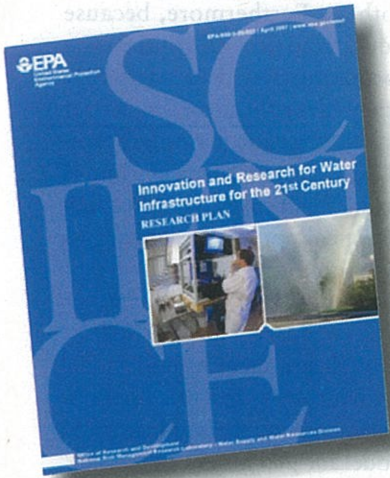


Open-cut construction has long been the historical default option for small water main rehabilitation.

DAVID S. PYZOHA

An economical and sustainable alternative to open-cut construction for small-diameter water main rehabilitation

AS AN ALTERNATIVE TO OPEN-CUT CONSTRUCTION, CURED-IN-PLACE PIPE REHABILITATION OFFERS SUCH ADVANTAGES AS REDUCED POTENTIAL FOR EASEMENTS, LESS NEED FOR TRAFFIC CONTROL, A SHORTER CONSTRUCTION PERIOD, MINIMAL PAVEMENT RESTORATION, AND SIGNIFICANT COST SAVINGS.

A major challenge facing water providers is the condition of their aging water distribution systems. Some utilities have portions of their service and transmission mains that date as far back as the 1800s. For planning purposes, the service life of water mains is often considered to be about 50 to 75 years. Today, water utilities are looking at repairing or replacing components of systems built around 1960 and earlier.

In 2001, AWWA commissioned a study, Reinvesting in Drinking Water Infrastructure: Dawn of the Replacement Era, that looked at the advent of annual replacement needs of 20 utilities (AWWA, 2001). The report warned of an increasing financial burden that municipal utilities face in the twenty-first century and concluded that rehabilitation and replacement should begin immediately. Three years after the AWWA report, researchers forecast that by 2030, pipe replacement would cost a utility four times the current (i.e., 2004) levels (Heijin & Larson, 2004). Drinking water infrastructure in the United States continues to deteriorate at an estimated rate of more than 240,000 main breaks annually (Rush, 2011). The challenge is to replace and maintain distribution system assets at a high level of service through cost-effective sustainable asset rehabilitation.

The Safe Drinking Water Act became law in 1974 with amendments in 1986 and 1996 (USEPA, 1996, 1986, 1974). This law gave the US Environmental Protection Agency (USEPA) power to regulate public drinking water systems and the states the power to implement and enforce the regulations. For water systems, treatment processes and source water protection have constituted the primary focus of technological advancement, whereas the restoration of distribution infrastructure has largely been ignored for nearly 30 years. For some utilities, cement–mortar lining, because of its cost and durability, has proved to be a successful rehabilitation method to extend the service life of 4- to 144-in. water mains. However, this method is a surface maintenance patch and not a structural rehabilitation method to replace unsound host pipe. In cases where the physical condition of the existing main was poor, replacement generally was carried out by open-cut construction, the historical default option for small water main rehabilitation. In highly developed areas, however, open-cut construction can have significant and expensive surface restoration consequences.

Recognizing the looming rehabilitation problem, the USEPA Office of Research and Development initiated a program to evaluate technologies in water main rehabilitation that were emerging in response to the nation's aging water distribution systems (USEPA, 2007). The program, Innovation and Research for Water Infrastructure for the 21st Century, was a top priority for the US Conference of Mayors.

The USEPA research was targeted at finding cost-effective rehabilitation alternatives to open-cut construction. Many types of replacement and repair material and construction methods have emerged in the marketplace. Their use depends on a project's objective, budget, site constraints, prevalence of service lateral connections, valves, fittings, allowable pipe type, alignments, and social and environmental impacts. Advancements for sewer pipe rehabilitation that were part of the emergence of the trenchless technology industry for sanitary sewer system rehabilitation have since been translated into solutions for water mains.

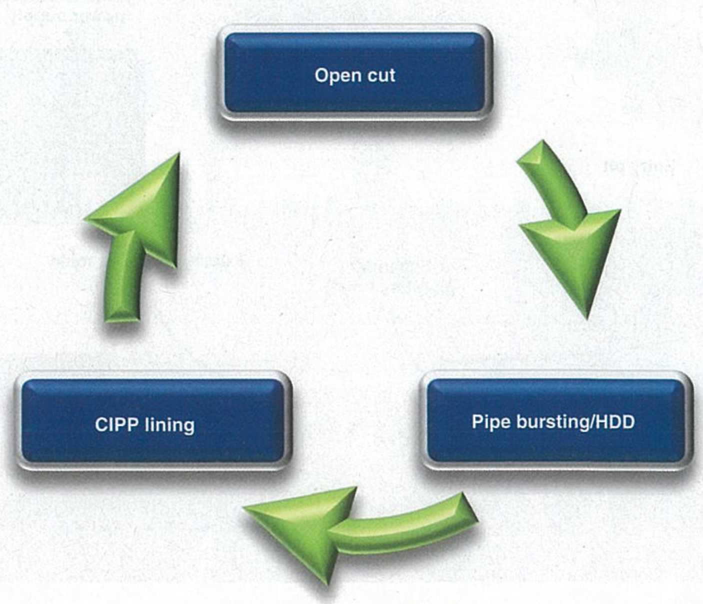
Most water utilities are conservative and averse to change, whether it pertains to materials, standards, equipment, or construction methods. Given that the commodity that utilities supply is safe public drinking water, such aversion to any but tried-and-true approaches may be understandable. In fairness, until recently, water providers have had few technology options to evaluate.

