically applies. The optional preliner is made of the same material, but it is smooth on both sides. The inside liner is manufactured with embedded anchors on its outer surface, as shown in Fig. 5-15. The anchors are available in heights of 0.394 in. (10 mm), 0.512 in. (13 mm), or 0.748 in. (19 mm). The HDPE panels used to make the inside liner are homogenously extruded with the anchors as one piece, with a minimum of 39 anchors per 1 ft^2 (0.093 m^2) of panel.

The portion of the HDPE panels exposed at the ends of the culvert must contain UV protection, such as carbon black. The translucent panels typically used for sanitary sewer rehabilitation do not provide suitable UV protection for the exposed ends of culvert applications and do require the application of additional UV protection measures at the culvert ends.

The grout used with GIPP technology is a low-viscosity, quick and ambient-curing, expansive, cementitious polymer mortar of high strength.



(a) (b) (c) (d)

Figure 5-16. Available Shapes for HDPE Panels. (a) Oval, (b) arch with sharp corners, (c) circular with small channel, and (d) arch with smooth corners.

The 28-day compressive strength of the cementitious grout exceeds 10,000 psi (70 MPa). The HDPE GIPP technology essentially forms a polyethylene-encapsulated cementitious pipe tightly fitted inside the old culvert pipe. See Fig. 5-16 for various host pipe shapes.

HDPE GIPP installation and design are governed by existing European standards, with ASTM standards under development. The design life is

Table 5-5. Technical Envelope of Grout-In-Place HDPE Sheets Pipeliner

Parameter	HDPE Grout-in-Place Pipeliner
Available sizes	8 in. (203 mm) to 120 in. (3,048 mm) and larger
Maximum length[a] (as determined by grout flow limits)	600 ft (up to 40 in.) or 183 m (1,016 mm) 400 ft (up to 50 in.) or 122 m (1,270 mm) 200 ft (up to 80 in.) or 61 m (2,032 mm)
Pipe category	Gravity and pressure (with support from host pipe)
Bends	Gentle bends are naturally accommodated; larger bends are accommodated by cutting and rewelding in place to conform
Other options	Available options include self-cleaning invert, hydrocarbon barrier, monitorable dual containment, embedded microcabling (fiber-optic) conduit system

[a] Any length of continuously welded pipeliner is possible, but it must be installed with interim grout ports as per these maximum lengths.

for 50 years minimum with high resistance to corrosion and abrasion while providing independent structural integrity.

5.7.2.2 Technical Envelope. The capabilities and limitations of the HDPE GIPP method are in Table 5-5.

5.7.2.3 Effect on Flow. The flow capacity of a deteriorated culvert or storm sewer has frequently been significantly reduced over time by the deterioration of the invert and by the resulting debris collected. The pipe preparation and precleaning process frequently restores most of the original design flow capacity. HDPE GIPP is highly resistant to corrosion and abrasion and is not subject to comparable flow deterioration over time. A specially engineered, textured, "self-cleaning" invert can be incorporated into the GIPP tube to assist in preventing future siltation and deposition.

The HDPE materials have a material Manning coefficient of approximately 0.009. The enhanced surface smoothness after lining can significantly increase the flow speed, thus reducing future debris deposition. Although the pipeliner slightly reduces the culvert inside diameter, the renewal results in no loss of flow capacity. Even though it is generally not the primary reason for culvert renewal, the increased flow rate resulting from lining can be significant. As a result, project engineers should be cautious to consider the prospects of downstream scouring after lining and to include additional outlet modifications as needed.

5.7.3 Method Description

5.7.3.1 Preparation. Before pipeliner installation, the culvert needs to be properly cleaned and prepared, with a final cleaning and inspection to be completed during preparation for pipeliner insertion. Proper cleaning should include derooting, if applicable, and removal of debris or deposits in the culvert.

5.7.3.2 Insertion. Water flow must be temporarily stopped, bypassed, or diverted during the GIPP installation. Once all site preparations have been completed, the preliner is pulled through the existing pipe by means of a winch cable extending to a distant access point. The preliner is then provisionally inflated with compressed air and tested for leak tightness. Each anchored inside liner is then pulled through the preliner (Fig. 5-17).

Figure 5-17. Insertion of the Anchored Liner.

5.7.3.3 End Welding. After insertion of all pipeliner tube layers, the annular space, as established by the height of the anchors, is sealed at both ends by PE extrusion welding. Because the grout is injected into the sealed annulus between the pipeliner layers, bulkheads are not required. Grouting ports are connected to the void spaces at the downstream access point, and air-release ports are connected at the upstream access point. Smoke testing is used to check the airtightness of all welds and of the pipeliner walls before grouting. In worker-entry sizes, tube leaks can be readily repaired in situ with welding techniques.

5.7.3.4 Forming. Once confirmed to be leak-free, the pipeliner tubes are ready for forming. Smaller pipeliners (30 in. or 762 mm and smaller) can be plugged and pressurized to conform to the host pipe with either air or water. Water pressurization is generally preferred for culverts larger than 30 in. (762 mm), despite the increased cost and potential waste of water, because water is not compressible and is therefore considerably safer than air. A water column is generally used for water pressurization to more readily control the pressure consistency. The pipeliner is pressurized internally to keep the pipeliner formed tightly against the host pipe while offsetting the grout pressure. For culverts or storm sewers larger than 80 in. (2,030 mm) in diameter, or of irregular geometry, the use of formworks, instead of pressurization, is generally required for various constructability reasons.

5.7.3.5 Grouting. Once the pipeliner tubes have been formed against the host pipe and structurally supported by pressure or formworks, the grouting process can begin (Fig. 5-18). The required grout quantity can be estimated by the fixed volume of the anchor-defined annulus. The sealed annulus within the pipeliner layers precludes environmental contamination by grout leakage and ensures consistent grout strength through controlled water to grout mixing ratio. Only potable water should be used for grout mixing. A sufficient quantity of grout mixing units is required to ensure that the estimated quantity of grout can be injected. After complete grouting of the HDPE GIPP section, the grout must be allowed to cure, generally overnight. The forming pressure or formworks cannot be removed until the grout is cured. Figure 5-19 shows a completed HDPE GIPP.

5.7.4 Construction Requirements and Quality Assurance and Quality Control

5.7.4.1 Construction Requirements. Access must be available at both ends of the culvert pipe to string a winch cable. The required installation equipment is portable and requires a minimal jobsite footprint.

Figure 5-18. Attachment of Grouting Ports.

Figure 5-19. Completed HDPE GIPP Installation.

As necessary, the pipeliner and smaller equipment such as winches can generally gain off-road access to remote culvert or storm sewer ends.

