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COSTS FOR WATER SUPPLY DISTRIBUTION SYSTEM REHABILITATION

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Abstract: There is growing concern over the need to rehabilitate, replace and repair drinking water distribution systems and wastewater collection systems in the United States. A recent survey conducted by the United States Environmental Protection Agency (U.S. EPA) found that $138 billion will be needed to maintain and replace existing drinking water systems over the next 20 years. It is estimated that $77 billion of this expenditure will be dedicated to repairing and rehabilitating pipelines. Given the cost and disruption caused by replacing distribution system pipe using conventional open trench technology, utilities are beginning to increase the application of rehabilitation or trenchless replacement technologies to extend the life of existing pipes. This paper discusses the various types of technologies that can be used for rehabilitation and repair of drinking water distribution components. It also presents representative costs that can be used by utility managers to estimate order-of-magnitude budgetary costs for rehabilitation and replacement of distribution system components.

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INTRODUCTION

There is growing concern over the need to rehabilitate, replace and repair drinking water distribution systems and wastewater collection systems in the United States. Water distribution systems and wastewater collection systems represent major investments by municipalities. Because of the potential public health and safety implications of an inadequate water and wastewater system, maintaining these systems in good condition is an extremely important responsibility. This is particularly true with regard to the maintenance and repair of drinking water distribution systems.

In the U.S., 24% of the waterborne disease outbreaks reported in community water systems over the past decade were caused by contamination entering the water distribution system, i.e., not due to poorly treated water (Clark et al. 1998). For example, in Cabool, Missouri, during the period of December 15, 1989 to January 20, 1990, residents and visitors (population 2,090) experienced 240 cases of diarrhea and six deaths. An investigation concluded that the illness was caused by waterborne contaminants that entered the distribution system through a series of line breaks and meter replacements (Geldreich et al. 1992).

Of the approximately 200,000 public water systems in the United States, about 30% are community water systems that serve primarily residential areas and 90% of the population. There are approximately 863,000 miles (1,380,800 km) of distribution system in the United States with an annual rate of new installations estimated at 11,900 miles (19,040 km) and annual replacement rate estimated at 4,100 miles (6,560 km)

(based on extrapolation from American Water Works Association data) (AWWA 1992, 1998). A survey conducted by the U.S. EPA found that $138 billion will be needed to maintain and replace existing drinking water systems over the next 20 years with 56% ($77 billion) of this dedicated to pipelines (U.S. EPA 1997; Heavens 1997).

This paper presents representative costs that can be used by utility managers to estimate order-of-magnitude budgetary costs for rehabilitation and replacement of distribution system pipelines. Cost data were acquired from personnel who have experience in rehabilitation, contact with manufacturers and construction contractors, and articles that appeared in journals and conference proceedings. This cost data is considered accurate enough for preliminary planning and budgetary purposes. This should not be considered to be a construction cost estimate for performing a certain rehabilitation/replacement technology. Actual cost information should be obtained from local contractors. The cost of rehabilitation and replacement is a function of a number of factors such as total length of the project; pipe diameter; product pipe; obtaining access to the pipe; cleaning prior to lining application; excavation of insertion and receiving pits; pavement removal/replacement above the access pits; removal and replacement of existing valves, fire hydrants, and other contingent work; bypass piping and connections to existing services; and other items such as traffic control, removal of obstruction, etc.

WATER DISTRIBUTION SYSTEM PIPE PROBLEMS

Water distribution pipe problems can be addressed through either rehabilitation or trenchless or open-cut replacement. Rehabilitation is defined as improvement of the functional service of an existing pipeline system by lining the interior. It involves placing a water tight surface inside of an existing pipe without requiring extensive excavation of the soil. Replacement means installing a new pipeline without incorporating the existing pipeline by either open cut or trenchless replacement. Both rehabilitation and trenchless replacement reduce the amount of excavation required to repair pipe, but neither eliminates it completely. Typical costs for these technologies are summarized in Table 1.

WATER DISTRIBUTION SYSTEM REHABILITATION METHODS

Pipeline rehabilitation methods use the existing pipe either to form part of the new pipeline or to support a new lining. Rehabilitation is proceeded by cleaning the pipe to remove scale, tuberculation, corrosion, and other foreign matter. Linings, to be effective, must make intimate contact with the pipe surface. Proper surface preparation significantly affects the strength and bonding of lining (Ashton et al. 1998). These methods can be divided into two categories: nonstructural and structural.

Nonstructural Lining

Nonstructural lining involves placing a thin coating of corrosion-resistant material on the inner surface of the pipe. The coating is applied to prevent leaks and increase

the service life. However, coating does not increase the structural integrity of the pipe. The only coatings considered as proven techniques for water distribution pipes are cement mortar and epoxy.