In light of new advances, however, utilities with aging systems should start to consider evolving trenchless technology methods to complement open-cut construction, which will always be the default method. Candidate areas for pilot trenchless technology projects would include systems with reduced water pressure, main breaks attributable to lost structural integrity of pipe material, water loss, lead joints, significant internal corrosion, and water quality degradation. This article focuses on one trenchless technology—cured-in-place pipe (CIPP) lining—and its potential as a cost-saving strategy for reestablishing the sustainability of small-diameter mains for 75 years and beyond. CIPP lining for water mains introduces an additional option for engineers and utility owners and operators to consider when rehabilitating their systems.

METHODS FOR WATER MAIN STRUCTURAL REPLACEMENT

There are essentially two options for structurally rehabilitating a small-diameter water main: install a new pipe or install a structural (CIPP) liner. Installation of a new pipe or structural liner can be accomplished by different methods including conventional open-cut construction; a trenchless technology method such as pipe bursting, horizontal directional drilling (HDD), or CIPP; or a combination of open-cut construction and a trenchless method (Figure 1). Each of these approaches should be assessed on a project-by-project basis to determine the most appropriate and cost-effective solution for the project in question.

FIGURE 1 Design options for pipe installation or rehabilitation



CIPP—cured-in-place pipe, HDD—horizontal directional drilling

(Microtunneling—although technically another in situ method—is usually associated with rerouting water mains to another or deeper alignment; therefore, it is not considered rehabilitation in the context of this discussion.)

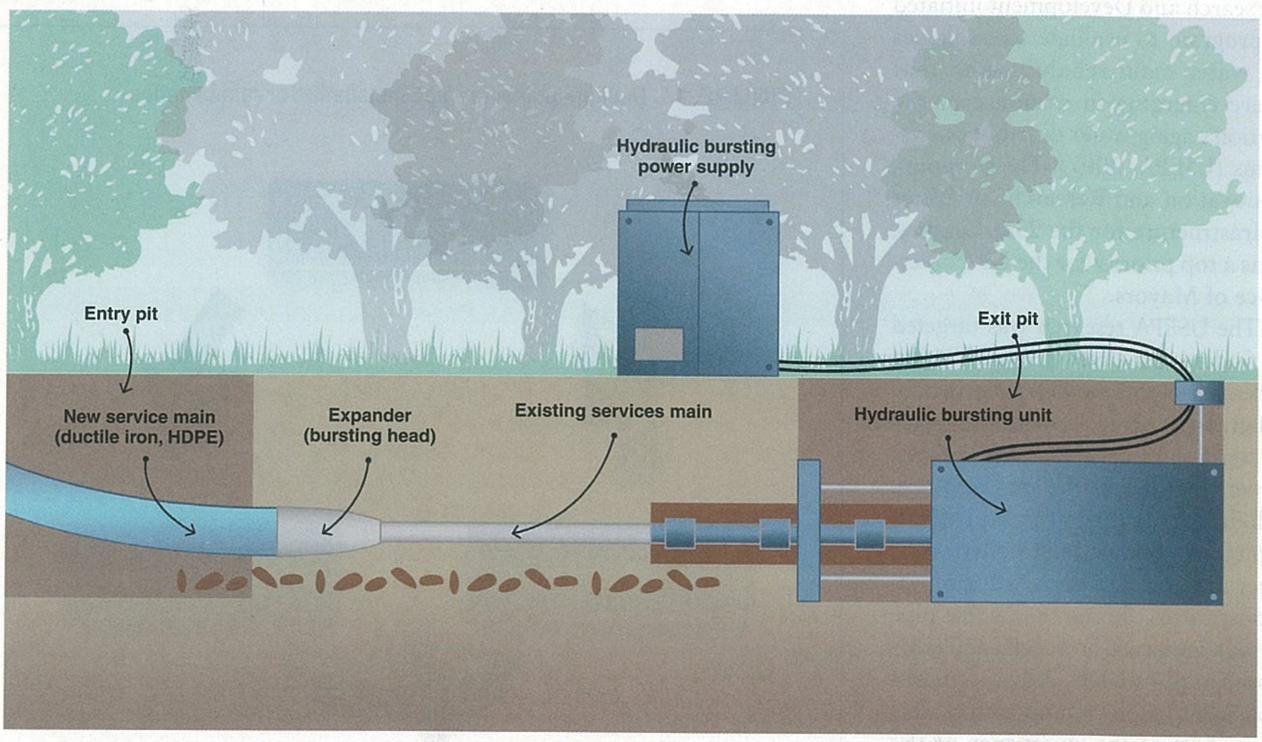
Open-cut construction. Typically open-cut construction entails excavating a trench parallel to the existing main and installing a new pipe and appurtenances. Service laterals are reconnected once the new main has been tested and deemed ready for service; the old main is usually abandoned. Because the service time disruption is usually short, no temporary water supply system is required with this method. System owners choose the type of pipe and backfill material according to their specifications.

HDD. This trenchless technology method is usually considered when open-cut construction will lead to deleterious surface or subsurface consequences related to excavation. It is also combined with the open-cut method when a rehabilitation process crosses major street intersections or railroad tracks, for example. HDD can be used to install several types of pipe materials to meet local specifications and standards.

Pipe bursting. This process uses specialized equipment to crack and burst the old pipe in order to pull a new pipe of equal or larger size along the alignment of the old pipe (Figure 2). Pipe bursting has a growing popularity in several areas of the United States. However, it can be largely affected by the surrounding soil conditions and the proximity of other utilities and structures, and depth of cover is another major factor. The pressures generated by the bursting process can cause ground heave, which could be an issue if pipe bursting is performed under pavement. Another significant concern with the process is the maintenance history of the pipe. Excavation is required to remove repair bands, valves, fittings, and service connections. In addition, the choice of pipe bursting can limit the type of material used for the replacement pipe. Potential collateral damage is the main concern associated with use of this technique.

