AUCSC

Appalachian Underground Corrosion Short Course

Water and Wastewater Course

Appalachian Underground Corrosion Short Course
West Virginia University
Morgantown, West Virginia

Day 1

Session 1 – 9:30 – 10:30 AM: Water Loss Prevention Through an Effective Corrosion Control Program
Michael Nordstrom, Corrpro Companies, Inc.

Session 2 – 10:40 – 11:40 AM: Cathodic Protection Application for Water and Wastewater Tanks
Michael Nordstrom, Corrpro Companies, Inc.

Session 3 – 1:30 – 2:30 PM: Corrosion and Its Control, Polyethylene Encasement (V-Bio®), for Ductile Iron Pipe
Allen Cox, Ductile Iron Pipe Research Association

Session 4 – 2:40 – 3:40 PM: Linings and Coatings for Ductile Iron Pipe
Conor Madden, U.S. Pipe

Session 5 – 3:50 – 4:50 PM: Mitigating Corrosion on Spiralwelded Steel Pipe
Anooj Kothari, American

Day 2

Session 6 – 8:15 – 9:15 AM: Concrete Pipe and Corrosion Control Techniques

Jeff Leblanc, Thompson Pipe Group

Session 7 – 9:25 – 10:25 AM: Corrosion Control Installation Procedures for Water and Sewer Pipeline Infrastructure
Joe Greulich, Washington Suburban Sanitary Commission

Session 8 –10:35 – 11:35 AM: Stray Current and Ductile Iron Pipelines
Paul Hanson, Ductile Iron Pipe Research Association

Session 9 – 1:30 – 2:30 PM: CIS and DCVG Survey over Pipelines
Sasan Hosein, Pond & Company

Session 10 – 2:40 – 3:40 PM: Corrosion Failures in Water & Wastewater Facilities (Part 1)
Anil Kumar Chikkam, Matergenics

Session 11 – 3:50 – 4:50 PM: Corrosion Failures in Water & Wastewater Facilities (Part 2)
Anil Kumar Chikkam, Matergenics

Day 3

Session 12 – 8:30 – 9:30 AM: Installation of Cathodic Protection Systems in Water Towers
Adam Freeman, Freeman Industries, Inc.

Session 13: 9:45 – 10:45 AM: Linings, Wet Wells and Manholes: This is how we roll (and spray)
Steve Roetter, Sherwin Williams

Water Loss Prevention Through an Effective Corrosion Control Program

Michael Nordstrom, Corrpo Companies, Inc.

mnordstrom@aegion.com

Water Loss Prevention Through an Effective Corrosion Control Program

March 28, 2001
West 38th Street,
Cleveland, Ohio

Aging pipe breaks; six schools closed

This story was written by James F. Sweeney with reporting from Alana Baranick, John P. Coyne, Gina Jacocks, Lila J. Mills and Michael Sangiacomo.

City crews are working this morning to repair a water main that burst yesterday afternoon in Ohio City, flooding streets and requiring residents of the near West Side to boil all tap water until 10 tonight.

People who live in the area bordered by the Shoreway on the north, Denison Ave. on the south, W. 65th St. to the west and Scranton Rd. to the east should bring water to a boil for at least three minutes before drinking it or cooking with it, said Michael G. Konicek, city public utilities director.

Officials said six schools would be closed today because of low water pressure:

- Lincoln West High School
- Max Hayes Vocational High School
- Blessed Sacrament elementary
- St. Rocco elementary
- Metro Catholic elementary
- Urban Community elementary

It was the city's third major water main break in just over a year.

The 30-inch main under W. 38th St. near Franklin Blvd. is the latest section of the city's aging network of pipes to give way in dramatic fashion, damaging streets, inconveniencing residents and requiring repairs.

The line beneath W. 38th connects to the Garrett A. Morgan water-filtration plant north of the Shoreway and feeds smaller connecting lines.

Konicek said last night that he did not know how old the pipe was.

He estimated that "several million gallons" of water poured out through the pavement in front of Kentucky Elementary School, less than the estimated 25 million gallons lost during a break in January 2000 at E. 9th St. and Rockwell Ave.

This one is "not quite as bad" as the E. 9th St. break, Konicek said.