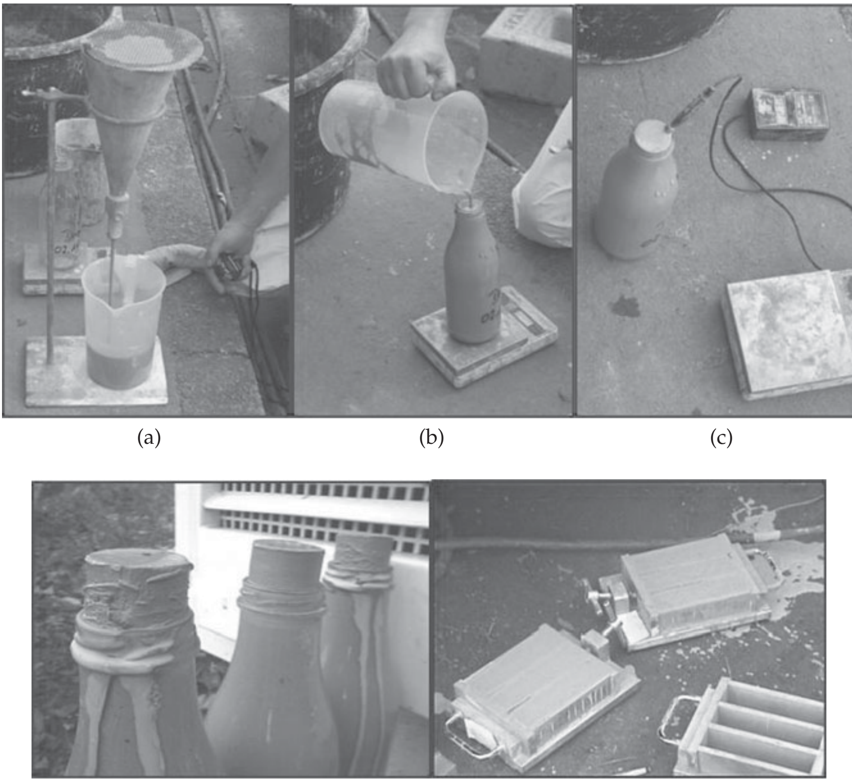
5.7.4.2 Quality Assurance and Quality Control. The wall thickness and corrosion resistance of HDPE GIPP is unalterably established during the premanufacturing of the HDPE pipeliner panels. However, the HDPE GIPP culvert rehabilitation technique is still largely a field manufacturing process, which is inevitably subject to variables that may affect the quality of constructed culvert pipeliners. Besides the quality assurance and quality control procedures at the manufacturing facilities of the HDPE panels and the grout, quality assurance and quality control at the construction site are essential to control the influence of field variables.

The following inherent technology characteristics facilitate the quality assurance and quality control of HDPE GIPP pipeliners:

1. The minimum thickness of the pipeliner is the height of the embedded anchors and is unalterable by field conditions or by construction crew decisions.
2. The grout is injected into the sealed annulus between the layers of the pipeliner using a gravity column, instead of pumping; this injection tends to preclude the creation of grout voids inside the pipeliner.
3. The required volume of grout necessary to achieve the structural wall thickness requirements is established and controlled by the fixed, sealed annulus between the layers of the pipeliner.
4. The application of the optional preliner prevents the grout from escaping, washing away, or losing strength because of dilution by groundwater.
5. The weld quality and the watertightness of the HDPE GIPP are confirmed during the installation process.

Because critical structural design properties of the HDPE GIPP are established during field manufacturing, additional field quality tests are essential before and during the grouting process to ensure that design values are being achieved under varying field conditions. With HDPE GIPP, design compliance is monitorable and confirmable during installation. Required field quality tests of the structural grout include viscosity, weight, water–cement ratio, temperature, and material expansion, as shown in Fig. 5-20.

Voids are unlikely to form with such a low-viscosity grout, which is injected by gravity column from the low end to the high end of the culvert. With the translucent HDPE panels, an internal visual inspection, even by CCTV, can confirm the lack of voids in the grout. For worker-entry sizes, a "tapping test" can confirm the lack of voids behind an opaque HDPE panel.



(a) (b) (c)

(d) (e)

Figure 5-20. Grout Tests for GIPP. (a) Viscosity, (b) Weight, (c) Temperature, (d) Material Expansion, and (e) Strength.

5.7.4.3 Shipping and Handling. HDPE panels are coiled on reels, and the grout is bagged for shipping and storage. On site, the HDPE panels can be stored outside within manufacturer-recommended temperatures. In case of temperatures outside this range, special measures should be taken inside a warehouse, controlled-climate trailer, or other storage facility. As a quality control precaution, storage of the HDPE panels and tubes under direct solar radiation is not permitted; this restriction is of particular importance for the translucent panels, which do not contain UV protection. The HDPE panels must always be covered with a suitable protection after delivery to the site. The grout must be stored under dry conditions at manufacturer-recommended temperatures. With proper storage, the pipeliner tubes are warranted by the manufacturer as shelf-stable for a period of one year after production and are expected to remain shelf-stable thereafter.

5.7.4.4 Environmental Considerations. Both the HDPE GIPP installation process and the final product are safe for the environment. The grout curing occurs at ambient temperature by hydration. The HDPE panel material does not contain any fillers, plasticizers, lead, cadmium, phthalates, or styrene. The HDPE panel material contains no VOCs and has been NSF-approved for potable water use. When a pipeliner is used, the grout is completely encapsulated within the HDPE tube layers, preventing release, which could otherwise spoil nearby waters.

5.7.5 Asset Management Requirements

The quality assurance and quality control at the manufacturing facility, which is comparable to the requirements for direct burial plastic pipe, ensures the consistency of the pipeliner's wall thickness and corrosion resistance. The field installation practice does not change these critical design properties. The grout strength is fully controllable with the on-site quality assurance and quality control protocols, thereby ensuring the consistency of the as-constructed final product. Relatively minimal performance variability is expected from line segment to line segment, thereby enhancing asset manageability.

The material consistency and familiarity of the material components of HDPE GIPP provide additional life-cycle cost savings. Maintenance personnel are generally highly familiar with the inspection, operation, and maintenance of both cementitious and HDPE piping materials, including how to clean them without damage. If and when excavation is required, a host pipe can be readily removed without damaging the HDPE GIPP. Commonly inventoried saddles, compression fittings, and repair sleeves can be used with HDPE GIPP with minimal adaptations and with no special training required. Because the dimensions of an HDPE GIPP are not standard but rather conform to the irregular inside diameter of the host pipe, it is advisable to use a 50-year urethane between the pipeliner and standard saddles and sleeves to ensure a leak-proof seal. Potential damage to the HDPE tubes can be repaired with standard HDPE welding techniques.