CIPP. Typically this method involves a woven polyester-fiber hose injected with an epoxy resin that cures to full structural integrity. In the CIPP process, the liner is pulled through the host pipe and expanded with water pressure and a mandrel to fit the internal diameter of the host pipe. The epoxy is cured by filling the liner with hot water for a designated period of time. Unlike polyester and vinyl ester resins used for sanitary sewer lining, the epoxy resin will not shrink during the cur-

FIGURE 2 Schematic of the pipe bursting process



HDPE—high-density polyethylene

ing process (Sanexen Environmental Services, 2012). With CIPP, existing service connections can be robotically reinstated from within the new pipe liner, negating the need for surface excavation. This is the key cost-saving element of current CIPP liner systems.

Here are some factors that utilities may want to consider when choosing between new pipe installation and CIPP lining:

- CIPP allows for nearly all existing service laterals to be reinstated by robotic equipment internally in the pipe. For new pipe installation, all service laterals must be excavated or directionally drilled under pavement.
- CIPP eliminates joints that can be potential sites for future main breaks or leaks.
- CIPP allows a utility to resolve the removal of lead joints in an existing main.
- CIPP creates less surface disruption, which yields social and environmental benefits.
- CIPP takes less time to install.
- CIPP increases hydraulic characteristics and can save energy costs because of enhanced flow characteristics.
- CIPP has been demonstrated to offer considerable savings (10–50%) in total project construction cost.
- CIPP offers resistance to chemical degradation.
- CIPP does not require quality control of pipe stability (bedding and side support).
- CIPP is certified by NSF International to meet ANSI/NSF 61 standards.
- CIPP may provide the longest sustainable service life of any rehabilitation method.
- CIPP does not require any future maintenance, will not allow deposits to attach or form on the inside wall of the pipe, and is three times more durable than cement–mortar lining.

When the existing main must be taken out of service, a temporary water supply (bypass) is installed on the surface and ensures uninterrupted water service to the residents during the project.

CIPP systems. All current CIPP lining systems that compete in the small-diameter water main rehabilitation market are NSF/ANSI 61-approved, meet the requirements of ASTM F1216, and are pressure-rated to 150 psi. There are currently three major products and suppliers (Hoeft & Pasko, 2011): Aqua-Pipe® developed by Sanexen Environmental Services of Montreal, Canada; NORDIPIPE™ from by SEKISUI SPR, Liege, Belgium; and Insitu-Main® from Insituform, St. Louis, Mo. The three systems are all reliable products from substantial companies, and their product installation processes are generally similar.

During the past 20 years, Insituform has been the leading supplier of CIPP lining for nonpotable water pipe rehabilitation. Insituform, which revolutionized the sanitary pipe repair–replacement industry, was the first to develop the robotic reinstatement of lateral pipes and helped create the trenchless technology business.

In February 2012 USEPA published a technical report that was a product of the 2007 initiative to evaluate emerging technologies. The report, Performance Evaluation of Innovative Water Main Rehabilitation Cured-In-Place Pipe Lining Product in Cleveland, Ohio (USEPA, 2012), evaluated data from the installation of an Aqua-Pipe CIPP lining system in about 2,000 linear ft of 6-in. cast-iron mains that were 40 to 60 years old. The liner installation was performed by Sanexen, which at the time had a considerable installation résumé, having successfully rehabilitated more than 1.2 mil ft (approximately 230 mi) of water main pipe, primarily in Canada.

The USEPA study yielded several conclusions:

- The CIPP process works well for small, medium, and large structural replacement.
- The process requires trained liner installers.
- Pre- and postconstruction services can be performed by utility personnel.
- The CIPP liner surface provides a significant (43%) increase in Hazen-Williams C factor.
- The rehabilitation process created minimal social and environmental impacts.
- The CIPP liner has been tested and rated as a class IV liner.
- Nearly all service laterals can be reinstated internally.

However, despite these USEPA findings and the success of some US demonstration projects undertaken by Sanexen in Charleston, S.C., and

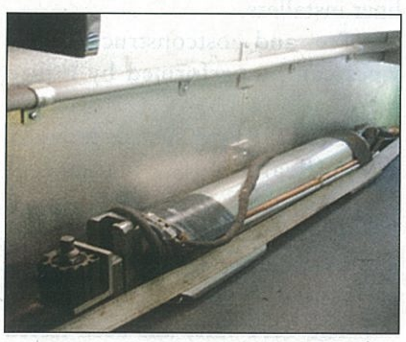
Workers are shown in an access pit installing a cured-in-place pipe liner in an old water main.

Omaha, Neb., acceptance of the CIPP method has been slow.

CIPP INSTALLATION PROCESS

The CIPP installation process can be broken down into seven steps (Sanexen Environmental Services, 2012). Although each product from the three major suppliers may differ slightly, installation generally adheres to the following steps.

Determination of the existing pipe location and other underground infrastructure. Unlike sewer mains, water mains are not as visible from the surface. Although equipment can locate mains, details of the construction are buried. Whereas valve boxes, hydrants, and meter pits can provide a general location of the main, vertical and horizontal bends, crosses, and other fittings require as-built records. Often records are not complete, and main construction details cannot be guaranteed by the water utility. The presence of pot holes may also be used to verify buried conditions.



A closed-circuit television (CCTV) camera is used to inspect pipe following cleaning to verify that the rust and deposits have been removed. After the cured-in-place pipe liner has been installed, CCTV is used to guide a remote-controlled mechanical robot in opening service connections.

