# Protecting Underground Assets With State-of-the-Art Corrosion Control

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This article discusses the corrosion control program for the water piping infrastructure of Howard County, Maryland. It describes how corrosion control is provided for new piping and how existing piping is evaluated. The program implements proactive measures to protect existing water mains and to install new mains that will last virtually forever.

The Howard County Department of Public Works (Columbia, Maryland) supplies potable water throughout a 110-sq-mile (285-km$^2$) area to ~220,000 customers, delivering ~27 million gal (102 million L) of water per day. The pipelines in the system range from 4 to 48 in. (10 to 122 cm) in diameter with a total length of more than 900 miles (1,448 km).

Managing a relatively new but constantly expanding distribution system presents many challenges. Some of the major challenges include scheduling capital projects such as pipe replacement, predicting maintenance costs, minimizing maintenance and service interruptions, and minimizing maintenance and maximizing service lives of existing mains. Howard County's oldest water mains are 70 years old.

Howard County proactively addressed the above challenges by implementing a corrosion protection program for underground water mains. The program has three categories:

- Category 1: new transmission pipelines
- Category 2: existing pipelines that were installed with corrosion control systems
- Category 3: existing pipelines that were installed prior to the establishment of the corrosion control program.

## Evaluation and Monitoring Procedures

The county has developed a procedure that is implemented during the design of new (Category 1) water pipelines. The corrosion evaluation procedure establishes the parameters necessary to determine the appropriate corrosion control so that water mains achieve their design life. These steps minimize maintenance costs, service interruptions, and premature pipe replacements.

After new pipelines with corrosion protection are placed in service (Category 2), the corrosion control systems are routinely monitored to verify continued effectiveness.

Existing water mains (Category 3) are evaluated as necessary to determine their present condition and to estimate their remaining life. This is done by potential surveys, soil corrosivity analyses, stray current investigations, direct inspections at test pits, corrosion rate measurements, and hydraulic testing.

### CATEGORY 1: NEW PIPELINES

In 1995, a corrosion control program was initiated for new water transmission

FIGURE 1


Polyurethane-coated ductile iron pipe.

pipelines. Some of the transmission pipes in Howard County's system are more than 50 years old. The need to schedule pipe replacement, some of which would be under pavement, coupled with the expense of installing new transmission mains (pipe installation costs ranging from $100 to $750 per foot) warranted a proactive corrosion protection program. The program is applied to new pipeline installations. It will extend the life of transmission pipes by orders of magnitude, minimize maintenance costs associated with leak repairs, and improve customer relations by minimizing service interruptions.

### *Corrosion Evaluation*

Corrosion evaluations are routinely performed as part of the new water pipeline design process for transmission mains, or other mains that are in areas of known corrosion activity. The site-soil-corrosivity evaluation is conducted through in situ testing as well as laboratory analyses of soil samples, in accordance with ASTM International test methods. The soil corrosivity tests include in situ resistivity measurements and relevant layer analyses to determine resistivity at the anticipated pipe depth. In situ pH measurements are obtained in order to determine soil pH with a minimum exposure to oxygen. Soil samples collected by the geotechnical consultant from pipe depth are chemically analyzed in the laboratory for levels of resistivity, pH, chloride and sulfate concentrations, redox potential, and the presence of sulfides. These six soil characteristics must be correlated and are the minimum data required for a comprehensive evaluation of soil corrosivity. In situ measurements of resistivity and pH are critical because they provide data representing actual site conditions with respect to soil compaction, moisture, and oxygen content.

Investigations are conducted to identify sources of, and to test for, stray direct current (DC) along the new pipeline alignment. Stray current sources are typically impressed current cathodic protection (CP) systems operating on other pipelines; such stray current can cause accelerated corrosion on metallic water mains installed in the vicinity.

Pipelines installed parallel to or crossing overhead electric transmission lines may be affected by induced alternating current (AC) interference during and after construction. Corrosion engineers identify potential sources of induced AC interference, conduct AC potential measurements on existing structures in the area, and measure electric fields so that induced AC mitigation devices can be incorporated into the design. Mitigating induced AC is an important safety consideration. Induced AC mitigation typically includes the installation of zinc anode ground mats.