Cement Mortar Lining

Cement mortar linings are unique, because they are porous. Corrosion protection is achieved by the development of a highly alkaline environment within the pores, which is a result of the production of calcium hydroxide during cement hydration. Cement mortar is applied using a variety of equipment, depending on pipe size and overall project length. Access to the pipeline is accomplished by excavation and removal of a length of pipe. The thickness of the lining varies with pipe diameter and type of pipe and varies from 1/8 inch (0.3 cm) for 4-inch (10.2-cm) diameter pipes to ½ inch (1.3 cm) for 60-inch (152.4-cm) diameter pipes. Water mains from 4 inches (10.2 cm) to 60 inches (152.4 cm) in diameter have been rehabilitated by cement mortar lining techniques. It has a useful life in excess of 50 years. It can significantly improve the Hazen-Williams coefficient of pipe friction, C (Deb et al. 1990).

Epoxy Lining

Epoxy resin lining of water mains is an alternative to cement mortar lining. It has not been widely used in U.S. However, it has been practiced in several countries including United Kingdom and Japan. In the United Kingdom, epoxy lining competes with cement mortar lining for pipe sizes 4 inches (10.2 cm) to 12 inches (30.5 cm) with respect to price (Conroy et al. 1995). Epoxy lining has an estimated life in excess of 75

years (Watson 1998). The lining thickness for epoxy as practiced in the industry is only 0.04 inches (1 mm) regardless of the pipe size, which minimizes the impact of diameter reduction on smaller pipes.

Structural Lining

Structural lining involves placing a watertight structure in immediate contact with the inner surface of a cleaned pipe. A variety of technologies including sliplining, cured-in-place pipe, fold and form pipe, and closed-fit pipe lining are available. This is the only rehabilitation technique that improves structural integrity of a pipe.

Sliplining

Sliplining is the oldest rehabilitation method. In this process a new pipeline of a diameter smaller than the pipe being repaired is inserted into the defective pipe and the annulus grouted. It has the merit of simplicity and is relatively inexpensive, but there is a reduction in flow capacity (35% to 60%) depending upon pipe size (Spero 1999). Sliplining is applicable to mains with diameters ranging from 4 to 108 inches (10.2 to 274.3 cm) (Spero 1999). The most commonly used material for sliplining are high density polyethylene and fiberglass reinforced polyester. Excavation is required for insertion and receiving pits. All service connections, valves, bends, and appurtenances must be individually excavated and connected to the new main.

Cured-In-Place Pipe

Cured-in-place pipe (CIPP) involves placing a fabric tube impregnated with a thermosetting resin that hardens into a structurally sound jointless pipe when exposed to hot circulating water or steam into a cleaned host pipe using the inversion process described below. Access to the pipeline is accomplished by excavation and removal of a length of pipe. There is no reduction in flow capacity. However, the flow must be completely stopped or by passed during installation and curing. All service connections, valves, bends, and appurtenances must be individually excavated and connected to the new main.

Insituform Technologies®, Inc. offers a range of solutions in North America for rehabilitating water mains (Oxner and Allsup 1998). It has a design life which exceeds 50 years (TTC Technical Report 1994).

Fold and Foam Pipe

Fold and form pipe (FFP) utilizes thermoplastic materials (PVC or PE) which is heated and deformed at the factory from a circular shape to a “U” shape to produce a net cross-section that can be easily fed into the pipe to be rehabilitated. The FFP is fed from a spool into the existing pipe where hot water or steam is applied until the liner gets heated enough to regain its original circular shape and create a snug fit within the host pipe (Spero 1999). All service connections, valves, bends, and appurtenances must be individually excavated and connected to the new main. Excavation is required

for insertion and receiving pits. It has a design life of greater than 50 years. Fold and form is applicable to mains with diameters ranging from 8 to 18 inches (20.32 to 45.72 cm) (Spero 1999).

Close-Fit Pipe

Close-fit pipe lining involves pulling a continuous lining pipe that has been deformed temporarily so that its profile is smaller than the inner diameter of the host pipe. This lining method is often referred to as the *modified sliplining approach*. Close-fit pipe lining makes use of the properties of PE or PVC to allow temporary reduction in diameter and change in shape prior to insertion in the defective pipe.

As with sliplining, excavation is required for insertion and receiving pits. All service connections, valves, bends, and appurtenances must be individually excavated and connected to the new main. Close-fit pipe has a design life of greater than 50 years. This method has been used for pipes with diameters ranging from 2 to 42 inches (5.1 to 106.7 cm) (Heavens 1997).

WATER DISTRIBUTION SYSTEM REPLACEMENT METHODS

Replacement of pipelines can be accomplished by using either trenchless or open-trench techniques. Cost information on these technologies is summarized in Table 1.

Trenchless Replacement

Trenchless replacement involves inserting new pipe along or near the existing pipe without requiring extensive excavation of soil. Trenchless replacement can be done with minimal disruption to surface traffic, business, and other activities, as opposed to open trenching. There is a significant reduction of the social costs associated with construction. The best known trenchless replacement techniques are pipe bursting, microtunneling, and horizontal directional drilling.

