AWWA Iowa Section : 10/17/2018

Practical Solutions to External Corrosion Problems on Buried Water Mains

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Topics to be Covered

1. **Corrosion Problems Facing Water Utilities**
2. **Corrosion Chemistry**
3. **Pipe Materials and Coatings**
4. **Basic Cathodic Protection**
5. **CP for Existing WMs using an Anode Retrofit Program**
6. **Cathodic Protection for New Water Mains**
7. **Solving Corrosion Problems at Water Main Breaks**
8. **Cathodic Protection Performance Verification**

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Section 1

Corrosion Problems Facing Water Utilities

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What's the Rest of the (Unexcavated) Pipe Look Like?

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State of the Water Industry Report – Year 2018

The Top 3 Issues Facing the Water Industry by All Respondents

1. Renewal & replacement of aging water and wastewater infrastructure.
2. Financing for capital improvements.
3. Public understanding of the value of water systems and service.

Source: "2018 State of the Water Industry: The Challenge of Building Resilience", *Journal AWWA*, 110:8, Aug-2018, pp. 61-71.

"Issues identified as critically important have changed very little over the past five years."

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What is the leading cause of many water main breaks?

Corrosion!

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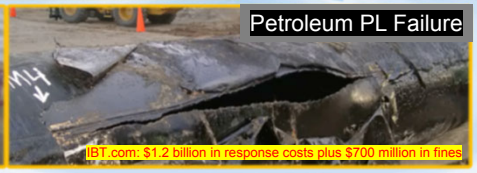
What Are the Consequences of Pipeline Failures?



"Average" Cost of a Water Main Break: $3.5 to $7K

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Section 2

Corrosion Chemistry

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Corrosion: Practical and Scientific Definitions

Practical Definition	The Tendency of a Metal to Revert to its Native State
Scientific Definition	Electrochemical Degradation of Metal as a Result of a Reaction with its Environment

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Four Components of a Basic Corrosion Cell

- **Anode** – A metal electrode in contact with the electrolyte which corrodes.
- **Cathode** - A metal electrode in contact with the electrolyte which is protected against corrosion.
- **Electrolyte** – A solution or conducting medium such as soil, water or concrete which contains oxygen and dissolved chemicals.
- **Metal Path** – An external circuit that connects the anode and the cathode.