At the conclusion of the corrosion evaluation, site specific corrosion control measures are selected for the particular pipe material(s) being considered. Soil corrosivity, DC stray current, induced AC interference, pipe wall thickness, and the design life of the pipeline are considered in selecting the required corrosion control measures. When alternative pipe materials such as ductile iron, steel, or prestressed concrete are being considered, the resulting corrosion control systems establish an equal footing with respect to design life for each pipe material.

### *Corrosion Control Design*

Site specific corrosion control measures are designed for each new pipeline. When designs for alternative pipe materials are being considered, corrosion control designs are also prepared for each pipe material based on the corrosion evaluation. Corrosion protection measures usually include one or more of the following: electrical isolation, electrical continuity, external bonded coatings, electrical sectionalization, test facilities, stray DC current mitigation, induced AC mitigation, and galvanic CP.

All water transmission pipelines in Howard County are considered "critical" to water supply operations. The following corrosion control measures are the minimum provided for each pipe material:

- Steel: external bonded coating, electrical continuity, test facilities, galvanic CP, and electrical isolation at tie-ins
- Ductile iron: external bonded coating, electrical continuity, test fa-

FIGURE 2


Tape-coated ductile iron pipe.

FIGURE 3

Polyolefin-coated ductile iron pipe.

cilities, galvanic CP, and electrical isolation at tie-ins

- Prestressed concrete: electrical continuity, electrical isolation at tie-ins, and test facilities for corrosion monitoring.

For ductile iron pipe, the main concerns relevant to external corrosion are graphitization and pitting corrosion. For steel pipe, the main concerns are uniform surface corrosion or pitting corrosion. The only method available to stop these types of corrosion is CP. The CP systems used to protect Howard County water mains are similar to those that have been installed on gas and oil pipelines for more than 40 years. The external bonded coating and galvanic CP system for steel and ductile iron piping is typically designed to stop corrosion for 30 to 40 years. At the conclusion of this design life, the anodes will be replaced so that the underground water main remains corrosion free.

Most new transmission mains are made of ductile iron and are protected with an external bonded coating and galvanic CP. The project specifications for these mains typically include options for the use of three different types of external coating systems—polyurethane (Figure 1), a three-layer tape wrap system (Figure 2), and a polyolefin system with extruded butyl rubber adhesive and a polyethylene (PE) topcoat (Figure 3). All three coating systems have been successfully installed, meaning that the coating integrity has held up very well during construction. They have yielded 98% or better coating efficiencies, as found during CP testing.

The county does not use PE encasement, a loose wrap of plastic sometimes intended as corrosion control for ductile iron piping.

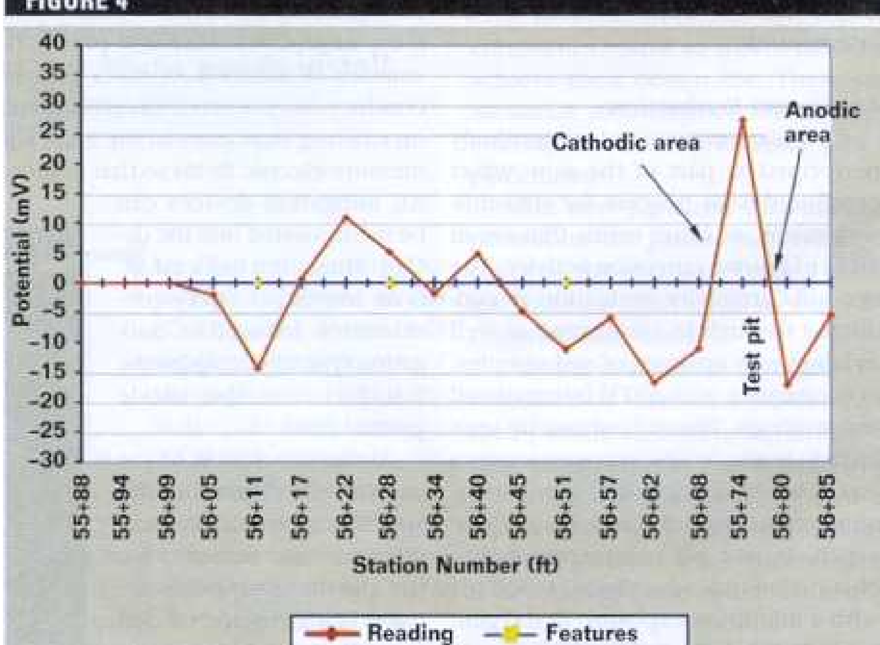
For large mains, prestressed concrete cylinder pipe is accepted for county projects. Prestressed concrete cylinder pipe is subject to a different type of corrosion mechanism from steel and ductile iron. A layer of cement mortar protects the steel prestressing wires. In benign (minimally corrosive) environments, the steel prestressing wires passivate (stop corroding) in response to the high pH of the cement mortar. Over time, however, the soil constituents migrate through the cement mortar and attack the passivating film that was established on the prestressing wires; this occurs in corrosive soils, especially those with elevated levels of chloride ions. The loss of passivation leads to corrosion of the prestressing wires. After the wires start to break, a corrosion failure is often dramatic because of the pipe construction and the internal water pressure.