"We have water, such as it is, but it is certainly not drinkable. I boiled it, and there was this disgusting brown stuff at the bottom of the pot."

DIANE LECHNER,
a Franklin Blvd. resident

Another water main broke last August at Euclid Ave. and Huron Rd. in Playhouse Square. That was caused by a construction crew installing fiber-optic cable, city officials said.

The cause of yesterday's break remains under investigation. Crews worked late last night on the edge of a hole about 6 feet deep and 20 feet wide filled with muddy water on W. 38th near Terrett.

Konicek said the break was reported at 4:45 p.m. and crews had shut off water to the line by 6:15 p.m. At least 10 valves had to be shut to stop the flow — some of the valves so large they had to be turned by hand 350 times, he said.

SEE WATER/10-A

Water gushes from a broken main at W. 38th St., just south of Franklin Blvd. in Cleveland yesterday.

Past breaks

Aug. 30, 2000
- **Where:** Euclid Ave. and Huron Rd. near Playhouse Square.
- **What happened:** Break in 30-inch main.

Jan. 13, 2000
- **Where:** E. 9th St. and Rockwell Ave.
- **What happened:** Hole blown in 36-inch water pipe caused 25 million gallons to spill.

Jan. 26, 1995
- **Where:** Diamond Building at E. 12th St. and Superior Ave.
- **What happened:** Water main rupture.

June 29, 1994
- **Where:** E. 9th and Superior.
- **What happened:** Break in 30-inch water main.

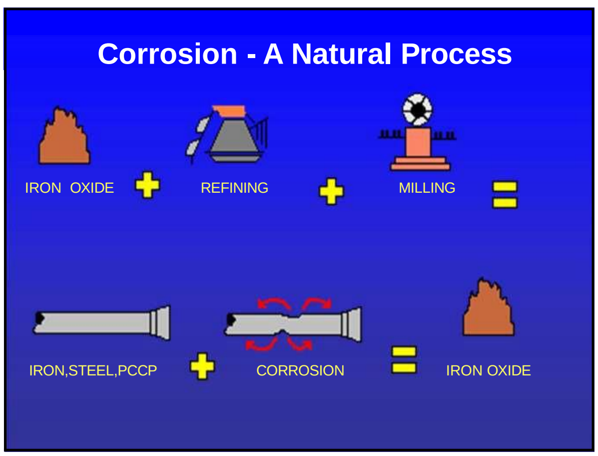
May 22, 1992
- **Where:** East Side.
- **What happened:** 30-inch water main erupted just outside the Fairmount pump station.

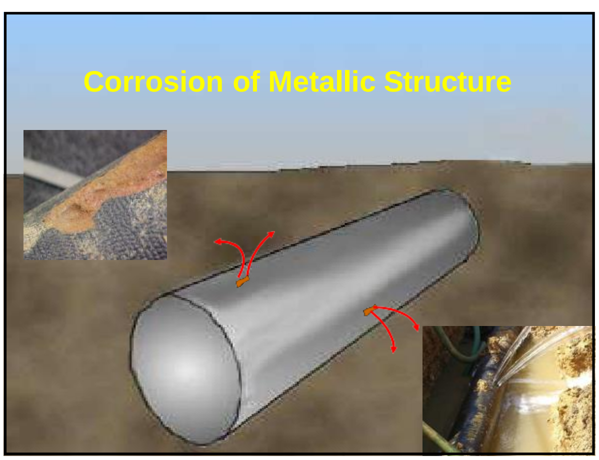

30" West 38th Street - 3/28/2001

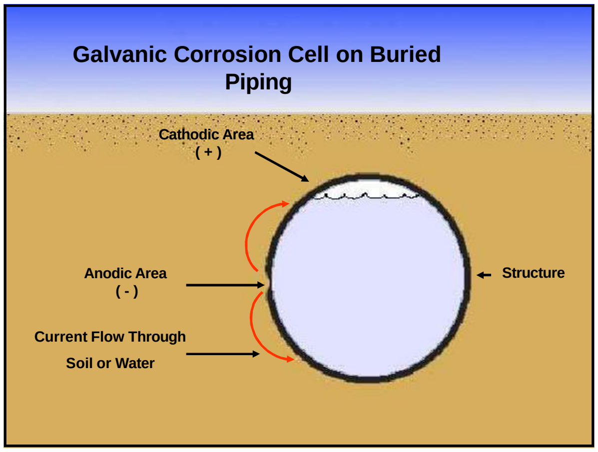

Traffic Disruptions
Water Loss
Fire Protection
Damages
Legal & Environmental Claims