The water provider must also be aware of any other utilities (e.g., gas, telecommunications) that may be found in the path or vicinity of the water main in order to avoid damaging these utilities or infrastructures during excavation of the access pits. Knowing the alignment and placement of appurtenances is essential to siting of access pits on the job site.

Installation of a temporary water supply. Because the CIPP liner requires that the existing main be taken out of service, a temporary water supply (bypass) system is required. This is a system of pipes and hoses connected to an outside spigot on each structure served. If required, plumbing may have to be modified so that the house can be supplied with drinking water. Corporation stops will be closed and sometimes replaced if they are frozen open. Once installed on the surface, the system ensures uninterrupted water service to residents during the project. Cold-weather installation can be a problem, so timing of the project tasks should be considered in the project bidding and construction timeline.

To save construction dollars and minimize potential issues in dealing with the public, the utility may want to have its own personnel install the temporary water supply. Issues to consider are maintenance during construction and the potential for a time-delay change-order if the contractor must stop work because potable water service has been interrupted and must be repaired. The utility will need to weigh the risks versus rewards of having its personnel perform this work.

Maintenance of traffic (MOT). CIPP installation is typically a continuous process that proceeds from one construction zone to the next (with zones normally about 500 ft apart) within a closure area. Traffic can continue to flow around the construction zone in accordance with local or state standards for traffic control plans. The installation process requires placement of appropriate signs, barricades (cones and drums), and flagmen as well as pit protection during nonworking hours. Because the equipment needs are different for opening the pits and installing the liner, there will likely be two standard MOT details for each of these operations. Road classification, speeds, and traffic volumes will dictate approved methods.

Excavation of access pits. Access pits will be located to minimize excavation. Typically, the pits will be placed at water main intersections or appurtenances (e.g., tees, crosses, valves, hydrants). Because the CIPP liner does not go through valves, valves tend to be the common location. Ideally, pits will be spaced to maximize the length of pipe to be rehabilitated (e.g., 500 linear ft). Pits are fitted with a trench box to ensure a safe work environment, and proper signage is

At the downstream end of the cured-in-place pipe liner, a pressure fitting is used to hold water pressure inside the line during the curing process.

required for optimal traffic control. A typical access pit requires an excavation of 9 × 6 ft and a depth of 12 in. below the pipe.

Cleaning of the existing pipe. Cleaning of the pipe is an essential step in the rehabilitation of a water main. Rust and scale buildup are removed to allow the new composite liner to properly expand within the host pipe and essentially restore the internal diameter. Cleaning is accomplished using a variety of tools and methods depending on the type and extent of the buildup. Following the cleaning, the pipe is inspected with a closed-circuit television (CCTV) camera to verify that rust and deposits have been adequately removed. Existing stainless-steel water main repair clamps do not affect the rehabilitation process because all work is carried out from inside the existing pipe. Although the level of robotic reinstatement of service connections is quite high, there is the potential that robotic reinstatement may not work. Research is ongoing to make the identification, sealing, and internal reinstatement of service connections even more reliable.

Liner insertion and curing. Lining involves three main steps: impregnation of the liner, insertion in the host pipe, and curing of the liner inside the host pipe. The idea is to have an absorbent fibrous matrix (polyester) that will allow the epoxy to penetrate the material and harden in place. The combined effect of polyester with a hardened epoxy results in the composite liner.

The liner is pulled inside the host pipe with the help of a winch at the receiving access pit. The pulling of the liner can be performed in small spaces. Once pulled into place, the liner rests flat inside the host pipe and must be formed or inflated. The liner is pushed outward against the inside walls of the host pipe with the help of a swab (pig) and water pressure. In the process, any air trapped between the liner and the pipe is evacuated, and all voids and cracks are filled with epoxy. These steps allow the liner to fit tightly against the inside walls of the existing pipe and provide a watertight environment after the liner has cured.

Curing involves heating the impregnated liner to initiate a reaction between the components of the polymeric resin. The reaction causes the polymeric resin to reticulate and harden to confer mechanical rigidity to the liner. Heat is supplied and transported by water. At the end of these three steps (total time of approximately 16 h), the liner has become a solid structural pipe inside the host pipe.

If required by the owner, the water main will be subjected to a hydrostatic pressure test before reinstatement of the service connections. The pressure test and the allowable leakage will be carried out according to the owner's criteria.

Opening of service connections and inspection. The key advantage of the CIPP lining system is that it allows for service to be reinstated from the inside of the renewed pipe, thus avoiding open-cut replacement of every service lateral. A remote-controlled mechanical robot guided by CCTV is used to open the service connections. The robot is water-tolerant and small enough to fit in a 6-in.-diameter pipe and still allow for the freedom of movement necessary to reach and penetrate the service connection.

Equipment to reinstate service connections is combined with video viewing and recording equipment for final inspection of the relined water main. The reinstatement of the service connections does not affect water tightness. In fact, water tightness is maintained by the epoxy, which fills all voids around the threads of the service connection.

Following the reinstatement of all service connections, the required fittings and accessories are installed in the access pits, and the rehabilitated pipe is rinsed, disinfected, and returned to service. Regular pipe and fittings readily available in the marketplace and as specified by the utility are used for these connections to the rehabilitated pipe.

Most utility owners will take advantage of the rehabilitation work to replace old valves and hydrants, adding to the sustainability and service life of the new system. In addition, valves and hydrants may be installed or abandoned because of changes in the codes and regulations. Replacement and addition of new valves and hydrants are carried out through local excavations that, whenever possible, are used as access pits. Furthermore, restoration of the roadway infrastructure is performed after

A remote-controlled robotic cutting tool is used to reinstate service connections from inside of the renewed pipe.

the rehabilitation in order to leave the environment as it was before the work began. Restoration involves pavement, curbs, sidewalks, and any other infrastructure that was removed to access the water main.

