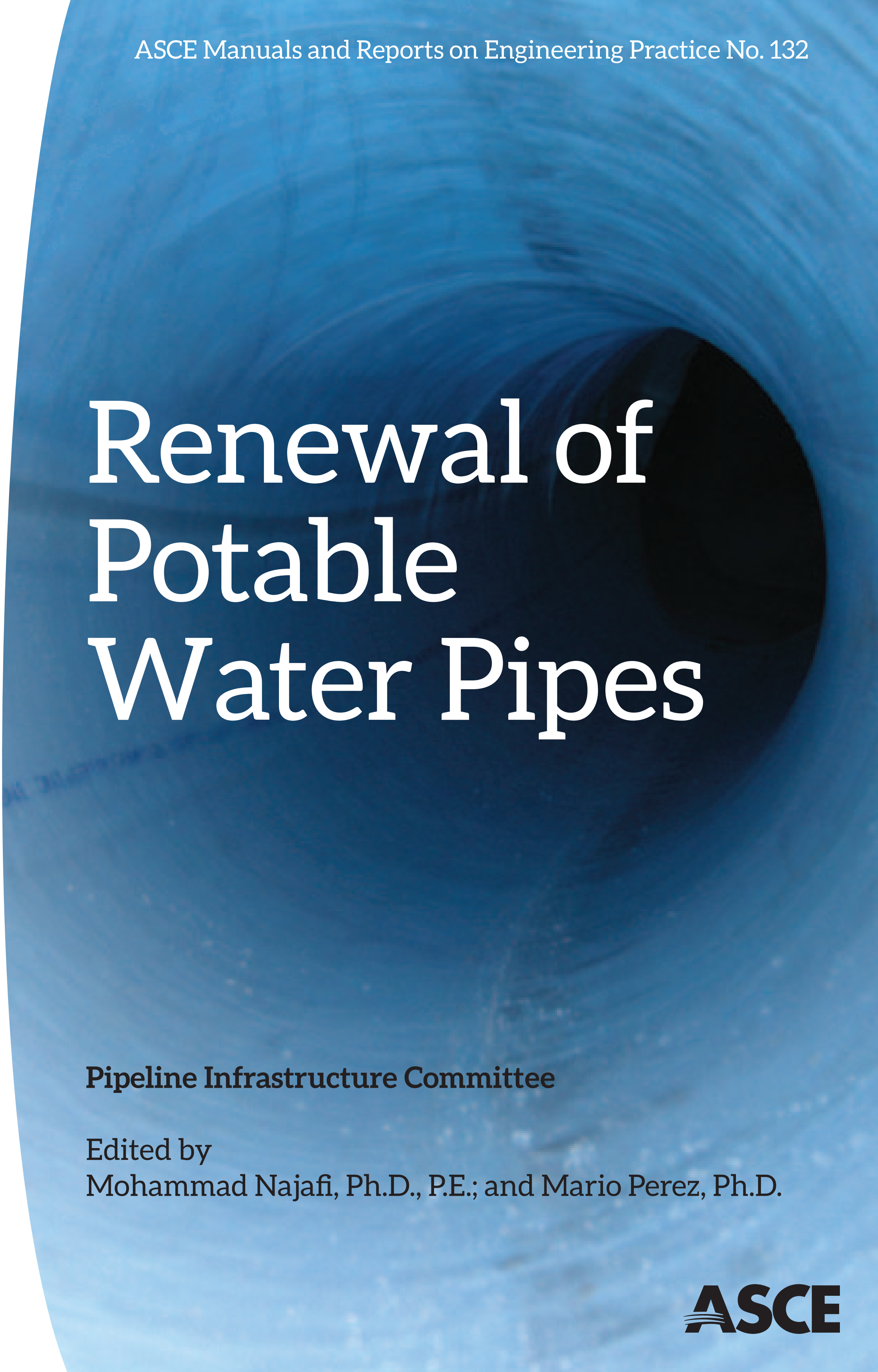

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Renewal of Potable Water Pipes

Pipeline Infrastructure Committee

Edited by
Mohammad Najafi, Ph.D., P.E.; and Mario Perez, Ph.D.

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PREFACE

The purpose of this manual is to provide engineers, water agencies, consultants, pipeline owners, and municipalities with a resource to use when considering a trenchless water pipe renewal project. This manual focuses specifically on renewing potable water pipes. The reader is referred to *Pipe-Bursting Projects*, ASCE Manual of Practice No. 112, for consideration of trenchless pipe-bursting and replacement approaches. The objective is to provide an updated and comprehensive review of the trenchless pipeline renewal methodologies for potable water pipeline applications, with emphasis on planning and construction operation. A set of references and standards is provided so that the reader can obtain further details on a particular subject. This document is organized to reflect the order in which a trenchless potable water renewal project is typically carried out.

This manual covers such topics as planning and construction requirements, cleaning and pre-renewal inspection, lining operation, safety, certification, and final inspection. Trenchless renewal methods applicable to potable water pipes are described in Chapter 5. In this chapter, important topics, such as background information, installation procedures, design considerations, and special installation requirements, are presented. The topic of condition assessment of host pipelines will be covered in a future ASCE Manual and Report on Engineering Practice.

CHAPTER 1
GENERAL INFORMATION

1.1 OVERVIEW

Several good textbooks and manuals describe pipe renewal techniques. However, this Manual of Practice (MOP) addresses a gap in the literature and provides a resource for design engineers, municipalities, federal and state government agencies, consultants, and others who are not familiar with or need a refresher course on *potable water pipeline renewal technologies*. At the same time, this MOP is intended as a reference document for those who engage in pipeline renewal on a daily basis, such as water pipeline owners, engineers, technicians, and operators responsible for the implementation of water pipeline renewal projects.

This manual provides background information on water pipeline renewal design and describes technologies with enough detail to provide assistance in selecting the right technique for a given set of specific project conditions and requirements. It should be noted that the terms "renewal," "rehabilitation," and "relining" are used interchangeably in this manual; however, they do not include pipe bursting and replacement. Renewal and rehabilitation include all aspects of upgrading performance of a host pipeline with an improved or new design life. Pipe bursting can be used to replace water pipelines and is used particularly to upsize the capacity of a host pipe. Pipe bursting can also be used in situations where open-cut (OC) techniques on the entire stretch of the pipeline are not possible or where excavation is very expensive and social costs of using the open-cut method or installing a parallel line are high. ASCE MOP No. 112 presents pipe bursting and replacement methods using trenchless technology in detail, and the reader is referred to this manual for more information on these techniques.

Although not a trenchless method, open-cut always needs to be considered as an option for pipe replacement. Open-cut involves disturbing the ground (both surface and subsurface) and requires potentially costly pavement repair or replacement and/or proper disposal of any contaminated soil that might be discovered. Compared with a trenchless method, OC is often more costly and takes more time to complete (Najafi 2013). Most of the extra cost of OC over trenchless methods (approximately 70% of the open-cut costs) is for restoration of the site, shoring installation and removal, traffic control, backfill, and embedment and compaction, and there is a possibility of pipe damage during compaction and embedment efforts. The OC method can also disrupt traffic and damage trees and green areas (refer to Najafi 2005, for more information).

1.2 CHALLENGES AND CONCERNS

Renewal and maintenance of buried pipelines is a major challenge faced by engineers, utility owners, and decision makers. The U.S. Environmental Protection Agency (USEPA) estimates that nearly $1 trillion will be needed in critical drinking water and wastewater investments over the next two decades (ASCE 2013). Efficient management of these funds will require tools that managers and decision makers can employ to optimally allocate funds and prioritize infrastructure improvements (Deb et al. 1999).

The deterioration rate of buried pipes is a function of many factors such as material, age, soil conditions, flowing fluid composition and its hydraulic character, and the frequency or lack of maintenance. Usually the cumulative effects of these different factors rather than each individual factor determine the condition of the pipe (Fig. 1-1). Pipe failures affect customers with service stoppages and traffic disruptions (Kanchwala 2010).

According to a report by the American Water Works Association (AWWA), both internal and external forces on water mains have major impacts on their expected useful life (AWWA 2001 and AWWA 2014). Fig. 1-2 illustrates the deterioration rate over time for cast iron pipes.

As shown in Fig. 1-2, water pipes, like any other asset, decrease in performance level with time. The life of pipes can vary subject to their environment (soils, water quality, internal and external pressures and loads, temperature changes, soil movement, joint condition, etc.). Furthermore, each pipe component is part of an integrated system, and its behavior may affect the overall service of the pipeline system. However, the expectation for quality of service is not constant; for instance, new legislation, changes in urban development, and customer needs and expectations may change the quality criteria. The fact that most water

Fig. 1-1. Effects of tuberculation, age, and corrosion on water pipes
Source: 3M Water Infrastructure; reproduced with permission

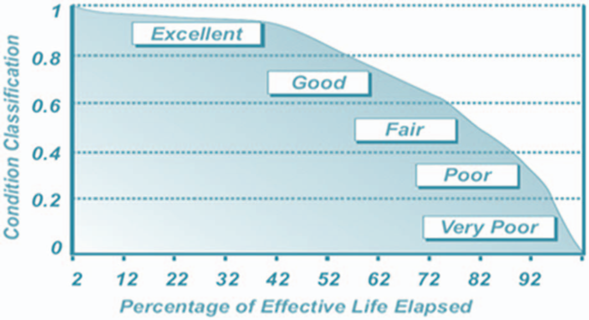

Fig. 1-2. Lifecycle deterioration curve for pipes
Source: USEPA (2002)

pipes are buried adds complexity and cost to the problem of assessing their condition. Water pipe asset management is, therefore, a complicated and challenging matter (Alegre and Cabrera 2006).

Beginning in the mid-1800s through the 1950s, most water pipes installed in the United States were manufactured from gray cast iron. In some parts of the country, aggressive water has caused deteriorating conditions, reducing the structural integrity of unlined metallic pipes and resulting in the loss of hydraulic capacity due to internal corrosion and tuberculation.

1.3 ENVIRONMENTAL AND SOCIAL IMPACTS

As mentioned in the overview, water pipe renewal or rehabilitation, in contrast to open-trench pipe replacement, minimizes excavation by utilizing access pits with minimal impacts during the process. But it is important to recognize that there are some impacts with pipe rehabilitation activity as well. Entry point access may in some cases have some undesirable effects, such as traffic disruptions, dust, and noise. Perhaps the largest disruptions from rehabilitation construction are caused by temporary service lines placed along the curb. This exposed piping might be a traffic hazard and a potential target for vandalism.

On balance, renewal methods can yield significant benefits and reduce environmental and social impacts. The limited work areas that are typical of rehabilitation projects mean a decreased need for heavy equipment and less movement of materials and equipment in the work area. Social benefits of using trenchless renewal instead of open-cut replacement may include

- Reducing the possibility of damage to surrounding utilities, structures, and pavement;
- Reducing vehicular traffic disruptions;
- Reducing negative effects on businesses;
- Enhancing public safety by reducing the amount, size, and duration of open excavations; and
- Decreasing the time needed to complete the work.

1.4 SUSTAINABILITY ISSUES

Sustainability considerations are increasingly important in the planning, design, and implementation of construction projects as well as pipeline renewals. A design engineer must consider the impact of the selected renewal product and application process on economic, social, and environmental sustainability—considerations known as the triple bottom line. As an industry, trenchless and renewal technologies are now in the mainstream of sustainable solutions to environmental and infrastructure-related challenges.

The 1987 Bruntland report from the World Commission on Environment and Development (WCED 1987) defined sustainable development as “development that meets the needs of the present generation without compromising the ability of future generations to meet their needs” (resolution adopted by the General Assembly of the United Nations). The renewal of water lines should promote practices that are part of infrastructure sustainability.

Long-term internal corrosion typically found in unlined ferrous mains can result in tuberculation, thereby reducing the pipe's carrying capacity and increasing water-quality issues. The reduction in carrying capacity requires increasing investments in power and pumping, causing a trade-off between the reduction in hydraulic capacity and the increased operation and maintenance costs to get water from one point to another. Bacterial growth within tubercles may cause a potential health problem. Along with tuberculation and internal corrosion, a metallic pipe weakens progressively due to external corrosion. Reductions in pipe strength and increased pumping pressures can result in pipe ruptures and additional repair costs.

The USEPA has defined the following four pillars of infrastructure sustainability (USEPA 2014):

- **Better management** of water and wastewater utilities can encompass practices such as asset management and environmental management systems. Consolidation and public/private partnerships could also offer utilities significant savings.
- **Full cost pricing** ensures that utility rates reflect the true cost of service and asset maintenance.
- **Efficient water use** is critical, particularly in those parts of the country undergoing water shortages. Utilities can provide incentives through their water rates to encourage more efficient use of water by customers to protect limited water resources. Water wasted includes not just leakage but also excessive flushing to overcome poor water quality.
- **Watershed approaches** look more broadly at water resources in a coordinated and regional way.

Renewal of water pipes in long-term planning should address sustainability. Improved decision making, prioritization, and selection of rehabilitation technologies offer advanced infrastructure management and watershed approaches that consider the full impact of alternatives to the environment. Cost-effective solutions such as pipe rehabilitation will enhance the ability of water utilities to meet full cost pricing by reducing overall lifecycle costs and providing service more affordably to customers. Solutions that provide long-term planning minimize water loss and therefore provide efficient water use. Replacing water infrastructure is expensive, as are the social costs incurred when infrastructure repeatedly fails. If a system is well maintained, it is more likely to operate safely over a long period of time. Water utilities should have an ongoing process of inspection, evaluation, maintenance, and replacement of their water assets to maximize the useful life of their system.

1.5 PURPOSE AND SCOPE

The purpose of this Manual of Practice is to provide information on appropriate renewal technologies with a focus on design, evaluation of candidate methods, and installation. It includes a discussion of material selection, method applicability and host pipe cleaning and requirements.

1.6 CERTIFICATIONS

National standards regulate materials used for water pipe renewal because of contact with the public water supply. Adopted in 1988, NSF/ANSI 61 (NSF 2013) addresses a crucial aspect of drinking water system components: whether or not contaminants that leach or migrate from the product or material into the drinking water meet acceptable levels in potable waters. When a material is certified under NSF/ANSI 61, its certification will specify any use restrictions such as maximum use temperature or surface area to volume ratio. The certification also specifies how the material is applied or made ready, such as main flushing requirements. Unlike most materials certified under NSF/ANSI 61 for use in water contact, some rehabilitation lining products are introduced into the potable water market after many years of experience with original material in other applications. Ensuring that the renewal product is compliant, applied properly, and utilized for the intended application and service environment, is important.

In almost all cases, NSF/ANSI 61 is the relevant standard specified by various states and Canadian provinces. General classes of materials are not certified by these certifying bodies; rather, specific products and formulations are certified, with annual recertification.

Additional certifications and standards apply to plastic pipe lining techniques. According to the Plastics Pipe Institute (PPI), high-density polyethylene (HDPE) is manufactured according to AWWA C901 (AWWA 2008b) (3 in. [75 mm] and smaller) or AWWA C906 (AWWA 2007a) (4 in. [100 mm] and larger, up to approximately 63 in. [1,575 mm]). PVC pipe is manufactured to specified standards for PVC water pipe and can be certified to AWWA C900 (AWWA 2007c) and AWWA C905 (AWWA 2010). Water utilities must consider these additional guidelines and standards with use of HDPE and PVC materials.

1.7 CHAPTER SUMMARY

With aging infrastructure, water utilities face a major challenge with renewal and replacement of their potable water pipelines system. Pipeline renewal (rehabilitation) methods provide cost-effective and environmentally friendly solutions compared with traditional open-cut replacement and installation methods. In addition to costs and environmental and social benefits, water utilities need to consider sustainability and renewal material certifications. This Manual of Practice provides information regarding appropriate renewal technologies with focus on design, method applicability, and installation.

CHAPTER 2

PLANNING AND RENEWAL SELECTION PHASE

2.1 PLANNING ACTIVITIES

Proper planning helps to ensure that the renewal of potable water pipes will meet the standards, and needs of the owner. The major activities that typically are performed during the planning phase include

- Establishing project requirements and objectives;
- Assessing background: identifying risks, constraints, etc.;
- Identifying and screening alternatives;
- Collecting data; and
- Evaluating and selecting design alternatives.

To ensure an appropriate rehabilitation method is selected, planning should also reflect on information gathered about the pipe to be renewed or rehabilitated. This is especially true if nonstructural pipe rehabilitation is under consideration.

2.2 PREDESIGN SURVEYS

Predesign surveys help to identify and obtain preliminary information needed for the design of the project. Typically, the owner and/or the engineer should obtain as much information as possible to incorporate into the design, rather than shifting this responsibility to contractor. Information critical to the contractor's successful completion of the project can then be verified by the contractor in the field, prior to beginning the work. The bidding and contract documents should delineate the extent to which the bidders (the contractors) can rely on information supplied by the owner.

2.2.1 Site Conditions and Surface Survey

Site conditions, including surface improvements, must be thoroughly investigated and documented. The following details should be part of this documentation:

- A thorough mapping of the host pipe being considered for renewal, including depth, size, and pipe material. The data shown on as-built drawings of the original project must be verified.
- Determination of valve and fitting locations.
- Location of other existing utilities, both parallel and perpendicular to the host pipe. This detailing should include the depth of these other utilities if they are within the potential zone being impacted by the renewal process.
- Detailed notes showing surface improvements such as trees and shrubs, type of ground cover, and pavement condition. All pedestrian and motor vehicle traffic paths should be noted.
- Condition assessment data and related information about pipe performance (fire flow tests, main break history, water-quality complaints, etc.).
- Type of paving identified as public or private, with jurisdiction (state, county, local, etc.).

When any of these details cannot be ascertained, the plans should be noted to reflect that the information is missing. All of these missing items should be field verified by the contractor prior to beginning work.

2.2.2 Subsurface Survey

In the design and specification of trenchless renewal, the existing underground site conditions (or subsurface conditions) should be investigated and documented at least to the degree appropriate for the technology selected. The following items may be considered for renewal of water pipes:

- Excavation of the host pipe must be done to document the pipe material and joint design if insufficient design drawings and as-built information are available.
- Internal inspection can help to identify other conditions within the host pipe that can affect renewal, including pipe tuberculation, repair couplings and fittings, offset or misaligned joints, and the location and protrusion into the pipe of service connections.
- Sampling and testing of the host pipe water quality allows a determination of the suitability of the lining.
- A flow test can indicate the condition of water pipeline interiors. This can be done by measuring flow and estimating the internal pipe wall friction and roughness.

Some of the available renewal technologies simply do not work successfully in certain ground conditions or are not compatible with specific host pipe materials. In terms of understanding the potential savings of rehabilitation when compared with open-cut, knowing the type of pavement and traffic conditions is helpful. For example, cutting or trenching into a concrete state highway has a far different cost than trenching into a typical suburban street. Proper information at the planning stage is essential in selecting the proper materials and methodology for the project.

2.3 PERMITS

Permits are typically permissions granted to the utility owner to construct, replace, or renew a pipeline under an existing facility or public right-of-way. Although the permitting entity will hold the water pipe owner ultimately responsible for any violations of the permit, the contractor will also be responsible (to the water pipe owner) for compliance with permit requirements pertaining to the construction. Permits can require a lengthy processing time to obtain, and therefore are typically obtained by the water pipe owner during the project design phase. Therefore, the contract documents should list all construction requirements for all permits obtained for the project. The contract should also require the contractor to adhere to the requirements of the permits. The required permits must be identified as early as possible during the project planning phase, and measures to secure the permits in a timely fashion must be taken.

2.4 BUDGET CONSIDERATIONS

Renewal of water pipes project costs are based on direct costs (labor, materials, and equipment), indirect costs (field overhead and home office overhead), and markup (insurance, bonding, contingency, and profit). Design and consulting engineers and water utilities need to evaluate the specific conditions of each project and select the renewal method or methods that can safely and cost-effectively fulfill specific project objectives and requirements. The selection of a renewal method should not always be left to contractors, because contractors may be optimistic and may want to execute a project for several reasons, such as a current lack of work and availability of equipment and crews.