5.8 SPIRAL-WOUND LININGS

5.8.1 Introduction and Background

The spiral-wound lining system uses a rigid plastic profile that is closely formed inside an existing pipe by interlocking the continuous strips of plastic profile using a specially designed winding machine or by manually locking the successive wraps of profile using a jointing strip, as

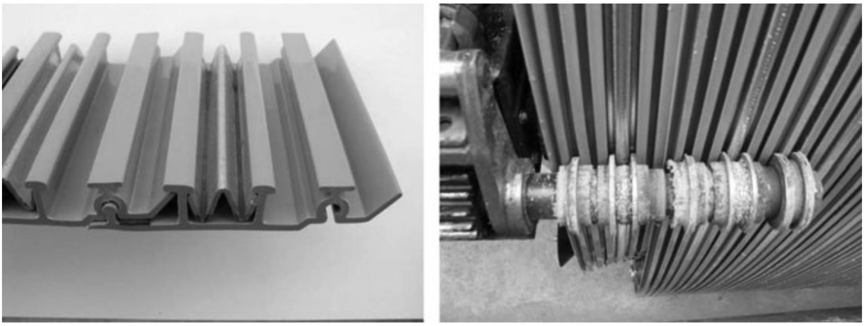


Figure 5-21. Spiral-Wound Profile and Joint.

shown in Fig. 5-21. The system is able to rehabilitate circular as well as noncircular pipes, such as box culverts and horseshoe shapes.

All the materials and equipment required to carry out a spiral-wound project can, if required, be entered into the existing pipeline through manholes. The equipment is designed for assembly inside the pipeline, with the equipment road surface footprint at a minimum.

A spiral-wound lining system can be designed and installed either for corrosion protection or as a fully structural renewal for existing pipelines. The system has the ability to renew straight pipe lengths as well as bends and curves within existing pipelines. The spiral-wound lining system creates a rehabilitated conduit with improved chemical resistance characteristics, improved flow coefficients, and, where required, structural enhancement for the host pipe.

5.8.2 Product Main Characteristics

Depending on the condition of the host pipe, the design of the spiral-wound liner pipe is carried out based on either a partially deteriorated host pipe design or a fully deteriorated host pipe design.

5.8.2.1 Partially Deteriorated Host Pipe Design. In a partially deteriorated pipe design, the host pipe is assumed to be able to support the soil and surcharge loads throughout the design life of the rehabilitated pipe, with the soil adjacent to the existing pipe providing the required side support and bedding. The spiral-wound pipe is designed to withstand groundwater hydrostatic pressure without buckling.

The partially deteriorated design theory looks at plastic pipe design theory that uses the stiffness of the plastic profile combined with the support of the host pipe and soil to determine the maximum external hydrostatic pressure allowed before the spiral-wound liner pipe buckles.

5.8.2.2 Fully Deteriorated Host Pipe Design. In a fully deteriorated pipe design, the spiral-wound liner pipe is designed to support all hydrostatic, soil, and live loads specified, with a safety factor.

The fully deteriorated design theory looks at the composite structure of spiral-wound liner pipe, grout, and any residual structural capability of existing host pipe as one structural unit. The design of this particular theory is based on either reinforced concrete pipe design or Water Research Center (WRC) Type I design.

5.8.2.3 Durability. Each manufacturer of the spiral-wound lining system has undertaken testing to determine the durability of their product for a 50-year design life. This testing includes that of plastic's short- and long-term tensile and bending strengths and the flexural modulus to make sure the structural capability of the plastic is sustained over 50 years. Also, the thickness design of the PVC sheet in contact with the pipe flow is such that the final spiral-wound liner pipe is made to resist a minimum of 50 years of abrasion from sand and other solids that might be flowing through the pipe.

5.8.2.4 Hydraulic Considerations. Some unevenness in wall roughness can be found in all commercially available pipes. In spiral-wound liner pipe, there is also irregularity of surface because of the spiral-wound joint connecting each successive profile wrap. However, documented testing by the spiral-wound pipe manufacturers has shown that little difference in roughness coefficient exists between regular PVC pipe and the spiral-wound pipe.

Professional practice today uses the Darcy–Weisbach equation, the Hazen–Williams equation, or the Manning equation to determine the roughness of a pipe material. As a standard for spiral-wound PVC–HDPE plastic pipes, the surface roughness used in the Darcy–Weisbach equation is 0.002 in. (0.045 mm), the Hazen–Williams roughness coefficient is 150, and the Manning roughness coefficient is 0.01.

5.8.2.5 Capabilities. Spiral-wound lining systems can accommodate round pipes upward from 6 in. (152 mm) in diameter and nonround pipes from 42 in. (1,067 mm) and upward. For nonround pipes, the spiral-wound system requires worker entry to execute the process.

The spiral-wound lining system is able to rehabilitate round pipes, square and rectangular box section pipes, and horseshoe-shaped pipes (Fig. 5-22). The spiral-winding system is not limited to straight pipe renewal because curves and bends can also be seamlessly accommodated.

5.8.2.6 Limitations. Because the spiral-wound lining system constructs the pipe on site, any obstructing pipe or structure within the host pipe needs to be removed before installation.

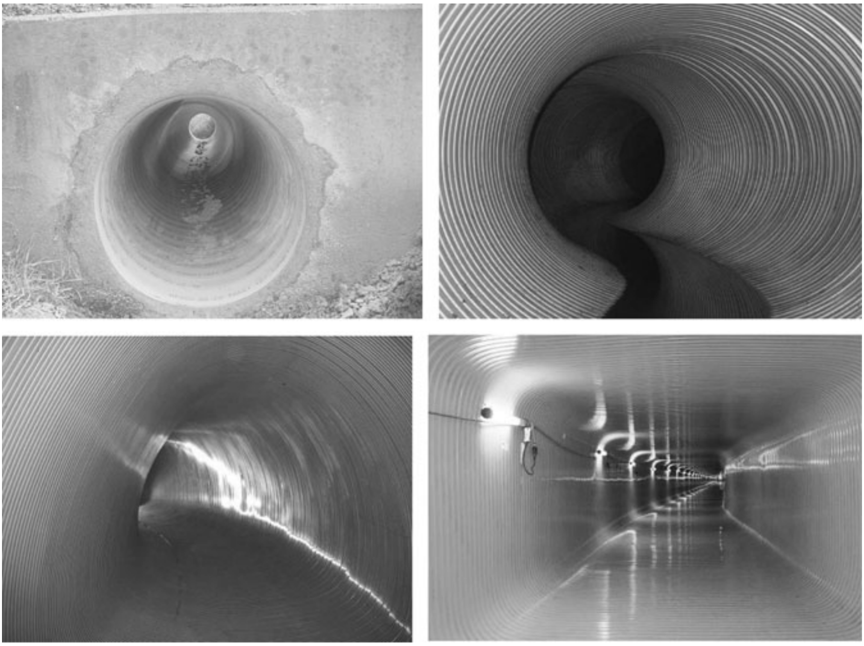


Figure 5-22. Different Renewed Culvert Shapes.