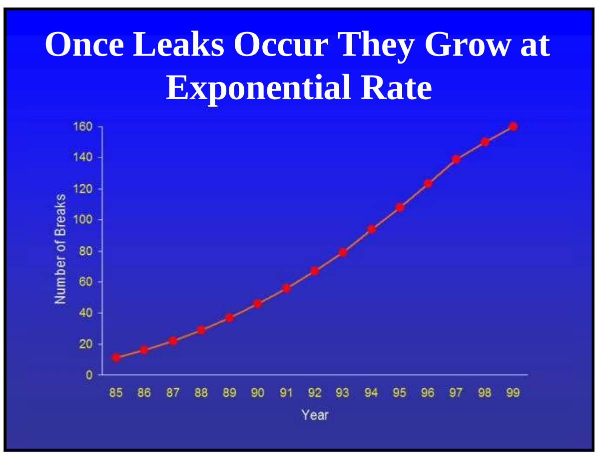

Corrosion


Temporary Fix ?


Corrosion - A Natural Process
IRON OXIDE
REFINING
MILLING
IRON,STEEL,PCCP
CORROSION
IRON OXIDE


Corrosion of Metallic Structure


Galvanic Corrosion Cell on Buried Piping
Cathodic Area
(+)
Anodic Area
(-)
Structure
Current Flow Through
Soil or Water


Once Leaks Occur They Grow at Exponential Rate
Number of Breaks
0
20
40
60
80
100
120
140
160
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
Year


Adverse Conditions for Metallic Pipe
- High Chlorides
- Low Soil/Water Resistivity
- High Sulfates
- Acidic Soils
- Wet/Dry Fluctuations
- Bimetallic Couplings
- Stray Current Interference

History of Iron Pipe

Cast Iron

- Introduced to North America during the 1800's and installed till the 1970's.
- Early on, statically cast process produced a thick walled, heavy pipe.
- No longer produced in North America.

Ductile Iron

- Introduced in 1955 as an improvement to cast iron.
- Centrifugal casting process produces a thinner walled, lighter pipe which is stronger and more ductile than cast iron.

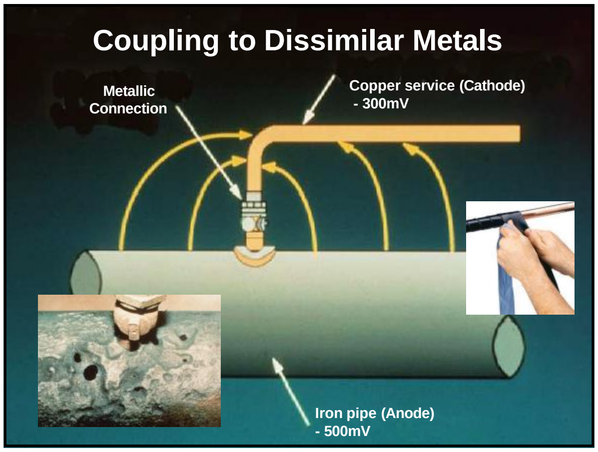
Cast (Grey) Iron

Graphitization leaves pipe brittle and weakened.

corrpro

Ductile Iron

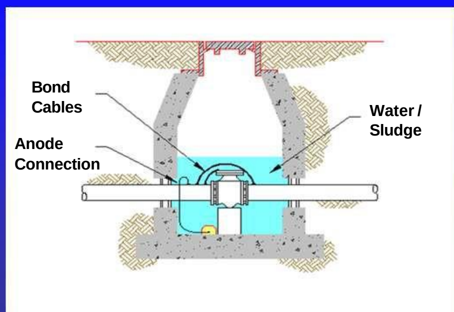
Pitting (concentrated) corrosion attack on ductile iron pipe.