Another important consideration is the social costs of the water pipe renewal, which typically are not included in typical cost breakdowns. As mentioned in Chapter 1, social costs include inconvenience to the public;

traffic disruption costs; damage to pavement, existing utilities, and nearby structures; noise and dust problems; loss of business; safety hazards of trenching; and damage to the environment and green areas. Trenchless technology renewal methods typically reduce social costs, and, if these costs are considered, renewal projects may be more cost-effective than open-cut methods of replacing or renewing the pipe. However, contractors cannot include these costs in their bids unless they are specifically provided by owners and engineers within a lifecycle-cost approach in project planning.

Project-specific conditions are cost drivers for all construction projects. Consulting and partnering with experienced and reputable contractors can assist in the planning process.

2.5 SELECTION OF RENEWAL TECHNIQUES

Weighing the project requirements against the capabilities and limitations of various available trenchless renewal methods can be overwhelming. Using a decision support system or decision tree can optimize the method-selection process based on the requirements of the project and priorities set by the project owner. No textbook or software program can make a proper recommendation for specific conditions and requirements of a project, so consulting and design engineers should work with project owners to rank and weigh project priorities and then make recommendations for specific methods. The specifications can allow for multiple renewal methods to gauge the methods against the costs. Decision support trees and logic to guide in selecting a technique can be found in Deb (2002), Najafi (2005), Najafi (2010), and Matthews et al. (2012). A decision tree is also provided in AWWA M28 (AWWA 2014).

2.6 GENERAL DESIGN CONSIDERATIONS

The proper selection of lining materials, their physical properties, and application methodology provide a way to find suitable solutions for a range of pipe and pipe conditions. This process includes consideration for host pipe valves and appurtenances, bends, and service connections. Other factors include pipe material and conditions, operating and surge pressures, number of service connections, installation length, renewal objectives, structural capabilities of the host pipe, and soil and live loadings. If a lining is proposed, determination of the liner thickness is an important design parameter, and the physical properties of the liner material have great bearing on it. Depending on how much deterioration is present in the pipe to be renewed, project designers may choose to utilize liners among the categories described in AWWA M28 (AWWA 2014) as summarized below:

- **Class I linings**: These linings are nonstructural systems used primarily to protect the inner surface of the host pipe from corrosion, such as the traditional cement mortar lining (CML) and nonstructural polymers such as epoxy.
- **Class II and III linings:** These linings are called semistructural because they interact with the host pipe. According to AWWA M28 (AWWA 2014), Class II and III liners are not expected to survive burst failure of the host pipe, because their long-term (50-year) internal burst strength is less than the maximum allowable operating pressure (MAOP) of the host pipe. Some of these liners are capable of bridging certain holes and gaps. Class II liners have minimal ring stiffness and depend entirely on adhesion to the pipe wall to prevent collapse if the pipe is depressurized. Class III liners are self-supporting with no dependency on the pipe wall adhesion. Use of Class II and III liners is recommended when the host pipe has discernible internal corrosion leading to pinholes and leakage, leakage from faulty joints, and localized external corrosion. Examples of Class II and III liners are close-fit semistructural linings that can span holes and gaps in the host pipe, but have minimal thickness and require support from the host pipe to prevent collapse during depressurization.
- **Class IV linings:** These linings are fully structural—essentially a pipe within a pipe—and they possess a 50-year internal burst strength, when tested independently from the host pipe, equal to or greater than MAOP of the host pipe. They also have the ability to survive any dynamic loading or short-term effects associated with sudden failure of the host pipe due to internal pressure loads. Class IV linings are sometimes considered to be equivalent to replacement pipe, although such linings may not be designed to meet the same requirements for external buckling or have the same longitudinal/bending strength as the original pipe.

It should be noted that some renewal technologies can offer Class II, III, and IV linings, depending on the type of application, MAOP, their material characteristics, design thicknesses, and installation methods. For more information, refer to AWWA M28 (AWWA 2014).

2.7 CHAPTER SUMMARY

This chapter presented planning considerations for a potable pipeline renewal project. It is important that design and consulting engineers along with water utilities conduct a thorough investigation of host pipe conditions to select appropriate renewal methods based on the short-term and long-term objectives. Among factors to consider are surface and subsurface conditions, operating and surge pressures, external loadings, pipe bends and appurtenances, and degree of corrosion. Depending on the material properties, thickness design, and installation conditions, some liners may provide semistructural or structural application.

CHAPTER 3
PRECONSTRUCTION PHASE

3.1 INTRODUCTION

The purpose of any water transmission and distribution system is to maintain a continuous supply of safe water to satisfy customers' needs, which often include fire protection. This charge remains of primary importance even as rehabilitation work is performed. Depending on the cleaning or lining method used, temporary distribution system shutdowns may occur. Many water pipeline networks are built with sufficient redundancies in their large-diameter transmission mains to allow for pipeline downtime without causing disruption to customers. For pipelines without redundancies, some processes require only brief shutdowns, tolerable for customers, allowing work to be completed without the installation of bypass lines. However, most renewal techniques require more extensive shutdowns that require the installation of bypass piping if redundancies within the host pipeline network are not in place.

3.1.1 General Description

Generally the water utility provides the general design of the temporary bypass system. The plan should include the pipe diameter, layout of the bypass piping, the type and locations of temporary fire hydrants, and their connections to still-active pipelines at the perimeter of the project area.

3.1.2 Bypass Piping

Prior to installation, the water utility and contractor should jointly review the plan, keeping in mind customer service issues and traffic concerns. Other considerations include points of connection to individual customer services, overall demand, and fire protection demand (i.e., pipe sizing). Bypass supply typically comes from fire hydrants or other temporary connections outside the area of the shutdown. The use of bypass piping allows long shutdowns while still maintaining acceptable service to consumers. The hydraulic requirements of the area affected by the renewal work establish the parameters for sizing the bypass piping network. Temporary connections may be required for customer fire protection (sprinkler lines), depending on local jurisdiction. After the bypass piping has been sized and installed, it must be disinfected as directed in ANSI/AWWA C651 (AWWA 2014) before being placed in service. Connections should always maintain positive pressure in the bypass pipes. Leakage should be minimized to enhance water conservation, limit possible hazards, and maintain customer confidence, using high-quality pipe materials that are appropriate for the project conditions.

In laying out a temporary water system, putting pipe on both sides of the street is generally necessary. Typically, a 4-in. (100-mm) pipe is used on the side where temporary hydrants will be installed, and a 2-in. (50-mm) pipe is used on the opposite side of the street where only domestic water is required. Thus, if a project includes the rehabilitation or replacement of 5,000 ft (1,524 m) of pipe, approximately 10,000 ft (3,048 m) of temporary bypass piping may be required. Of course, additional piping will be required to connect to the active system, which is generally accomplished at hydrants. Valves should be installed at all sources and tees and on the temporary line every 500–1,000 ft (150–300 m).

Temporary pipe street crossings are generally buried in a shallow trench. Driveway crossings may be buried, ramped, or covered with blacktop (asphalt concrete) or other suitable materials. Residential connections are made through a meter pit if available or a hose bib or interior pipes if necessary.

Water-consuming commercial and industrial connections are likely to be larger than those found in residential areas and may require larger bypass piping. Connections to the larger services may require excavations and connections near the curb valves to avoid the necessity of larger diameter pipes crossing sidewalks. Temporary water systems are usually made of galvanized iron, flexible hose, butt-fused high-density polyethylene (HDPE), or restrained joint PVC.

3.1.3 Installation and Removal

A separate crew may be used to perform preinstallation work to include installing the temporary water system for a typical residential or light commercial bypass project. Work includes the pipe taken out of the truck or trailer, coupled together, and then followed by a crew covering driveway crossings with sand, cold asphalt patch, or another suitable material.

Where road crossings are necessary, pavement is cut ahead of time so that the pipe can be installed below the surface. Piping can also be installed through storm drain crossings (culverts), if available, thus avoiding pavement cutting and restoration. Approximately 15,000 ft (4,570 m) of 2-in. (50-mm) or 10,000 ft (3,000 m) of 4-in. (100-mm) pipe make up a load of pipe carried on a tractor trailer. The weight of the pipe is not the limiting factor for truck capacity.

For galvanized iron pipe, production rates of about 1,500 ft (457 m) of 2-in. (50-mm) or 1,000 ft (300 m) of 4-in. (100-mm) pipe can be installed per day per crew, taking into account the items to be completed as previously outlined. This compares with 2,500 ft (760 m) of 2-in. (50-mm) and 1,500 ft (460 m) of 4-in. (100-mm) for PVC pipe. For HDPE pipe, approximately 1,000 ft (300 m) of 4-in. (100-mm) and 750 ft (230 m) of 6-in. (150-mm) can be installed per day with the same crew as outlined. Removal can be performed faster. The galvanized iron pipe, with the appropriate couplings, needs only to be loosened to pull the joints apart. Two workers are generally required to handle even the 2-in. (50-mm) pipe, because a 20-ft (6-m) length weighs more than 70 lbs (32 kg). A 20-ft (6-m) length of 2-in. (50-mm) PVC pipe weighs about 13 lbs (6 kg), so handling a PVC pipe is much easier.

Butt-fused HDPE pipe has the potential advantage, on some occasions, to have long lengths of 500 ft (150 m) or more pulled intact to the next street or section, thus avoiding the need to disassemble and reassemble the pipe. When the butt-fused HDPE pipe is removed, it is first cut into 40-ft (12-m) lengths with a saw. Cuts are made away from any service taps that may have been installed such that the pipe can be fused again on the next project. Restrained joint PVC can be moved in long segments, also minimizing disassembly and reconnection of pipe segments.

3.1.4 Flushing and Disinfection

As with any water system that has been exposed to possible contamination, flushing and disinfecting the temporary water system is necessary. This process is usually completed with the slug method of disinfection using 50 mg/L (4.17×10^{-4} lbs/gal) of 5.25% chlorine solution as outlined in ANSI/AWWA C651 (AWWA 2014). In other words, 1.3 lbs (0.6 kg) of solution is needed to disinfect 1,000 ft (300 m) of 2-in. (50-mm) pipe, 5.2 lbs (2.34 kg) for 4-in. (100-mm) pipe, and about 12 lbs (5.45 kg) for 6-in. (150-mm) pipe. Once the pipe has been exposed to the 50 mg/L (4.17×10^{-4} lbs/gal) solution and flushed, samples are taken for bacteria analysis.

3.1.5 Service Hoses

Most residential and small commercial users are connected to the temporary water system with a 0.75-in. (19-mm) NSF International-approved service hose. Hose bibs, meter pits, curb stops, and inside meter locations are all used to make the connection to the temporary service hose. All are viable options, although inside connections, which require entering buildings to make the connection, will increase liability exposure and can give customers concern about security. It should be noted that connections at the curb stop require excavation.

Large commercial and industrial services, including fire services, may require excavations and taps to be made into the customer service line if no other means of providing water is available or if higher flows are necessary.

3.1.6 Cost Considerations

Many variables go into the cost of a temporary water system. These include, but are not limited to, the size and length of pipe required; number, size, and type of services to be connected; number of hydrants to be provided; number of street crossings; number of driveways to be crossed; proximity of feed hydrants to the temporary system; number of traffic signs required during installation and removal; and length of time that the temporary system will be required.

The contractor is generally responsible for the maintenance of the system during off hours, including weekends and holidays. A 24/7 call system is usually part of the bypassing program. In some cases, maintenance of the bypass line may be provided by the water utility.

The cost of the temporary system can be a significant portion of the rehabilitation project. Temporary water systems may be bid as a lump sum item or bid on a per foot basis, depending on pipe size, and separately from host pipe cleaning and lining. Temporary water systems may be quoted on a monthly rental basis as well.

3.2 CONTRACT DOCUMENTS AND SPECIFICATION DEVELOPMENT

3.2.1 Prequalifications

The purpose of prequalifying contractors is to ensure that the project specification yields the highest quality product or technical process that the design engineer has developed for the benefit of the taxpayers or utility customers. The requirements for contract documents, specifications, and bid submittals may vary significantly depending on the rehabilitation technology. This section provides a general framework for prequalifying contractors.

Prior to the project bid, each project prequalification statement is reviewed by the project owner to determine whether the contractor is qualified. The experience of the contractor's field personnel and the equipment used on the project are analyzed in this statement. The materials and technology used in the project are reviewed and approved in the appropriate sections of the project specifications.

The following items are to be included in the prequalification statement:

- The experience of field personnel who have performed, successfully, on similar projects.
- A complete list of the equipment to be used on the project.
- A contact list of water utilities that have successfully completed similar projects with the contractor. The project list from the contacts would detail such information as the diameter of the water pipeline, scope and difficulty of the project, the specific type of renewal technology used, and any special conditions. The water utility should feel free to contact other water utilities to secure additional information.
- Experience with a minimum total footage of process or product, similar to that specified for the project, can be required at the discretion of the water utility. This requirement may increase the success of the project.

3.2.2 Bid Submittals

The engineer should provide the contractor with flexibility to establish the renewal procedure (i.e., installation lengths, pit locations, etc.), or require a work plan prepared by the contractor to be approved by the engineer and/or the owner. The specification should not describe how to locate pits except in areas that the contractor cannot excavate or locate equipment (e.g., major intersections or hospital or fire station access). The contractor should submit the following information with the bid:

- Cost of liner per linear foot with extended total;
- Shop drawings that indicate location of installation and liner dimensions;
- A bypass pumping plan or temporary service system;
- Emergency response plan in the event of bypass failure;
- Manufacturer's recommendations for storage of material at project location;
- Certification proving the contractor is currently licensed by the appropriate lining material manufacturer to perform installation;

- A certified affidavit, signed by an officer of the company, stating that the onsite construction field superintendent has received proper training by the manufacturer for liner installation methods and procedures; and
- Third-party or liner manufacturer's laboratory test results according to the relevant standards.

3.2.3 Measurement and Payment

The contractor is paid for the cost of equipment, material, and labor, calculated on a per foot per pipe diameter basis in accordance with the unit prices contained in the contract. Payment should also include unit prices for additional work such as bypass pumping, cleaning, pre- and post-CCTV inspection, pit excavation and sheeting, shoring and/or bracing, reconstruction of access pit locations, safety, dust/erosion control, testing, site restoration, service connections and connections of appurtenances, and all other work required to complete installation.

3.3 CHAPTER SUMMARY

In the preinstallation phase, the contractor typically installs temporary water systems to provide a continuous supply of safe drinking water to water utility customers during renewal projects. Pipe materials used in temporary water systems have evolved such that the systems can be installed and removed quickly and with less labor. Temporary water service interruptions attributed to traffic, vandalism, or other causes can be minimized with 24/7 on-call maintenance of the bypass. Temporary water services are important, but they can be a major expense of a renewal project.

Properly planned, installed, and maintained temporary water systems provide the added benefit of allowing a utility the time and ability to deal with unforeseen problems that can arise during a rehabilitation or replacement program without the concern of rushing to put the system back in service.

Prequalification of contractors and installers is a prudent step to ensure a successful and quality renewal project according to specifications and guidelines. The contractor and the field personnel must be certified by the system manufacturer. Bid submittal requirements and payment plan were presented in this chapter.

CHAPTER 4

CONSTRUCTION AND CLEANING

4.1 CONSTRUCTION

Various lining techniques require specific construction procedures, but in general, the following steps describe the common construction operations.

4.1.1 Work Plan

A work plan is a hierarchical and structured breakdown of the work to be executed by the project team to complete the project as designed and specified. The work plan organizes and defines the total scope of the project. Each descending level in the work plan structure represents an increasingly detailed definition of the project work. The project owner should provide the contractor with any as-built drawings for the host pipeline and nearby facilities, geotechnical reports, and the results of any exploratory excavations that were completed to ensure the pipeline is appropriate for the renewal method. The owner should note on the contract drawings any areas where the contractor is not permitted to excavate or place any other necessary constraints within the work area.

The following elements should be considered in the work plan:

- Setup of traffic control signs and barriers;
- Host pipe access excavations (entry and exit pits);
- Setup of bypass service lines, including arrangements for fire protection (if required, see Chapter 3);
- Preparation of the host pipe (to remove tees or valves, to cut out a portion of the pipe, etc.);

- Pipe cleaning and dewatering as required for the specific renewal method (using high-pressure water, drag scrapers, pigs, or other methods);
- Proper disposal of waste from cleaning operation;
- Preinspection (pre-CCTV) as required;
- Locating service connections and plugging them to shut off flow as needed;
- Installation of liner pipe or renewal materials using proper equipment;
- Pressure testing if required (typically performed prior to reinstating service lines);
- Post-inspection (post-CCTV);
- Specific remedies for any faults or failures in the renewal process;
- Connecting rehabilitated pipe to start flow;
- Disinfection and bacteria testing (BacT);
- Resetting of valves, fire hydrant connections, and other appurtenances in the project area;
- Reinstatement or replacement of service lines (internally or through excavation);
- Removal of temporary bypass system;
- Backfill of access excavations; and
- Surface restoration and cleanup.

The contractor, the owner, and the engineer should meet and jointly review the detailed schedule of activities and ensure that the schedule meets the contractual requirements. The contractor should revise the schedule of activities to address any necessary adjustments to meet project requirements and provide more details for construction operations if necessary.

4.1.2 Work Space

The work space should provide enough space for the safe operation of equipment and storage of materials. Minimum work space requirements are specific to the project and renewal method. The work space is dependent on the equipment used on the site and bypassing and access pit requirements, which vary from project to project.

As an example, the following is a list of common equipment required at the jobsite:

- Refrigerated truck (for cured-in-place resin-impregnated tubes);
- Resin delivery rig (for spray-in-place applications);
- Boiler truck (in case heating is necessary for resin cure);
- Space for storing and laying out new pipe for close fit and sliplining;
- Space for pit excavation and to stockpile backfill soils, temporary hose, pavement cutters, etc.;

- Delivery dump trucks;
- CCTV truck;
- Pickup trucks (two to three);
- Backhoe or other excavating equipment necessary to perform excavation of pits;
- Installation device for inversion (cured-in-place only, see Chapter 5);
- Cleaning equipment (jet truck, winch, and scrapers);
- Cross-section reduction machine (close-fit operation, see Chapter 5);
- Vehicles to haul away excavated materials and pipe cleaning waste;
- Butt fusion machine (sliplining and close-fit operations);
- Forklift and other lifting devices; and
- Pumps and other miscellaneous items.

4.1.3 Initial Setup: Excavation

Once the bypass is established, excavation pits are dug and proper shoring is installed. Shoring must meet Occupational Health and Safety Administration (OSHA) standards Sections 1926-650–1926.652 (including Appendixes A–F). Then portions of the system to be rehabilitated are shut off and depressurized. Next the host pipe is exposed and opened, providing access to the system. When close-fit pipe is used as the renewal method, insertion points sometimes require large excavations, and thus special attention must be given to traffic control and public safety. Excavations may also be required at host service connections if they cannot be reinstated internally (such as sliplining and close-fit). Where possible, excavations should be located away from heavily traveled areas. Storage of material and equipment should be in a secured area.

4.1.4 Host (Existing) Pipe Access

Following the installation of the temporary water system, access to the host pipeline must be provided. Topography, bends, tees, in-line valves, hydrant locations, and traffic conditions all influence the locations of excavations for installation of the renewed pipe. These conditions also affect the method used to clean the pipe. The capabilities of the specific renewal technique should be evaluated based on the host pipe bends. In some instances, removal of bends may be an option. The host pipe can be completely drained when the access pits are excavated. Where temporary services are provided and connections remain connected to the host pipe, checking curb stops to isolate the host pipe from the temporary system is prudent to ensure they are effectively closed.