Depending on the structural design requirements, the cross-sectional area of the rehabilitated pipe may have to be significantly reduced. However, the improved roughness coefficient between the spiral-wound plastic pipe and the host pipe may compensate for this size reduction.

5.8.2.7 Preinstallation Requirements

Inspection Requirements. Because the majority of spiral-wound lining systems are installed as fixed-diameter pipes, the preinstallation host pipe measurement is important. The host pipe can be measured either manually or by using laser profiling. Standard practice for the manual method requires a worker-entry procedure, with the host pipe horizontal and vertical dimensions recorded every 10 ft (3.1 m) along the full pipe length.

The interior of the host pipe should also be inspected through visual inspection or by CCTV to determine if there are any protruding service taps, collapsed or crushed pipe, out of roundness, significant sags, or deflected joints. These defects may prevent proper installation of spiral-wound liner pipe, and they should be noted and repaired before installation.

Cleaning Requirements. Cleaning of the host pipe is required before the installation of the spiral-wound pipe. The purpose of this cleaning is to remove all debris from the existing pipeline and to prepare the host pipe surface by removing the loose debris from the host pipe wall. This process increases the bonding capability between the host pipe and the annular space grout. The cleaning process is usually accomplished by using high-pressure-water cleaning equipment.

Bypass Requirement. The spiral-wound liner system can typically be installed under partial flow conditions, which means that it does not require a dry pipeline. In case of worker-entry spiral winding, the safety of the installation workers dictates the amount of flow allowed in the host pipe. If the flow level or velocity are too high for safe entry, partial bypass may be required.

5.8.3 Method Description

5.8.3.1 Installation Procedures and Requirements. The spiral-wound lining system is installed by interlocking a continuous strip of plastic profile using a specially designed winding machine or by manually locking the successive wraps of profile using a joiner strip. In the case of installation by winding machine, there are two categories: a stationary winding machine or a traveling winding machine.

Stationary Winding Machine. The winding machine is placed in the manhole or insertion pit and oriented so that the plastic profile can be spirally wound and inserted directly into the existing pipe. The plastic profile is fed into the winding machine that forms the profile into the required spiral-wound liner pipe diameter. Simultaneously, this newly created pipe rotates and is pushed into the host pipe (Fig. 5-23). This process requires the new pipe to be smaller in diameter, similar to sliplining with a rigid pipe, than the traveling method, which creates a tight-fitting liner.

Traveling Winding Machine. The winding machine itself is placed into the host pipe through an existing manhole or convenient opening and is allowed to travel directly within the host pipe while forming the spiral-wound new pipe. The plastic profile is fed into the winding machine that rotates and moves along the existing pipeline, forming the new spiral-wound round or nonround pipe shape and size. Because this process leaves the wound pipe behind the machine, there is no friction between the formed profile and the host pipe. As a result, much longer installation lengths are possible (Fig. 5-24).

Figure 5-23. Spiral-Wound Stationary Winding Machine.

Figure 5-24. Traveling Winding Machine.

Manual installation requires each successive profile wrap to be manually locked together by installing a profile-locking strip and manually hammering it into place (Fig. 5-25).

Depending on project specifications and design, grout may be needed to fill the annular space between the new installed spiral-wound liner pipe and the host pipe. The grout may be injected at openings in the end seals, at reconnected service connections, at grout holes drilled in the spiral-wound liner pipe, or at grout holes drilled from the ground surface. Before commencing the grouting operation, all service openings must be

Figure 5-25. Manual Installation. Courtesy of Danby of North America.

opened and steps must be taken to prevent the grout from entering the service connections or the spiral-wound liner pipe.

The grouting operation may take place in one lift or several lifts. When grouting in one lift, a bracing system needs to be installed within the spiral-wound liner pipe to ensure that the newly wound liner pipe does not buckle because of the weight of the injected grout. When grouting in multiple lifts, a bracing system may or may not be required.

In the case where a bracing system is not installed, the amount of grout injected for each lift is limited by the spiral-wound liner pipe deflection. The manufacturer of the spiral-winding pipe system determines grout pressures that can be used.

Regardless of whether a bracing system is used, methods must be adopted to prevent flotation of the profile during the grouting process.

5.8.3.2 Modifications for Culvert Applications. Modifications for culvert applications using a spiral-wound lining system are minimal. When rehabilitating corrugated metal pipe, an additional bottom railing may be needed to guide the wound liner pipe into the host pipe so that it does not get caught by the corrugations within the host pipe.

Also, unlike sanitary sewer, the defects observed on culverts and storm sewers usually occur on the bottom of the host pipe, instead of on the top. If the bottom of the culvert or storm sewer is severely corroded, the bottom needs to be repaired before the installation of the spiral-wound liner pipe.

5.8.4 Construction Requirements and Quality Assurance and Quality Control

5.8.4.1 Quality Assurance and Quality Control. The plastic profile used in the spiral-wound lining system is distinctly marked on its surface at appropriate intervals with a code number identifying the manufacturer, plant, date of manufacture, and profile designation. When structural grout is required by the design, the grout should be sampled and tested, as designated by the owner. The properties that should be tested may include compressive strength, bleeding, shrinkage, and flowability.

5.8.4.2 Inspection Requirements. After the completion of installation, the spiral-wound liner pipe should be inspected either by physical visual inspection or by CCTV.

5.8.4.3 Special Requirements. The spiral-wound lining system is designed for installation through existing manhole shafts and access points. However, in some cases, the manhole top cone may need to be removed or an excavation may need to be made to enable cleaning to progress if the host pipe has high levels of silt and debris. All equipment needed for the spiral-winding installation may be installed through a standard manhole shaft.

5.8.4.4 Acceptance and Delivery. The spiral-wound pipe is wound continuously over the entire length of the host pipe and is free from defects, such as foreign inclusions, holes, cuts, tears, and grout voids. Any splices or grout holes should be repaired with manufacturer-recommended material, and no infiltration of groundwater through the spiral-wound liner pipe should be observed. All service connections should be accounted for and unobstructed. Any defect that will, or could, affect the structural integrity or performance of the renewed conduit must be repaired using means and methods approved by the owner before the final acceptance of the product.

5.8.4.5 Time and Cost Considerations. The production speed and the cost of the spiral-wound lining process depend on individual project conditions and the method of installation (e.g., manual or machine wound).