Coupling to Dissimilar Metals
Metallic Connection
Copper service (Cathode) - 300mV
Iron pipe (Anode) - 500mV

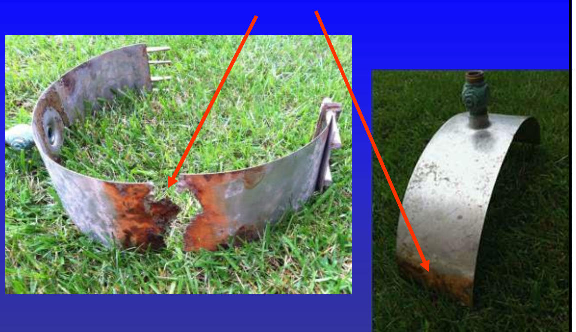

Gate Valve Corrosion


Meter Vault Corrosion
08/22/2007

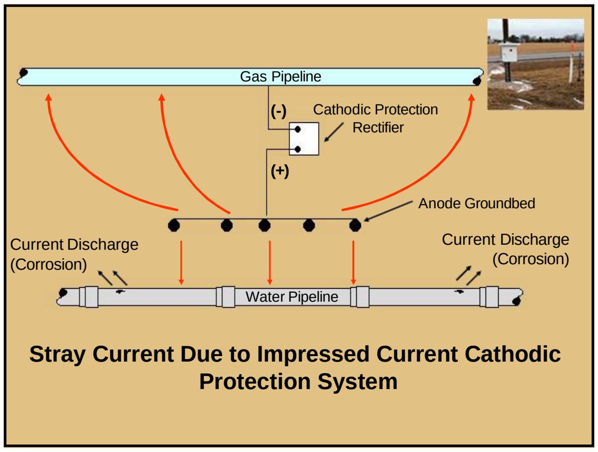
Meter Vault with Anode

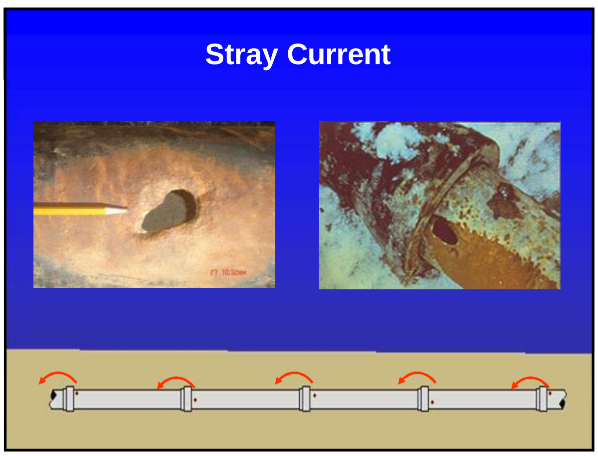


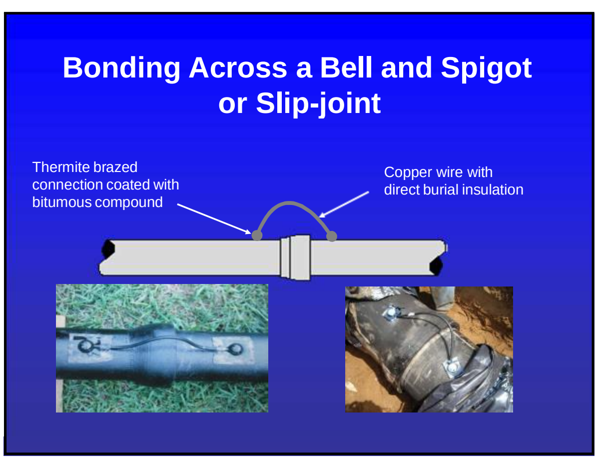
Stainless Steel Corrosion

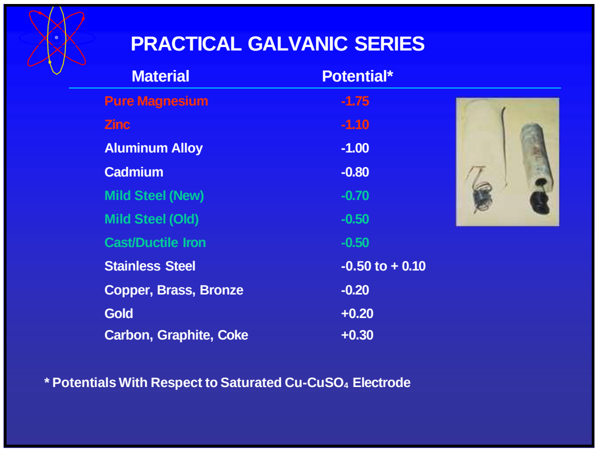


Stray Current Corrosion


Gas Pipeline
(-)
Cathodic Protection
Rectifier
(+)
Anode Groundbed
Current Discharge
(Corrosion)
Current Discharge
(Corrosion)
Water Pipeline
Stray Current Due to Impressed Current Cathodic Protection System


Stray Current

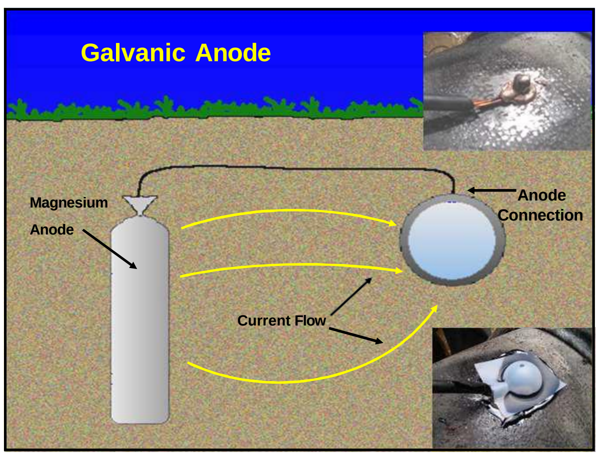