Full-diameter line valves within the rehabilitation zone must be removed and replaced. In some cases, the interior of the valve can be removed to allow renewal to be made through the valve. Access points often coincide with valves to be removed and are generally 300 to 1,500 ft

(90 to 460 m) apart depending on the renewal method, pipe diameter, locations of fittings, bends, etc. Once access to the pipeline is obtained, a 4- to 5-ft (1.2- to 1.5-m) section of cast iron pipe is removed using a handheld power saw or traveling saw. Steel pipe is generally cut using torches.

If the host pipe is to be lined, it is cleaned and inspected with CCTV, which records length measurement and allows for locating service connections. The camera data can be utilized to measure the distance between excavation pits inside the pipe. Current systems allow for measurement accuracy within 1/8 in. (3 mm). Damaged sections or host service connections are noted in case point repairs or replacement of services is required. For cured-in-place pipe (CIPP), all host service connections are plugged from the inside of the host pipe to prevent resin from migrating into the service connections. Relining with PVC or high-density polyethylene (HDPE) has different requirements for cleaning and preparation. Making sure no water infiltrates into the host pipe prior to lining is important. Any leaking service connections may have to be removed and replaced after the lining process is complete. If the host pipe has cracked sections that affect the ability to install the liner or has significant groundwater inflow, a point repair can be made internally or externally. Depending on the lining technique chosen, an external sleeve for the damaged section may have to be utilized as part of the repair.

4.1.5 As-Built Drawings and Documentation

As-built drawings are sometimes provided for the host pipeline; however, often these as-built drawings have to be corrected and updated during the renewal work. New as-built drawings may include before and after video files and results of disinfection testing because the pipeline owner typically requires that videos be submitted as part of the contractor's work. Additionally, new as-built drawings should verify the engineer's design drawings showing installed pipe locations and elevations (alignments and profiles).

4.2 CLEANING

Cleaning must be performed in advance of pipeline renewal work. Before a section of pipeline is cleaned, it must be isolated from the remainder of the system and provisions must be made for disposal of removed sediments. The cleaning technique chosen depends on the host pipe conditions, renewal method requirements, and lining and entry point locations. A broad review of pipe cleaning methods can be found in AWWA M28 (AWWA 2014).

4.2.1 Purpose and Scope

The purpose of cleaning is to remove all loose and adhered material prior to rehabilitation and to make sure the pipe is suitably dewatered or dry, depending on the process, to receive the renewal material.

Proper cleaning in itself brings several advantages to the water utility owner, as removal of interior deposits, sediment, and tuberculation will result in:

- Improved water flow and energy efficiency;
- Reduced bacteriological concerns;
- Reduced customer water-pressure complaints; and
- Reduced customer water-quality complaints (such as red water).

A thorough cleaning of unlined ferrous pipe by itself is not considered a proper rehabilitation, because conditions remain for the oxidation process to start again and accelerate the corrosion in the pipe. There is a possibility that, if the host pipe is in poor condition with a somewhat thin remaining wall, the pipe can be damaged during the cleaning process. Linings that are structural (and possibly semistructural) can be installed in these situations. For nonstructural linings, sufficient wall integrity must remain to allow operation of the pipe at the maximum allowed internal pressure. Besides holes and cracks, graphitization is a concern. This commonplace type of damage in cast iron pipes is primarily characterized by the separation of iron from its remaining carbon content and is caused by corrosion. Graphitized walls are structurally weak and, unlike most holes and cracks, may not be readily detected. Condition assessment methods, including performing forensics on pipe samples, should be used to reduce the potential of applying an inappropriate renewal method to a structurally weak pipe.

4.2.2 Approved Pipe Cleaning Methods

In all cases, the pipe is cleaned by gaining access through a section of pipe that has been exposed. The cut-away pipe segment must be at least 4 ft (1.2 m) long to allow insertion of cleaning and renewal equipment. A second access point is typically made about 350–500 ft (100–150 m) away. The application length depends on the pipe diameter to be renewed, the layout of the street and pipeline, valve locations, and the renewal technique. Many cleaning methods use water; alternate systems employ air containing abrasive materials. One method blows garnet through the pipe. A relatively new system draws air through the pipe and employs rocks as the abrasive material. Flushing water is introduced at the opposite end from where cleaning is occurring. A steady flow of water must be available during the cleaning process to flush away debris. Water jet cleaning methods are an exception because they deliver their own water. Debris-laden water will then flow into the access pit side, where cleaning

Table 4-1. Water-Assisted Cleaning Methods for Water Pipes

Cleaning Method	Suitable Pipe Diameter	Best Use
Water Assisted		
Water Jet	All	Biofilms and somewhat loose debris
Rack Feed Boring	4–10 in. (102–250 mm)	Heavy encrustation
Drag Scraping	12 in. (300 mm) and greater	Heavy encrustation, exposed leaded joints
Plunging	12 in. (300 mm) and greater	Removal of sediment and standing water after cleaning by drag scraping
Air Blasted		
Garnet blown	0.5–12 in. (12–300 mm)	Smaller pipe, any material
Vacuum	4–8 in.* (100 mm–200 mm)	Heavy encrustation

*Vendor is pursuing higher range up to 12 in. (300 mm)

equipment is introduced. Adequate pump capacity must be available at this side of the pit to keep the water level below the pipe invert. In all cases, disposal of cleaning water, chlorination water, and construction debris must be in accordance with local regulations. Table 4-1 lists a few cleaning methods available for water pipes.

4.2.3 General Operating and Cleaning Procedures

The general cleaning operation procedures can be summarized as follows:

1. Review all drawings for pipe bends and the presence of valves. Bends greater than 22.5 degrees present a challenge for the passage of the cleaning equipment and later the lining process and movement of lining devices. Debris can also accumulate in hydrant tees and large service connections. Consideration should be given to placing access pits at pipe bend locations and where valves may be renewed.
2. Provide temporary water supply for affected customers and temporary fire protection where necessary.
3. Identify locations and provide valves and curb stops to be used to isolate the system.

4. If desired, clean abandoned open gate valves and line in place.
5. Identify sources of water to be used for flushing the pipe during cleaning (not required for the water jet cleaning method and air-based cleaning methods).
6. Excavate entry and exit points and isolate and depressurize the host pipeline.
7. Expose host pipe sections to be cut out, remove pipe sections, and drain pipe.
8. For water cleaning methods, initiate water flow entering at the far pit (usually where pipe has higher invert) and begin the cleaning process at the near pit (entrance for the cleaning equipment).
9. Depending on the cleaning method, repeat the cleaning process until desired level of cleaning is achieved.
10. Collect all debris to dispose of at an approved location.
11. Use a plunger to remove the last of the sediment and/or swab the pipe with foam pigs to remove remaining particles and standing water.
12. Run a CCTV camera through the pipe to verify degree of cleaning and absence of standing or flowing water. If there are structural issues identified, excavate and repair as needed.
13. A preinstallation video should be produced for the record. If the host pipe is not suitably clean, repeat the cleaning process as described above.

4.2.4 Rack-Feed Bore

The rack-feed bore machine is large and must be towed to the jobsite. An engine-driven hydraulic unit is used to rotate 15-ft (4.5-m) spring steel rods that are projected into the pipe in sections using quick-connects. At the tip of the rods is the bore head, which generally contains two steel flails or cutting blades that provide the scouring action. Starting at one access point, with water flowing in from the opposite end, the bore head with flails is inserted into the pipe. With powered rotation at about 750 rotations per minute (rpm) or more, the flails are pushed through the pipe until another section of steel rod is required. The process continues until the bore head reaches the opposite pit. With a controlled upstream water flow continuing to flush out the debris, the bore head is pulled back while rod sections are disassembled and removed. Generally the rack-feed bore method is preferred for smaller-diameter distribution pipe (less than 12 in. [300 mm] internal diameter). This method may damage protruding service connections. Fig. 4-1 is a schematic diagram of a rack-feed borer. Fig. 4-2 shows rack-feed equipment in operation.

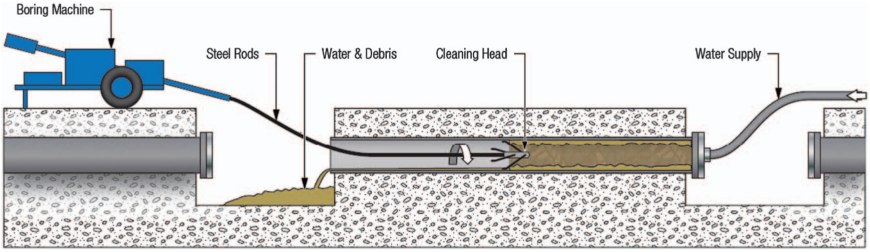

Fig. 4-1. Schematic diagram for rack-feed borer
Source: 3M Water Infrastructure; reproduced with permission

Fig. 4-2. Rack-feed bore pipe cleaning machine
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4.2.5 Drag Scraping

Drag scraping is accomplished by pulling spring steel scrapers with adjacent rubber squeegees through the pipe. A powered winch, usually truck mounted or available on construction equipment such as a front-end loader, is used to pull the scrapers through the host pipe by means of a cable that has been placed along the length of the pipe. The scrapers are mounted on a central shaft that is equipped with a towing eye to provide the capability to pull the scrapers back and forth. As with the rack-feed boring process, flush water is introduced into the pipe to remove the loosened sediment and debris. Generally drag scrapers are preferred for larger-diameter distribution pipes (12 in. [300 mm] ID and larger) and can

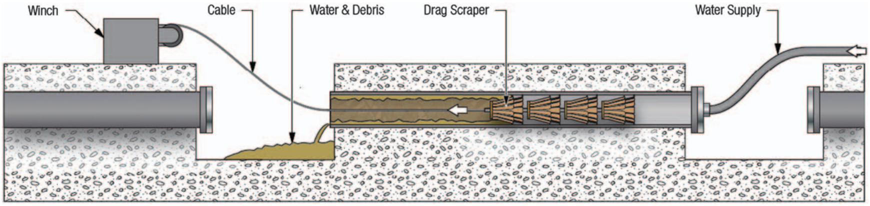

Fig. 4-3. Schematic diagram for pipe cleaning using drag scraping
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be used with bends up to 22.5 degrees. However, this method may damage improperly installed protruding service connections. Drag scraping may also be useful as an initial cleaning method, which is then followed by rack-feed boring, especially if the pipe is extensively plugged with tuberculation and sediment. Drag scraping may also be the preferred method if the pipe has poorly installed lead joints that may include lead deposits in the pipe interior. Fig. 4-3 presents the schematic diagram for drag scraping.

4.2.6 Water Jet Cleaning

High-velocity water jets, when pulled through the pipe, can be an effective means of cleaning pipe with modest corrosion or biofilms. Debris and deposits are removed with nozzle water pressures that can exceed 10,000 psi (690 bars). Typically in such operations, the dislodged particles are retained in the water stream and act as an abrasive, thereby assisting removal of additional corrosion. Flush water is not introduced into the pipe during this process. However, after the water jet equipment is removed, the pipe must be thoroughly flushed to remove the loosened material and sediment. Fig. 4-4 presents the schematic diagram for water jet cleaning.

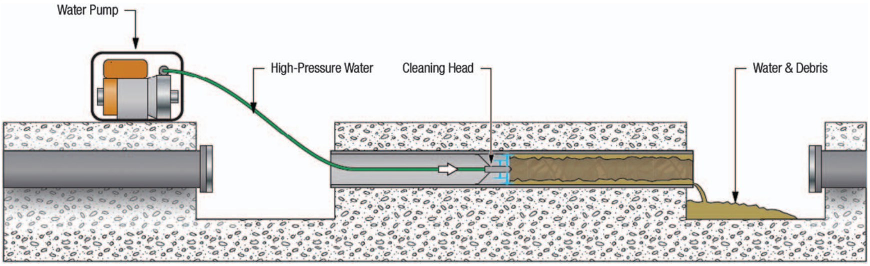

Fig. 4-4. Schematic diagram for pipe cleaning using water jets
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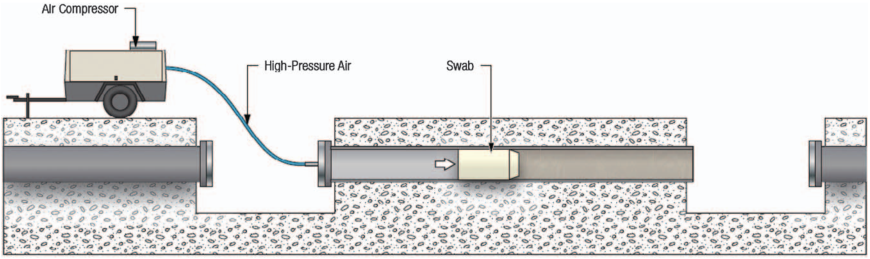

Fig. 4-5. Schematic diagram for pipe cleaning using foam swabbing
Source: 3M Water Infrastructure; reproduced with permission

4.2.7 Swabbing

Swabbing is effective after initial cleaning to obtain a surface suitable for lining by removing residual material and water. Low-pressure air in the 5 to 10 psi (0.35 to 0.7 bars) range is typically used to move a plug through the pipeline. Swabs are generally polyurethane foam plugs, or "pigs," that are forced down the length of the pipe by compressed air supplied from an onsite air compressor. The swab size is determined by the pipe diameter to ensure a snug fit. Several swabs may be required to remove standing water and debris that may adhere to the pipe interior. If truly effective, the swabs will become successively cleaner and drier. Swabbing is always performed after the main cleaning process. Fig. 4-5 presents a schematic diagram for foam swabbing.

4.2.8 Plunging (Squeegee)

Like swabbing, plunging is performed after cleaning, especially after the drag-scraping process. Plungers consist of one or more rubber squeegee disks around a central shaft and are usually slightly larger than the pipe internal diameter (ID). They are fitted with a tow eye at each end. Plunging can be accomplished in conjunction with drag scraping. The plungers can be part of the drag-scraping "train," or they can be pulled through the pipe separately after the mechanical cleaning to remove retained sediment and standing water. Swabbing is required after plunging to assist with drying the pipe interior and to remove debris. Fig. 4-6 presents a schematic diagram for plunging. Plungers are effective when there is a drop in the pipe alignment that can cause an accumulation of water and debris.

4.2.9 Chemical Cleaning

The advantage of chemical cleaning is that it can be performed without access points or pits to enter the host pipeline. However, chemical cleaning

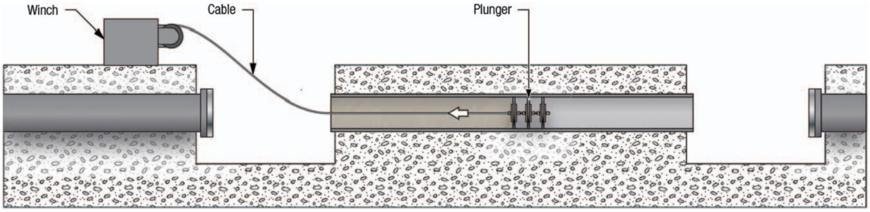

Fig. 4-6. Schematic diagram for pipe cleaning using plunging
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can accelerate corrosion in ferrous pipes and fittings if the chemicals are not effectively removed and the pipe supplemented with a lining. Several chemical combinations can be utilized to dissolve and remove deposits. These methods improve pipeline surface smoothness and therefore decrease pressure drops. Prior to use of this method, the user must verify compatibility of cleaning system with liner manufacturers.

4.2.10 Air Blast and Vacuum Cleaning

Air blast and vacuum cleaning usually involve abrasive materials or mineral aggregates that are impacted against the pipe wall with air pressure or suction. These techniques provide a way to prepare the surface to improve adhesion of spray-on lining materials to the pipe wall. Thus, these cleaning methods are most useful for the ultimate preparation of a surface, but the pipe may have to be precleaned by another method to remove severe tuberculation. The degree of finish is defined by the four categories that the Society for Protective Coatings (SSPC) has provided: white metal blast, near white metal blast, commercial blast, and brush-off blast (Hansel 2000).

4.3 PREAPPLICATION INSPECTION

Part of the preliminary activity for renewal systems is recording the environmental or specific site conditions. Conditions can vary from wet or humid to dry and from hot to cold environments, and curable resins have various degrees of sensitivity to these conditions. In addition, the inspector must document site and host pipe conditions and ensure the renewal is performed according to the contract and technical specifications. The inspector must become thoroughly familiar with the contract documents for the project, and most importantly, the technical specifications. The technical specifications will guide the inspector regarding inspection areas, documentation requirements, pressure testing of the system, and test samples (identification, type, number of test samples required, location, maintenance and delivery, testing agency, and other documentation) to ensure that the liner is installed with specified quality.

4.3.1 Assessment and Quality Assurance

Host pipe assessment and quality assurance measures can be summarized as follows:

1. After cleaning, the pipe interior must be free of corrosion by-products and be smooth and free of particulate matter.
2. Standing water must be removed, and no leakage into the pipe should be observed. Refer to the recommendations of the rehabilitation system manufacturer regarding the level of dryness required.
3. The inspection is conducted with a CCTV camera and recorded on suitable media. Fig. 4-7 shows a typical setup.
4. CCTV inspection can be used to check for unsatisfactory conditions, either from the cleaning process or from the degree of deterioration prior to the lining process. Such issues could include:
    - Protruding, damaged, or plugged corporation stops or service connections;
    - Poorly fitted joints (gaps);
    - Sags in the pipe alignment; and
    - Leaking water into the pipe from services or other locations.

4.3.2 Tape Test Method

If the pipe is sufficiently dry (i.e., as required by the specific renewal method), a simple test for surface particulate matter can be applied to the pipe that is similar to a standard clear pressure-sensitive tape. This test is qualitative only, but it provides a good indication of surface acceptability especially for spray-on liners. Because subjective factors are used, the test

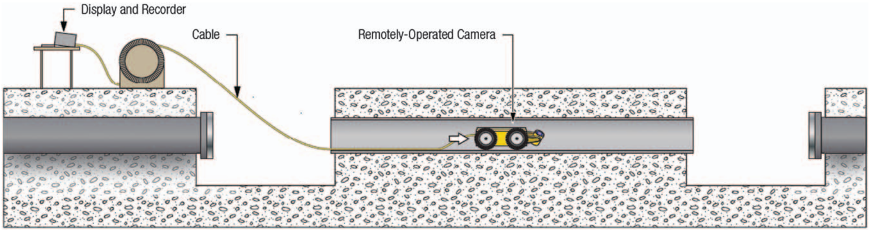

Fig. 4-7. CCTV inspection of pipe after cleaning
Source: 3M Water Infrastructure; reproduced with permission

does not provide a precise determination of dust on the pipe surface. However, when it is used to compare a surface with required standard, useful information is provided. The test may be used for a pass/fail decision regarding the need for additional cleaning and/or swabbing and can also be used as a retention record by mounting the tape specimens on white cardboard. The procedure follows:

1. Remove approximately 8 in. (200 mm) of tape from the roll.
2. While touching the adhesive side of the tape only at the ends, press about 6 in. (150 mm) of the tape firmly onto the pipe interior surface through access from one end of the pipe. This is performed by moving the thumb at a constant speed three times in each direction.
3. Remove the tape from the surface and adhere it to a white cardboard surface.
4. Compare the quantity of dust on the tape with the pictorial reference shown in Fig. 1 of ASTM D3359 (ASTM 2009e). Record the quality rating (1–5) with the closest match.
5. If the tape is discolored overall, usually with a reddish brown or black color, record this as rating 5. This indicates microscopic dust that will cause serious adhesion interference with the renewal coating.
6. Repeat at the other end of the pipe.
7. Report the quality rating for each end of the pipe. If either end of pipe receives a dust quality rating of 4 or 5, the pipe must be cleaned and/or swabbed again and retested.