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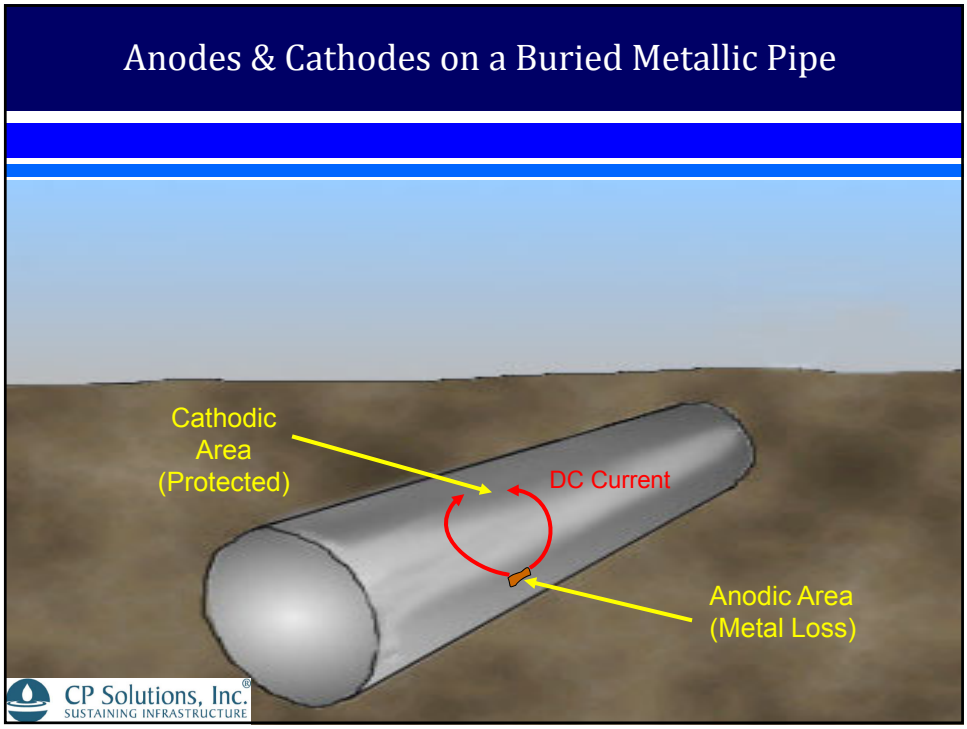
Anodes & Cathodes on a Buried Metallic Pipe
Cathodic Area (Protected)
DC Current
Anodic Area (Metal Loss)
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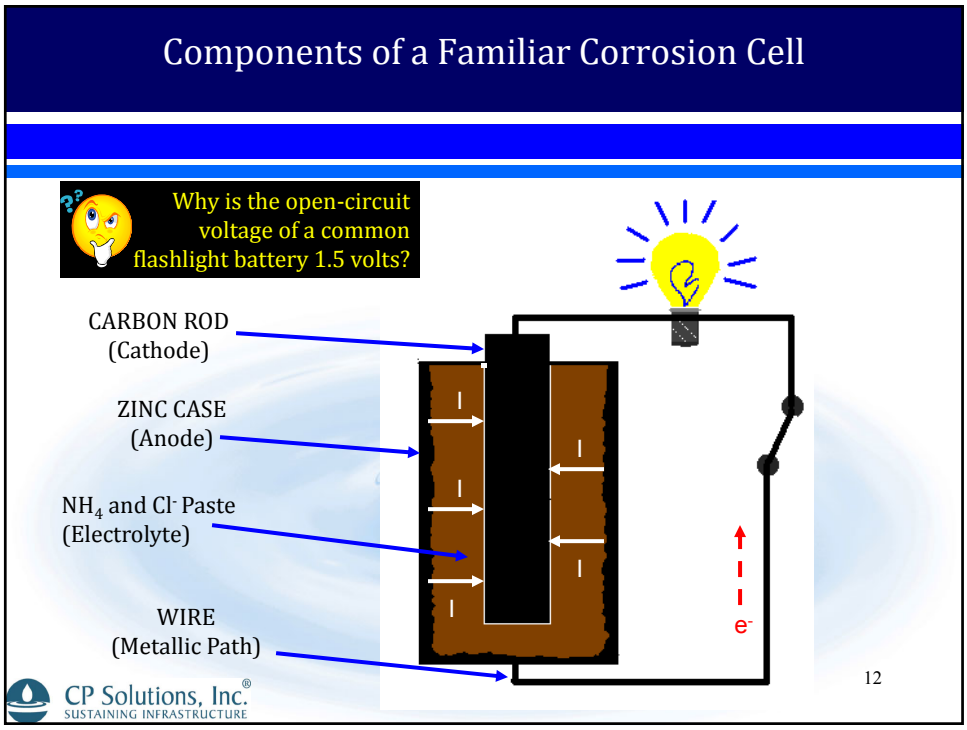
Components of a Familiar Corrosion Cell
Why is the open-circuit voltage of a common flashlight battery 1.5 volts?
CARBON ROD (Cathode)
ZINC CASE (Anode)
NH4 and Cl- Paste (Electrolyte)
WIRE (Metallic Path)
e-
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Practical Galvanic Series

Material	Potential*
Pure Magnesium	-1.75
Magnesium Alloy	-1.60
Zinc	-1.10
Aluminum Alloy	-1.00
Mild Steel (New)	-0.70
Mild Steel (Old)	-0.50
Cast / Ductile Iron	-0.50
Stainless Steel	-0.50 to + 0.10
Copper, Brass, Bronze	-0.20
Gold	0.20
Carbon, Graphite, Coke	0.40

*Measured in Volts versus a Cu-$CuSO_4$ Reference Electrode

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Section 3

Pipe Materials and Coatings

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Basic Electrochemistry – Anodic & Cathodic Reactions

- At the anode: $2Fe \rightarrow 2Fe^{+2} + 4e^-$
- At the cathode: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$
- Initial Combined Reaction (iron oxidizes)

  $2Fe + O_2 + 2H_2O \rightarrow 2Fe^{+2} + 4OH^-$
- Ultimate Reaction (hydrated iron oxide)

  $4Fe + 3O_2 + 6H_2O \rightarrow 4Fe(OH)_3$

Note: The electrons just facilitate the reaction!

Hydroxyl ions cause alkaline conditions on the cathode's surface

If water and oxygen cannot reach the metal surface, will corrosion be stopped?

