Protecting an Existing Ductile Iron Water Main Using Linear Anodes

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A Wisconsin water utility has implemented a demonstration project using horizontal directional drilling equipment to install a continuous linear anode directly alongside an existing water main that has experienced significant external pitting corrosion. The results of the initial demonstration project suggest that a 40-year life extension of the water main may be achievable at a cost that is significantly less than the replacement cost of the pipe.

The American Water Works Association (AWWA) began tracking the critical issues that face the water industry in 2004,[1] and in 2006, aging water infrastructure became the major issue facing the water industry.[2] The U.S. Environmental Protection Agency estimates that the water industry will need nearly $184 billion for capital expenses on water transmission and distribution systems over the next 20 years.[3] A recent study by the U.S. Federal Highway Administration and NACE International concluded that external corrosion of water mains can be effectively mitigated by the application of coatings and cathodic protection (CP).[4] This article demonstrates a unique CP technique that water utilities can install for existing ductile iron (DI) water mains in an urban environment at a cost that is significantly less than replacing the pipe.

Background

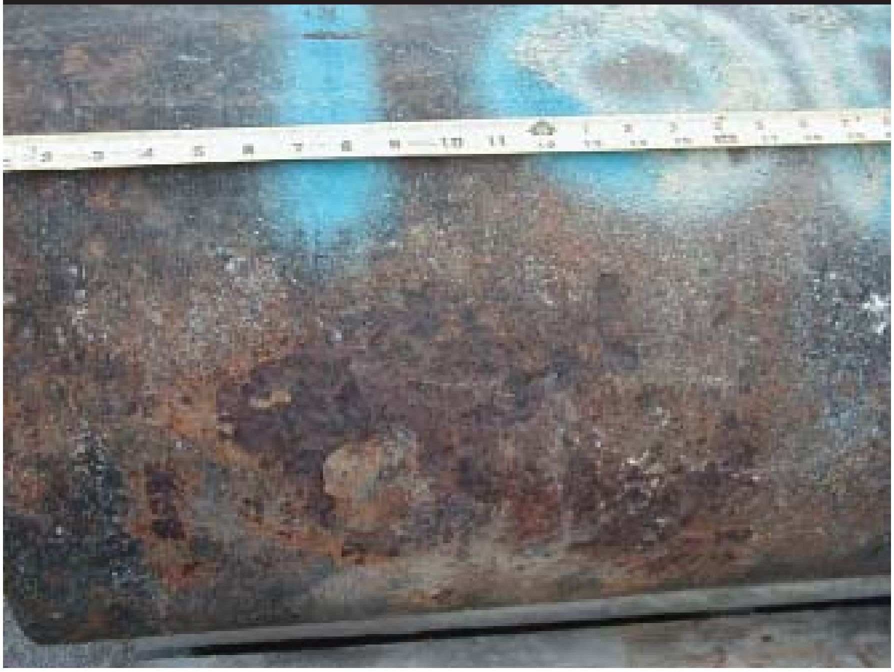
In 2003, the LaCrosse Water Utility (LWU–LaCrosse, Wisconsin) uncovered a water transmission main to relocate a portion of the pipe as part of a pending road improvement project. The entire water main runs along a major county trunk highway (CTH B) for ~1.25 miles (2.0 km) and consists of 12-in. (30.48-cm) and 16-in. (40.64-cm) DI pipe (AWWA Class 50) that was installed in 1986. During the excavation, a 5-ft (1.52-m) section of the main was found to have significant external corrosion (Figure 1).

A metallurgical analysis was performed on the same section of pipe that had been removed from the water main for reconstruction of the highway. The analysis, which consisted of a visual inspection, chemical analysis of the pipe, tensile and hardness tests, scanning electron microscopy, and a longitudinal metallographic cross section of the pipe wall, concluded that the pipe's wall thickness was reduced to 0.10 in. (0.3 cm) at the thinnest point due to severe localized corrosion with pit depths up to 0.27 in. (0.7 cm). This reduction in the wall thickness is equivalent to a 71% wall loss based on an original nominal wall thickness of 0.34 in. (0.9 cm).

The pipe is believed to have been installed with no means of corrosion protection other than the standard 1-mil (25.4-mm) asphalt coating. A small portion of the 1 1/4-mile (2-km) water main was reportedly installed with loose polyethylene (PE) encasement.[5] The pipe was cable-bonded at each pipe joint to achieve electrical continuity for thawing purposes during extremely cold weather and the electrical continuity of the main was verified in 2003.

Since a large portion of the water main is located beneath the reconstructed county highway, excavating to repair or replace the main would be both disruptive and prohibitively expensive. Waiting for a failure to occur is not an option since the water main is a primary supply line to the area that it serves. Options for sacrificial anode retrofits,[6-7] or "remote" impressed-current anode groundbeds, were also not feasible. As an alternative, the LWU implemented a demonstration project using horizontal directional drilling (HDD) equipment to install a continuous linear anode (CLA) system directly alongside the water main. Approximately 1,500 ft (457.2 m) of contiguous pipe was considered for this project to assess the effectiveness of such an approach for the remainder of the water main in future years.