4.4 CHAPTER SUMMARY

Each construction operation requires a detailed work plan. The work space requirement must be evaluated based on jobsite conditions, renewal method, and type of equipment used. For a successful pipeline renewal, proper pipe surface preparation and cleaning are required. This chapter provided an overview of different pipe cleaning methods and their applications. The cleaning method and execution must be compatible with the selected renewal method. Construction inspectors should be knowledgeable about the renewal methods and technical specifications, as well as requirements for quality control and testing.

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CHAPTER 5

PIPELINE RENEWAL METHODS

Pipe rehabilitation goes back to the 1930s with the advent of cement mortar lining. However, most pipe renewal technologies described in this chapter are somewhat recent for use on potable water pipes. Many evolved from other infrastructure applications. Examples are fiber-reinforced systems, which have been utilized for strengthening and retrofitting bridges and for making stand-alone pipes; cured-in-place pipe (CIPP) lining systems, which have been utilized for sewer pipe rehabilitation; and spray-applied systems that started as thin corrosion protection coatings for other structures. In addition, plastic piping has also been adopted for potable water pipe renewal through innovations in close-fit sliplining into the host pipelines. The methods covered in this chapter are cured-in-place pipe, cement mortar lining, spray-in-place pipe, sliplining, close-fit pipe, and fiber-reinforced polymer linings.

5.1 CURED-IN-PLACE PIPE

5.1.1 Introduction and Background

Cured-in-place pipe is one of the most widely used methods of trenchless pipeline renewal for both structural and nonstructural purposes. CIPP designs typically are formulated to provide a design life extension of 50 years.

The CIPP method involves a liquid thermoset resin-saturated material that is inserted into the host pipeline by hydrostatic pressure inversion or air inversion or by mechanically pulling it in with a winch and cable and then inflating it. The uncured tube is held against the inner wall of the host pipe by internal water or air pressure. The resin is thermally cured with hot water or air and steam, or a resin is used that can be cured with ultraviolet (UV) light. The result is a close-fit CIPP within the host pipe.

As for any other pipeline renewal method, CIPP design and installation are based on factors such as the host pipe condition and material (ductile iron, cast iron, or PVC), defects, operating pressure, application (type of water and its properties), nature of problem or problems involved, number of connections, appurtenances, and bends, and future use of the pipeline. A host pipeline system can exhibit several defects. These defects can be structural, operational, or maintenance related; built into the system during construction; or a mix of different types of problems (Najafi 2005). Other factors include age of the system and location and access to the pipeline system.

5.1.2 Host Pipe Conditions and Considerations

Depending on design pressure, all types of water mains from 6-in. (150-mm) to 72-in. (1,800-mm) diameter can be structurally renewed using a fully structural CIPP lining system. (Different CIPP products may span portions of this range, but the diameter range is intended to represent all CIPP products combined.) Cast iron and ductile iron water pipes are the most common pipe materials renewed using CIPP, but pipe materials such as asbestos cement, steel, PVC, concrete, or others can be renewed as well.

5.1.3 New Lining Considerations

The primary components of a fully structural CIPP are a flexible fabric tube and reinforcing fibers impregnated with a thermosetting resin system. For pressure pipelines, these resins generally fall into the generic groups of epoxy for bonding and vinyl ester for structure, each of which has distinct chemical resistance and structural properties.

5.1.4 CIPP Composite Design

CIPP composite wall design must be in accordance with ASTM F1216 (ASTM 2009a) equation X1.6 for Class III designs and equation X1.7 for Class IV designs. Burst testing of representative composite CIPP is recommended to determine if the desired factor of safety or design factor is being met. Physical properties of the composite materials are quite variable depending on manufacturer and application. However, tensile strengths in the 6,000 to 15,000 psi (41,000 to 103,000 kPa) range are common. It should be noted that Class IV design is most commonly used, because the process for Class III and Class IV are similar but Class IV provides additional structural support at additional cost. Refer to AWWA M28 (2014) for more information on structural, semi-structural and non-structural applications.

This subject is currently under review by AWWA Standards Committee on Pipe Rehabilitation.

5.1.5 Initial Setup

After the construction protocol and cleaning by an appropriate method such as those described in Chapter 4 are completed, all existing service connections are plugged from the inside of the host pipe to prevent resin from migrating into the service connections. It should be noted that no water should infiltrate into the host pipe prior to lining. The plug employed may be mapped or contain a marker that can be located by a robotic drill when it comes time to reinstate the service.

5.1.6 Resin Impregnation/Wet-Out Process

In pressure CIPP, a tube and a specially formulated resin system can be brought to the project site together or as separate components. A catalyzed resin or resin-impregnated tube may require a refrigerated truck. For pressure applications, the tube is typically reinforced with fiberglass, carbon, or carbon–glass fiber hybrids. These tubes are custom manufactured to suit the specification and project conditions. The tube is installed after the pipeline is cleaned and televised and services are plugged. A thin elastomeric layer is applied to the tube during the manufacturing process before the tube is impregnated with the resin. This coating is generally on the exterior of the tube, and as the tube is inserted with inversion into the host pipe, it will become the new inside surface of the water main. In the case that tube is pulled into the host pipe, the coating is applied to the inside of the tube. Then the tube is impregnated with the catalyzed resin (also known as the wet-out process) to prepare it for insertion through the entry point of the host pipe. The tube must be totally saturated to provide consistent physical properties required by the design. Fig. 5-1 illustrates the resin impregnation, or wet-out process.

5.1.7 CIPP Installation

There are two basic methods of CIPP installation: the pulled-in-place process and the inversion process. Different manufacturers provide specific variations of these techniques. This section provides details for each method.

Pulled-in-Place Process Using a winch, the impregnated tube is pulled through the entry point of the host pipe [Fig. 5-2(a)], fully extending the tube to the next designated entry or termination point [Fig. 5-2(b)]. Water, air, or both are used to inflate the tube after it is pulled into the host

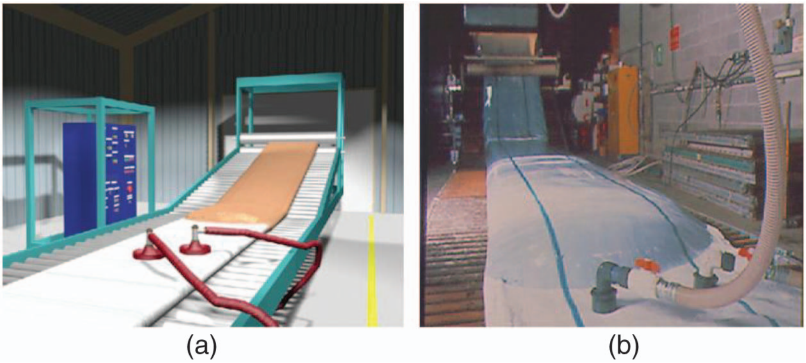


Fig. 5-1. Resin impregnation or wet-out process
Source: Insituform Technologies, LLC; reproduced with permission

Fig. 5-2. (a) Impregnated tube inserted in entry pit; (b) use of winch to pull impregnated tube
Source: Insituform Technologies, LLC; reproduced with permission

pipe. Care needs to be exercised during pull-in not to overstress or damage the tube as a result of increased friction, especially where curved alignments, offsets, protruding services, and other friction-producing host pipe conditions are present. The pulling force induced on the tube as it is being pulled into the host pipe should be monitored and should not exceed the recommended maximum allowable pulling force for the size and thickness of the tube being installed.

Inversion Process In the inversion method, the resin-saturated tube is inserted through an entry point and then installed into the host pipe by means of pressurized water or air with a volume sufficient to fully extend the tube to the next designated entry or the termination point. The speed of inversion typically should not exceed 30 ft per minute (9 m per minute) for small-diameter tubes. Larger-diameter tubes should be installed significantly more slowly, as recommended by the manufacturer.

To monitor the curing temperature, a thermocouple or temperature-measuring device is installed at the access points between the host pipe and the CIPP tube and at the pipe invert or at the six o'clock position. These devices can be placed at each end and at all intermediate access points along the length of the installation, or they can be installed in continuous lengths throughout the pipe for continuous temperature monitoring along the entire length to be renewed. The manufacturer should be consulted for a recommended use of thermocouples applicable to its CIPP system. The thermocouple wires can be used for both pull-in and inverted techniques and are critical for monitoring the curing of the resin-catalyst system. These sensors must be installed before the tube is in place and certainly before the tube is pressurized. These sensors are an option when curing is done with UV. Fig. 5-3 presents the inversion process for a water pipe.

5.1.8 CIPP Curing

Curing of the resin is done by hot water, steam, or UV. The most common method for curing is hot water (Fig. 5-4) produced by a boiler truck onsite. For a large pipe, it may take up to 10 hours to cure the CIPP. Curing temperatures are monitored at access points and at each end of the installation. The second method of curing is using steam or hot air. In this method, once the tube is in place and properly inflated with air, the resin is cured with steam or hot air. Typically, the CIPP components (such as tube material and resin) require an integrated system specially designed for steam curing. UV curing requires that a UV light train be inserted into the

Fig. 5-3. Inversion process
Source: Insituform Technologies, LLC; reproduced with permission

Fig. 5-4. Curing process
Source: Insituform Technologies, LLC; reproduced with permission

inflated liner and curing is accomplished using a controlled speed of the light train through the liner pipe.

5.1.9 Features and Benefits

- CIPP is a jointless system creating a smooth interior surface, which typically improves the flow capacity of the host pipe, with a slight decrease in diameter.
- CIPP is capable of accommodating bends. The bend capability depends on host pipe conditions and type of tube used.
- CIPP is designed as either a Class III or a Class IV; see AWWA M28 (AWWA 2014).

5.1.10 Limitations

- CIPP blocks fire hydrants and service connections.
- Maximum pipe bend is typically 45 degrees.
- CIPP uses robotic reestablishment of services. The resulting product is difficult to inspect for effectiveness.
- In most cases, temporary water service for area residents and fire protection is required.
- Excavation is typically required for host pipe access.

5.2 SIPP WITH CEMENT MORTAR LINING

5.2.1 Introduction and Background

Spray-in-place pipe (SIPP) generally refers to water pipe renewal through spray-on of a material to the pipe interior. This method now includes polymeric applications, but the original SIPP material was cement mortar lining. Cement serves as a chemical inhibitor against iron oxidation formation when alkali-containing water comes in contact with iron. Because the cement and sand in a cement-mortar lining is porous, water can penetrate through the lining to the pipe wall, becoming alkaline in the process. Consequently, pipe that is lined with cement mortar is protected from oxidation because of the composition of the Portland cement.

Cement-mortar linings were first installed in host pipelines using the centrifugal process in the mid-1930s. However, this method was limited to pipelines large enough for a person to enter. In the 1960s, remote lining processes were introduced. Today, cement mortar is applied to new ductile-iron pipes and most new steel pipes before installation, making this method a standard in the water industry. Cement mortar lining should not be used when the water is soft and aggressive, which can lead to leaching of the cement, with a resulting loss of liner and an elevated pH in the water. Cement lining is nonstructural and should not be applied unless the host pipe is structurally sound.

AWWA first developed a standard for in-place lining of water pipelines in 1955. It has been revised numerous times since then; the eighth edition was published in 2006 as ANSI/AWWA C602 (AWWA 2006b).

5.2.2 Applicability

The cement mortar spray-applied technique is suitable for structurally sound cast iron, ductile iron, and steel pipes with diameters of 4 in. (100 mm) or greater. For small diameters (non-worker entry pipes), cement mortar is spray applied by a rotating head powered by an electric or pneumatic motor. Cement mortar is delivered to the lining head by either high-pressure hoses or other mechanical means. The lining head is equipped with a conical drag trowel or rotating trowels, depending on pipe diameter, to provide a smooth finish. The thickness of the lining varies with pipe type and diameter.

5.2.3 Lining Application

Mixing equipment is located near the access hole where a cement mortar mixture consisting of one part silica-type sand and one part type II portland cement is prepared. The mixed mortar is then delivered to the lining machine by one of the several methods, depending on the pipe diameter. In 4–24-in. (100–600-mm) diameter pipe (sometimes larger), the mortar is pumped through high-pressure hoses to the lining machine. Specially designed winches pull the lining machine through the pipe at a constant speed, ensuring a uniform lining thickness.

For larger-diameter pipelines, mechanical feeding equipment shuttling between the access excavation (where the mortar is mixed) and the lining machine delivers mortar to the lining-machine hopper. The lining-machine operator then regulates the mortar application. Mechanically driven rotating trowels are used with this manually operated equipment.

5.2.4 Connections and Repairs

Cement mortar lining can block corporations during application and may require the connections to be blown out (by compressed air or robotic restoration). For the most part, the in situ cement-mortar–lined pipe will react as factory cement mortar–lined pipe. The same situation applies for repairs to an in situ lined water main.

5.2.5 Benefits

Cleaning host pipeline before cement mortar lining is a renewal technique in which tuberculation in host pipelines is removed and a cement mortar lining installed. This process restores hydraulic capacity by improving the flow characteristics, prevents future formation of tuberculation, reduces pumping costs, and improves water quality at a fraction of the cost of replacement.

5.2.6 Limitations

- Cement mortar lining cannot be applied where the water is soft and aggressive, because the cement leaches from the pipe and elevates the pH of water.
- Cement mortar lining can block small service connections and, if air cannot blow out the service, they must be excavated.
- Cement mortar lining must be thicker than alternative products, such as polymers, and reduces the inside diameter of host pipe.
- Cement mortar lining for non-worker entry pipelines can only be used for nonstructural applications.

5.3 SIPP WITH POLYMER LININGS

5.3.1 Polyurea Lining

Introduction and Background Polyurea is a polymeric material similar to polyurethane, but it can be formulated to obtain extremely fast cure times. Like other polymers, it comprises two component materials: an isocyanate (base) and a polyamine (activator). Polyurea material has a cure time of one hour, offering the potential to renew a section of host water pipeline and put it back to service in one day, thereby significantly improving productivity and possibly eliminating bypassing costs.

Host Pipe Conditions and Considerations Polyurea lining is intended primarily for renewal of cast and ductile iron pipes with diameters of 4 in. (100 mm) and larger. Liner thicknesses of 40 mils (1 mm) to 140 mils (3.5 mm) can be achieved in a single pass of the spray head although multiple layer application is dependent on manufacturer's recommendation.

New Lining Considerations The initial decision to specify SIPP for water pipe renewal should be based primarily on the condition assessment of the pipe and on the history of main breaks. An estimate of the remaining pipe wall thickness is helpful in estimating the remaining life of the pipe. For a pipe with an estimated remaining service life of 20 years or more, where the primary concern is deterioration due to internal corrosion, a polyurea lining may extend the remaining service life by inhibiting further internal corrosion. Pipes with an estimated service life of less than 20 years may be more suitable for complete replacement or another renewal method. Table 5-1 presents typical physical properties of polyurea SIPP compounds.

Table 5-1. Typical Physical Properties of Polyurea Spray-in-Place Compounds

		Material Type	
Physical Property	Test Method	Rigid Polyurea	Elastomeric Polyurea
Flexural Modulus (psi)	ASTM D790 (2010c)	>100,000	<100,000
Elongation (%)	ASTM D638 (2010b)	<10%	>10%
Shore Hardness	ASTM D2240 (2010a)	>70	<70
Cure to Immersion Service		60 minutes	
Glass Transition Temperature (°C)	ASTM D7028 (2008b)	>50	
Impact Resistance (joules)	ASTM D2794 (2004)	<15	
Water Absorption (%)	ASTM D570 (1999)	>2	

Note: 50°C = 122°F; 1 psi = 6.894 kPa

Design Principles Polyurea can be formulated to different levels of flexibility from elastomeric to rigid (brittle), which can achieve a significant advantage through the ability to match the polyurea material to meet various requirements, such as structural enhancement of the host pipe. The host pipe service life is generally influenced by the level of corrosion and the ability to resist fracture under load from overhead traffic, soil shifts, etc. Because cast iron is brittle, a pipe fracture type of failure is generally catastrophic with the potential to cause serious damage to the surface and nearby utilities, as well as potential disruption to the public, businesses, and transit systems. AWWA has convened a committee to review and revise the definitions of structural, semistructural, and nonstructural for linings.

In a partially deteriorated design, as defined by ASTM F1216 (ASTM 2009a), the existing soil-pipe system is capable of supporting the soil, groundwater, and surface load. A SIPP installed in an underground pressure pipe is designed to support external hydrostatic loads due to groundwater and to withstand the internal pressure in spanning across holes in the host pipe wall. The pressure pipe design equations found in Appendix X1 of ASTM F1216 (ASTM 2009a) have been used in SIPP designs.

Another important consideration is the pipe alignment. As with many other trenchless renewal methods, short radius bends, the presence of valves, etc., may prevent insertion of cleaning equipment, umbilical hoses, and camera equipment. Generally bends up to 22.5 degrees can be accommodated. Valves and sharp bends will need to be excavated, but with proper planning, they can provide suitable access pits for the lining process. In many cases, lining through old gate valves that are intended to be abandoned in place is possible.

Application Polymerics in most systems are spray applied to the water distribution pipe by means of a lining rig. Typically mounted onto a trailer with separate generator and compressor support, the rig contains the tanks, pumps, and umbilical hose. Each tank holds the separate polyurea base and activator (parts A and B) that are maintained at a somewhat constant temperature by means of a water jacket system. The umbilical hose has multiple lumens: one each for the activator and base, one for the compressed air to the motor, and others that circulate the temperature-conditioning water-glycol mixture. The activator and base remain separate until passing through a short static mixer just prior to being sprayed onto the pipe interior wall. Computer control and multiple sensors ensure the right mix ratio is maintained. Fig. 5-5 shows a lining trailer with umbilical hose.

Once the pipe is ready for lining, the umbilical is unreeled and pulled through the pipe to the opposite end. Typical line lengths are 400 ft (122 m)

Fig. 5-5. Lining trailer with umbilical hose
Source: 3M Water Infrastructure; reproduced with permission

to 500 ft (150 m). With the umbilical winched to the far end of the pipe and the base and activator components properly conditioned, the pump mix ratio is confirmed by a manual measurement process and the air motor is "spun up." Components A and B are pumped through the static mixer and then to the spray head. The winch speed and flow rates are set such that the desired thickness is obtained.

When polyurea-based SIPP is applied at the recommended thickness of 140 mils (3.5 mm), small holes up to 120 mils (3 mm) in diameter will ordinarily be sealed, while the larger service connections remain unobstructed. In contrast, epoxy is applied at 40 mils (1 mm), and the sealing of small gaps and leaks is limited.

Lining wall thickness is determined by the rate of application of the polymer and the speed at which the umbilical is pulled back through the pipe. Once lining is complete, the crawler camera can be introduced within 10 minutes to inspect the lining. One hour after application of the polyurea, water can be introduced back into the main for flushing and disinfection. Spray head designs are frequently customized to the material used and to the pipe diameter. Figs. 5-6(a and b) present the host pipe after the cleaning and lining process with the spray head in the pipe's center.

Return to Service Following local approved practice, after disinfection, the water main may be pieced back together with suitable pipe segments at each pit location. Returning the water main to service shortly after lining is possible if a quick-cure polyurea product is used. However, local codes and approved practices will prevail where complete bacterial test results are required prior to reinstatement of service.