CIPP LINING—FUTURE MAINTENANCE, TAPPING, AND CONNECTIONS

Once installed in the old pipe, the CIPP lining will not require maintenance. The corrosion-free lining does not allow deposits to attach or form on the inside wall of the pipe. The new lining can be dry- or pressure-tapped. The only precaution is to ensure that utility workers use a saddle or tapping sleeve and a sharp shell cutter and have cut through the walls of both the existing pipe and the liner.

If a cut must be performed on a section of rehabilitated pipe, the same procedure as for cutting regular pipe can be used. The pipe should be cut with a circular saw equipped with a sharp diamond blade and then removed and replaced with a new section of pipe and fittings along with a coupling. To connect the rehabilitated pipe to the new pipe and fittings, regular pipe and fittings of standard materials (e.g., ductile iron, high-density polyethylene, polyvinyl chloride) can be used as specified by the water utility.

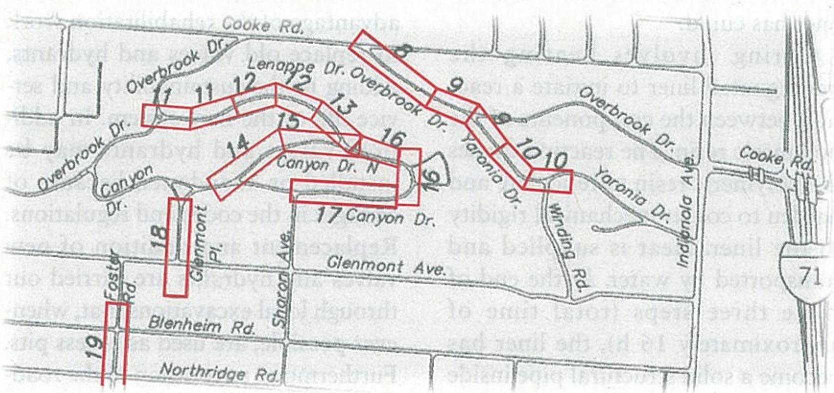
End seals are not required because the CIPP liner adheres to the host pipe whether the host pipe is made of cast or ductile iron, asbestos–cement, or any other material. The use of epoxy offers two advantages when it is heated during the curing process (Sanexen Environmental Services, 2012). First, unlike the polyester and vinyl ester resins used for wastewater, epoxy will not shrink during curing, thus allowing the liner to bond to the host pipe. Second, the epoxy becomes less viscous when heated and will flow like water to fill every crack and void inside the existing pipe. This ease of flow facilitates the distribution of epoxy throughout the length of the section being rehabilitated and provides adhesion throughout the entire section.

ASSESSING WHEN TRENCHLESS REHABILITATION IS COST-EFFECTIVE

Six years ago, USEPA recognized that alternative technologies were needed to upgrade aging water systems and help utilities maximize their limited capital funds (USEPA, 2007). Many water providers continue to default to open-cut construction, but a growing number of utility owners are starting to ask, "What method of rehabilitation is best for my project?"

CIPP lining, pipe bursting, and HDD are proving to be lower-cost alternatives for achieving structural replacement of aging infrastructure. The following sections profile three example projects in Columbus, Ohio, under the jurisdiction of the Department of Public Utilities Division of Water (DOW). To demonstrate approaches to selecting the most appropriate rehabilitation method, alternative technologies were evaluated against individual project objectives and requirements. None of the example projects was considered a candidate for pipe bursting.

FIGURE 3 Canyon Drive project area



The North Linden project area included multifamily residences and streets with curbs, gutters, and sidewalks.

Example 1: Canyon Drive. The appropriately named Canyon Drive winds through a rustic park-type area with a scenic stream (Figure 3). The area's existing water system was composed of 6- and 8-in. mains. Age and main breaks were the triggers for rehabilitating the existing mains. Because of the area's proximity to the stream, large mature trees, and curving, hilly roadways, environmental protection was a major goal of the project. The DOW was also concerned about social effects and environmental impacts on property owners stemming from possible road closures that would be required for open-cut construction.

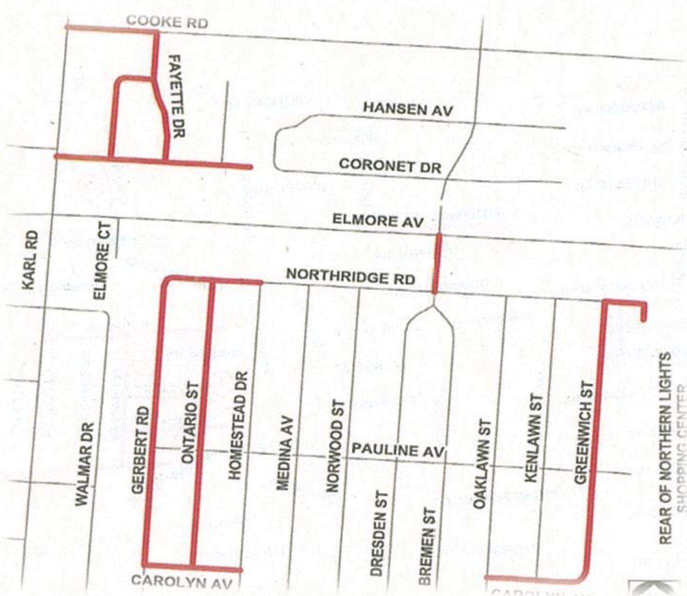
The DOW became interested in CIPP lining through the USEPA report of the Cleveland test project (USEPA, 2012; Rush, 2011). Because of the social and environmental concerns involved in the Canyon Drive rehabilitation, that project was selected to assess the use of CIPP lining. A major advantage of CIPP lining is that it can be installed safely on curving alignments and through horizontal and vertical bends up to 45°.

