field report

Klopfer

Schramuk

BY DANNY J. KLOPFER AND JEFF SCHRAMUK

A sacrificial anode retrofit program

for existing cast-iron distribution water mains

PUBLIC WATER UTILITIES FACE A SIGNIFICANT ECONOMIC BURDEN CREATED BY THE DETERIORATION OF THEIR WATER DISTRIBUTION SYSTEMS. APPLYING CATHODIC PROTECTION (CP) CAN EXTEND THE LIFE OF AN EXISTING WATER DISTRIBUTION MAIN SYSTEM.

For more than a decade, Canadian water utilities have been using an innovative installation technique for retrofitting CP anodes to existing watermains. In 2003, the Des Moines Water Works (DMWW) implemented an in-situ sacrificial anode retrofit program to reduce main breaks and extend the life of its system. The results of a 2003–04 pilot program show that a 20-year life extension can be achieved at less than 10% of the replacement cost of the piping. Implementation of a full-scale program should prove to be a viable economic alternative to either repairs or water main replacements in the coming years.

THE COSTS OF CORROSION

In 2001, the Federal Highway Administration (FHWA) and NACE International released a report of a study that investigated the annual costs of corrosion in the United States (Koch et al, 2001). The report indicated that the annual direct cost of corrosion for drinking water systems is roughly $23 billion/year. This figure includes the costs of replacing aging water piping, lost water because of leakage, and corrosion control measures. The FHWA report concludes that external corrosion of water mains can be effectively mitigated by the application of coatings and CP.

More recently, the American Society of Civil Engineers released its annual assessment of the nation's infrastructure (ASCE, 2005). The report states that the United States faces a serious shortfall of $11 billion/year to replace aging water infrastructure. Federal funding will provide less than 10% of the total national requirement for fiscal year 2005, with no increases in funding planned for fiscal year 2006.

Public water utilities face a significant economic burden created by the deterioration of their water distribution systems (Cromwell et al, 2002; Ellison, 2001; Rajani et al, 2000; O'Day et al, 1986). The failure to manage the consequences of an aging water infrastructure can result in product loss, economic loss, and increased public health risks. With the economics clearly defined and the technological

TABLE 1 Summary of installation costs

Section Name	Cost per Anode $	Cost per Foot Pipe$
Muskogee Avenue	372.34	6.17
3rd Street	488.11	9.18
8th Street	602.57	12.01
Average	499.66	9.22

After an anode borehole is drilled and the remaining soil is removed with vacuum extraction equipment, a steel stud is welded to the top of the pipe (left). The stud fits into the end of an insulated extension tool (right) that is used to allow the welder to reach the top of the pipe and contact the pipe surface.

means in place to mitigate the problem, this article presents an example of how applying CP can extend the life of an existing water distribution main system at a significantly lower cost than that of pipe repairs or replacements.

PILOT STUDY INVOLVES SEVERAL WATER MAINS

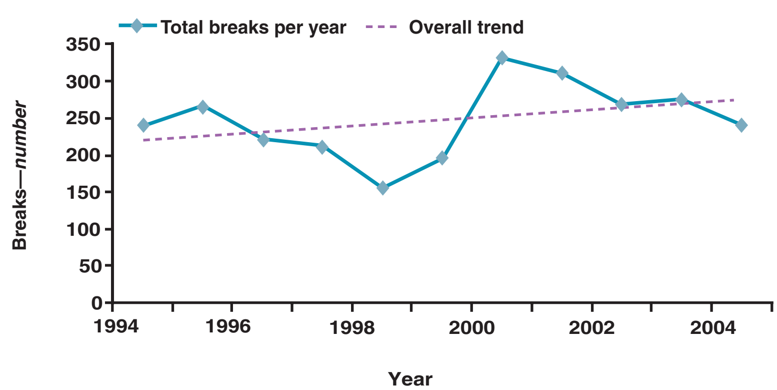
The DMWW is currently responsible for maintaining 1,013 mi (1,630 km) of water distribution piping. Water main occur at a rate of approximately 27 breaks per 100 mi (161 km) of pipe. The trend in main breaks from 1994 to present day includes a steady increase in failure rates (Figure 1). Excluding third-party excavation pipe damage, most of the water main breaks in the system are related to corrosion.

For more than a decade, several foreign water utilities have used an innovative installation technique to retrofit CP anodes to existing water mains (Clemens, 1998; Green, 1992; Doherty, 1990). On the basis of this work, the DMWW implemented a pilot study to examine whether an in-situ sacrificial anode retrofit program (ARP) could reduce its main breaks and extend the life of its system. In June 2003 several areas within the city were selected for consideration for inclusion in the initial ARP. These areas generally had the highest annual main break rate per mile of pipe. The water main data were reviewed, evaluated for constructability, and prioritized for the pilot study.