FIGURE 1



Corrosive attack to 16-in. water main (71% wall max. pit depths).

FIGURE 2

CLA materials (sock anode on right, parallel cable on left reel).

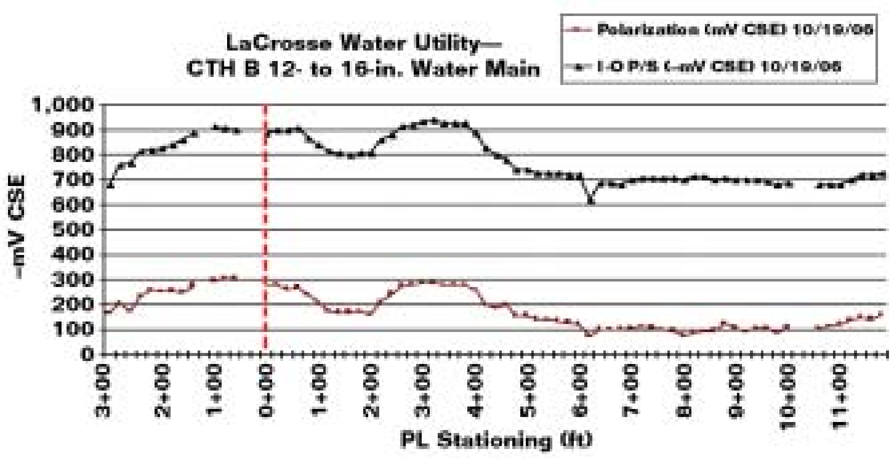
Cathodic Protection System Description

The CLA system (Figure 2) is factory assembled and consists of five basic components. A central #8 AWG-ethylene chlorotrifluoroethylene (ECTFE) insulated copper cable serves as a low-resistance conductor to deliver the required direct current (DC) without incurring a substantial longitudinal voltage drop. A continuous copper-cored mixed-metal oxide (MMO) anode wire provides low attenuation for reduced splicing to the #8 copper header cable. Prepackaged calcined petroleum coke breeze surrounds the MMO anode, enhancing anode efficiency by carrying the DC electrolytically from the anode wire. A porous, acid-resistant fabric jacket ("sock") centralizes

FIGURE 3

Horizontal directional boring equipment.

FIGURE 4



P/S potential profile (dashed vertical line is at rectifier STA 0+00).

the anode wire within the coke breeze. Finally, a protective monofilament braiding surrounds the fabric jacket and tightens firmly in place around the coke breeze when pulled by HDD equipment (Figure 3).

A conventional air-cooled rectifier energizes the CLA system. The CLA system has two individual anode branches—one for the 300-ft (91-m) pipe section west of the rectifier and the other for the ~1,200-ft (366-m) pipe section east of the rectifier. Each anode branch has a second parallel (redundant) #8 AWG-high molecular weight PE (HMWPE) cable that is looped and field spliced to the primary anode cable to provide another current path to the MMO anode wire. An insulated #8 AWG-HMWPE stranded copper cable runs from the rectifier DC negative output terminal to a fire hydrant located next to the rectifier.

Results and Interpretation of the Pipe-to-Soil Potential Data

The selection of a pipe-to-soil (P/S) potential criterion to significantly reduce corrosion rates for a bare or poly-wrapped DI water main is not as exact and typically not as critical as for coated steel pipelines that convey hazardous gases or liquids. For the latter structures, the current-applied on –0.85 V criterion, the –0.85 V instant-off criterion, or the 100 mV polarization decay criterion are the minimum accepted CP standards for government-regulated energy pipelines.[8] These NACE criteria are very conservative for the effective control of corrosion for nonregulated structures such as water mains, however. For example, CP data recorded for sacrificial anode retrofit projects has shown that ~100 mV of current-applied potential shift (P/S on–P/S baseline) from the baseline readings (prior to applying CP) decreases water main breaks by up to 90 to 95% during the life of the CP system.[9]

Baseline (off) P/S data were measured relative to a portable copper/copper sulfate ($Cu/CuSO_4$) reference electrode (CSE) placed at 20-ft (6-m) intervals along the top of the water main. After allowing the rectifier to operate continuously for approximately two weeks, on and instant off potential measurements were recorded at these same locations. The effectiveness of the CLA system (as measured by the degree of polarization of the structure) was also evaluated by calculating the arithmetic difference between the instant off and baseline P/S potentials. These data are shown in graphical form (Figure 4). If portions of the main are actually encased in loose PE wrapping, the P/S data represent the potential of the metal surface only at the defects in the poly wrap, but do not necessarily represent the actual potentials at the pipe surface underneath any gaps in the poly wrap and the pipe surface.

When considering the polarization profile for the water main, the effectiveness of the CLA system is shown by the fact that 86% of the P/S data meet or exceed the conservative NACE 100 mV polarization criterion. Areas where the P/S potentials decrease slightly are at points where the water main is valved or is connected to other water mains where additional metallic surface areas decrease the current density (CD) applied to the subject water main. The local gas utility corrosion engineer reports no deterioration in the potential data (interference) on a natural gas pipeline crossing in the area.