The contractor on the Canyon Drive project installed an Aqua-Pipe system liner. The DOW realized a construction cost savings of about 18% over the estimated cost of open-cut construction. During an onsite construction demonstration, the national sales director for Sanexen suggested that construction savings of 20–50% could be achieved, depending on project conditions (Lupien, 2013). The Canyon Drive contractor believed that savings could have been higher but were reduced because of some unexpected site conditions and the fact that this was the first such project undertaken by the DOW.

Example 2: North Linden. The North Linden area northeast of downtown Columbus is a typical urban residential neighborhood consisting of many single-family homes, a shopping center, and a mixed-use, multifamily area with more than 50 apartment buildings. The cast-iron water lines serving the neighborhood range from 6 to 8 in. in size and from 50 to 80 years in age. Low water pressure was a major reason to rehabilitate the mains in the project area.

The DOW requires a design report as a precursor to preparation of construction documents. The goals of the North Linden project were to eliminate dead-end lines, improve connections to major transmission mains, and provide a reliable long-term sustainable supply of water to the community. The design report for the North Linden project (GS&P/OH, 2010) allowed the

FIGURE 4 North Linden project area



DOW to confirm that the project fit within budget and also took into account special issues to be evaluated before beginning preparation of construction documents. During the preparation of the North Linden design report, the Canyon Drive construction project was already under way (Korda Engineering, 2010). Because that installation was proceeding well, the DOW asked that the North Linden design report evaluate CIPP and compare the method with open-cut construction.

On initial observation, the two project areas—Canyon Drive and North Linden—were totally different. North Linden presented curb-and-gutter streets with sidewalks. The water mains for the most part are under the sidewalk in the 7-ft distance from the back of the curb to the right-of-way. The other obvious difference was the contrast between North Linden's grid alignment of water mains (Figure 4) and the curves and hills of Canyon Drive. The topography of North Linden is relatively flat, lots are of consistent size, and the horizontal layout and connection of the water mains are consistent from street to street. This makes a temporary water system relatively easy to lay out. The vertical alignment of the water mains was not as consistent, and the depth varied from street to street, primarily because of crossings of various other utilities.

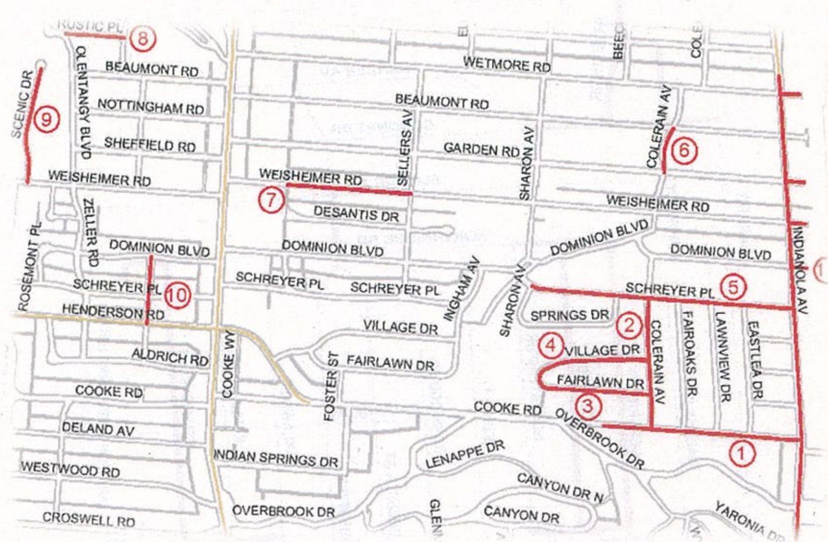
With the North Linden and Canyon Drive projects as well as other efforts it may undertake in the future, the DOW is building a database of essential information and lessons learned regarding CIPP. One of the criteria being evaluated is determining the minimum length of CIPP liner at which the method becomes cost-effective from a project perspective. On the basis of the available data, a project should have at least 1,500 linear ft of CIPP to offset the cost of mobilization, setup, and materials.

In the North Linden design report (GS&P/OH, 2010), each street in the project area was evaluated separately for open-cut construction and CIPP lining. The general approach was to locate potential access pits on top of existing valves. The maximum distance between pits did not exceed 500 ft. Typically each street had a minimum of two access pits. The existing mains were built with horizontal 45° transition fittings that would easily allow the liner to negotiate the turns between connecting streets. The nature of the project required that some main replacement be open-cut to complete interconnections or move the location of the main, as well as to accommodate new valves and hydrant changes.

The next step was an evaluation of where CIPP could replace open-cut construction. Given that the existing mains were located under sidewalks, the only logical place to install a new main by open-cut construction would be under street pavement. Lot sizes in North Linden are small, and the area has numerous large and mature trees that would be affected by project work outside of the right-of-way. In addition, MOT would be affected by the choice of rehabilitation. Street parking is heavy in this area, especially near the apartments. CIPP installation would result in minimal disruption of street parking, whereas open-cut construction would close half of the street for several days. Greenwich Street in particular, with its numerous apartment units and excessive on-street parking, was an ideal candidate for showcasing CIPP benefits such as minimized inconvenience and increased cost savings. The recommendations for water main replacement/rehabilitation were primarily predicated on reduction of pavement restoration, MOT reduction, restoration of service lateral connections, time of construction, and reduced effects on local residents.

In the design report (GS&P/OH, 2010), the opinion of probable construction cost (OPCC) for the total project was 36% higher for complete open-cut construction than for the combination of CIPP and some open-cut construction at locations where lining was not feasible. After project changes that occurred through the design process, the OPCC at time of bid was $2.17 mil-

FIGURE 5 Cooke Road project area



Numbers indicate designated locations of water mains to be rehabilitated or upsized.