The polyurea lining process typically takes no longer than 45 minutes (Fig. 5-7). Application thickness is controlled by the lining rig logic controller that monitors flow rates and the speed of the spray head through the pipe. The polymer lining will accept installation of new service

Fig. 5-6. (a) Pipe after the cleaning and (b) lining process with the spray head in the pipe's center
Source: 3M Water Infrastructure; reproduced with permission

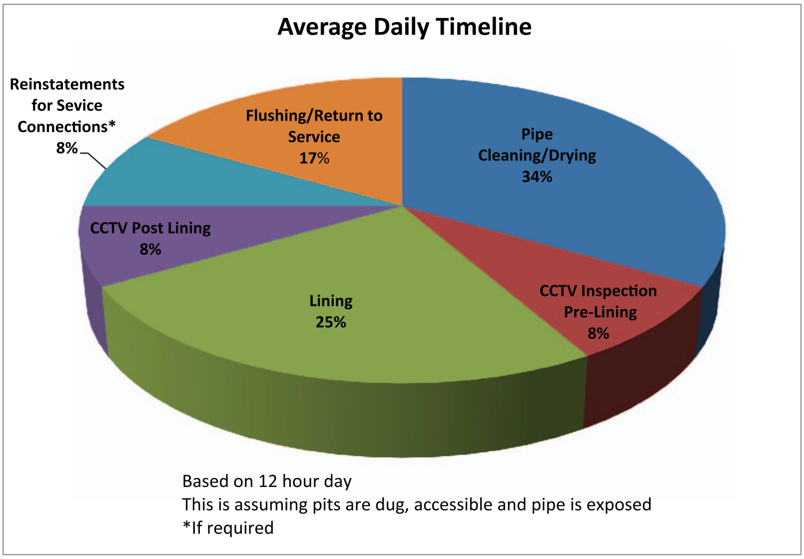


Fig. 5-7. Breakdown and relative timeline of polyurea SIPP process over a 12-hour day
Source: 3M Water Infrastructure; reproduced with permission

connections or cutting of the pipe when using approved methods. Chemicals may be added after the water main is pieced back together at each pit location. Returning the water main to service shortly after lining is possible with quick-cure polyurea product and a chlorine residual of

Table 5-2. Features and Advantages of Polyurea

Category	Features	Advantages
Environmental	Minimum excavation; contains no volatile organic compounds (VOCs)	Pass local air quality standards and reduces carbon footprint
Rate of Application	May allow same day return to service	Construction cost savings and enhanced customer satisfaction
Annular Gap/ Adhesion	Bonded to the host pipe	Minimize or eliminate annular gap flow
Service Connections	Existing corporation stops are typically not plugged during the lining. Usually there is no need to re-establish connections	Significant cost savings, and no need for secondary excavations

50 ppm. The water main must be flushed and may be pressure tested if preferred by the water utility.

Features and Benefits Table 5-2 presents the features and advantages of polyurea.

Limitations

- Substrate cleaning and preparation are critical.
- Installers must be certified by the manufacturer, as quality of installation is important.
- Polyurea polymers are sensitive to temperature and humidity.

5.3.2 Epoxy Lining

Introduction and Background The use of epoxy linings to protect and renew water mains originated in the United Kingdom during the 1970s and has been used successfully primarily as a protective barrier lining to prevent corrosion of cast iron pipe. While epoxies can be formulated and applied as a semistructural liner for deteriorated pipe, the most common application is for arresting corrosion and water-quality issues. Epoxy tends to greatly improve the hydraulics in tuberculated pipe. It provides a relatively thin and smooth layer. As a class of materials, epoxies have longer curing and return to service times; a 16-hour return to service is common. Epoxies are more surface and moisture tolerant, which provides improved adhesion to less-than-adequately prepared substrates. In contrast to other spray-applied lining materials, epoxies have an extensive history of use and are generally approved for long-term exposure in drinking water.

Host Pipe Conditions and Considerations Epoxy linings can be utilized in pipes generally 4 in. (100 mm) in diameter and greater, with spin-cast application methods limited to pipes approximately 36 in. (900 mm) in diameter. However, alternative automated or manual airless spray systems can be utilized in larger-diameter pipes. Historically, the high cost of epoxy material has affected the applications on larger diameters.

Epoxy application to steel, cast iron, and ductile iron is common, and it can also be applied to asbestos cement pipe, concrete, and cement mortar-lined pipes. Because nonstructural epoxy lining relies on adhesion to the host pipe, application to PVC or HDPE pipe is typically not recommended.

Typical application thickness ranges from 40 mil (1 mm) to greater than 200 mil (5 mm), with thicker applications required for severely deteriorated or pitted host pipe and/or for structural enhancement. As such, pipe capacity is not significantly reduced and is typically offset by improved hydraulics.

Joints and tees can be problematic for thinner epoxy applications and may require excavation, special treatment, or thicker applications to be adequately sealed. Lining valves is not recommended. The ability to apply epoxy through bends is restricted by the preparation and application equipment and varies by the installer's capabilities. In most instances, 45-degree transitions are not an issue, and in larger pipe sizes (typically more than 6 in. [150 mm]) 90-degree bends can be accommodated.

Lining Considerations The specification of epoxy solutions should be considered based on renewal design requirements and application accessibility/timeline that will be necessary as an alternative to more disruptive renewal options. In general, host pipelines requiring little or no structural enhancement benefit from the minimally invasive application of epoxy SIPP.

In general, other polymeric SIPP materials are superior to epoxy lining in regard to structural enhancement. However, epoxy SIPP is most efficient for renewal of pipe where water quality is the main issue, especially where cement mortar lining is precluded by water conditions or by installation timelines. Project durations for SIPP are typically 30–40% less than those for open-cut replacement methods. Return to service commonly occurs on the same or next day, including time for bypass setup to return to main line flow; however, a 16-hour curing and 48-hour bacteriological tests may prevent a one-day operation.

Service life of epoxy systems is generally 40 years (pipes are still in service after 40 years) or more depending upon the formulation and application thickness. With extensive use in Europe, epoxies have proven to be an effective long-term solution for pipe renewal applications.

Design Principles Most epoxies (in general, there are various mixtures) utilized for water main renewal are designed to act as a barrier coating to prevent corrosion of the host pipe, reduce the accumulation of deposits, improve water quality and hydraulics, and, in some cases, impart a degree of structural enhancement. Epoxies are generally slower to cure and tend to be more brittle than other polymeric compounds. Epoxies have been replaced in most water main applications because of the need for faster cure and return to service.

Epoxy is commonly applied as a nonstructural material. Structural evaluation of the pipe to be renewed is of utmost consideration. In nonstructural applications, epoxy SIPP serves to halt and prevent future deterioration of the interior of the host pipe. Thus, if the host pipe has limited service life remaining after internal corrosion is removed, alternative means of renewal or replacement should be considered.

Epoxy lining can be used to enhance or renew the structural integrity of the host pipe within certain limits. The structural application is typically achieved with specialty formulations and thicker and layered (more than 200 mil [5 mm]) applications. In this case, while actual application time and material usage are higher than with thin applications, the general project cost is not significantly affected, because much of the cost is incurred in bypassing, pipe access, mobilization, and other processes required regardless of application thickness. While structural enhancement can be achieved, epoxies typically have elongation values less than 5% and so are subject to cracking or shearing with movement of the host pipe. For this reason, and because epoxy applications are dependent on bonding with host pipe, they should not be considered as fully structural.

Application See Section 5.3.1, as epoxy and polyurea systems are similar.

Return to Service See Section 5.3.1, as epoxy and polyurea systems are similar.

Benefits

- Epoxy is an effective and somewhat thin barrier to corrosion in cast iron and steel pipes, maximizing the flow capacity of the host pipe.

- Epoxy is resilient against all types of water, including soft and aggressive water.
- Epoxy is a proven material dating back to the 1970s with an AWWA standard effective code of practice, AWWA C620, for the user to employ (AWWA 2007b).

Limitations

- Epoxy is not typically used in structural applications.
- It tends to have longer cure times than other polymeric mixtures and it is less flexible.

5.3.3 Polyurethane Lining

Introduction and Background Different polymer formulations have been used for water pipe renewal for several years. Recently, polyurethane polymers have entered the marketplace. Polyurethane, similar to polyurea, is made up of two components: an isocyanate (base) and a polyol (activator). The resultant polyurethane material can be formulated in numerous ways, including variations in physical properties with the two primary variants being elastomeric and rigid. Elastomeric polyurethanes have been used extensively in larger tanks and treatment structures such as clarifiers and digesters. To date, these elastomeric polyurethanes have been utilized only for corrosion protection, and their suitability in the water pipe renewal market will remain in this category. Only the development of rigid polyurethanes made structural rehabilitation of conduits possible. Both elastomeric and rigid polyurethanes offer extremely short cure times with the ability to return the pipe back to service within 30–60 minutes. Therefore, as with polyureas, construction efficiency is greatly enhanced.

Host Pipe Conditions and Considerations Polyurethane linings can be applied to almost every material that exists in a typical municipal or industrial water system. Only HDPE and PVC may cause adhesion issues. Polyurethane can be applied to materials such as fiberglass, metal, concrete, and brick with the proper surface preparation. Currently, the ability to apply elastomeric polyurethanes in small-diameter and medium-diameter water pipes (3–24 in. [75–600 mm]) is limited. Current application technology mirrors that of epoxy and polyurea systems. Rigid polyurethanes have been applied only in worker-entry (30-in. [750-mm] and larger) pipelines. The rigid polyurethanes have been successfully utilized not only to provide corrosion protection, but also to provide complete structural repair to many water lines. Life extension of these conduits with rigid polyurethane has added significant additional serviceability to the renewed pipelines.

Table 5-3. Typical Physical Properties of Polyurethanes

Product Name	Flexural Modulus (Short term)	Elongation	Shore Hard	Tensile (Short term)
Rigid Polyurethane	>700,000 psi	<4%	>85	>7,000 psi
Elastomeric Polyurethane	<80,000 psi	>40%	>60	>2,700 psi

Note: 1 psi = 6.894 kPa

New Lining Considerations As mentioned in the previous section, elastomeric polyurethanes offer a significant ability to prevent additional internal corrosion, thereby adding years to the serviceability of the potable water pipe. Rigid polyurethanes, based on their 50-year design life, offer a significantly greater capability for renewal. The ability to structurally restore the conduit to handle both internal and external pressures offers a great advantage in the renewal of the pipe utilizing rigid polyurethane. Table 5-3 presents some of the physical properties of elastomeric and rigid polyurethane.

Design Principles As discussed previously, polyurethanes can be formulated to achieve numerous physical characteristics. The primary discussion for design includes guidelines for rigid polyurethanes where they are utilized for structural rebuild or enhancement. The formulas presented in ASTM F1216 (ASTM 2009a), Appendix XI, offer guidelines for the proper design thickness calculations for rigid polyurethanes in circular geometry water line renewal. These formulas consider both internal and external pressure loads. The key design element is the condition of the host pipe and whether it is partially deteriorated (PD) or fully deteriorated (FD). The design engineer must review the condition of the host pipe as well short-term and long-term lining material properties, and determine the proper lining thickness.

Application Elastomeric polyurethanes are applied in a manner similar to polyureas and epoxies. The lining rig, cleaning, and CCTV equipment are essentially the same with some variation in the computer signal feeds and nozzle technology. All the same basic cleaning equipment is used to prepare the host pipeline by removing tuberculation, sediments, and other debris from the pipe. After debris removal, the pipe is inspected using CCTV equipment to assess any additional issues such as damaged service connections, gaps in the joints, or other conditions that would potentially cause an unsatisfactory installation condition. The line is then ready for renewal, and the procedures outlined in the epoxy and polyurea lining processes are utilized. Thicknesses applied can vary from 60 to 125 mils (1.5 to 3.0 mm) utilizing the elastomeric polyurethane. Due to the discharge angle of the spray equipment, service connections are not blocked by the polyurethane application. Lining distances currently can extend as far as 600 ft (180 m), but as newer techniques and equipment are developed, pipeline lengths of more than 1,500 ft (460 m) could soon be renewed from one access point, although length is often controlled by distance between bends, valves, and other appurtenances. As with the other resin chemistries, after the lining is completed, a CCTV inspection is performed to assess the renewal success. After the inspection is completed, the line is ready to be disinfected and put back into service. Both rigid and elastomeric polyurethanes have excellent resistance to chlorine and other disinfectant chemicals.

Surface preparation for rigid polyurethanes is similar to that for elastomeric polyurethanes, but the process is simplified by the fact that the rigid polyurethanes are applied in worker-entry–size pipelines, which makes properly preparing the substrate easier because of the direct access. After mechanical cleaning of the substrate, the inside of the host pipe is thoroughly dried before the application of the rigid polyurethane. After drying, the rigid polyurethane is spray-applied utilizing a two-part plural component system. The proper design thickness is applied by highly trained and certified personnel utilizing calibration equipment on the discharge side of the distribution pump. Within 45–60 minutes, as with the elastomeric polyurethane, the renewed pipeline is ready to be put back into service (after the proper disinfection and flushing procedures are completed). Rigid polyurethanes are a high-build material and can be applied in thicknesses from 60 to 500 mils (1.5 to 13 mm) in one application. This high-build capability and the high physical strengths of the rigid polyurethane make it an excellent choice for structural renewal in worker-entry sized (more than 30-in. [760-mm] diameter) pipelines.

Return to Service Host pipelines lined with elastomeric polyurethanes are returned to service in a manner similar to polyureas and epoxies.

Features and Benefits

- 100% solids; there are no solvents in the formulations;
- VOC free;
- Abrasion resistance; polyurethanes offer excellent resistance to mechanical actions that may occur in standard maintenance procedures;

- Structural renewal; rigid polyurethanes offer excellent results with available liner design to meet the requirements of either PD or FD conditions; and
- Quick return to service (45–60 minutes) may be possible.

Limitations

- A significant structural flaw (such as a broken pipe) in the host pipe may not be resolved by the spray application.
- Restoration of services requires robotic restoration.
- Polymers cannot be sprayed through operating valves.
- Spray devices cannot negotiate 45-degree bends.

5.4 SLIPLINING

5.4.1 Introduction and Background

Sliplining (SL) is one of the earliest forms of trenchless pipeline renewal methods and can be used for structural or nonstructural purposes. The technique has been used since the 1940s for renewal of deteriorated pipes.

The sliplining method involves accessing the deteriorated line at strategic points within the system and inserting fused polyethylene, PVC, or restrained ductile iron sections joined into a continuous pipe. This technique has been used to renew transmission and distribution potable water lines and other piping structures with satisfactory results. Sliplining with polyethylene pipe is further described in Chapter 11, "Pipeline Rehabilitation by Sliplining with PE Pipe," of the *Handbook of Polyethylene Pipe* (Plastics Pipe Institute 2008) and ASTM F585 (ASTM 2013a). For sliplining with PVC pipe, refer to Uni-Bell (2013), Chapter 13.

5.4.2 Host Pipe Conditions and Considerations

As with close-fit lining, sliplining requires a clear and unobstructed host pipe. Fouling by tuberculation, mineral deposits, or biological growth and protrusions extending into the pipe (weld fragments, broken fragments, overinserted service pipes, repairs, etc.) must be removed. Minor deflection at joints or gentle sweeps can normally be sliplined. Bends (angle points) may require removal or special evaluation. There are cases of sliplining PE pipe through 11.25-degree elbows, but this may require greater annular space clearance between the existing inside diameter and the liner outside diameter. Where localized obstructions or blockages require host pipe replacement, that location should be considered for an entry or an exit pit. The long-term structural condition of the host pipe should be evaluated to determine its capability to support external earth and traffic loads. The remaining strength of the host pipe may affect the liner pipe dimension ratio (DR) (stiffness) selection.

5.4.3 New Lining Considerations

The new liner pipe is sized to slip inside the host pipe with minimal clearance. Consequently, the liner's inside diameter will be smaller than the host pipe's internal diameter. A hydraulic analysis is required to determine flow with the reduced diameter lining. The smooth inner surface of HDPE or PVC lining helps offset some of the reduction in diameter. If prior to lining, joints had been leaking, the liner pipe might provide more flow, and tuberculation is no longer a factor if the pipe was unlined iron. The new liner pipe may have to support future earth and traffic loading if the host pipe is deteriorated or continues to deteriorate after lining.

Prior to sliplining, the host pipe must be cleaned and inspected. Access pits must be located, and staging areas must be provided for pipe fusion and stringing. The host pipeline must be shut down and bypassed, and customers must be supplied by other means. Lining is accomplished by pull-in of the new continuous pipe. Afterward, the new sliplined pipe can be disinfected, tested, and commissioned although pipes that have been disinfected have been pulled through the host pipe. Fig. 5-8(a) shows insertion of 30-in. (762-mm) DIPS HDPE pipe into a 36-in. (914-mm) cast iron (CI) main and Fig. 5-8 (b)

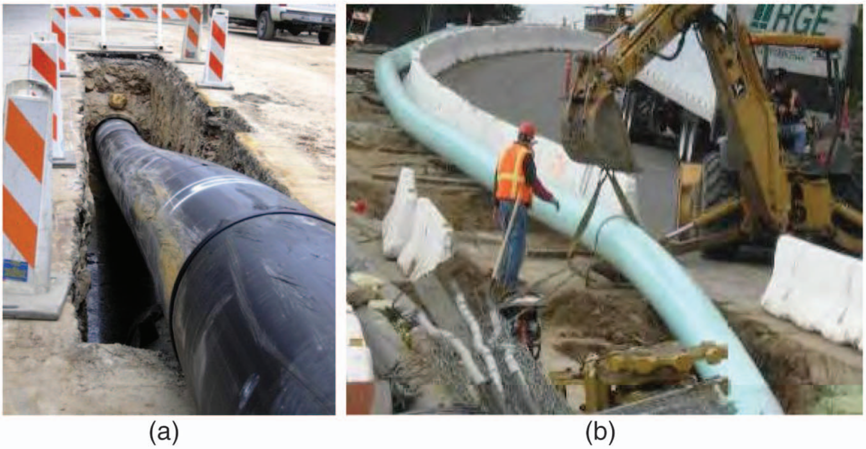

(a) (b)

Fig. 5-8. (a) Insertion of 30-in. DIPS HDPE pipe into a 36-in. CI main; (b) insertion of 20-in. DIPS fused PVC pipe into a 24-in. CI main
Source: Plastics Pipe Institute; reproduced with permission

Fig. 5-9. Fusion of 30-in. DIPS HDPE pipe
Source: Plastics Pipe Institute; reproduced with permission

Fig. 5-10. In-pit fusion of 24-in. PVC
Source: Underground Solutions, Inc.; reproduced with permission

shows insertion of 20-in. (508-mm) DIPS-fused PVC pipe into a 24-in. (610-mm) CI main. Fig. 5-9 presents fusion of 30-in. (762-mm) DIPS HDPE pipe, and Fig. 5-10 presents in-pit fusion of 24-in. (610-mm) fused PVC.

5.4.4 Design Principles: Pipe Material Alternatives

HDPE Pipe Material and Specifications A black PE material used to manufacture polyethylene pipe and fittings is typically PE 4710 high-density polyethylene with an ASTM D3350 (ASTM 2014a) cell classification of 445574C (formerly PE 3408 meeting 345564C per ASTM D3350 [ASTM 2002 and ASTM 2014a]). It is listed under the pipe and fitting manufacturing section of PPI (Plastics Pipe Institute) TR-4 with a standard grade HDB rating of 1,600 psi (110 bars) at 73°F (23°C). The material should be certified for potable water applications in accordance with NSF/ANSI 61. Water service pipe (0.5-in. [13-mm] to 3-in. [76-mm] IPS) is manufactured in accordance with either AWWA C901 (AWWA 2008b) or requirements of ASTM D3035 (2014a). Distribution and transmission pipe (4 in. [102 mm] through 65 in. [1,651 mm] in IPS and DIPS sizes) is manufactured to the requirements of ASTM F714 (ASTM 2013c) or AWWA C906 (AWWA 2007a). (It should be noted that outside diameter of IPS-sized pipe matches iron pipe outer diameters, and the outside diameter of DIPS-sized pipe matches ductile iron pipe outside diameters. AWWA M55 (2006a) presents PE pipe design and installation; however, fusion joints for liner pipes must be according to ASTM F2620 (ASTM 2013b) and PPI TN42, "Recommended Minimum Training Guidelines for the Pipe Butt Fusion Joining Operators" (Plastics Pipe Institute 2013). The HDPE material must be approved by ANSI/NSF 61(NSF/ANSI 2013) or ANSI/NSF 61G (NSF/ANSI 2013) as needed.