Two mA/ft^2 (21.5 mA/m^2) of pipe surface is often used as a conservative design CD for structures placed in poorly drained soils. Net CP CDs with a properly installed and maintained poly wrapping can be several orders of magnitude less, however.[10] If the CP current that is being drained by the interconnected water mains, water service lines, and possible interconnections to the AC power neutral are ignored, the current applied from the entire CLA system to the subject water main alone can be estimated. Based upon the actual current applied to the water main, the applied current per unit surface area and per unit pipe length can be derived (Table 1). Note that in reality, these interconnections do account for a portion of the total cathodic current. Accordingly, the actual average current per unit surface area and actual average current per unit length will be less than the values shown.

TABLE 1

Summary of CLA anode current applied to the water main

Name of Pipe Section	Pipe Diameter (in.)	Pipe Length (LF)	Sfc. Area of Section (ft²)	Applied Current (mA)	Current by Area (mA/ft²)	Current by Length (mA/LF)
East	12	1,200	3,770	5,160	1.4	4.30
West	16	300	1,257	2,310	1.8	7.70

Economic Analysis of Installing a CLA System for the Existing Water Main

With proper attention to design, installation, and operation, retrofitting CP to an existing pipeline having high corrosion rates is a cost-effective and technically sound alternative to complete main replacement. CP is a proactive decision unlike continuing to tolerate and repair main breaks. This approach can significantly curtail and often eliminate the reactive maintenance costs and related social costs (e.g., service disruption and traffic delays during repairs) typically associated with corrosion-caused failures in urban areas.

In the case of the LWU demonstration project, a CP system was furnished and installed for the 1,500-ft (457-m) pipe section at a cost of $47,622 ($31.75/linear ft [$104.17/m]). In comparison, the total cost to replace this section of main is estimated at $192,200 ($128.13/linear ft [$420.38/m]). Thus, the total initial cost of the CP system is <25% of the replacement cost of this section. When expressed over the 40-year life expectancy of the CP system, the annualized cost is only 0.6% per year. These calculations, even though oversimplified, indicate the CP system will extend the life of the water transmission main by at least 40 years at a cost that is much less than replacement of the main. This is particularly noteworthy given that the CLA CP approach can be successfully applied in congested areas with all the technical and economic benefits associated with present day trenchless technologies.

The cost effectiveness of the corrosion control strategy presented here is based on the pipe joints in the test section having effective electrical continuity without the additional costs for excavations to establish the requisite continuity. Unlike using sacrificial anode CP for a service life extension, electrical continuity is required to realize corrosion control using the impressed current CLA system described herein.

Conclusions

The data for the 2006 demonstration project show that the CLA system is providing both efficient and cost-effective protection for the water main. The anode manufacturer rates the product for a 40-year operating life. Since the CLA system is operating well below the manufacturer's recommended DC output, with proper maintenance, the data suggest that a 40-year life extension of the water main is possible at a cost that is significantly less than the replacement cost of the pipe. Based upon the favorable results of the 2006 pilot installation, the LWU anticipates completing the CP system for the entire pipeline in 2008.

References

1 J. Runge, J. Mann, "2004 State of the Industry Survey: A Checkup and Guide to Good Health," J. AWWA 96, 10 (2004): p. 40.

2 J. Runge, J. Mann, "2006 State of the Industry Survey: An Eye to the Future," J. AWWA 98, 10 (2006): p. 64.

3 U.S. Environmental Protection Agency, "Drinking Water Infrastructure Needs Survey and Assessment," EPA 816-R-05-001, Office of Ground Water & Drinking Water (Washington, DC: EPA, 2003).

4 Federal Highway Administration, "Corrosion Costs and Preventative Strategies in the United States," Report FHWA-RD-01-156, Office of Infrastructure Research and Development, Washington, DC (2001).

5 American Water Works Association, Manual of Water Supply Practices M41, Ductile Iron Pipe and Fittings (Denver, CO: AWWA, 1996).

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6 American Water Works Association Research Foundation, "Reducing Main Failures in Brown Deer, Wisconsin," Research Applications #8, Report DS-54/98-8 (Denver, CO: AwwaRF, 1995).

7 D. Klopfer, J. Schramuk, "A Sacrificial Anode Retrofit Program for Existing Cast Iron Distribution Water Mains," J. AWWA 97, 12 (2005): p. 50.

8 NACE Standard RP0169, "Standard Recommended Practice—Control of External Corrosion on Underground or Submerged Metallic Piping Systems" (Houston, TX: NACE, 2002).

9 D. Raymond, "Cathodic Protection Program, Water Division, Water Distribution Branch Region's Experience," Ottawa-Carleton Utilities Commission: Ottawa-Carleton, Ontario, Canada, 1998.

10 J. Schramuk, V. Rash, "Cathodic Protection for a New Ductile Iron Water Transmission Main," MP 44, 10 (2005): p. 20.

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