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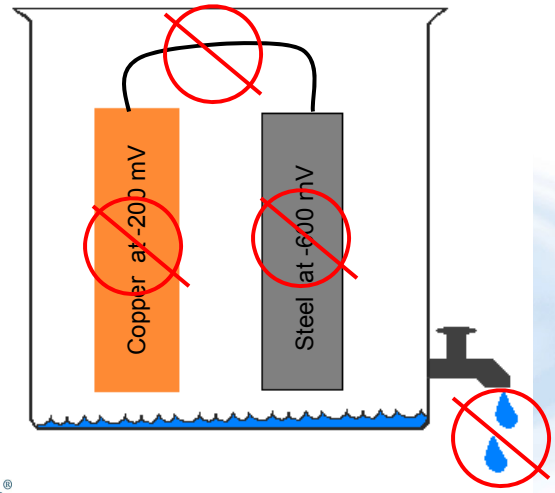
Eliminating the Corrosion Cell



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Prestressed Concrete Cylinder Pipe – Concrete Jacket

Photo Credits: Thompson Pipe Group/Formerly Forterra, Inc.

The high alkalinity of the cement mortar coating passivates the embedded steel members providing corrosion resistance.

An alkaline material or solution has a pH >7.0

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High Alkalinity Affects the Corrosion of Carbon Steel

After just 24 hours of immersion

L: Well Water R: Well Water + Baking Soda

Approximately 7 months later

L: Well Water R: Well Water + Baking Soda

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Photo Credits: CP Solutions, Inc.

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Mortar Integrity on Reinforced Concrete Pipe

New installation looks good…

…but is there latent damage?

Photo Credits: CP Solutions, Inc.

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Coated Steel Pipe - Factory-Applied Coating Systems

AWWA C-214 Standard Tape Wrap

Photo Credits: Northwest Pipe

AWWA Standard C-222 Polyurethane

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Large Diameter Coated Steel Pipe – Installation Photos


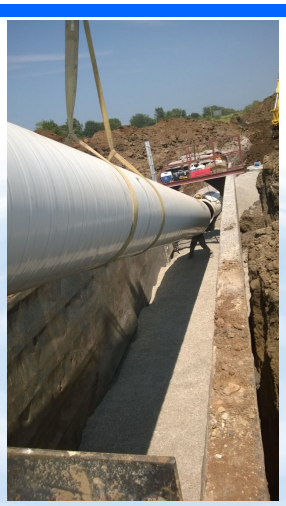


Photo Credits: CP Solutions, Inc.

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Coating Integrity on Coated Steel Pipe

New installation looks good…

…but is there latent damage?

Photo Credits: CP Solutions, Inc.

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Consider Long Term Pipe Coating Damage

Does it adequately resist soil stress?

Photo Credits: CP Solutions, Inc.

Will my pipe coating resist damage from third-party "hits" after burial?

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Pipe Coating/Tape Wrapping– Long-Term Effectiveness

Photo Credits: CP Solutions, Inc.

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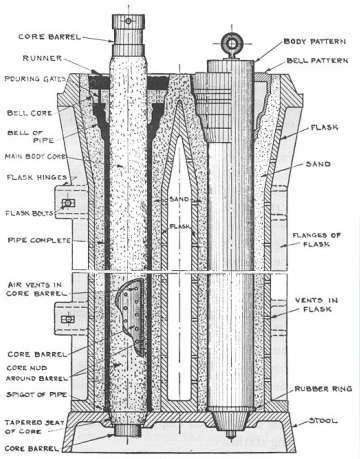
Pit-Cast Iron Water Pipe (Circa 1915)



Left Photo Credit: CP Solutions, Inc.

Right Photo Credit: Ductile Iron Pipe Research Association

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Graphitization of Gray Cast Iron Pipe

Graphitization weakens the cast iron pipe wall

Corrosion causes the pipe wall to fail

Photo Credits: CP Solutions, Inc.

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Ductile Iron Water Pipe (Contemporary)

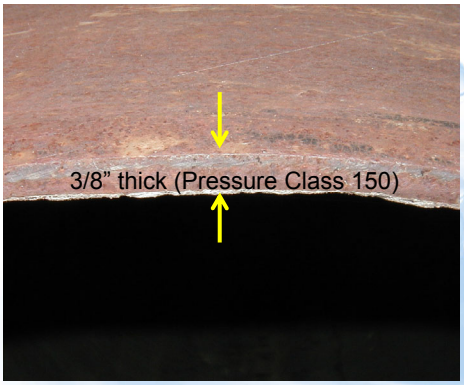

Photo Credit: CP Solutions, Inc.