Bonding Across a Bell and Spigot or Slip-joint
Thermite brazed connection coated with bitumous compound
Copper wire with direct burial insulation



PRACTICAL GALVANIC SERIES

Material	Potential*
Pure Magnesium	-1.75
Zinc	-1.10
Aluminum Alloy	-1.00
Cadmium	-0.80
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	+0.30

* Potentials With Respect to Saturated Cu-$CuSO_4$ Electrode



Galvanic Anode
Magnesium
Anode
Anode
Connection
Current Flow

Temporary Fix ?
corrpro

Leak Repair Should Include Anode Installation

Incomplete

Complete

Water Municipality Anode Kit (Kept in Storeroom/Truck)

Includes:

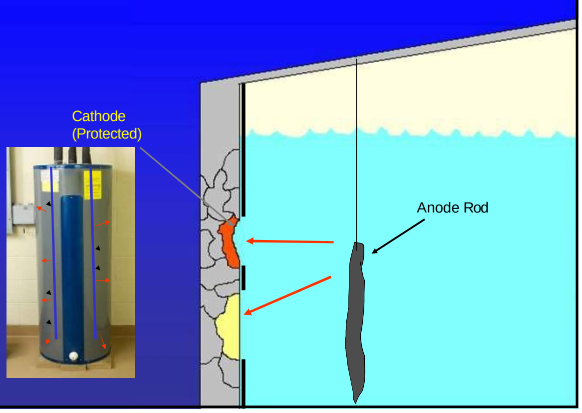
Installation instructions.

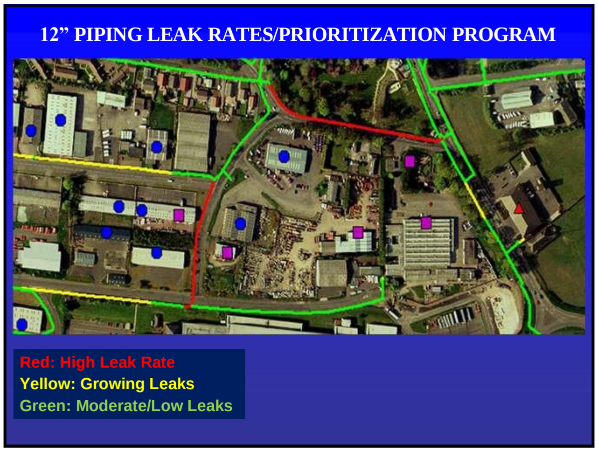
One day onsite technical assistance.

