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

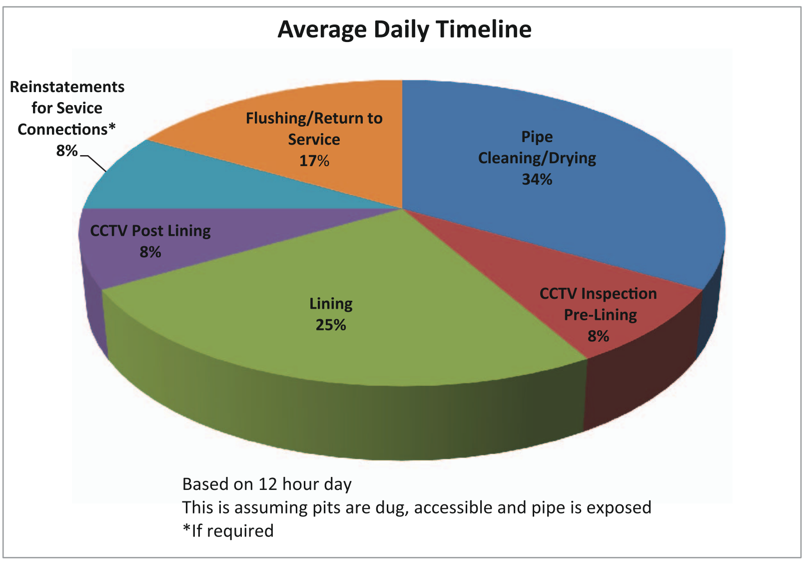

Fig. 5-7. Breakdown and relative timeline of polyurea SIPP process over a 12-hour day
Source: 3M Water Infrastructure; reproduced with permission

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)

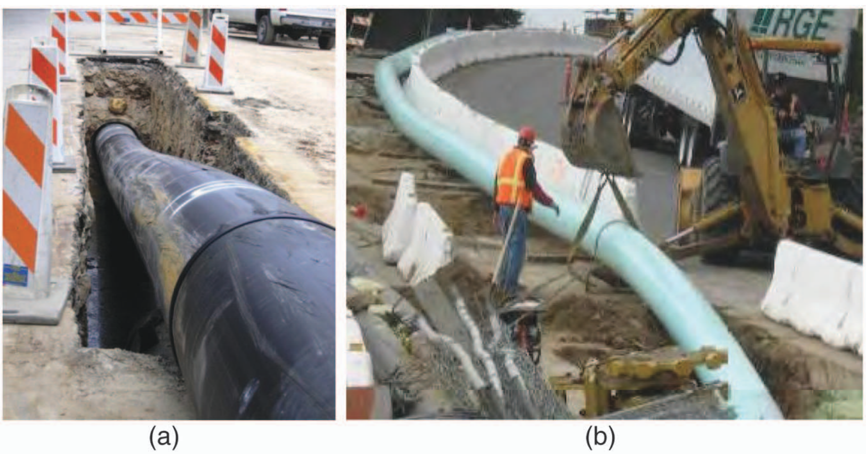

Fig. 5-8. (a) Insertion of 30-in. DIPS HDPE pipe into a 36-in. CI main; (b) insertion of 20-in. DIPS fused PVC pipe into a 24-in. CI main
Source: Plastics Pipe Institute; reproduced with permission

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.