TABLE 1 Attributes of different work areas inside the Cooke Road project

Attributes	Cooke Road (1) Indianola Avenue to Valve 450 ft West of Colerain Avenue	Colerain Avenue (2) Cooke Road to Schreyer Place	Fairlawn Drive (3) Colerain Avenue to Village Drive	Village Drive (4) Fairlawn Drive to Colerain Avenue	Schreyer Place (5) Sharon Avenue to Indianola Avenue
Pipe length by replacement main size					
6 in.			1,150 ft	1,100 ft	
8 in.		1,250 ft			2,500 ft
12 in.	1,950 ft				
Main location	Off north edge of pavement	4–6 ft off west RW line	4 ft off north RW line	5 ft off south RW line	4–6 ft off south RW line east of Colerain; 5 ft off north RW west of Colerain
Hydrants to be replaced—*n*	5	3	2	3	7
Right-of-way—*ft*	60	50	50	50	50
Pavement width—*ft*	26	26	26	26	26
Pavement condition	Poor	Good	Good	Good	Good
Sidewalks?	No	No	No	No	No
Curb and gutter?	No	Yes	Yes	Yes	Yes
Street parking?	No	Yes	Yes	Yes	Yes
Traffic conditions	High	Low	Low	Low	Medium
Existing water main age by main size					
6 in.			55+	55+	
8 in.	65+	55+			55+
12 in.	65+				
Sanitary sewer location	8 in. in pavement, Indianola Avenue to Eastlea Drive	1- to 10-in. crossing-north of Cooke Road before Fairlawn Drive	2- to 8-in. crossings west of Cooke Road	North side of RW parallel to pavement with 1- to 8-in. crossing	North side of RW; 2 crossings possible
Storm sewer location	Possible crossing or offset to 12 to 24 in. on north side, Indianola Avenue to Lawnview Drive	1- to 30-in. crossing north of Village Drive	South side of RW near curve to Village Drive; possible 18-in. crossing	18-in. crossing possible in curve area	12-in. crossings at Colerain Avenue; 24-in. crossing and Eastlea Drive.; three other 12-in. crossings possible
Gas lines	North side	NA	NA	NA	2-in. main North Side outside of pavement in RW
Overhead utility line concerns	South side	None	None	None	None
Tree proximity affecting construction	Mostly south side	On private property	Some near RW	On private property	On private property
Environmental methods/techniques	Possible	Possible	Possible	Possible	Yes
Comments			Three sewer crossings	Previous water service break	Speed bumps at intersections; school traffic on west half of street; seven to eight sewer crossings

NA—not available, RW—right-of-way

Numbers in parentheses indicate work area location shown in Figure 4.

The longest continuous section of the Cooke Road project (2,500 feet of 8-inch main) would be installed along Schreyer Place, a relatively straight and flat street.

For installation of the new main required for the section east of Colerain Avenue, the ideal strategy would be locating the water main on one side of the street and removing the crossing through the Colerain Avenue intersection.

lion for the entire project. The lowest bidder and second lowest bidder were within 5% of the OPCC. The OPCC estimate for just CIPP lining of 8,935 linear ft of the 6-in. main was $135/linear ft; the two lowest bids came in at $130/linear ft and $120/linear ft. For the lining of 1,289 linear ft of the 8-in. main, the OPCC estimate was $140/linear ft, and the two lowest bids were $148/linear ft and $133/linear ft. Two of the bidders proposed Aqua-Pipe, and the third proposed NORDIPIPE. Because prices were received for 6- and 8-in. open-cut pipe installation, the low bidder's estimate was extrapolated to estimate the project cost using open-cut construction. On the basis of that extrapolation, CIPP in combination with open-cut construction was projected to achieve a cost savings of more than 25% over open-cut construction alone. For comparison purposes, the North Linden project was forecast to have a greater savings than the Canyon Drive project realized.

From its experience with the Canyon Drive and North Linden projects, the DOW concluded that CIPP lining was worthy of consideration as a sustainable replacement strategy on water main rehabilitation projects. Beyond the potential cost savings, additional reasons to consider this emerging technology included a shorter construction period, reduced surface disruptions and inconvenience, robotic service lateral reinstatement, a sustainable structural solution, and environmental benefits of reduced construction operations and carbon dioxide emissions (Cote, 2010). The DOW project profiled in the following section provided an opportunity to go deeper into the assessment process.

Example 3: Cooke Road. The Cooke Road neighborhood north of downtown Columbus is a residential area consisting of many single-family homes and some storefronts. Cooke Road is one of several DOW maintenance projects designed to give new life to a water distribution infrastructure system that has provided service for more than 50 years. This particular project involved the rehabilitation and upsizing of water mains on 11 designated street locations (Figure 5).

The Cooke Road project shares some characteristics of the two previous project examples. Like Canyon Drive, the Cooke Road area has rural street sections with no curb and gutter and numerous mature trees, but it also has streets with curbs and gutters as in North Linden as well as a large commercial area along Indianola Avenue that would require new service laterals. As shown in Figure 5 (GS&P/OH, 2012), the construction areas are mostly separated from one another. This discontinuity had implications for construction staging and completion and, potentially, the construction method.

The Cooke Road project is ideal for demonstrating how to evaluate different construction methods. Key considerations in the selection of any construction method for water main rehabilitation should include

- geographic location of the existing main,
- proximity to existing utilities,
- need for permanent or temporary easements,
- intersection crossings,
- vertical and horizontal alignment of the existing main,
- location and type of fittings,
- pavement replacement,
- MOT,

• temporary service disruptions,
• upgrade of noncopper service connections,
• method of reestablishing service connections, and
• other special conditions in the project area.