CP anode installation technique. The anode borehole is initiated by a backhoe–auger that drills through surface materials down to about 12 in. (30 cm) above the pipe. To avoid damage to the buried water line, vacuum extraction equipment is used to remove the remaining soil in the hole down to the top of the buried pipe. Once the top of the pipe is exposed and cleaned, a stud is arc-welded to the top of the pipe (photo top left).

An insulated extension tool is used to allow the welder to reach the top of the pipe and contact the pipe surface. The stud is soldered to each anode's number 12 American wire gauge (AWG) lead wire, and it fits snugly into a tapered copper sleeve in the end of the extension tool (photo top right). The extension tool is connected to the

FIGURE 1 Total main breaks per year for Des Moines Water Works



Once the stud is attached and the weld verified as secure, the prepackaged sacrificial anode is lowered into the hole (left). After it is placed in the hole, the anode is backfilled with limestone fines, native soil, and water (right).

welder's trigger handle by high capacity insulated cables. A steel rebar is used to make the ground connection between the pipe and the welder, also using an insulated cable. When electrical continuity is verified between the stud and the rebar ground, the operator initiates the weld by pushing a button on the trigger handle.

After the stud weld is verified as secure, a 6–12-in. (15–30-cm) layer of sand/limestone fines is poured into the hole over the weld to ensure that the anode does not rest directly on the stud. A prepackaged sacrificial anode is then lowered down into the hole (photo top left). To achieve the greatest life, a 32-lb (14.55-kg) high-potential magnesium anode was specified for all installations. Although the paperboard anode canister is filled with a low-resistance (hygroscopic) material, the hole is also backfilled with about 5 gal (19 L) of water to ensure that the anode can maximize current flow to the pipe (photo top right). Compacted native soil fills the balance of the hole. Pavement restoration or turf replacement completes the installation.

During the anode installations, a number 12 AWG test wire is attached at a minimum of two locations on each of the water main segments. The test wires are used to verify electrical continuity of the main instead of having to probe the pipe or contact the pipe through the valve boxes. These test locations will also facilitate over-the-line pipe-to-soil potential surveys after the anode installations. The test wires are contained in marked cast-iron valve boxes for future accessibility.

This method of applying CP assumes that a degree of electrical continuity exists throughout the piping. Although most mechanically coupled pipe joints will have high-resistance (or discontinuous) connections after being buried for several years, testing showed that several sections of water main were indeed electrically continuous over several city blocks. This phenomenon is likely attributed to the interconnections between the uninsulated copper water services and homeowner alternating current power system grounding. Additionally, some older water mains were originally installed with leaded joints that would be expected to be electrically continuous. Although these interconnections have enhanced the electrical continuity of the piping, they also drain the sacrificial anode's current from the poorly coated water mains.

Although these interconnections have enhanced the electrical continuity of the piping, they also drain the sacrificial anode's current from the poorly coated water mains.

Structures selected for the pilot study. ***Muskogee Avenue (SW 63rd–SW 59th Street).*** This 8-in (200-mm) water main was installed in 1949. The pipe is spin-cast -iron and approximately 1,267 ft (386 m) in length. The soil is black and silty with traces of clay. Anodes were spaced about 60 ft (18 m) apart. Twenty of 21 anodes were connected to the pipe using the stud-weld technique. To complete the remaining connection, the pipe was excavated and the anode wire was attached directly to the pipe using a prefabricated stainless-steel band clamp. Installation costs are summarized in Table 1.

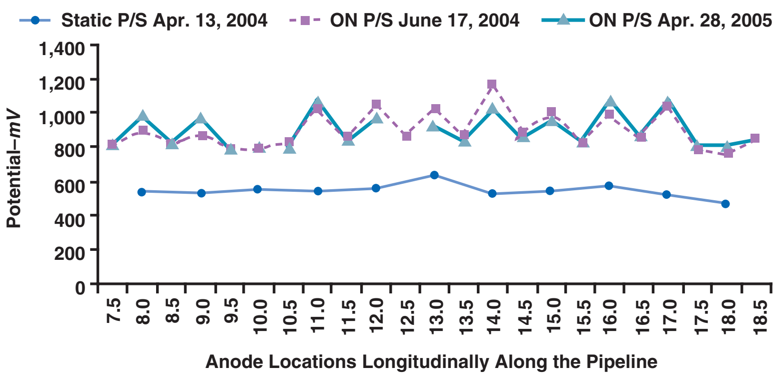
3rd Street (Laurel Street–University Avenue). This 8-in (200-mm) watermain was installed on 3rd Street in 1963. The pipe is spin-cast iron and approximately 957 ft (292 m) in length. The soil is a sandy clay consistency. Eighteen anodes were spaced an average of 53 ft (16 m) apart. Sixteen of the 18 anodes were connected to the pipe using the stud-weld technique. To complete the remaining two connections, the pipe was excavated and the anode wires were attached directly to the pipe using prefabricated stainless-steel band clamps. Installation costs are summarized in Table 1.