In order to avoid prestressed concrete pipe failures, corrosion monitoring systems are designed to record the level of corrosion activity on the prestressing steel. Should corrosion activity be present, the pipeline can be retrofitted with galvanic CP as necessary. In severely corrosive soils and in stray current areas, external bonded coatings (typically epoxy) are also applied to provide a barrier over the cement mortar.

### *Corrosion Control Installation*

The corrosion control design engineer's representative monitors corrosion control installation. The corrosion engineer routinely provides on site training to the contractor's personnel concerning the proper installation methods and pipe handling procedures to ensure quality control during installation. Acceptance testing is conducted

FIGURE 4




Plotted cell-to-cell potential survey data.

upon completion of the corrosion control installation and includes verification of effective pipe continuity, adequate electrical isolation, proper test wire attachments, correct anode installations, and a corrosion potential survey. Detailed operations and maintenance manuals are prepared that include as-built sketches of the corrosion control test facilities.

## CATEGORY 2: EXISTING PIPELINES WITH CORROSION CONTROL SYSTEMS

Existing pipelines with corrosion control systems are monitored periodically. Generally, the county's corrosion protection systems do not require maintenance. They simply require monitoring to ensure their continued operation and effectiveness.

For pipe with galvanic CP systems, the county normally conducts tests every 2 years to verify that protection levels are maintained in accordance with NACE International criteria. A 2-year cycle was selected for the periodic monitoring because most galvanic CP systems operate naturally and continuously, without significant damage or loss in protection levels. To further ensure the reliability necessary for a 2-year monitoring cycle, galvanic CP systems are carefully designed so that system components are not easily damaged by third-party excavations. The anode groundbeds are connected to the pipeline at multiple locations, and the anode header cables are buried near pipe depth to minimize accidental damage to the cables. This design approach has yielded galvanic CP systems that resist damage.

## CATEGORY 3: EXISTING PIPELINES WITHOUT CORROSION CONTROL SYSTEMS

Category 3 includes pipelines installed prior to the establishment of the corrosion control program and small-diameter distribution pipelines for which corrosion control systems are not considered to be cost effective. The small-diameter distribution pipelines typically are cast or ductile iron and were not installed with bonded joints or test facilities. These pipelines are evaluated when failures occur. Pipeline failures are mapped so that areas with multiple failures can be selected for additional study. Failure analyses are conducted on some mains to determine the cause of the failure, identify evidence of graphitization, conduct corrosion pitting analyses, inspect for evidence of stray current corrosion and potential stray current sources, and analyze soil corrosivity in the area of the failures.

**FIGURE 5**

Twenty-three-year-old ductile iron pipe with pitting and graphitization corrosion.