PVC Pipe Material and Specifications PVC pipe materials (compound) must meet the cell classification of 12454 as required in ASTM D1784 (ASTM 2011b). PVC carries a hydrostatic design basis HDB of 4,000 psi (276 bars). This is the key parameter used in determining the pressure rating of a thermoplastic pipe. The HDB is multiplied by a design factor of 0.5 or divided by a safety factor of 2.0 when used to determine the pressure rating. The HDB is also an important factor for sliplining. A high HDB will provide for a thin wall for a given pressure rating. This allows a larger internal diameter for flow considerations for the same outside diameters and pressure rating. PVC is joined in multiple ways for sliplining, including mechanical joints, sliplined joints, and fused joints. PVC used in potable water transmission and distribution piping system must be manufactured according to AWWA C900 (AWWA 2007c) for CI outside diameter sizes from 4 in. (102 mm), to 12 in. (305 mm), AWWA C905 (AWWA 2010) for CI outer diameters from 4 in. (102 mm) through 48 in. (1,200 mm) and for IPS outer diameters 4 in. (102 mm) through 36 in. (900 mm). IPS sizes are also extruded according to ASTM D2241 (ASTM 2009c). AWWA standard for installation, AWWA C605 (AWWA 2013), must be followed for PVC installation. Fused PVC pipe carries the NSF/ANSI 61G (NSF 2013) certification for drinking water applications.

Pipe Sizing Maximum flow will be achieved by selecting the largest diameter possible for the liner pipe. Sufficient clearance should be provided between the host pipe and the liner pipe so that interference does not occur. For gasketed pipe, the bells and mechanical couplings are normally larger in diameter than the pipe; an inspection of the interior of the host pipe is required to determine the clearance. For pipes with a clear inside or that have been cleaned, the following applies: for 18 in. (475 mm) and smaller HDPE pipes, the diameter should be approximately 10% less than the inside diameter of the host pipe to provide for clearance. For HDPE pipes greater than 18 in. (457 mm), a difference of 2 in. (50 mm) is generally sufficient. For fused PVC, a difference between the host pipe internal diameter and new pipe outer diameter is approximately 2 in. Length of insertion and degree of curvature are parameters taken into account when selecting the new pipe outside diameter. Short, straight slip line alignments can be done with less clearance than long-deflected host alignments.

The flow capacity for HDPE or PVC pipe is generally determined using the Hazen-Williams equation with a C factor of 150. Due to the rounded nature of the polyethylene bead and small triangular shape of PVC when fused and the slightly higher actual C factor, the C factor is not reduced for fused joints with internal beads.

Pipe Dimension Ratio The pipe should be of sufficient DR to withstand the operating and surge pressures of the pipeline and fatigue from repeated surges. The pressure rating and the allowable surge pressure for HDPE pipe is given in AWWA C901 (AWWA 2008b) (for service tubes) and AWWA C906 (AWWA 2007a) for water transmission and distribution and in AWWA C900 (AWWA 2007c) and AWWA C905 (AWWA 2010) for PVC. Design equations for internal pressure and external pressure loading are available for PE and PVC in Plastics Pipe Institute (2008) and in the Uni-Bell *Handbook of PVC Pipe* (2013), respectively.

5.4.5 Special Construction Considerations

The sliplining procedure depends on whether the liner pipe is continuous (such as a fused-joined pipe) or incremental (gasket-joined pipe). Fusion-joined pipe is normally inserted by pulling it into the host pipe. This process requires a pipe-stringing area adjacent to the insertion pit. To allow a long string to enter the host pipe, the insertion pit may be longer than in the one required for the segmental sliplining. A powered winch, located at the termination (pulling) pit, pulls the liner into the host pipe. For longer pull-ins, a hydraulic rod-pulling machine such as that used for static pipe bursting can be used. This application eliminates the stretch and rebound in elastic wire rope used with a winch, giving a higher degree of control over the insertion process. In the incremental process, pipe is lowered into the pit and then joined to liner pipe already inserted into the host pipe. A hydraulic ram or backhoe is used to push the pipe into the host pipe.

It is recommended that the annular space created between the host pipe and the sliplined pipe be treated to eliminate the air void next to the new pipe, provide support and longitudinal frictional resistance for the pipe, eliminate a pathway for nuisance water collection and flow, and aid in the reduction of possible subsidence and external loading issues in the future. Typically, a flowable grout mix is pumped into place to meet these goals. Grout mixes for use in sliplined pipe annular space treatment tend to fall into one of two categories: a sanded or otherwise traditional cementitous mixture or a highly air-entrained "cellular," low-density grout mix. Grout mixes should meet installation and compressive strength requirements for the installation per the requirements of the project. Consideration should be given to interaction of the grout with the pipe, particularly if the pipe is prone to expand and contract.

Grout testing requirements should also be in accordance with the project and may include cylinder sampling, curing, and testing. The contractor may incorporate grout additives to improve its flow properties, provided that strength property requirements are met. If required, samples of grout shall be obtained in accordance with ASTM C495 (ASTM 2012).

The sliplined pipe should be filled with water prior to the grouting procedure. This will aid in keeping the pipe from floating or collapsing during grouting operations and also aid in dissipating the heat of hydration and its effects on the sliplined pipe as the grout cures. This can be done in coordination with the hydrostatic testing performed on the sliplined pipe. In certain jurisdictions, to shorten downtime, it is possible to prechlorinate and test the sliplined pipe before insertion.

5.4.6 Features and Benefits

HDPE and PVC pipes are corrosion resistant and do not undergo galvanic corrosion. They are hydraulically smooth, do not undergo tuberculation, and have lower surge pressures than metallic pipes. HDPE and PVC pipes can be joined, repaired, and tapped using mechanical connectors. Fusion-jointed pipes provide essentially a continuous pipe. Gasketed joints can be eliminated, reducing the potential for leakage and backflow. In addition, fused joints eliminate the need for thrust blocks at bends (the one exception is when transitioning from a fused system to a gasket-jointed system). To protect the gasket joints from pulling apart, anchors or restraints are needed at the transitions; refer to AWWA M23 (AWWA 2002) and AWWA M55 (AWWA 2006a). In addition, HDPE is flexible (highly ductile) and resistant to impact, soil movements, and fatigue. PVC is less flexible due to its higher strength. This higher strength allows the new pipe wall to be about 60% thinner, providing a greater internal flow area for the same outside diameter and pressure rating in a sliplining application. HDPE and PVC pipes are lightweight, and small diameters can be hand carried. Further consideration should be given to expansion and contraction with temperature changes and to the areas that may contain hydrocarbons.

5.4.7 Limitations

- A major limitation of sliplining is the loss of cross section when compared with close-fit lining solutions.
- Similar to any sliplining process, any deficiencies and access to the HDPE or PVC liner is screened by the host pipe.
- Proper casing spacers must be used, and the annular space must be grouted.
- In order to make connections with the slip-lined pipe, the host pipe must be carefully removed.
- The host pipe may shield issues with the sliplined pipe, such as leaks.

5.5 CLOSE-FIT PIPE

5.5.1 HDPE

Introduction and Background Close-fit techniques involve inserting a thermoplastic pipe which has had its cross section temporarily reduced to allow sufficient clearance for insertion into a host pipe. When the pipe later returns to its approximate original shape, it provides a close-fit or tight-fit liner in the host pipe. Close-fit pipe (CFP) can be used to renew transmission and distribution systems for raw water as well as treated, potable water.

Two main types of close-fit systems with HDPE are symmetrical reduction systems and folded systems, as described below:

- **Symmetrical reduction systems**. These systems involve using a round thermoplastic pipe with an outside diameter the same size as or slightly larger than the inside diameter of the host pipe. This new pipe is passed through either a static die or an array of compression rollers that temporarily reduce its diameter to allow it to be inserted into the host pipe. After insertion, the pipe is allowed to revert to its original dimensions and fill the gap between the PE pipe and host pipe. In some cases, this reversion is accelerated by the application of internal pressure. Symmetrical reduction techniques generally use polyethylene pipe to take advantage of the material's

Fig. 5-11. (a) Roller-based symmetrical reduction liner machine; (b) fusing expansion head for symmetrical reduction process
Source: Insituform Technologies, LLC; reproduced with permission

molecular "memory" for the dimensions formed at the time of extrusion. Figs. 5-11(a and b) present the roller-based symmetrical reduction (Rolldown) and pipe stretching (Swagelining) liner machine and fusing expansion head for symmetrical reduction process.

- **Folded systems**. These lining systems involve modifying the cross section of a thermoplastic pipe into a folded C or U shape. After insertion of the folded pipe into the host pipe, the pipe is returned to its original shape and diameter using pressure.

Host Pipe Materials, Diameters, and Alignment Conditions Close-fit renewal can be applied to various host pipe materials, including cast iron, ductile iron, and steel. While most host pipelines can be renewed with close-fit liners, this renewal method is best suited for host pipes that exhibit the following characteristics:

- Where poor structural integrity of host pipes makes other lining methods, such as cement mortar, not applicable.
- Where the lined pipe needs to provide adequate capacity compared with the host pipe. With close-fit lining, the reduction in the host pipe's inside diameter is offset by the reduced friction factor of the liner pipe.
- On pipes that are straight or that contain minor, sweeping bends.
- On pipes containing no offset joints or protruding obstructions such as weld beads inside the pipe. Care is needed in lining pipes with significant local variations in internal diameter because of manufacturing tolerances, joint offsets, or other potential

obstructions, including protruding service connections. These variations may reduce or even eliminate insertion clearance needed for CFP.
- On pipes with long, straight sections where long insertions may be possible, leading to less surface disruptions and lower costs.

New Lining Considerations: Thickness and Material Properties Factors to consider when selecting the liner pipe include

- The wall thickness needed to achieve the desired internal pressure rating at the design temperature, and
- The ability to withstand the external pressure of soil and traffic loads.

The internal pressure rating is determined by the type of piping materials and the DR, which is the ratio of the outside diameter to the wall thickness. All pipe diameters with a given DR value (DR-9, DR-17, or DR-26) will have the same pressure rating and can be combined into one piping system.

Flow through HDPE and PVC may be calculated using a Hazen-Williams coefficient, C, of 150, considering the effective reduction of host pipe diameter, which will be twice the liner pipe thickness. Where vacuum may occur within the piping system or if the host pipe condition renders it is unable to safely carry the necessary external loads, ensuring that the pipe is of a sufficient DR to resist collapse is necessary.

Plastic pipe may be gouged or cut more easily than most other types of pipe materials. However, a pipe's ability to withstand the rigors of the insertion process generally relates to the use of proper installation procedures, thickness, and the quality of pipe material.

Design Principles

Site Compatibility A site is considered to be compatible with close-fit renewal when space is available to allow entrance and exit pits to be excavated. In addition, close-fit may be an appropriate solution under these site conditions:

- When service connections and branches are limited and protruding connections can be economically backed out and restored;
- Where a structure has been constructed over an existing main, making open-cut replacement economically impractical; and
- Where a main crosses under railroads, roads, bridges, rivers, or other obstacles.

Wall Thickness Design Close-fit HDPE pipe can be designed as a semistructural, interactive (Class III) or independently structural (Class IV) renewal. Whether or not the HDPE pipe is Class III or IV depends upon the project requirements, diameter, and operating pressures. At low pressures, most classes of HDPE can be Class IV renewals. For example, for PE, a DR-50 yields a Class IV pressure rating of 41 psi (3 bars). As the operation pressure increases, the same HDPE can only function as a Class III solution.

New Pipe Lining Material Physical Characteristics and Handling Practices Close-fit HDPE pipe can handle moderately high temperatures (140°F [60°C] for pressurized lines) and highly corrosive and abrasive liquids in nearly all applications. It is particularly durable and able to withstand the impact of cold weather. Understanding that HDPE expands and contracts with variations in temperature is important. Most HDPE pipe materials are treated to tolerate exposure to sunlight.

Application The total time required to complete a close-fit installation depends on the work that must be done to prepare the pipe for renewal and the length of the host pipe to be renewed. Generally, a minimum of 48 hours is needed before the insertion to conduct site preparation, and 48 hours are needed after the insertion for project closeout. Once access to a host pipe is established and the host pipeline is clean, crews can typically install up to 3,000 ft (900 m) of close-fit pipe per day. Prechlorinating is an option that can potentially accelerate the renewal process, depending on local and jurisdictional requirements, which must be investigated and followed.

1. **Close-fit pipe preparation:** Lengths of HDPE pipe are fused together using a butt-fusion welding process at the job site. This machine produces a true joint with the same structural integrity and tensile strength as the pipe itself. The fused pipe is then fed through cross-section reduction equipment, which temporarily reduces the pipe's diameter or cross section so it fits within the host pipe. Fig. 5-12 presents a site-folded HDPE liner.
2. **Installation**: After the host pipe is properly prepared, typically a winch cable is fed through it and attached to a bullet-shaped pulling head that has been attached to the close-fit liner. The liner is then pulled through the host pipe using a power winch or other pulling devices. Depending on the close-fit technique, other equipment may assist in the pushing or pulling of the liner. Caution must be exercised during insertion to prevent gouging the liner exterior as it is pulled into the host pipe.
3. **Rerounding:** In some cases, the inserted close-fit pipe will revert back to its original profile upon release of winch tension. In other cases, the close-fit pipe may require pressurization with water. In that case, with the application of water pressure, the HDPE pipe reverts to its original size and shape, forming a close fit with the host pipe.

Fig. 5-12. Site-folded HDPE liner
Source: Insituform Technologies, LLC; reproduced with permission

Features and Benefits Two key advantages of close-fit pipe are as follows:

- **Greater retention of hydraulic cross section:** Despite the reduction in cross-sectional area, thin liners typically improve the flow capacity of the host pipe through improved smoothness (C value) and lack of joints in the liner.
- **Flexibility of liner thickness**. Liner thickness can be selected to provide either fully structural or semistructural internal pressure capability.

Other advantages of close-fit solutions include the following:

- HDPE pipe can be heat fused to form a joint that is leak-free and as strong as the pipe itself.
- HDPE pipe can be bent to a radius 25 times the nominal pipe diameter (e.g., a 12 in. [300 mm, DR-13.5] HDPE pipe can be cold formed in the field to a 25-ft [7.62-m] radius), so it is suitable for use in soils prone to ground movements, including areas prone to earthquakes. For pressure pipes with fittings in the area of a bend, a minimum bend of 100 times the nominal pipe diameter of the pipe is recommended.
- PE 4710 has a high slow-crack growth resistance equal to or greater than 500 hours.
- PE 4710 with 0.63 design factor allows use of thinner pipe walls, resulting in larger pipe internal diameters. A 0.5 design factor is presently the standard for potable water pipelines (AWWA C906 [AWWA 2007a]). According to ASTM D2837 (ASTM 2013d), "Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products,"

a design factor is a number less than 1.0 which takes into consideration all of the variables and degree of safety involved in a thermoplastic pressure piping installation in order to provide a continuous life with reliable confidence. Refer to the Plastics Pipe Institute (PPI) website and AWWA C906 (AWWA 2007a) for more information on the design factor for PE 4710.
- PE is a ductile material that resists impact and fatigue.

Limitations

- Close-fit solutions cannot navigate elbows or sharp bends.
- Sufficient site space may be required to accommodate butt-fusion welding of polyethylene pipes into long sections prior to diameter reduction and during subsequent insertion.
- Some processes are unable to negotiate manufactured bends, and local excavation is required at these locations as well as service connections and any other in-line fittings.
- Access points to insert the HDPE liner requires careful removal of the host pipe.

5.5.2 Fusible PVC

Introduction and Background Tight-fit structural lining with PVC is accomplished by expanding a specifically formulated AWWA C900 (AWWA 2007)/AWWA C905 (AWWA 2010)/ASTM D2241 (ASTM 2009c) PVC that has been butt-fused together in a continuous length. The liner pipe is inserted into the host pipe and then brought to tight-fit dimensions through a combination of heat and pressure. The lining maintains and/or increases flow capability by providing the C value of PVC that normally more than offsets the slight reduction in flow area.

Host Pipe Considerations With the host pipe condition known from the CCTV inspection, consideration is then given to access and receiving points. Typical distance between these access points can be up to about 500 ft (150 m). Access points normally are collocated with fittings, valves, or changes in direction that would have to be excavated in most cases.

New Lining Considerations Considerations for the new PVC lining are as follows:

- The wall thickness for the new liner must be selected to meet the required pressure rating for the renewed pipe or system. The liner pipe supplier needs to be consulted for pipe thickness selection.
- The PVC pipe sections can be delivered to job site in lengths up to 40 ft (12 m). In some cases, a 45-ft (13.7-m) length may be available.

This length will be determined by whether or not the PVC pipe sections can be fused together before insertion. In this case, the longest available length should be used. If there are area restrictions for insertion requiring fusion to be done inside the pit, then shorter lengths should be ordered to fit the available pit space.
- The connection scheme after expansion must also be determined. This can influence PVC pipe wall thickness and expansion hardware selection to size the expansion to the end connection configuration.
- The external bead is removed at each fusion joint to allow the PVC liner pipe to expand smoothly against the host pipe.

Design Principles Basic design principles are as follows:

- This type of close-fit liner can be designed to be fully structural so it can stand alone with no contribution of the host pipe for its pressure rating. The pressure rating is determined in the same manner as prescribed in AWWA C900 (AWWA 2007c) or AWWA C905 (AWWA 2010) using the standard pressure or ISO equation, which provides for a safety factor of at least 2.0 and a design factor of 0.5 or better.
- The expansion limits are typically less than 40%, measured as the difference between the internal diameter (ID) of the host pipe and the outside diameter (OD) of the PVC pipe. This is determined at the largest point of expansion, which typically is in the end and connection area.
- Installation of the PVC pipe is controlled by allowable bending radius (the minimum pipe length required to make a 90 degree curvature) of the starting stock material.

Special Construction Considerations and Installations The installation for the close-fit PVC structural liner process is as follows (Fig. 5-13):

- The starting PVC pipe selection is based on the internal diameter of the host pipe and the required pressure rating for the new pipe. The PVC pipe is analyzed to determine the amount of expansion needed. The pressure capacity of the expanded pipe is determined on a standalone, fully structural basis. No contribution of the degraded host pipe is assumed or used in the determination.
- In most conditions, the maximum recommended length for close-fit fusible PVC is approximately 500 ft (150 m).
- As for HDPE close-fit, prior to installation of the PVC liner, the host pipe is cleaned and inspected. The cleaning is done to remove any debris, sediment, or accumulated tuberculation to achieve the internal diameter expected. When completely expanded, the PVC liner does not adhere to the inside surface of host pipe, so a bondable

Fig. 5-13. Starting stock inserted in host pipe
Source: Underground Solutions, Inc.; reproduced with permission

surface is not required. The preinsertion inspection is normally performed with CCTV inspection. This allows assessment of the host pipe for any restrictions that could affect the expansion. The CCTV inspection looks for abandoned valve bodies and fittings, inline reducers, protruding connections, or other such restrictions that would prevent a successful close-fit insertion of the PVC liner. The inspection also looks for sharp edges or points that could damage the PVC liner during insertion and expansion. The alignment of the host pipe must also conform to the bend radius of the selected PVC pipe. With the host pipe cleaned and inspected and the starting stock fused together, the PVC pipe is inserted in a manner similar to a conventional sliplining operation (refer to Section 5.4), where the new liner pipe is inserted without a diameter reduction (Fig. 5-13). Normally, it is pulled into place with a winch, but it can be pushed as well.