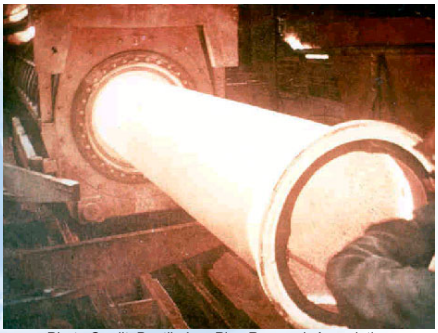

Photo Credit: Ductile Iron Pipe Research Association

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Poly-Wrap Integrity on Ductile Iron Pipe

Inner poly wrap is damaged exposing DIP wall with abraded 1-mil asphalt coating

Photo Credit: CP Solutions, Inc.

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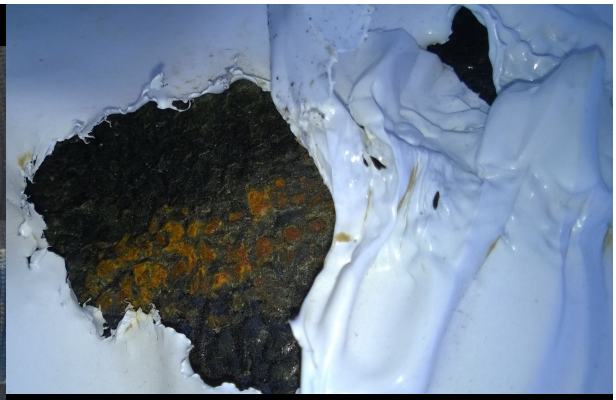
DIP Asphalt Coating – A True Corrosion Barrier?

Sticky label pulls off coating



Close-up of abraded 1-mil asphalt coating

Photo Credits: CP Solutions, Inc.

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How NOT to Install DIP w/Polyethylene Wrapping

Photo Credits: CP Solutions, Inc.

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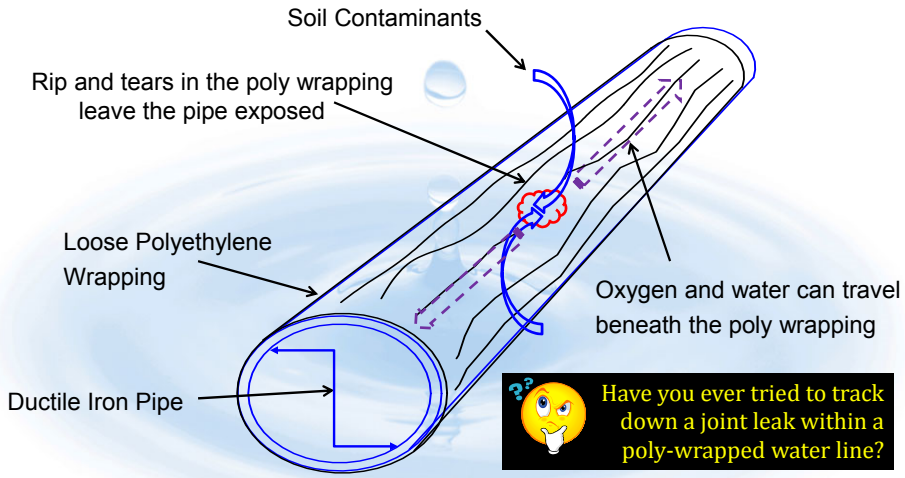
Loose Poly Wrapping – An Effective Corrosion Barrier?



Have you ever tried to track down a joint leak within a poly-wrapped water line?

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Section 4

Basic Cathodic Protection

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How Cathodic Protection Works

- **Basic Corrosion:** Corrosion occurs where DC current discharges from the metal to the electrolyte.
- **CP Objective:** To allow your structure to receive DC current (be cathodic) from an expendable anode placed in the soil.