5.8.5 Asset Management Requirements

5.8.5.1 Maintenance Requirements. There are no special maintenance requirements needed for spiral-wound pipe. Requirements are similar to those for PVC and HDPE culverts.

5.8.5.2 Inspection Requirements. All spiral-wound pipes have a minimum 50-year design life. However, the pipe should be inspected periodically in accordance with the owner's asset management plan to ensure that there is no excessive accumulation of debris that would reduce the flow capacity of the spiral-wound liner pipe. At the end of its design life, the spiral-wound pipe could be renewed by installing another spiral-wound pipe inside the old pipe.

5.9 SLIPLINING WITH FIBERGLASS-REINFORCED RESIN PIPES

5.9.1 Introduction and Background

Sliplining rehabilitation using fiberglass-reinforced thermosetting resin (FRTR) pipes is a semitrenchless renewal method that is accomplished by pushing slightly smaller diameter, factory-made pipes into the host line. Sliplining is normally used for circular host pipes, but it can and has been used to line other shapes. FRTR pipes are available in sizes ranging from 12 in. (305 mm) to 110 in. (2,800 mm) and can generally be used to line host pipes ranging from 15 in. (381 mm) to 120 in. (3,050 mm) in diameter. Liner pipe insertion is typically done through the open end of culverts or storm sewers or through an access pit. The existing line may be empty or may have flow present during the lining process. Bypass pumping or diversion of existing flows is not required. After insertion, the residual annular space is usually filled with grout to fix grade and enhance the liner pipes' structural characteristics. When sliplining is properly completed, the lined host is structurally restored, corrosion protected, leak-free, and hydraulically improved.

5.9.2 Product Main Characteristics

Prime ingredients in FRTR pipes are thermoset resin (typically polyester or vinyl ester), fiberglass reinforcements, and aggregates. FRTR pipes have high compressive strength, burst capacities exceeding 100 psi (689 kPa), and typical pipe stiffnesses of at least 36 psi (248 kPa). Field assembly is most often a pushed-together, gasket-sealed coupling or a bell and spigot joint. Pipe segment lengths for sliplining are typically 20 feet (6.1 m), although shorter pipes are sometimes used to negotiate curves or for insertion through small access pits. Characteristics, materials, and performance for FRTR pipes are defined in ASTM D3262 (2006).

The normal maximum liner pipe outside diameter is approximately 95% of the host pipe inside diameter or smallest cross-sectional dimension. This measurement causes a diameter reduction of less than 10%, which frequently results in an increased flow capacity because of the liner pipes' Manning *n* value of 0.009. Typically annulus grouting is the most severe loading condition that the liner pipe ever experiences, even if the host pipe eventually structurally fails. For an annulus grouting pressure of 5 psi (34.5 kPa), the recommended minimum pipe stiffness is 36 psi (248 kPa). Pipe stiffness should be increased for higher annulus grouting pressures. Once the liner pipe is grouted in place, it is almost always then sufficient to safely withstand a "fully deteriorated" host line condition. Liner pipe insertion push distances of 1,000 ft (305 m) to 2,000 ft (610 m) are common and routine. The longest known single-drive push distance is 5,600 ft (1,707 m). Curves in the host pipe can sometimes be lined with shorter length pipes, but they may require elbows or even excavation if the radius is quite small. Each curve must be individually evaluated to ensure the passage of the liner pipe and the seal of the joint. Depending on diameter, it is possible to push through and seal at angles of 1 to 3 deg. For larger host pipe angles, elbows are needed to maintain the liner continuity.

5.9.3 Method Description

Sliplining rehabilitation is generally begun by assessing the host pipe condition relative to such items as size, shape, grade, sags, collapses, debris, curves, and angles. Workers confirm the liner pipe diameter for proper insertion fit. They then gain access to the host pipe from the open end or through an access shaft constructed over the line. Next they remove any debris and repair collapses or sags in the host line so that the liner pipe may be inserted without obstruction. No bonding to the host pipe is needed, so surface cleaning is not required. Workers then verify sufficient clearance for the liner pipe insertion by measurements or by pulling a mandrel or a pipe section through the host line. They slide the liner pipes into the host pipe by pushing consecutively as a "train." Organized contractors can insert a pipe every 5 min, resulting in up to 2,000 ft (610 m) lined in an 8-h day. Next, the workers confirm successful insertion by internal inspection via walk-through or by CCTV (all joints fully assembled and the liner undamaged). Last, they bulkhead the annulus at both ends of the run and fill the annulus with grout. This step may require blocking of the liner pipe or ballast to prevent flotation or excessive distortion.

5.9.4 Construction Requirements and Quality Assurance and Quality Control

To perform quality assurance and quality control, workers first verify that the liner pipe is undamaged and that all joints are fully assembled by an internal inspection via walk-through or by CCTV. If any liner pipe diameter distortion is noticeable, they verify that the liner pipe deflection is less than or equal to 5%. If required, they test the renewed pipe for leakage by infiltration, exfiltration, or low-pressure air testing.

5.9.5 Asset Management Requirements

There is no routine maintenance required for FRTR pipes. Cleaning may be done by washing and squeegee methods. If use of high-pressure spray is desired, workers can test small areas to determine safe conditions, such as nozzle type, distance, angle, and pressure to avoid damage to the pipe. Using metal buckets should be avoided to prevent surface damage.

5.10 COATINGS AND LININGS

5.10.1 Introduction and Background

Coatings shall be considered applications where a corrosion barrier is the only benefit derived from the renewal material being applied. The term *linings* implies that a corrosion barrier, a structural benefit, or both have been applied to the structure. Coatings and linings have been applied to culverts and storm sewers for many years. Applications include pipelines, catch basins, holding ponds, and numerous other elements of storm sewer infrastructure.

The principal objective of a coating or lining is to apply a monolithic layer that inhibits further degradation of the structure. The type of deterioration depends on the conditions surrounding and inside the culvert or storm sewer. Most corrosion problems are dictated by the type of soil around the structure. Acidic soils can cause deterioration in which collapse is the failure mode. Corrosive fluids from storm water runoff can also cause internal corrosion. This corrosion, coupled with the abrasive nature of sand and gravel transported in a storm event, can cause damage in the areas of the pipes exposed to the fluid being conveyed. The area that receives the most damage to abrasion is the invert of culverts and storm sewers.

Both coatings and linings can mitigate further degradation of these structures, but only linings can structurally enhance or structurally repair culverts and storm sewers. The most common materials used for renewal of these structures are cement mortar, 100% solids thermoset polymers, and sheet linings.