- The expansion hardware is installed, and the liner pipe filled with water.
- The liner pipe is heated in a controlled manner with hot water.
- Upon reaching the proper conditions (temperature), pressure is added in the form of additional hot water under pressure. This initiates the expansion.
- Expansion completion is determined by several methods:
    - First a calculated volume of expansion is determined prior to start. While the internal diameter of the host pipe may vary somewhat, the amount of expansion achieved within a range around this calculated amount is a good indicator of a completed expansion.
    - As the expansion is completed, the pressure will rise as the host pipe restricts further expansion.

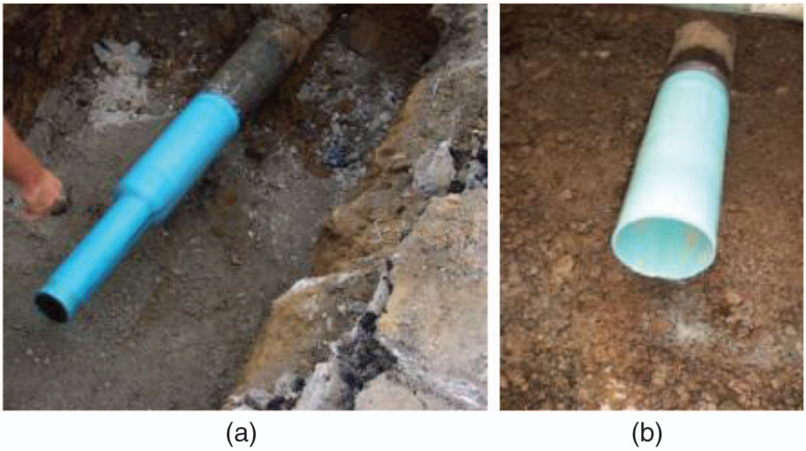


Fig. 5-14. (a) Expanded structural liner with hardware removed; (b) expanded structural liner with prepared end
Source: Underground Solutions, Inc.; reproduced with permission

  - At the pipe ends and at any intermediate expansion point, visual inspection can be done to see that the liner pipe has expanded against the host pipe internal diameter.

Included in the expansion hardware is a sizing sleeve that allows the pipe ends outside the host pipe to be expanded to a diameter that will accept a standard fitting for reconnection. In most cases, this will be the outside diameter of the host pipe, thus allowing the same size fittings to be used. Intermediate points can be exposed, sections of host pipe removed, expansion sleeve installed, and an expanded portion of the liner pipe sized to cut for a tee or other fitting. Fig. 5-14(a) presents an expanded structural liner with hardware removed, and Fig. 5-14(b) presents an expanded structural liner with a prepared end.

Features and Benefits

- The PVC close-fit liner can be designed as fully structural because it does not rely on the host pipe for its long-term pressure rating.
- Depending on the relationship between the internal diameter of the host pipe and the outside diameter of the PVC pipe (percent expansion), pressure ratings in the 200 psi (14 bars) range are possible for lower levels of expansion and typically are in the 150 psi (10 bars) range for the upper limit of expansion.
- The expanded PVC liner maintains a C value of 150 for pressure flow considerations. In many cases, no flow capacity is lost due to the

higher C value offsetting the slightly reduced internal diameter of the expanded liner.

- The liner can be configured to connect back to standard size pipe using off-the-shelf fittings.
- For inline reconnections, the lining pipe is sized to the same outside diameter as the host pipe. Standard waterworks fittings are then used for reconnection. For pipe taps, standard PVC tap saddles are used in areas where the liner has been expanded to the outside diameter of the host pipe. Properly installed adjustable tap saddles can be used on pipes expanded to the internal diameter of the host pipe.

Limitations

- Insertion lengths are normally limited to less than 500 ft (150 m) dependent on the host pipe diameter.
- Access to the PVC liner requires careful removal of the host pipe.
- As with any sliplining, the host pipe, if intact, can shield flaws in the inserted pipe, such as leaks.

5.6 FIBER-REINFORCED POLYMER LININGS

5.6.1 Introduction and Background

The use of fiber-reinforced polymer (FRP) liners to rehabilitate pipelines started in the 1990s. Typical rehabilitation projects include targeted structural repair of corrosion damage in prestressed concrete and steel pipes by simultaneously mitigating the corrosion process and restoring the structural capacity of the deteriorated pipeline (Ojdrovic and Zarghamee 2007). FRP liners can also be used to increase internal pressure and improve the flexural and buckling capacity of deteriorated or non-deteriorated pipes.

FRP liners consist of carbon or glass reinforcing fabric that is saturated with an epoxy resin and then applied using the wet layup process to the prepared surfaces of the host pipe. Carbon-fiber–reinforced polymers (CFRPs) are typically used for pressure pipelines. Glass-fiber–reinforced polymers (GFRPs) are typically used as the first layer of material to contact any metallic substrate to provide a dielectric barrier between the metallic substrate and the CFRP materials. When the interior surface of pipeline is lined, all FRP materials, equipment, and labor can be introduced through access points and pits; thus some excavation is required. For aboveground pipelines, the FRPs can be applied to the exterior surface without compromising their functionality and structural performance. If such pipelines are exposed to direct sunlight, ultraviolet radiation protective coatings can be used. FRP liners have inherent chemical resistance, are chemically inert, and are not subject to corrosion, which makes them viable for lining potable water pipelines. However, FRP properties can vary significantly among resin systems; therefore, extensive materials testing is necessary prior to approval of any specific resin to validate durability, structural performance, and compliance with drinking water requirements. Properly designed and installed FRP liners can address severe deterioration of the host pipe and achieve a service life of 50 years or more.

5.6.2 Host Pipe Conditions and Considerations

The bond between FRP liners and the host pipe is critical to ensuring proper structural performance of the lining. Therefore, proper surface preparation of the host pipe is necessary. High-pressure water jetting or other abrasive methods are required to remove bond-inhibiting substances (such as scour, loose rust, etc.). The pull-off strength at the substrate-FRP interface is ascertained by field testing in accordance with ASTM D4541 (ASTM 2009d). For concrete substrates, the surface shall be profiled using hydro surface profiling or other abrasive blasting to remove all contaminants (laitance, surface lubricants, broken mortar pieces, etc.) and to achieve a minimum profile of International Concrete Repair Institute (ICRI) CSP 3 (refer to ICRI Guideline No. 03732—*Selecting and Specifying Concrete Surface Preparation for Coatings, Sealers, and Polymer Overlays, and Concrete Repair*). Heavily deteriorated substrate conditions may also require surface repairs, such as removing loose substrate material and corroded reinforcement, patching large voids, and injecting grout into cracks. For steel substrates, the surface must be prepared to near-white finish with all contaminants and salts removed from the surface.

5.6.3 New Lining Considerations

FRP liners are typically a composite combination of fiber reinforcement and polymer adhesives or resins constructed from fabrics containing carbon or glass fibers that are impregnated with epoxy resin. All materials should be compatible and come from one manufacturer. The CFRP repair system should be qualified for use based on mechanical, durability, and physical tests and required properties, including short-term tension test data determined according to ASTM D7290 (ASTM 2011a), durability tests with minimum required percent retention of tensile properties per ASTM D3039 (ASTM 2014c) for at least 10,000 hours, average glass-transition temperature higher by at least 40°F (22°C) than the maximum operating temperature, and long-term water absorption less than 2%. The material and applicator should be prequalified prior to or at the time of bid by providing the necessary material test results and experience requirements.

The saturated fabric is directly applied to the pipe surface and cured in place to generate an adhered laminate. Cured-in-place FRP liners are typically installed using hand layup methods; thus, when the liner is installed on the pipe interior surface, the internal diameter of the pipe must be 30 in. (750 mm) or larger to accommodate safe worker access into the pipeline. Obviously, there is no practical limitation on the maximum or minimum diameter of pipe that can be repaired when the FRP is installed on the exterior surface of the pipe. These liners can be applied over straight segments and complex geometry zones, such as bends, diameter transitions, or connection zones. Developments are underway for robots that could facilitate repair of smaller diameter pipes with this technique soon.

5.6.4 Design Principles

The objective of the CFRP design is to ensure the liner will remain functional when subjected to service loads during its design life with the necessary strength, reliability, and durability. At present, no standards for design of CFRP repairs exist. AWWA has an active committee that is developing a standard for CFRP repairs of PCCP. For a viable design of CFRP liner, all limit states relate to one or both of the following two design approaches: CFRP liner acting as a stand-alone buried flexible pipe, or CFRP liner and portion of the host pipe (inner concrete core in PCCP or remaining steel thickness in steel pipe) acting as a composite system. The limit states that should be satisfied include the following:

- Rupture of CFRP laminate in the circumferential direction due to internal pressure and external loads;
- Buckling of CFRP laminate in the circumferential direction due to external loads, external pressures, and internal negative pressure;
- Rupture of CFRP laminate in the longitudinal direction due to pressure-induced thrust, Poisson effect of internal pressure, and temperature change, and due to differential radial expansion of pipe with variable stiffness along the length;
- Buckling of CFRP liner in the longitudinal direction due to temperature change; and
- Interlaminar shear failure of CFRP at pipe ends and adequate development length between the sheets of fiber.

5.6.5 Initial Setup, Surface Preparation, and/or Repairs

The pipe segment targeted for repair must be completely drained of all standing water in the repair zone. Next, all required access points are opened and applicable confined space work protocols implemented. For access points located in streets, proper traffic control measures must be implemented prior to the opening of the access. Finally, high-quality

Fig. 5-15. Surface preparations on concrete substrate: cleaning using ultra-high–pressure water blasting
Source: Fibrwrap Construction Services, Inc.; reproduced with permission from Insituform Technologies, LLC

surface preparation and/or repairs are performed (see Section 5.6.2). Fig. 5-15 illustrates typical surface preparation procedures.

5.6.6 Sealing of the Substrate Surface

To promote adhesion, the substrate must be sealed with a thin film of saturating resin or thickened epoxy paste (tack coat). The tack coat also prevents sliding or sagging of the saturated FRP sheets due to self-weight before the resin cures; thus, it is usually applied only on the upper half of the pipe section, and the lower half is sealed with the saturating resin. Fig. 5-16 shows the application of tack coat and saturating resin sealer on the pipe substrate.

5.6.7 Cured-in-Place FRP Liner Installation

Cured-in-place FRP liners can only be installed using wet layup method with fully impregnated sheets of fiber. The dry layup method should not be used for pipe repairs, because it may result in partially impregnated sheets that would be difficult to detect and repair.

The wet layup method requires saturation of the carbon or glass fabric prior to installation. Mechanical saturators, such as the one shown in Fig. 5-17(a), are often used to guarantee fast, uniform saturation rates of the sheets. The mechanical saturator is a device in which the unsaturated fabric roll is mounted, passed through a bath of saturating resin, and then passed in between two rollers that evenly spread the resin. The spacing between the rollers is calibrated to the fabric being used, and is verified as


(a) (b)

Fig. 5-16. (a) Application of tack coat to upper half of pipe; (b) bottom half of pipe sealed with saturating resin
Source: QuakeWrap, Inc.; reproduced with permission


(a) (b)

Fig. 5-17. Wet layup method: (a) saturation of the carbon fiber sheet and (b) application of the carbon fiber sheet
Source: Fibrwrap Construction Services, Inc.; reproduced with permission from Insituform Technologies, LLC

part of the quality assurance/quality control (QA/QC) process. The saturated fabric is rolled up on a reel that can be taken off the machine and transported to the point of installation. Fig. 5-17(b) illustrates carbon-fiber FRP sheets installed using the wet layup method where fabric applied to the walls has already been impregnated with epoxy using the mechanical saturator as shown in Fig. 5-17(a). The fabric is hand-pressed against the pipe wall to eliminate entrapped air pockets (blisters). The joints and terminations of repair must be detailed to prevent the water from penetrating behind the CFRP liner.

5.6.8 FRP Liner Curing

After the installed FRP sheets have been properly detailed, the FRP installation must be left undisturbed to allow the saturating resin to cure. The curing time depends on the ambient temperature. Heaters can be used to increase the ambient temperature and significantly reduce the curing time of the resins if the installation schedule does not allow for standard curing times. The manufacturer should provide data on required temperature, time, and percent cure, and provide the percent cure vs. hardness relationship that can be checked by inspectors prior to letting water into the pipeline.

5.6.9 Application of Top Coats

When additional abrasion resistance is desired, colored epoxy top coats can be applied to the FRP liner per manufacturer's recommendations. Light scuffing is required if the top coat is applied to fully cured FRP liners to eliminate the glossy finish and thus improve adherence. The color in the top coat can achieve two objectives: match the natural color of the substrate and facilitate future inspections of the FRP liner. Fig. 5-18 shows top coat application and the final appearance of the FRP liner with the top coat.

5.6.10 Inspecting FRP Installation

Detailed quality control procedures must be implemented to minimize the inherent variability of hand installation methods (Engindeniz et al. 2011; Ojdrovic 2011). Quality control and assurance instructions are usually included in FRP project specifications and must be strictly followed by the installation contractor under the supervision of a certified inspector. The inspector must be present as soon as the pipeline is dewatered to inspect the existing substrate conditions and supervise surface preparation

Fig. 5-18. Final appearance of top-coated FRP liner
Source: Fibrwrap Construction Services, Inc.; reproduced with permission from Insituform Technologies, LLC

and repair procedures. The inspector must also record the ambient temperature and humidity inside the pipe before and during the installation of the FRP and during the FRP curing period. The inspector must also keep a record of the lot number of the resin and fabric roll used to fabricate each FRP strip and the location inside the pipe where each strip was installed. Similarly, the inspector must record lot numbers of containers and application locations of tack coats, top coats, and sealers. The overall objective of the inspector is to ascertain that the FRP installation job is done in accordance with the project drawings and specifications.

An independent testing agency usually witnesses adhesion pull-off tests performed by the contractor to evaluate the bond strength at the FRP-substrate interface and performs tensile tests on cured test samples fabricated and cured in a similar manner as the pipe repair. Since pull-off tests are destructive, they may be performed on FRP liner mockups installed right next to the actual FRP liner. Tensile test reports usually include tensile strength and modulus of elasticity and ultimate strain at failure—values that are compared with the values given in the FRP manufacturer's product data sheet. Care must be taken to ensure that the laboratory performing tension tests on the FRP coupons has the right equipment and is familiar with the gripping requirements of such samples.

5.6.11 Features and Benefits of FRP Liners

- FRP liners can be fully structural liners that can be designed to restitute the internal pressure and flexural and buckling capacity of deteriorated water pipelines. The FRP can also be designed to increase the structural capacity of the pipeline to accommodate unforeseen design conditions, such as the increase of overburden pressure due to the construction of new roads or buildings over the pipe. FRP liners can be designed as stand-alone flexible pipes when the host pipe is considered to be fully deteriorated or can be designed to work in composite action with the host pipe.
- The adhesive resin used in FRP liners bonds well to the surface of concrete, steel, cast iron, and other pipes.
- At least three FRP liner manufactures are listed in compliance with NSF/ANSI 61 (NSF 2013) for use in potable water lines, so multiple system providers are available with competitive pricing.
- The installation of FRP liners does not require excavation of the pipeline (trenchless repair technology). All FRP materials, tools, and equipment can easily fit through the diameter of typical access points.
- FRP liners are light weight and hand applied and do not require sophisticated installation equipment. This facilitates the training and certification by the FRP manufacturer field technicians of installation

crews recruited from locally available labor, thus significantly reducing travel-related installation costs.
- FRP installation projects can accommodate tight schedules that minimize downtime. Using multiple crews in parallel is possible, further reducing the repair and renewal time. However, a minimum pipeline shutdown of several days is needed for any internal repairs to allow time to dewater the repair area, perform surface preparation, apply the FRP liner, and allow the FRP material to cure before the pipeline is placed back in service.
- FRP liners can be applied with relative ease over straight and complex geometry pipeline segments such as bends, diameter transition and connection zones.

5.6.12 Limitations of FRP Liners

- Only large-diameter pipelines (36 in. [900 mm] or larger) can be renewed at this time.
- Installation and curing may take more time than other methods.
- The treated section must be thoroughly clean and dry before it can receive the FRP liner.

5.7 CHAPTER SUMMARY

This chapter presented an overview of potable water pipe renewal methods. Special considerations were given to type of material, installation methods, applicable site and host pipe conditions, and features, benefits, and limitations. The decision to select a specific method depends on many factors, including the host pipe structural conditions and hydraulic capacity. Renewal methods are designed as structural or semistructural (Class III and IV), based on project requirements. The installation productivity and same return to service are other important considerations to reduce or possibly eliminate bypassing costs. In addition to methods described in this chapter, for small pipes, such as those inside buildings, one option is to use forced hot air to distribute the lining material, but the effectiveness should be verified. For large pipe, a new technique uses a pair of rotating spray heads that each apply the one component of the polymeric with an oscillating motion to avoid shadowing that can occur with a one direction spray head application.

ENDNOTES

1. According to ASTM D 2837 (2013d), “the procedure for estimating long-term hydrostatic strength or pressure-strength is essentially an extrapolation with respect to time of a stress-time or pressure-time regression line based on data obtained in accordance with Test Method D1598 (2009). Stress or pressure-failure time plots are obtained for the selected temperature and environment: the extrapolation is made in such a manner that the long-term hydrostatic strength or pressure strength is estimated for these conditions.”

2. PE 4710 is a recent development (5 to 10 years), with improved polyethylene compound for pressure pipe with increased tensile strength, stiffness increased design stress, increased reliability, chemical resistance, and increased slow crack growth (SCG) resistance.

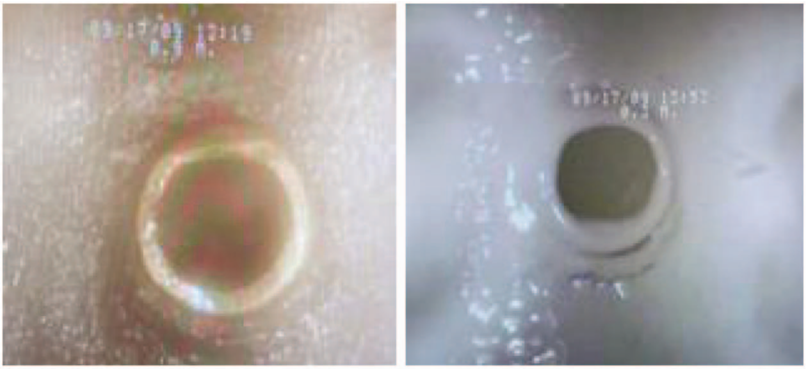
CHAPTER 6

POSTLINING AND CLOSEOUT PHASE

6.1 QUALITY CONTROL

A postlining inspection should include all pertinent information of the new installation as it applies to each individual technology: visual appearance of lining and its thickness measurements from ends or coupons, any defect location and its description, areas that were repaired, locations of new connections, valves or changes in the pipeline appurtenances, grouting, level of adhesion and results of pull-out tests, reconnection quality, construction close out, and landscape restoration. It should be noted that connections require special attention and future remediation and repair of connections can be costly. Figs. 6-1(a and b) illustrate corporation stops before and after lining. A contractor should submit final inspection and testing results before requesting final payment.

For a thin spray lining, a smooth surface of the lining is not to be expected, because the underlying pipe surface will be pitted and uneven. Also radial bands of lining that appear to be waves—referred to as ringing—will likely be apparent. Unless excessive, this is no cause for concern where the areas of minimum thickness are below a specified limit. The ringing effect is caused by friction of the umbilical cable as it is pulled back the length of the host pipe. The key is for the thinnest covering to meet the application criteria. For thermoplastic insertion projects that need liner rerounding, temperatures and pressures need to be recorded.



(a) (b)

Fig. 6-1. Corporation stops (a) before and (b) after lining
Source: 3M Water Infrastructure; reproduced with permission

6.2 WATER MAIN RECONNECTION

After lining installation, supporting heavy valves (12 in. [300 mm] and larger) with treated timbers, crushed stone, concrete pads, or a thoroughly tamped trench bottom in contact with the valve is necessary.