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Practical Galvanic Series

Material	Potential*
Pure Magnesium	-1.75
Magnesium Alloy	-1.60
Zinc	-1.10
Aluminum Alloy	-1.00
Mild Steel (New)	-0.70
Mild Steel (Old)	-0.50
Cast / Ductile Iron	-0.50
Stainless Steel	-0.50 to + 0.10
Copper, Brass, Bronze	-0.20
Gold	0.20
Carbon, Graphite, Coke	0.40

*Measured in Volts versus a Cu-$CuSO_4$ Reference Electrode

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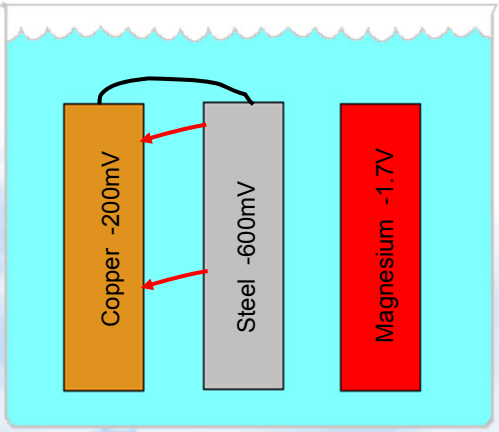
Galvanic Corrosion – No Cathodic Protection Benefit

1. Anode
2. Cathode
3. Electrolyte
4. Metal Path



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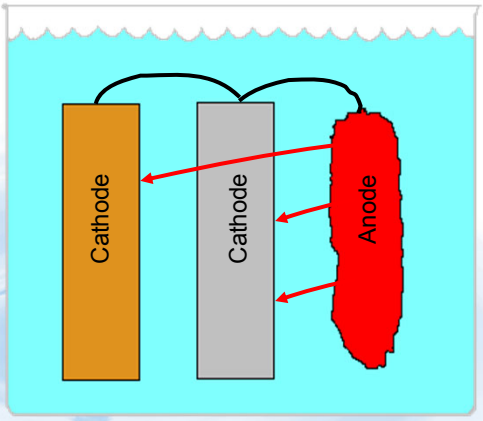
Galvanic Corrosion Mitigated w/Cathodic Protection

1. Anode
2. Cathode
3. Electrolyte
4. Metal Path



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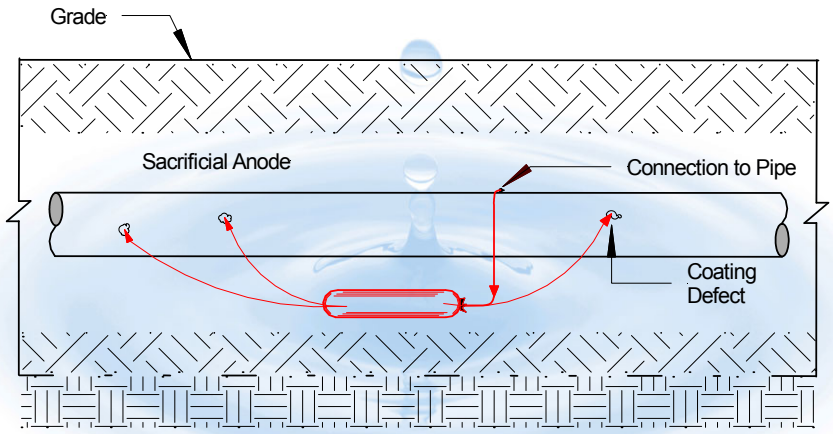
Typical Horizontal Sacrificial Anode Installation



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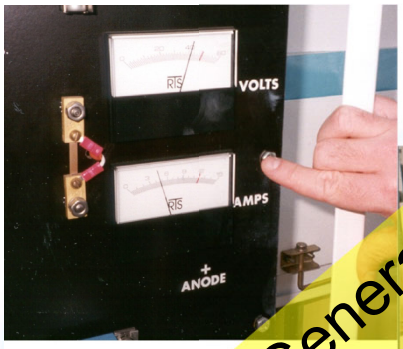
Rectified Anode Systems – Municipal Water Pipelines



Generally, they're not recommended!

Photo Credits: CP Solutions, Inc.

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Section 5

Cathodic Protection for Existing Water Mains using an Anode Retrofit Program

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Anode Retrofit Programs – An Overview

Anode **R**etrofit **P**rogram (ARP) - A method to install sacrificial anodes to buried water mains.