8th Street (Euclid–Boston Avenue). This 12-in (300-mm) watermain was installed on 8th Street in 1920. The pipe is pit-cast iron and approximately 1,405 ft (428 m) in length. The soil is black and silty with traces of clay. Twenty-eight anodes were spaced an average distance of 50 ft (15 m) apart. Seven anodes were connected to the pipe using the stud-weld technique. Thirteen connections were made by excavating the pipe and attaching the anode wires directly to the pipe using prefabricated stainless-steel band clamps. The remaining eight anodes were installed by connecting a wire from one anode to another. Installation costs are summarized in Table 1.

RESULTS

Data from several Canadian water utilities (Raymond; Wright & Nicholson, 1991) show that approximately 100 mV of current-applied potential shift from the baseline (before CP) readings will significantly reduce the rate of corrosion on existing watermains. This practice is consistent with industry experience that the first increment of CP is the most effective for

FIGURE 2 Potential profiles for Muskogee Avenue (stations 7.5–18.5)

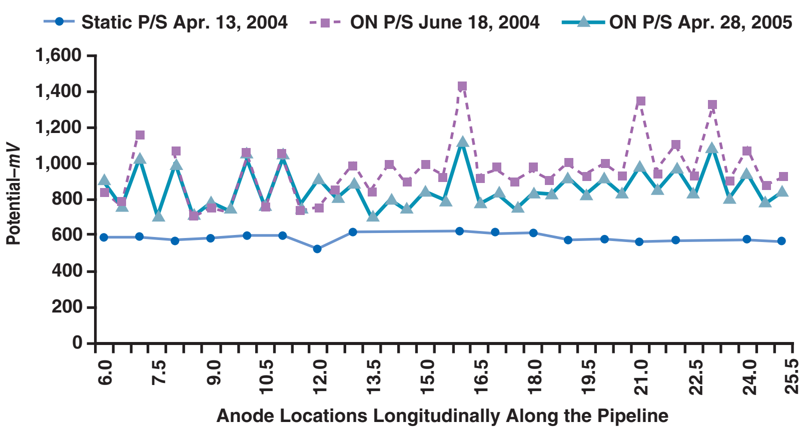


ON P/S—pipe-to-soil potential after cathodic protection, static P/S—pipe-to-soil potential before cathodic protection

Whole number values indicate locations at which anodes are installed; half number values indicate midpoints between anodes. Anodes are about 60 ft apart.

All P/S referenced to copper/copper sulfate electrode

FIGURE 3 Potential profiles for 8th Street (stations 6–25)



ON P/S—pipe-to-soil potential after cathodic protection, static P/S—pipe-to-soil potential before cathodic protection

Whole number values indicate locations at which anodes are installed; half number values indicate midpoints between anodes. Anodes are about 50 ft apart.

All P/S referenced to copper/copper sulfate electrode

mitigating corrosion on buried ferrous structures. Information obtained from large-scale installations in Canada indicates that after a relatively short transition period, (Kliener & Rajani, 2002) main breaks decreased 90–95% during the life of the CP system.

Using a wire reel, current-applied potentials were measured relative to a portable copper/copper sulfate reference electrode placed at regular intervals along each watermain. Anode current outputs and instant-off potential readings (indicating the degree of polarization) could not be accurately measured because the sacrificial anodes could be disconnected from the pipeline. However, because of the low soil resistivities, it was possible to accommodate the IR contribution for the potential measurements by approximating "remote earth" at the ends of the pipe segments.

The calculations, even though oversimplified and conservative, indicate that these methods will allow a 20-year life extension to be achieved at less than 10% of the replacement cost of the piping.

Typical potential profiles for Muskogee Avenue and 8th Street (Figures 2 and 3) indicate a shift of more than 100 mV, with the exception of one location on Muskogee Avenue in an area in which the pipe is believed to be electrically discontinuous. No potential measurements were made on 3rd Street before the anode installations; however, the current-applied potentials of 1,000 mV indicate the sacrificial anodes are significantly raising the water main's potential along this section of main.