5.10.2 Product Main Characteristics

5.10.2.1 Introduction. Coatings and linings may be applied to renew and protect aging culverts and storm sewers or to protect new structures to extend their service lives. The primary materials used for coatings and linings fall into the three broad categories of cementitious, polymers, and sheet liners. These methods are sometimes used in conjunction with one another to provide an optimum solution.

Several properties are important to the success of these materials. In conjunction with chemical resistance and monolithic coverage, adhesion is generally regarded as a required attribute of coatings and linings. Other properties vary greatly between polymers and cementitious applications, the two most prevalent types of renewal used for culverts and storm sewers. Some products are excellent for bridging cracks in concrete structures but have low chemical resistance. Others exhibit excellent long-term strength but poor adhesion in damp environments. As for any renewal option, true project needs should be evaluated and matched with proven product attributes.

Moisture can weaken a product's curing process as well as its ability to bond to the existing structure. Moisture provides challenges in the proper substrate preparation and must be addressed before application of the specified coating or lining. Cementitious products are more moisture tolerant than the other categories of materials. Polymers have the least tolerance for moisture, and therefore care should be taken in the surface preparation step. Other attributes that should be considered include structural enhancement, permeability, chemical resistance, quick return to service, and maintenance requirements.

5.10.2.2 Cementitious Materials. Cementitious materials are used quite often in culvert and storm sewer renewal. Cementitious lining systems are economical but might provide poor corrosion protection in a corrosive environment (Walker and Guan 1997). Also, mortar does not tend to bond well to the steel surfaces but is instead held in place by its rigidity and shape (Galka and Yates 1984; Walker and Guan 1997). In a thin application, the primary goal is to inhibit further corrosion and improve hydraulic capacity. In the event that structural capability needs to be addressed, a thicker application of a cementitious product, such as gunite or shotcrete, should be used. When shotcrete and gunite are used, the hydraulic capacity may be reduced because of the reduction of the flow area of the culvert or storm sewer.

5.10.2.3 Polymers. Accelerated corrosion problems in today's infrastructure, as well as greater awareness of corrosion issues, have led to the development and use of coatings and linings to increase infrastructure life expectancies. As a result of inherent safety, performance, and quick return-to-service attributes, solvent-free 100% solids polymers have advantages for successful structural renewal and corrosion protection. These thermoset coatings and linings are essentially inert plastics when cured and therefore resistant to most corrosion elements found in storm water environments. They have long life expectancies when properly applied. Because these products contain no solvents, they require no evaporative process to cure and do not emit VOCs. Polymers with 100% solids are safer in confined spaces and can also be formulated for thicker, structural applications. Many of these products are now used in the underground infrastructure protection industry because they can cure and bond to concrete, brick, steel, and cast iron in underground environments. Most polymers deliver superior chemical resistance in the most corrosive environments, although manufacturers should be consulted for specific recommendations. Polymers can be formulated for structural or nonstructural applications. Most polymers used in culvert and storm sewer renewal have been formulated for ultrahigh build thicknesses that range from 125 to 500 mils (3.2 to 12.7 mm) in a single coat. Polymer coatings are sometimes used to topcoat cementitious products to further protect the renewed structure from the corrosive elements.

Epoxies. Epoxies generally take 2–8 h to set. Although they may have some tolerance to moisture, it is better to have the existing surface as dry as possible. This dryness minimizes any potential for delamination and ensures good adhesion to the substrate. Epoxies are generally rigid and can be formulated with high tensile and flexural strengths in structural renewal. In addition, they offer excellent chemical resistance in the storm water environment.

Polyurethanes and Polyureas. Polyurethanes and polyureas or hybrid formulations of both are extremely fast setting (the range of set time is 5–30 s), depending on the formulation. They are moisture-sensitive and require care in the preparation of the substrate surface. In some cases, an epoxy primer is used to assist in the surface preparation before application. Some of the 100% solids polyurethanes are self-priming and do not require a primer. Manufacturers should be consulted as to the nature of each product. These resins can be formulated to be flexible for coatings or rigid for linings. The flexible formulations can be used for nonstructural corrosion barrier applications, whereas the rigid products, with their high flexural properties, can be used for structural rehabilitation and corrosion protection.

Figure 5-26 shows polyurethane being applied to a 60-in. (1,524-mm) corrugated steel pipe. Figure 5-27 shows a typical spray unit for polyurea for nonworker-entry size culverts and storm sewers.

Polyesters. Polyesters typically use styrenated resins, which are rigid, moisture-sensitive, and can require extensive ventilation procedures in confined spaces. Few polyester formulations are used as independent

Figure 5-26. Left, Culvert Before Rehabilitation. Right, Spray-Applying of Polyurethane. Courtesy of Sprayroq, Inc.

Figure 5-27. A Spray-On Robotic Unit for Coating Small Pipes.

coatings in underground applications. Those available require intensive field chemistry and trained installers. The primary use of polyester resins is with the cured-in-place-pipe (CIPP) process.

5.10.2.4 Sheet Linings. PVC or polyethylene sheet liners have been used to protect underground infrastructure for the past 50 years. Today these systems are more typical in new construction, where the sheets can be anchored into poured concrete by placing sheets inside concrete forms. Joints must be welded after the forms are released. Sheet liners are used in renewal, generally in conjunction with the application of a poured-in-place concrete system.

5.10.3 Method Description

5.10.3.1 Introduction. The application of any coating or lining system requires the proper surface preparation of the substrate. It is necessary to clean and profile the surface before application. Also, most protective materials require that all active infiltration be stopped before application and require a relatively dry surface to attain long-term adhesion. Coating and lining systems can be applied either by machine or by hand. In small diameters, such as less than 36 in. (914 mm), applications are generally carried out using spincast equipment, with a rotating head that is winched through the structure. Larger pipes may also use robotic equipment, but installation is typically with hand-held spray equipment.

The objective of surface preparation is to provide a clean, sound surface with adequate profile and porosity that is essential to ensure proper adhesion. There are typically unanticipated difficulties in the renewal of culverts and storm sewers, ranging from active infiltration to the presence of various contaminants and abrasive materials. There are resources available to assist both the specifier and the trained applicator in selecting the right surface preparation methods. The National Association of Corrosion Engineers (NACE), the Society for Protective Coatings (SSPC), and the International Concrete Repair Institute (ICRI) have prepared extensive guidelines, including visual guides that aid in the proper selection of coatings and linings, surface preparation, and application methods (NACE 1994, 1997, 2000, 2002; ICRI 1997).

Cleaning is the first task and is often inadequately performed. For cleaning in worker-entry structures, mechanical abrasion is preferred whenever practical, but rust, latent concrete, and other surface contaminants can generally be removed by low- to high-pressure water cleaning, abrasive blasting, shot blasting, and power or hand tooling. For small and hard-to-reach locations, hand grinders and wire brushing may be used. If oil, grease, or other hydrocarbon deposits have contaminated the surface, steam or hot water blasting can be used, or other methods may be necessary to clean and decontaminate the surface chemically.