- Since 1980's – Many Ontario (Canada) Water Utilities
- Since 2003 – Louisville (KY) Water Company
- Since 2004 – Des Moines (IA) Water Works
- Since 2014 – Several Midwestern Water Utilities
- More Recently – Several California Water Utilities

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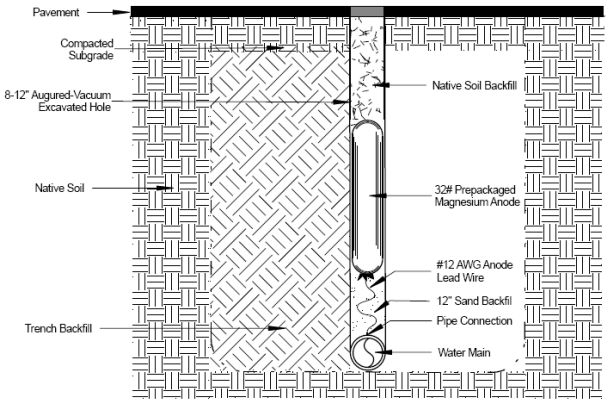
Typical Anode Retrofit Installation Method



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Keyhole to Pipe & Wire Connection

Exothermic Welding Tool Down the Hole

Photo Credits: CP Solutions, Inc.

Testing the Wire Connection

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Ten-Year Economic Data for DMMW's ARP

ARP Parameters (Years 2004-2014)	Totals
Water Main Protected (ft.)	117,628
Quantity of Anodes Installed	2,321
Total Cost of ARP	$1,518,780
Unit Cost per Installed Anode	$654.36
Project Cost (per linear foot of water main)	$12.91

Source: DMWW Corrosion Control Report Program Report (June 2016)

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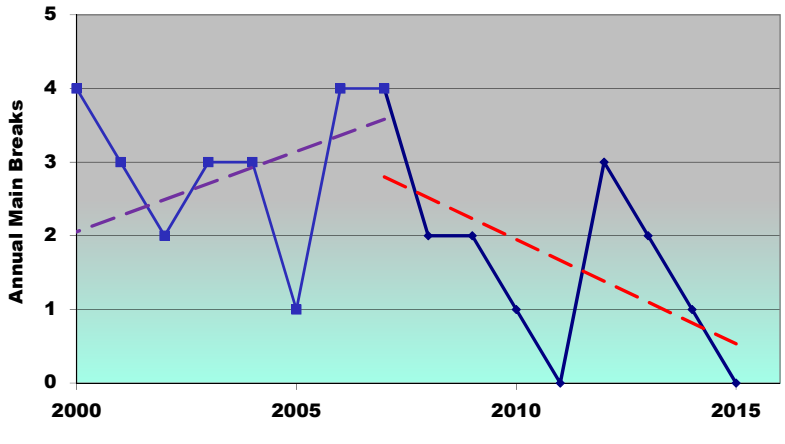
Example: Main Break Reduction on DMWW 2007 ARP



Data courtesy of Des Moines Water Works – Des Moines, IA

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Alternative (Non-Keyhole) Installation Methods

Photo Credits: CP Solutions, Inc.

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Economic Data for Cedar Rapid Iowa's ARP

ARP Parameters (Year 2014)	Totals
Water Main Protected (ft.)	2,250
Quantity of Anodes Installed	60
Total Cost of ARP*	$51,141
Unit Cost per Installed Anode	$857.50
Project Cost (per linear foot of water main)	$22.73

Source: Cedar Rapids, IA Water Division

*The anodes were installed with a mini excavator during pre-paving. Total cost include the anodes, test stations, and cable bonding of all exposed pipe joints and a small percentage of the overall project's sum of mobilization, construction staking, field engineering, and a Contractor performance incentive.

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ARP through Pavement – Excavating Anode Sites

Pavement Removal

Soil Removal

Photo Credit: La Crosse, WI Water Utility Construction Inspector

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ARP through Pavement - Exposing Pipe for Anode Install

Top of Pipe Exposed

Anode Placed into Excavation

Photo Credit: La Crosse, WI Water Utility Construction Inspector

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Section 6

Cathodic Protection for New Water Mains

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Cathodic Protection System – Keys to Success

1. Integrity of the pipe's coating/wrapping system
2. Pipe is electrically isolated from foreign structures
3. Pipe must be an electrically continuous structure
4. Pipe connections must be electrically secure
5. Install accessible test points to verify effectiveness
6. Install anodes simultaneously with the pipe