An integral component of any lining system is the end fittings. These are required for reconnection of a lined segment to the existing system or to another lined segment and to seal annular space. In some cases, these fittings eliminate the potential for the liner to retract following installation. A wide range of options is available, and a suitable fitting must be selected in the design of a lining system. End fittings can be applied using various methods, depending on the application. Strict attention must be paid to the pressure ratings of all fittings.

All valves should be inspected upon reconnection to ensure proper working order after installation. Valves should be set and jointed to a pipe in the manner set forth in AWWA M28 (AWWA 2014) standards for the type of connection ends furnished. All valves and appurtenances should be installed true to alignment and rigidly supported. Any damage to the aforementioned items must be repaired or replaced before they are installed.

Hydrants should be connected to the pipe as per the original location with proper thrust blocking. Hydrants should be installed in a manner that will provide complete accessibility and minimum possibility of damage from vehicles or injury to pedestrians. The outside of the hydrant above the finished ground line and hydrant concrete pad should be thoroughly cleaned to remove all dirt, dust, and debris.

6.3 DISINFECTION

Lining materials should be unaffected by highly chlorinated and standard disinfection methods per ANSI/AWWA C651 (AWWA 2014) should be used. Disinfection of water pipes after renewal is essential. In some methods, the renewed pipe is inserted fully predisinfected. The following describes four main types of disinfection methods.

6.3.1 Tablet Method

ANSI/AWWA C651 (AWWA 2014) recommends the use of an average chlorine content of 2.08×10^{-4} to 1.25×10^{-3} lbs/gal (25–150 mg/L) for a duration of 2,472 hours. Preferably, disinfection should be carried out overnight; however, it should not occur on a day before the weekend or holidays.

6.3.2 Continuous Feed Method

According to ANSI/AWWA C651 (AWWA 2014), the chlorine may be added in the form of dissolved calcium hypochlorite, sodium hypochlorite, liquid chlorine, or chlorine gas. Among these, dissolved chlorine gas offers the "best" disinfection; however, environmental concerns and regulations have made this option less desirable. The concentrations vary from 2.08×10^{-4} to 5×10^{-4} lbs/gal (25–60 mg/L) for durations of 24–72 hours.

6.3.3 Slug Method

This method is generally used in conjunction with the tablet method. After the tablet method is completed and flushed, a heavy concentrated slug of chlorine is added to the pipe and slowly forced through the system. The concentration of the slug is monitored during disinfection and if the free chlorine residual drops below 4.17×10^{-4} lbs/gal (50 mg/L), an additional amount of chlorine is added. Several utilities use this method at a concentration of 2.5×10^{-3} to 4.17×10^{-3} lbs/gal (300–500 mg/L). Disposal and treatment of the heavily chlorinated water can become a problem with the slug method ANSI/AWWA C651 (AWWA 2014).

6.3.4 Ozonation

As an unstable molecule, ozone readily gives up one atom of oxygen, providing a powerful oxidizing agent that is toxic to most waterborne organisms. Ozonation is an effective method to inactivate harmful protozoans forming cysts. This method also works well against almost all other pathogens. Ozone gas is prepared by passing oxygen through ultraviolet light or using a "cold" electrical discharge. To use ozone as a disinfectant, it must be created onsite and bubbled through the water. Ozone can quickly dissipate and provides no residual.

6.4 PROJECT CLEANUP AND RESTORATION

6.4.1 Surface Restoration and Site Clearing

When the renewal work is complete, temporary service materials, additional pieces of pipe, extra fittings, tools, and incidental materials, which include debris and spoil material, should be removed from the jobsite or street right-of-way. All undamaged walkways and pavements should be cleaned. All grass areas must be reseeded and/or replaced with sod, and shrubs, trees, and other plants must be replaced to their original condition or better. Damaged and removed pavement should be replaced according to the municipality, local government, or department of transportation permitting following their specifications and standards.

6.4.2 Waste Disposal

The contractor is responsible for being familiar with all regulations for handling and disposing of extra lining materials and chemicals. For example, the unused spillage and waste materials must be immediately disposed of and uncured material in an industrial or commercial facility should be incinerated, or uncured waste product should be disposed of in a facility permitted to accept chemical waste.

The contractor is responsible for ensuring that all permits and other types of disposal documentation are completed and distributed as required by regulatory agencies. Because regulations vary, applicable federal, state, and local regulations should be consulted before disposal.

6.4.3 Safety Issues

The contractor is responsible for safety on the jobsite. Safety should be covered according to the relevant OSHA standards. Special attention should be paid to safety of workers, pedestrians, and the traveling public during the entire pipe renewal project. Common safety issues may include trench and pit shoring (if required), vehicular traffic, existing utilities, and overhead power lines (Najafi 2007). Some products (polymerics) are hazardous, and workers should be fully protected and general public kept clear.

6.5 CHAPTER SUMMARY

This chapter presented some important project close-up and delivery requirements. Quality control, site restoration and cleanup, disinfection methods, water main reconnection, and some safety measures were discussed. Contractors and installers should be held responsible for proper project delivery, documentation, and site restoration. Contractors are also responsible for the safety of workers and general public throughout the project execution.

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APPENDIX A

COMPARISON OF TRENCHLESS RENEWAL METHODS

	Trenchless Renewal Methods				
Work Elements	Cured-in-Place Pipe (CIPP)	Spray-in-Place Pipe (SIPP)	Close-Fit Pipe (CFP)	Sliplining (SL)	Fiber-Reinforced Pipe (FRP)
Method Description	Renew the existing water pipe by installation of resin-impregnated flexible tube	Renew the existing water pipe by spraying the interior of the pipe	Renew the existing water pipe by insertion of reduced cross section of HDPE	Renew the existing water pipe by insertion of HDPE and PVC pipe	Renew the existing water pipe by insertion of glass- or carbon-reinforced fabric
References, Specifications, and Publications	ASTM F1216 (2009a) ASTM F1743 (2008a)	ASTM F1216 (2009a) AWWA C210 (2008a) AWWA C222 (2008c) AWWA C620 (2007b)	Plastics Pipe Institute (2008) AWWA M28 (2014)	Plastics Pipe Institute (2008) (Chapter 11) and ASTM F585 (2013) *Uni-Bell Handbook for PVC Pipe* (2013)	ASTM F2720/F2720M (2009b) ASTM D7290 (2011a) ASTM D3039 (2014c)
Access and Exit Pit Dimensions	Insertion and Receiving Pit: 6 ft × 12 ft possibly at valve and hydrant locations	Insertion and Receiving Pit: 5 ft × 7 ft possibly at valve and hydrant locations	Insertion and Receiving Pit: dependent on pipe diameter and depth	HDPE Insertion and Receiving Pit: Width: slightly wider than the liner Length: $2.5D + 12d$ D = Depth of the invert d = diameter of liner For PVC, see supplier pit-sizing tools	All required access points are dependent on pipe diameter and depth
Required Equipment	1. Refrigerated truck 2. Boiler truck 3. Equipment truck 4. CCTV truck 5. Pickup truck 6. Cleaning equipment (jet truck, winches, scrapers) 7. Installation device for inversion of CIPP 8. Forklift or other lifting device 9. Pumps and other miscellaneous items	1. Lining rig truck that accommodates lining devices 2. Equipment for excavation 3. Cleaning equipment (rack feed borer) 4. CCTV truck 5. Pumps and other miscellaneous items	1. Equipment truck 2. CCTV truck 3. Pickup truck 4. Cleaning equipment (jet truck, winches, scrapers) 5. Cross-section reduction machine 6. Butt-fusion machine 7. Forklift or other lifting device 8. Winch for pulling HDPE 9. Pumps and other miscellaneous items	1. Equipment truck 2. CCTV truck 3. Pickup truck 4. Cleaning equipment (jet truck, winches, scrapers) 5. Butt-fusion machine 6. Winch or static pipe burst machine for pulling HDPE or PVC 7. Pumps and other miscellaneous items	1. Equipment truck 2. Mechanical saturators 3. Pickup truck 4. Cleaning equipment 5. Heaters for curing

Installation Process	1. Set up traffic control 2. Access the pipe 3. Set up bypass service lines 4. Open the pipe 5. Clean the pipe 6. Inspect the pipe (pre-CCTV) 7. Locate, shut off, and plug service connections 8. Install CIPP 9. Cure CIPP 10. Reinstate services 11. Inspect the CIPP (post-CCTV) 12. Connect renewed pipe to adjacent piping 13. Reset valves, fire hydrant connections, and other appurtenances 14. Disinfect 15. Backfill excavations 16. Restore the surface	1. Set up traffic control 2. Access the pipe (locations not more than 500 ft apart) 3. Open the pipe 4. Clean the pipe 5. Inspect the pipe (pre-CCTV) 6. Locate, shut off, and plug service connections 7. Install SIPP 8. Inspect the SIPP (post-CCTV) 9. Reset valves, fire hydrant connections, and other appurtenances 10. Disinfect 11. Backfill excavations 12. Restore the surface	1. Set up traffic control 2. Access the pipe 3. Set up bypass service lines 4. Open the pipe 5. Clean the pipe 6. Inspect the pipe (pre-CCTV) 7. Locate and shut off service connections 8. String winch cable through pipe 9. Pull in reduced cross section of HDPE pipe 10. Expand pipe 11. Install end seals 12. Inspect the HDPE (post-CCTV) 13. Connect rehabilitated pipe to adjacent piping 14. Reset valves, fire hydrant connections, and other appurtenances 15. Disinfect 16. Backfill excavation 17. Restore the surface	1. Set up traffic control 2. Access the pipe 3. Set up bypass service lines 4. Open the pipe 5. Clean the pipe 6. Inspect the pipe (pre-CCTV) 7. Locate, shut off, and plug service connections 8. Join the lengths of PVC or polyethylene pipe 9. Install liner 10. Reinstate services 11. Inspect the lining (post-CCTV) 12. Connect renewed pipe to adjacent piping 13. Reset valves, fire hydrant connections, and other appurtenances 14. Fill the annular space with grout 15. Disinfect 16. Backfill excavations 17. Restore the surface	1. Set up traffic control 2. Access the pipe 3. Set up bypass service lines 4. Open the pipe 5. Clean and drain the pipe 6. Locate, shut off, and plug service connections 7. Seal the substrate surface 8. Saturate the carbon or glass fabric 9. Hand press fabric against wall of the pipe 10. Use heaters to cure 11. Apply epoxy top coats (if desired) 12. Perform pull-off test to evaluate the bond strength 13. Connect renewed pipe to adjacent piping 14. Reset valves, fire hydrant connections, and other appurtenances 15. Disinfect 16. Backfill excavations 17. Restore the surface

(Continued)

Documentation and Drawings	1. Contract documents 2. Updated as-built drawings after the installation of the lining 3. Preinstallation and postinstallation video files 4. Results of the disinfection test 5. Test results from laboratory
Cleanup	1. Complete the balance of work 2. Reconnect water mains 3. Surface restoration and site clearing 4. Waste disposal
Inspection and Monitoring	CCTV or similar methods are used for preinstallation and postinstallation. Monitoring is mostly done by third-party inspector.
Safety	It should be covered according to the relevant Occupational Safety and Health Administration (OSHA) and local standards.
Measurement and Payment	The payment includes equipment, material, and labor, calculated on a per foot basis per pipe diameter in accordance with the unit prices contained in the contract. Payment should also include considerations for additional work such as bypass pumping, cleaning, pre-CCTV and post-CCTV, pit excavation and sheeting, shoring and/or bracing, reconstruction of access pit locations, safety, dust/erosion control, testing, site restoration, service connections and connections of appurtenances, and all other work to provide a completed installation.

APPENDIX B
GLOSSARY

Bottom inversion—The CIPP tube is inverted through a specially designed elbow located at the elevation of the pipe, typically in a manhole or excavated pit.

Butt fusion—A method of joining polyethylene and PVC pipe in which two pipe ends are rapidly brought together under heat and pressure to form a homogeneous bond.

Bypass—A temporary pipeline utilized to divert the flow in the pipe to be renewed so that service is only minimally interrupted.

Bypass pumping—Taking all existing flow in a pipe and routing it around the section of pipe to be renewed, replaced, or repaired.

Carbon/glass fiber—A reinforcing material with a high aspect ratio integrated or mixed into a resin to strengthen a pipeline lining system.

Cement lining—The lining of cement inside a metal pipe. The pipe can be coated in situ or at the factory.

Chemical grouting—Method for the treatment of the ground around a shaft or pipeline using non-cementitious compounds to facilitate or make possible the installation of an underground structure.

CIPP (cured-in-place pipe)—A renewal technique whereby a flexible resin-impregnated tube is installed into a host pipe and then cured to a hard finish, usually assuming the shape of the host pipe.

Closed-circuit television (CCTV) inspection—Inspection method using a closed-circuit television camera system with appropriate transport and lighting mechanisms to view the interior surface of sewer pipes and structures.

Close-fit—Description of a lining system in which the new pipe makes close contact with the defective host 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.

Conventional trenching—See open cut.

Corrosion—The destruction of a material or the deterioration of its properties because of electrochemical reactions with its surroundings.

Cracks—Fracture lines visible by the naked eye around the circumference or along the length of a pipe, or both. Micro-cracks are visible only through microscopy.

Creep—The dimensional change over time of a material, such as plastic, under continuously applied stress after the initial elastic deformation.

Crown—Top of the pipe in the cross section.

Cured-in-place pipe—See CIPP.

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

Emergency repair—An unscheduled repair that must be made during a pipe failure or collapse. This type of repair may cost many times more (usually 10 times more, not including social costs) than planned repair costs and may not be as effective and/or permanent.

Epoxy—Resin formed by the reaction of bisphenol and epichlorohydrin.

Epoxy lining—A cured resin liner based on epoxy resins.

Exit pit—See receiving pit.

Flexural modulus—The slope of the curve defined by flexural stress versus resultant strain. A high flexural modulus indicates a stiffer material.

Flexural strength—The strength of a material in bending expressed as the tensile stress of the outermost fibers at the instant of failure also known as modulus of rupture.

Flexural stress—The longitudinal stress induced in the fibers of a material due to bending.

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

Fusible PVC—Polyvinylchloride pipes joined by butt fusion. The PVC material at the pipe ends is heated and then joined.

Grout—(1) Material, usually cement or polymer based, used to fill the annulus between the host pipe and the lining and also 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.

Heat cure—The application of either steam or hot water to cure a resin-saturated tube.

High-density polyethylene (HDPE)—Polyolefinic material with densities in the vicinity of 0.96 grams per cubic centimeter. See polyethylene also.

Host pipe—Existing old and/or deteriorated pipe in trenchless renewals.

Impervious coating—The outer layer of a CIPP tube that will prevent the installation water or steam from mixing with the resin system in the tube.

Impregnated tube—A felt tube fully saturated with a catalyzed resin system.

Invert—The lowest point on the pipe circumference. The inside bottom, or lowest elevation, of a pipe.

Joints—Point at which the sectional lengths of a pipeline come together to form a continuous and leak-free system.

Lateral—A service line that transports potable water or wastewater from or to individual buildings or households to a main potable water or sewer pipeline.

Lateral connection—The point at which a building or household fluid entrance or drain connects into a main pipeline.

Light cure—The curing of a thermoset resin liner using ultraviolet light energy in lieu of either heated water or steam.

Liner—A material utilized to renew or cover the interior surface of a cleaned deteriorated pipe.

Lining—A renewal process in which a new pipe or coating material is inserted, pulled in, inverted, or formed by spraying to extend the design life of a host pipe.

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

pH—A measure of the acidity or alkalinity of a solution. A value of 7 is neutral; lower numbers indicate more acidity, higher numbers more alkalinity. Range: fractional to 14.

Pipe bursting—A pipe replacement method for breaking the host pipe by brittle fracture using mechanical force. The deteriorated pipe remains are forced into the surrounding ground. At the same time, a new pipe of similar diameter as the cavity created is drawn in behind the bursting tool. Also known as pipe cracking and pipe splitting.

Polyester resin—The most common form of thermosetting resin used in cured-in-place pipe (CIPP) technology for sewer applications. Polyester resin is formed by the reaction of organic acids and alcohols. The viscosity of the original resin is lowered through an active monomer, such as styrene, which accounts for a large percentage of the weight of the overall resin composition.

Polyethylene (PE)—A ductile, durable, virtually inert thermoplastic composed of linear long-chain molecules of ethylenic repeating units. It is normally a translucent, tough solid.

Polymeric lining: Thermoset or thermoplastic lining system that comprises materials with high chemical resistance and low absorption of the fluid being conveyed in a pipeline. Made up of plastic-like epoxies, polyesters, polyurethanes, and polyureas. These materials should have high resistance. They are applied by trained professionals using special spraying equipment per the manufacturer's specifications.

Polyurethane, polyurea—A thermoset polymer derived from the reaction product of an isocyanate base and a synthetic resin blend activator. Amines and polyols are activators for polyurea and polyurethane, respectively.

Polyvinyl chloride (PVC)—A polymer prepared by the polymerization of vinyl chloride as the sole monomer.

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

Quality assurance—Includes developing inspection and testing methods to ensure products or services are designed and produced to meet or exceed owner requirements.

Quality control—Includes providing evidence needed (test results) to establish confidence among all concerned that quality-related activities have been performed.

Receiving or exit (access) pit—Excavation into which trenchless technology equipment is placed and recovered following the installation of the casing, product pipe, conduit, or cable.

Rehabilitation—See renewal.

Renewal—All aspects of upgrading pipelines with a new design life for the performance of host pipeline systems. Includes rehabilitation, renovation, and replacement.

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

Resins—Organic polymers, solid or liquid; usually thermoplastic or thermosetting.

Sliplining (SL)—(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 host 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.

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

Spray-in-place pipe (SIPP)—A two-component system designed specifically to provide a corrosion-resistant coating or a thick liner that extends the useful life of a host pipe.

Thermoplastic—A polymer material, such as polyethylene, that can be repeatedly softened when heated and hardened and reformed when cooled. Thermoplastics are generally much 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.

Trenchless technology (TT)—Also "no-dig"; the variety of techniques for underground pipeline and utility construction and replacement, rehabilitation, and renovation (collectively called renewal); repair; inspection; leak detection; etc., with a minimum of excavation at the ground surface.

Vinyl ester—A resin used in CIPP method for renewal of pressure and industrial pipeline applications, where special corrosion, solvent resistance, and higher temperature performance are needed.

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.

APPENDIX C

ABBREVIATIONS AND ACRONYMS

ASTM	American Society of Testing Materials
AWWA	American Water Works Association
BacT	bacteria test
CCTV	closed-circuit television
CFRP	carbon fiber–reinforced polymer
CFP	close-fit pipe
CI	cast iron
CIPP	cured-in-place pipe
CML	cement mortar lining
DIPS	ductile iron pipe
DR	dimension ratio
EPA	U.S. Environmental Protection Agency
FD	fully deteriorated
FRP	fiber-reinforced polymer
GFRP	glass-fiber–reinforced polymer
HDB	hydrostatic design basis
HDPE	high-density polyethylene
ICRI	International Concrete Repair Institute
ID	internal diameter
in.	inches
IPS	iron pipe size
ISO	International Standards Organization
lbs.	pounds
m	meters
mg/L	milligrams per liter or parts per million (ppm)
MFL	magnetic flux leakage
MOP	manual of practice

NSF	National Sanitation Foundation
OC	open cut
OD	outside diameter
OSHA	Occupational Safety and Health Administration
PCCP	prestressed concrete cylinder pipe
PD	partially deteriorated
PE	polyethylene pipe
PPI	Plastic Pipe Institute
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
SIPP	spray-in-place pipe
SL	sliplining
SSPC	Society for Protective Coatings
UV	ultra violet
VOC	volatile organic compound

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