Surface preparation procedures strongly depend on the type of surface being prepared and the profile necessary for the lining or coating being applied. Some recommended surface preparation procedures for different materials are discussed below. The performance standard for cleaning is important and must be followed closely.

5.10.3.2 Concrete and Masonry. All concrete and masonry surfaces must be sound, clean, and free of dust and contaminants. Existing coatings that have failed because of incompatibility or debonding must be completely removed. Any form of release, curing compounds, toppings, waxes, oils, grease, and the like must be removed before application.

Cleaning for concrete and masonry materials can generally be accomplished with water cleaning, using equipment capable of 5,000 psi at 4 gal./min (34.5 MPa at 15.14 L/min), according to the NACE No. 5/SSPC-SP 12 (2002) and NACE No. 6/SSPC-SP 13 (1997). Methods such as high-pressure water cleaning, water jetting, abrasive blasting, shot blasting, grinding, or scarifying may be used to remove previous coatings, linings, laitance, or disintegrated materials. Detergent cleaning and hot water blasting may be necessary to remove oil and grease from the substrate. Chemical cleaning, such as acid etching with muriatic acid, can be used in certain situations. However, care must be taken to remove all the residual acid before the application of a coating or lining system. Whatever methods are selected for use, a uniform, sound, clean surface without excessive damage must be obtained.

5.10.3.3 Steel. Steel structures being coated or lined should be prepared to a white or near-white metal according to NACE No. 1/SSPC SP-5 (2000) or NACE (1994), based on the intended service environment and manufacturer recommendations for the specific coating or lining product. Oils, grease, soluble salts, and other contaminants should be removed before blasting. All scale, deposits, weld splatter, and soluble salts should be removed, and all rough and sharp edges should be rounded off before application. Surface preparation is generally accomplished by dry abrasive blast or power tool cleaning. Vacuum sweep can be used to remove the remaining dust and debris. The coating or lining must be applied promptly to avoid flash rust or contamination of the prepared surface.

5.10.3.4 Repair Processes. Repair and patching are necessary for final surface preparation, especially on concrete and masonry substrates. The procedures used for these process also depend on the type of substrate and profile created during the cleaning process.

Concrete and Masonry. Where necessary, voids should be filled and jagged surfaces profiled with repair materials compatible with the coating or lining to be applied. Any area exhibiting movement or cracking caused by expansion and contraction should be grouted and patched according to appropriate crack repair or expansion joint procedure provided by the manufacturer. All surfaces that show exposed structural steel, spalling greater than 3/4 in. (19 mm) deep, or cracks greater than 3/8 in. (9.5 mm) wide should be patched using a quick-setting, high-strength cement mortar or high-build, nonsagging polymer grout after initial cleaning. All concrete that is not sound or that has been damaged by chemical exposure should be removed. If, in the area to be patched, reinforcement is missing and radical cracking from a spall site exists, steel replacement should be considered by the project engineer.

In masonry structures where loss of mortar has created gaps greater than 1/4 in. (6 mm) between bricks or blocks, the voids can generally be filled using a compatible quick-setting, high-strength cement mortar. Whenever structural integrity is questioned, a 1/2-in. (13-mm) or greater basecoat of high-strength cement or additional polymer coating or grout should be considered.

Steel. Steel surfaces should be thoroughly inspected, and when necessary, ultrasonically tested to detect thin spots that may need reinforcement. Fiberglass fabric patches can be applied for structural enhancement. Fiberglass fabric may be rolled into applied resin, or chopped glass may be sprayed with the resin. Additional polymer coats and fiberglass layers may be applied to achieve greater thickness, fill remaining voids, cover exposed fibers, or add additional strength.

5.10.3.5 Application Equipment and Process

Introduction. Coating and lining systems range widely in their applications. The material is applied in one or more layers to the surface of a structure that has been adequately cleaned and prepared. Many coating and lining systems provide for both mechanical and chemical adhesion. The systems can be used to coat the entire structure or a portion of the structure.

Cementitious. In nonworker-entry culverts and storm sewers, cement mortars are applied to form linings that inhibit the continuing corrosion and abrasion caused by the storm water environment. Application is generally carried out by a spraying machine (Fig. 5-28), which is either fed through hoses from the surface, or, in larger structures, may have a hopper containing premixed mortar. Forward speed control of the machine is important to produce a consistent thickness of mortar. Whatever system is used, it is essential to centralize the equipment within the structure so that the coating is of constant thickness around the complete area of the structure.

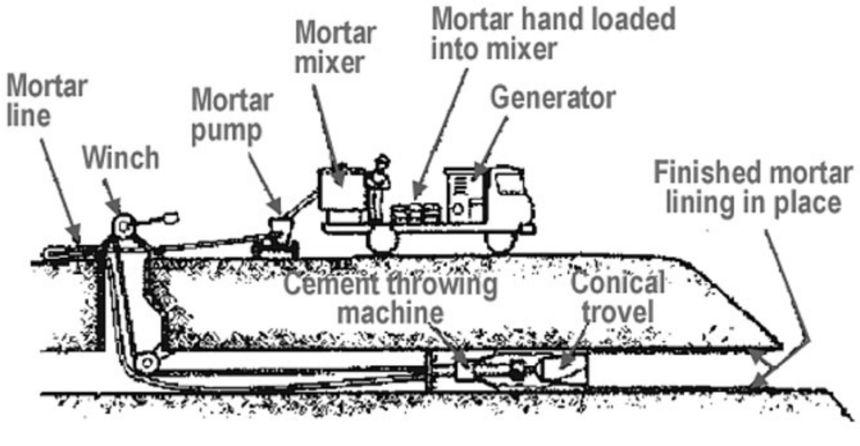


Figure 5-28. Cement Mortar Lining. Source: Caltrans (2002).

For worker-entry culverts and storm sewers, another method of spray-on lining is shotcrete or gunite, which is covered in Sections 5.3 and 5.4.

Polymers. In nonworker-entry culvert and storm sewers, polymer coatings and linings are generally applied with a spinning or rotating mechanical spinner nozzle. The polymer is applied only after the surface of the structure is properly prepared. Currently, nonworker-entry culverts and storm sewers are limited to corrosion protection applications. Recent developments in polymer chemistries show promise in the areas of structural reinstatement for these smaller diameter pipes.

Polymers have been widely used in worker-entry culverts and storm sewers. Because many storm water structures are not uniform in shape or size, the ability to use specialized spray equipment with a hand-spray gun is possible. Most polymer systems use plural component spray equipment customized to the characteristics of the particular polymer to ensure properly mixed and metered output. Such equipment can typically pump material more than 500 ft (152 m) to access difficult jobsites or can be placed into structures to accommodate extended application needs.