Economic analysis: CP versus main replacement. CP anodes were installed on approximately 3,629 ft (1,106 m) of pipe at a cost of $33,477. The replacement cost for this portion of the 8- and 12-in. water mains would have been more than $360,000. Assuming that the life expectancy of a new water main would be 100 years and the life expectancy of the CP system would be 20 years, the savings are $38,523 ([$360,000/100 × 20] – $33,477) over a 20-year period. The calculations, even though oversimplified and conservative, indicate that these methods will allow a 20-year life extension to be achieved at less than 10% of the replacement cost of the piping. The ARP is therefore a viable alternative to main replacement and should effectively lower the number of customer outages while minimizing increases in the distribution system's operating costs.

Economic analysis: CP versus main break repairs. Because funding for all necessary pipe replacement may not be available, a second approach is presented that ignores the fact that the pipe has reached its life expectancy and needs to be replaced. In this case, the cost of CP installation was compared with the ongoing cost of main-break repairs, which would be reduced through CP. Main break records show that DMWW should expect to experience 15 main breaks on these pipes during the next five years. Ignoring the fact that without corrosion control the break rate will increase, DMWW should anticipate 60 main breaks on these pipes over the next 20 years.

Using a conservative life estimate of 20 years for the CP system and assuming that the sacrificial anodes would reduce the number of water main breaks by 90% (compared with 95% in the Canadian studies), the following is calculated:

- $33,477 = cost of installing CP anodes on ~3,629 ft (1,106 m) of pipe.
- $22,926 = cost of the main breaks because of corrosion that CP would not stop (10% of 60 breaks over 20 years at $3,821/break).
- $10,000 = cost of in-house annual system testing at ~$500/year for 20 years.

The sum of these costs is $66,403. Comparing this with the estimate for three main breaks per year for 20 years ($3,821/break × 20 years equals $229,260) shows a net savings of over $160,000 by using an ARP instead of waiting for the pipe to fail and repairing it as it fails.

FUTURE CONSIDERATIONS

When considering whether to implement an ARP program, a water utility should base its decision on the following prioritization factors:

- number of main breaks per mile of pipe per year
- cost of main break repairs,
- water main installation costs,
- soil conditions,
- pipe characteristics,
- condition of pipe, and
- future construction activities planned in the same area.

In addition to these factors, annual pipe-to-soil-potential maintenance surveys will verify that continued CP is supplied to the water mains. This will increase the water utility's ability to estimate the life expectancy of its corrosion control anodes.

—Danny J. Klopfer is director of water distribution for Des Moines Water Works, 2201 George Flagg Pkwy., Des Moines, IA 50321. Jeff Schramuk, NACE cathodic protection specialist, is president of CP Solutions Inc., Bartlett, Ill.

REFERENCES

ASCE (American Society of Civil Engineers), 2005. 2005 Report Card for America's Infrastructure. ASCE, Reston, Va.

Clemens, D., 1998. The Status of the Cathodic Protection Program to Prevent Corrosion of Ductile Iron Watermains Within the Region of Durham. Durham Utilities Commission, Durham, Ont., Canada

Cromwell, J.E. et al, 2002. *Costs of Infrastructure Failure*. Awwa Res. Fdn., Denver.

Doherty, B.J., 1990. Controlling Ductile-iron Water Main Corrosion: A Preventive Maintenance Program. *Materials Performance*, 29:1:22.

Ellison, D., 2001. Distribution Infrastructure Management: Answers to Common Questions. Awwa Res. Fdn., Denver.

Green, B.M.; Johnson, F.; & DeRosa, J., 1992. In-Situ Cathodic Protection of Existing Ductile-iron Pipes. *Materials Performance*, 31:3:32.

Kliener, Y. & Balvant, R., 2002. Quantifying the Effectiveness of Cathodic Protection in Water Mains: National Research Council of Canada, Institute for Research in Construction. Presented at NACE seminar, Montreal, Que., Canada.

Koch, G. et al, 2001. Corrosion Costs and Preventative Strategies in the United States. FHWA-RD-01-156, Washington.

O'Day, K. et al, 1986. Water Main Evaluation for Rehabilitation/Replacement. AWWA Res. Fdn., Denver.

Rajani, B. et al, 2000. Investigation of Gray Cast Iron Water Mains to Develop a Methodology for Estimating Service Life. Awwa Res. Fdn., Denver.

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

Wright, A. & Nicholson, J., 1991. A Report on the Efficiency of the Cathodic Protection System Installed on the Water Mains in Peterborough. Peterborough, Ontario Utilities Commission, Peterborough, Ont., Canada