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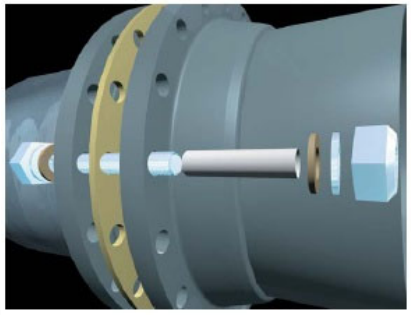
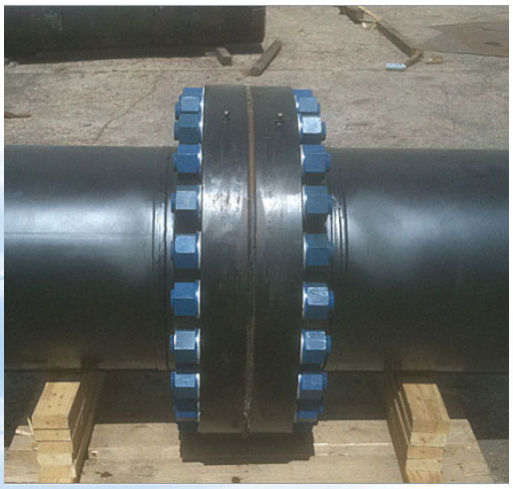
Flange Isolation Kit Components





FIK components should always meet NSF-61 requirements

Photos courtesy of Garlock Pipeline Technologies, Inc. – Wheat Ridge, CO

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HDPE Pipe Isolation (HDPI) Coupling

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Photo Credits: Water District #1 of Johnson County, KS

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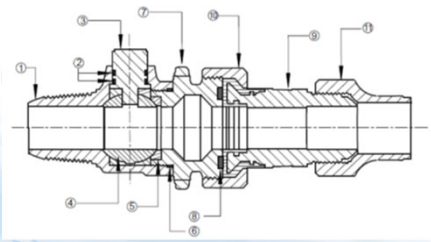
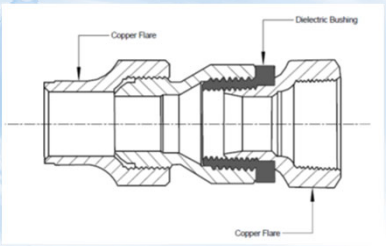
Isolation Corporation Stop

Photo Credit: CP Solutions, Inc.





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Casing Sleeve Isolation Spacers

Photo Credits: CP Solutions, Inc.

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Casing Sleeve – Typical Pipe End Seals

Link-Style End Seal

A suitable end seal prevents pipe-to-casing contact and also keeps soil/water from entering into the casing annulus!

Wrap-Around End Seal

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Photo Credits: CP Solutions, Inc.

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Wall Penetrations on Pipe With Cathodic Protection

Good Job!

Link-Style End Seal

Pipe welded to rebar of concrete wall!

Thru-Wall Pipe w/Anchor

No isolation of pipe-rebar

Photo Credits: CP Solutions, Inc.

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Continuity Bonds across Pipe Joints

Ductile Iron Pipe prior to Weld Coating

Ductile Iron Pipe after Weld Coating

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Photo Credits: CP Solutions, Inc.

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Proper Coating of Exothermic Welds Connections

Raw Connections before Coating

Photo Credits: CP Solutions, Inc.

Restore poly wrap over test station wires

Finished Connections Ready to Backfill

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A Suitable Post-Type CP Test Station Installation

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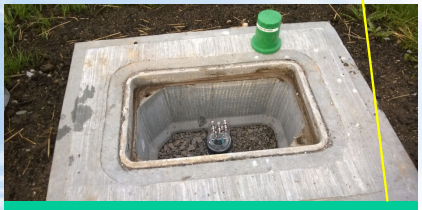
Suitable Flush-Type CP Test Station Installation

Terminal board is mounted to PE Pipe



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Sacrificial Anodes Installed in an Open Pipe Trench

Photo Credits: CP Solutions, Inc.

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Section 7

Solving Corrosion Problems at Water Main Breaks

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What's Your Biggest Cost to Repair a Main Break?

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Photo Credit: CP Solutions, Inc.

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"Hot-Spotting": CP Anodes at Water Main Breaks

Do I really want to re-excavate this hole for another water main break?

Install a sacrificial CP anode while the water main repair excavation is already open!

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Photo Credits: CP Solutions, Inc.

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AWWARF Shows that CP Reduces Main Breaks

- Document all leak and main break repairs as recommended by AwwaRF
- Install a sacrificial anode every time the main is exposed for repairs or tapping.
- Install the anodes where earlier leak problems have occurred

Source: *Research Applications, Proven Utility Benefits*, Paper #8, AwwaRF, August 1995.