Existing transmission pipelines that are usually constructed of ductile or cast iron and have experienced corrosion failures are selected on a case-by-case basis for detailed evaluations. The evaluations are conducted to determine the pipeline's condition, estimate its remaining life, conduct life-cycle cost analyses for rehabilitation measures and replacement, and determine the optimum plan to mitigate failures and eliminate service interruptions.

Transmission pipelines that were not equipped with bonded joints for electrical continuity are sometimes evaluated with a cell-to-cell potential survey (Figure 4), a stray current investigation, a soil corrosivity survey, and direct pipe inspections at distinct locations. The locations of the direct pipe inspections are based on the analyses and correlation of data from the cell-to-cell, stray current, and soil-corrosivity surveys in conjunction with the failure and maintenance history of the pipe. The pipe is exposed for examination in areas where the most severe corrosion damage is expected based on the data. Figure 5 shows one pipe excavation. The piping in the excavation is examined for external corrosion. Corrosion pitting analyses are conducted, graphitization is identified and quantified, and samples of the pipe and the surrounding soil are extracted for laboratory analyses. The soil from the excavation is chemically analyzed for parameters that influence the corrosion rate of metals. These parameters include resistivity, pH, chloride and sulfate concentrations, oxygen-reduction potential, and the presence of sulfides. The pipe sample is placed in the soil sample from the excavation, and linear polarization techniques are applied to determine the corrosion rate of the pipe and the estimated time-to-penetration of the pipe wall. Figure 6 shows the corrosion rate test equipment.

After the excavations are completed, "hot-spot" protection is normally installed to minimize accelerated corrosion that could occur on the repaired pipe. Such instances of corrosion result from the disturbance of the soil and the installation of repair clamps or replacement pipe sections.

Hydraulic and acoustic testing are also used in some cases to evaluate the internal conditions of the pipe.

The data from the evaluation are analyzed and correlated, and the expected remaining life of the pipeline is estimated. Areas of the pipe are usually prioritized according to the specific level of risk so that remedial action can be staged. The county considers the need for and merits of pipe replacement, retrofitting with external corrosion protection ("hot-spot" CP), and cleaning and lining. In some

**FIGURE 6**

Computerized corrosion rate equipment.

cases, upgrading the entire pipeline or segments of the pipeline with "hot-spot" CP is recommended to extend the life of the piping. A "hot-spot" CP system consists of magnesium anodes that are connected to each pipe length by using vacuum excavation techniques. Vacuum excavation minimizes the excavation size and the cost of applying anodes to existing nonelectrically continuous pipe. "Hot-spot" CP does not necessarily eliminate corrosion, but it reduces the corrosion rate of the pipe exterior and thus extends the time to pipe wall penetration.

Pipelines that exhibit significant internal corrosion (based on hydraulic testing, failures, or water-quality complaints) are selected for cleaning and lining. When piping is cleaned and lined, protection for the exterior is also considered because the interior cement mortar lining is not structurally adequate to maintain the required water pressure in the main.

If the extent of corrosion and metal loss from corrosion is significant, the pipeline—or sections of the pipeline—must be replaced. The replacement schedule is based on the estimated remaining life of the pipeline as determined by the detailed corrosion evaluation.

Howard County's approach to Category 3 water mains avoids unnecessary water main replacement, facilitates prioritization and long-term planning and budgeting of capital expenditures, and minimizes service interruptions and emergency maintenance costs by identifying areas at the highest risk of corrosion failure.

## Summary

Howard County recognizes the importance of protecting underground assets and minimizing risks associated with the failure of those assets. Its corrosion protection program protects the investment in infrastructure and maintains service to customers with minimal interruptions. New critical water mains are provided with corrosion protection in a scientific manner, assuring water main reliability and cost-effective installations and operations. Multiple pipe materials are usually considered for large-diameter pipelines. With corrosion control measures applied to these materials, competitive bids for pipe with equivalent design lives yield cost-effective projects. Risks associated with noncompatibility of pipe materials with the environment are eliminated. Existing underground assets are evaluated when there is reason to believe that corrosion is occurring or will lead to failures. Proactive measures are applied to minimize pipeline failures.

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