5.10.4 Construction Requirements and Quality Assurance and Quality Control

5.10.4.1 Introduction. Inspection and testing methods during installation of coatings and linings contained within this section are available through the product manufacturers and associations such as NACE, ICRI, and SSPC (NACE 1994, 1997, 2000, 2002; ICRI 1997). In general, some common procedures are included in the following discussions.

5.10.4.2 Visual Inspection. Visual inspection and project documentation should be carried out at a minimum by the project inspector. A trained inspector who is knowledgeable in the products used and their installation process should conduct the final visual inspection. Any deficiencies in the finished coating or lining system should be marked and repaired according to the manufacturers' recommendations.

5.10.4.3 Coating Thickness. For cementitious and epoxy polymers, thickness of the applied coating or lining can be randomly checked using a wet-film thickness gauge, such as those meeting ASTM D4414 (2007). This type of thickness gauge measurement is not practical for polyurethane and polyurea polymers because of their quick set times. For these types of polymers, an ultrasonic thickness gauge may be used for quality assurance. A more accepted process for ensuring the proper thickness is to perform a destructive pull test at randomly selected locations within a structure. Not only is the thickness verified by the pull test, as outlined in ASTM D4541 (2009), but the adhesion of the polymer to the substrate is also measured and verified. These test areas can be repaired easily with the proper procedure outlined by the polymer manufacturer.

5.10.4.4 Pinholes. Spark testing or holiday detection can be used to detect holidays or pinholes in a polymer coating or lining system and inadequately welded seams in sheet liners. After the protective coating or lining has set hard to the touch, the system can be inspected with a high-voltage holiday detection apparatus. Surfaces should first be dried; an induced holiday is then made on the newly protected surface. This induced holiday is used to calibrate the proper voltage to detect any additional pinholes or holidays that might be present. The proper starting test voltage can be determined by ASTM G62-87 (1998). All detected holidays are marked and repaired, following the coating or lining manufacturer's recommendations.

5.10.4.5 Adhesion. Bond strength of polymer coatings can be measured in accordance with ASTM D4541 (2009). Any areas detected to have inadequate bond strength should be evaluated by the project engineer. Further bond tests may be performed in that area to determine the extent of potentially deficient bonded areas and of repairs that should be made in accordance with the manufacturers' recommendations.

5.10.4.6 Vacuum and Exfiltration Testing. Additional tests are available for vacuum and exfiltration, in accordance with ASTM C1244 (2005) and ASTM C969 (2009) respectively. These tests have the primary objective of ensuring that the renewed culvert or storm sewer is completely monolithic.

5.11 HYDRAULIC CONSIDERATIONS

When renewing an existing culvert or storm sewer, one must take into account the existing conditions and the effect, if any, that renewal has on the system hydraulics. Original storm flow design calculations may be referenced, however careful attention should be given to changes in land use and design requirements that would change the calculated runoff tributary to the culvert or storm sewer. Once a storm water runoff discharge has been determined, the required diameter of the renewal method may be established. If original design calculations are not available, the project engineer should complete a thorough drainage study. A culvert diameter can be selected based on watershed attributes, design storm, allowable headwater, culvert entrance conditions, and other related design factors.

Table 5-6. Mature Gravity Pipe Manning *n* Values

Type of Conduit	Mature Sewer Design Values[a]	Average Worst-Case Field Values[b]
Polyethylene sliplining	0.010	0.013
PVC	0.011	0.013
Fiberglass	0.010	0.013
CIPP	0.010	0.013
Corrugated ID HDPE	0.022	0.025
Spiral-wound PVC	0.013	0.016
PVC fold and formed	0.010	0.013
HDPE deformed	0.010	0.013
Concrete		
Precast	0.013	0.016
Cast-in-place	0.013	0.017
Concrete box	0.013	0.018
Vitrified clay	0.013	0.015
Glazed brickwork	0.013	0.015
Brick and mortar	0.015	0.020
Cast iron	0.016	0.018
Ungalvanized steel	0.016	0.018
Cement mortar lined ductile iron	0.012	0.017
Corrugated metal–angular helical corrugations (CMP)		
68 × 13 mm (2 2/3 in. × 1/2 in.)	0.024/0.017	0.026/0.020
76 × 25 mm (3 in. × 1 in.)	0.027/0.024	0.029/0.027
127 × 25 mm (5 in. × 1 in.)	0.025/0.023	0.027/0.024
152 × 51 mm (6 in. × 2 in.)	0.035	0.036
229 × 64 mm (9 in. × 2 1/2 in.)	0.035	0.037
Paved invert	0.021	0.024
Fully paved	0.013	0.019

Note: Because field conditions vary widely, the designer must decide which *n* value to use from the range shown.
[a] Expected values when the full extent of field variables has occurred.
[b] Typical value with expected worst-case field variables.
Source: ASCE Pipeline Division (1996).

Typically, gravity-flow storm water systems are designed using Manning roughness coefficients with an *n* value between 0.012 and 0.024, depending on the pipe material type. Culverts or storm sewers in need of renewal typically do not have Manning *n* values equivalent to original design values. The renewal method may result in a lower Manning *n* value for the system and may therefore improve flow conditions in spite of cross-sectional reduction caused by the specific renewal method. Changes in the Manning *n* value or reductions in pipe diameter also can result in a velocity increase across the system. The potential for an increase in velocity and its effect on the culvert pipe and downstream erosion, if applicable, should be evaluated as part of the overall renewal process. Table 5-6 lists the Manning *n* values of renewed gravity pipes.

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6

SUMMARY

The purpose of this manual is to provide a resource for engineers, agencies, consultants, and others who are not familiar with or need a refresher on culvert and storm sewer renewal. The objective is not to provide details on all the issues related to culvert and storm sewer renewal. Some subjects are described in general, followed by supporting references and Internet links, where the reader can get more detailed information. For example, this book does not include a detailed defect classification and scoring system to determine culvert renewal priorities. However, culvert evaluation and assessment are described and references are provided where more detailed information can be found.

For the purpose of this manual, culverts and storm sewers are defined as having a diameter or equivalent diameter range between 12 in. (305 mm) and 144 in. (3,658 mm), with at least one open end. The manual covers such topics as safety, cleaning and inspection, condition assessment and evaluation, description of trenchless renewal methods, and life-cycle considerations. Chapter 5 presents renewal methods, where the most important information and the most detailed discussions are found. In this chapter, important topics, such as background information, installation procedures, design considerations, installation requirements, asset management, quality assurance and quality control and inspection requirements, are presented.

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