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Cathodic Protection Is Proactively Inexpensive

Cost of repairing a water main break
versus
installing a sacrificial anode during a pipe repair…

Average Cost of a Main Break
$3,500 to $7,000 (or more*)

Cost of a CP Anode and a Connection Device
Less than $175!

*Cromwell, J, H. Reynolds, N. Pearson, and M. Grant., *Costs of Infrastructure Failure*. AwwaRF: Denver, CO, (2002).

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Use a Secure Connection to Attach Sacrificial Anodes

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Photo Credit: CP Solutions, Inc.

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Safe Work Practice in Wet Trench Conditions

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Photo Credits: CP Solutions, Inc.

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Section 8

Cathodic Protection Performance Verification

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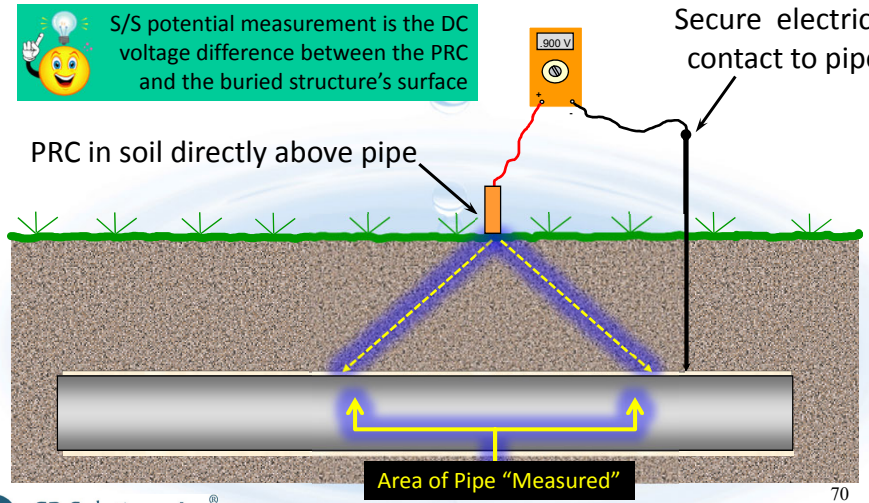
Structure-to-Soil Potential w/Portable Reference Cell

S/S potential measurement is the DC voltage difference between the PRC and the buried structure's surface



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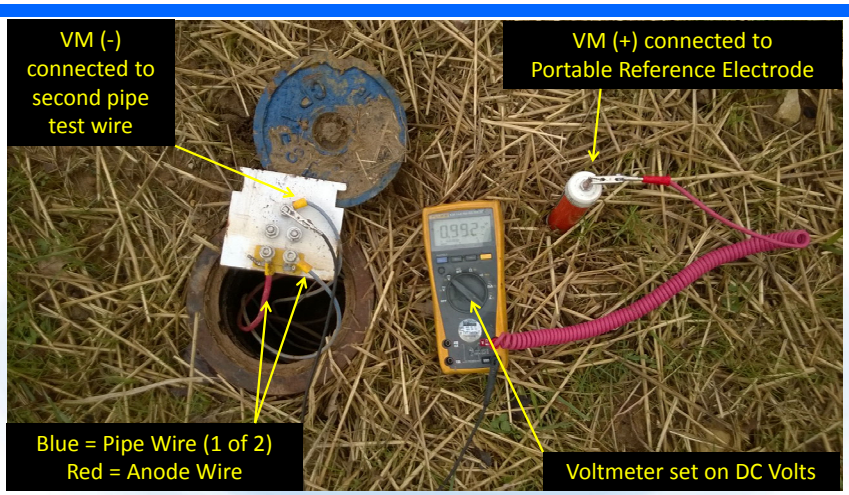
CP Performance Validation – S/S Potential Data



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The Real Benefits of Corrosion Mitigation by using CP

Remember that CP Value = Effectiveness/Installation Costs + O&M Costs

Water Main Life Extension of least 25 years at a cost that is much less than…

- Direct costs of pipe repairs and/or water main replacement.
- Indirect costs resulting from water loss/service disruptions.

Cathodic protection **saves $5 to $10** for every $1 spent resulting in…

- Increased water main service life
- Increased level of reliable water service to customers
- Increased health and security of the municipal water supply

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AWWA Iowa Section : 10/17/2018

Do You Have Any Questions?

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