To demonstrate the construction methodology screening process used in the design report (GS&P/OH, 2012), the following sections look at the rehabilitation of the mains along a particular Cooke Road project area—Schreyer Place.

Existing conditions. Schreyer Place (location 5 in Figure 5) is an alternative east–west connection between two major north–south collector streets that border the work area. This project segment starts at Sharon Avenue and extends eastward to Indianola Avenue. Because the Schreyer Place connection is not as direct as Cooke Road, there is slightly less traffic, and flow is further calmed by speed bumps at each major intersection.

The service life of new pipe or lined mains was expected to be comparable. For any methodology, utility research and marking are essential to avoid conflicts and provide proper clearance offsets. Table 1 compares the attributes of Schreyer Place with those of four other individual project areas.

Schreyer Place is relatively straight and flat and is the longest continuous section (2,500 ft of 8-in. main) of replacement. Sanitary sewers parallel the street to the north with backyard cross connections from the feeder streets to the south. The existing water main (from west to east) is on the north side of Schreyer Place up to Colerain Avenue, which intersects from the south. The existing main crosses to the south side across the intersection with Colerain Avenue. The main then crosses three additional connecting streets to a connection to a main at Indianola Avenue.

The south right-of-way area from Sharon Avenue to Colerain Avenue has no utilities and limited trees and appears to be a logical place to locate a new water main west of Colerain. The section east of Colerain Avenue will require construction of a new main outside of the pave-

FIGURE 6 Aerial view of Schreyer Place with an overlay showing alternative A

FIGURE 7 Aerial view of Schreyer Place with an overlay showing alternative C

CIPP—cured-in-place pipe

ment on the north side adjacent to the sanitary sewer (essentially reversing the current alignment). The ideal strategy would be to locate the water main on one side of the street and remove the crossing through the Colerain Avenue intersection.

The Schreyer Place segment has significant potential for multiple utility crossings (estimated at seven to eight) in the proposed work limits. An additional element affecting MOT and constructability is an elementary school at the west end of the project and its associated traffic and safety considerations. Vehicular and pedestrian traffic concerns also must be addressed. The potential for utility conflicts, traffic and safety concerns, and surface disruption underscores the importance of considering alternative construction methods. Easement acquisitions appear to be a minimal concern. The cost of the project would escalate greatly if the new main had to be installed under pavement.

Analyzing the options. On the basis of the street configuration and the research data collected, the design report looked at three construction alternatives (GS&P/OH, 2012).

Alternative A: open-cut construction. A new 8-in. water main would be constructed on the south side of Schreyer Place between Sharon Avenue and Colerain Avenue, with the main crossing to the north and continuing to Indianola Avenue (essentially a reversal of the existing main alignment location). The other option would be to build the new main under pavement. The cost of constructing a new main primarily in pavement was estimated to be in the range of $610,000. Figure 6 shows an aerial view of Schreyer Place with an overlay of the proposed open-cut water line and the existing water line, sanitary sewer, and storm sewer.

Alternative B: CIPP lining. This alternative focused on rehabilitating the existing main by installing CIPP liner. Surface disruption would be limited to six to eight access pits. Most important, all of the service connections could be reinstated internally without any surface disruption. A temporary water supply system would be required. Benefits of this alternative included shortened construction time, less inconvenience to residential homes, minimal MOT, reduced construction noise and pollution, and internal pipe reinstatement of service laterals. The cost of alternative B was estimated at $508,000.

Alternative C: combination of open-cut construction and CIPP lining. This alternative combined the benefits of alternatives A and B. Because the right-of-way on the south side of Sharon Avenue to Colerain Avenue does not have any utilities, an open-cut section of new water main pipe could be installed to Colerain Avenue with no conflicts. From Colerain Avenue, the existing main would be lined with CIPP. The result would be a new continuous water main along the south side of Schreyer Place. The cost of alternative C was estimated at about $484,750 or 20% less than alternative A—i.e., open-cut construction with the main located in the pavement. Figure 7 shows an aerial view of Schreyer Place with an overlay of the proposed combination of open-cut water line and CIPP lining and the existing water line, sanitary sewer, and storm sewer.

Summary. On the basis of lowest cost, alternative C would be selected. However, when a triple bottom line or business case analysis is used, the social and environmental benefits of alternative B edge out alternative C as the preferred choice. This selection is reinforced by the fact the project costs for the two alternatives do not differ significantly. Alternative A, although it results in significant surface disruption, is still cost-competitive. The design report analysis found that the cost of all open-cut construction would represent a good value (GS&P/OH, 2012), no matter what the DOW's decision on the use of CIPP lining at this particular project location.

The results of the Schreyer Place assessment would need to be combined with similar assessments for each of the segments shown in Figure 5 in order to develop an overall rehabilitation strategy for the Cook Road area project. Although CIPP has merit on Schreyer Place, its use elsewhere may not be as viable.

CONCLUSION

The importance of consistently delivering safe drinking water to ensure public health is undisputed. To achieve this goal, however, water utilities facing aging water distribution infrastructures and budget challenges need an expanded toolbox, especially given that the rehabilitation cost curve is predicted to steadily increase over the next few decades.

CIPP for water main rehabilitation is one innovative choice that delivers benefits in terms of cost savings, social outcomes, product sustainability, and environmental impacts. Despite CIPP's wide use in other countries during the last 10 years and an expanding roster of water main rehabilitation projects within the United States, utility acceptance of the method has been slow. As the US water industry moves inexorably from the "dawn of the replacement era" into a period of increased risk of infrastructure failure, CIPP and other evolving technologies will need more advocates in utility management to champion their use and effect positive change.

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