Pipe Bursting

Pipe bursting was developed and licensed by British Gas about 16 years ago. It is a method for replacing pipe by bursting from within while simultaneously pulling in a new pipe. The method involves the use of a static, pneumatic, or hydraulic pipe bursting tool drawn through the inside of the pipe by a winched cable, with the new pipe attached behind the tool. The bursting tool breaks the old pipe by applying radical force against the pipe and then pushes pipe fragments into the surrounding soil. The liner pipe can be the same size or as much as two pipe sizes larger than the existing pipe. Excavation is required for insertion and receiving pits.

Pipe bursting has been used to replace pipes with diameters ranging from 6 to 48 inches (15.2 to 121.9 cm). The liner pipes are normally PE or PVC.

Microtunneling

Microtunneling involves the use of a remotely controlled, laser-guided, pipe-jacking system which forces a new pipe horizontally through the ground. This trenchless method is used for constructing pipelines to close (±1 inch or ±2.54 cm) tolerances for line and grade. This method can be cost-effective compared to open-cut construction when pipelines are to be installed in congested urban or environmentally sensitive areas, at depths greater than 15 feet (0.6 m), in unstable ground, or below the water table. Microtunneling can be used in variety of soil conditions from soft clay to rock, or even when there are boulders to deal with. It can be used at depths of up to 100 feet (30.48 m) below the water table without dewatering. Types of pipes that can be installed include concrete, steel, PVC, clay, and fiberglass-reinforced pipe. It is applicable to mains with diameters ranging from 18 to 72 inches (45.7 to 182.9 cm).

Horizontal Directional Drilling

Horizontal directional drilling (HDD) consists of a rig that makes a pilot bore by pushing a cutting or drilling head that is steered and guided from the surface. Drilling fluid is pumped through the drill/push rods and displaces the cut soil. When the pilot bore is completed, pulling back a reamer enlarges the hole. Progressively larger back-reamers are used until the hole is large enough to pull in the pipe. HDD is applicable to mains with diameters ranging from 2 to 60 inches (5.1 to 152.4 cm) (Spero 1999). Types of pipes that can be installed include PVC, PE, steel, and copper. HDD is suitable for installing pipes under waterways, major highways, and other obstacles.

Open-Trench Replacement

Open-trench replacement is the most commonly used method for replacement of water mains. It involves placing new pipe in a trench cut along or near the path of the existing pipe. Open-trench replacement is cost intensive and is plagued with the expected problem of working within developed areas where pipes may be beneath streets, sidewalks, customer landscapes, utility poles, etc. There are two basic types of open-trench replacement: (1) conventional; and (2) narrow. The conventional open-trench method uses the same approach as that used to place new pipe. The narrow-trench replacement method is similar to conventional open-trench method, but the trench width is kept to the absolute minimum possible. It is primarily used for installing polyethylene pipes (Morris 1996).

SUMMARY AND CONCLUSIONS

This paper presents representative costs that can be used to estimate the order-of-magnitude costs for rehabilitation and replacement of distribution system pipelines. The costs given in this paper only address the base installation costs of rehabilitation/replacement technologies. A series of separate additive items should be added to the base installation cost to get the total cost. The additive items are removal and replacement of existing valves, fire hydrants, and other contingent work, traffic control, utility interference, removal of obstruction, and bypass piping and temporary service connections to existing services.

APPENDIX 1: References

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Table 1. Summary of Rehabilitation/Replacement Methods

Method	Pipe Size Range** (diameter in inches)	Common Materials	Generic Cost ($/inch diameter/foot)	References for Cost
Cement Mortar Lining	4 - 60	cement-sand	1 - 3	Gumerman et al. 1992
Epoxy Lining*	4 - 12	epoxy resin	9 - 15	Conroy et al. 1995
Sliplining	4 - 108	HDPE, PVC, fiberglass reinforced polyester	4 - 6	Gumerman et al. 1992
Cured-in-Place Pipe (CIPP)	6 - 54	polyester resins	6 - 14	Gumerman et al. 1992
Fold and Form Pipe	8 - 18	HDPE, PVC	6	Jeyapalan 1999
Close-Fit Pipe	2 - 42	PE, PVC	4 - 6	Arthurs 1999
Pipe Bursting	4 - 36	HDPE, PVC, ductile iron	7 - 9	Boyce and Bried 1998
Microtunneling	12 - 144	HDPE, PVC, concrete, steel, fiber glass	17 - 24	Boyce and Bried 1998
Horizontal Directional Drilling	2 - 60	HDPE, PVC, steel, copper, ductile and cast iron	10 - 25	Boyce and Bried 1998

Note: * Cost is in $/foot
** To covert from inches to centimeters, multiply by 2.54
HDPE - High Density Polyethylene; PVC - Polyvinyl Chloride; PE - Polyethylene