Cathodic protection components/connection materials suitable for 10 repairs.

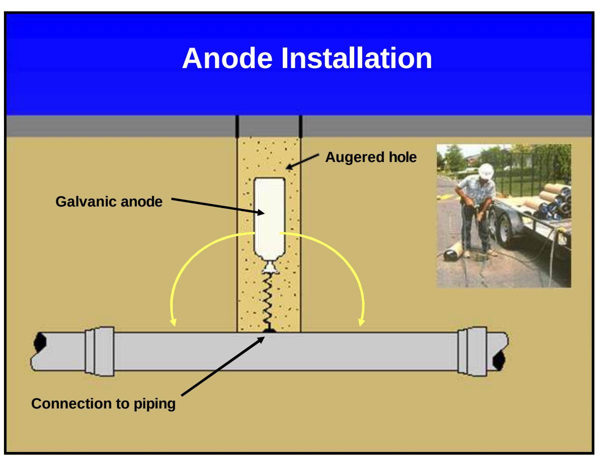
Can be kept on shelf/truck

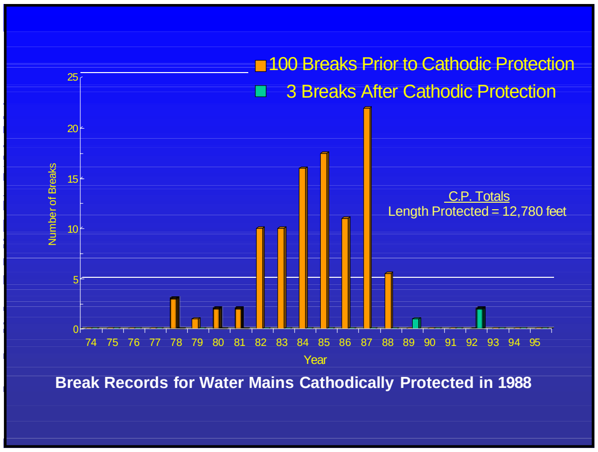
Cathodic Protection Anode Use on Household Water Tank

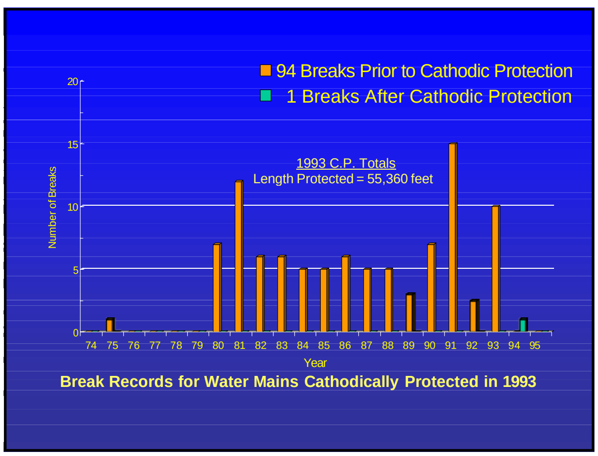


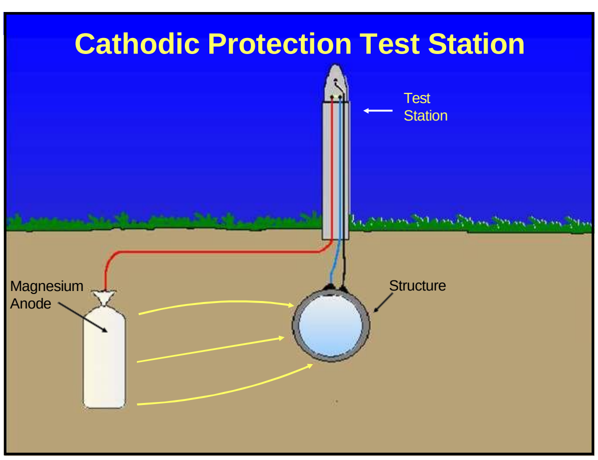

12” PIPING LEAK RATES/PRIORITIZATION PROGRAM
Red: High Leak Rate
Yellow: Growing Leaks
Green: Moderate/Low Leaks

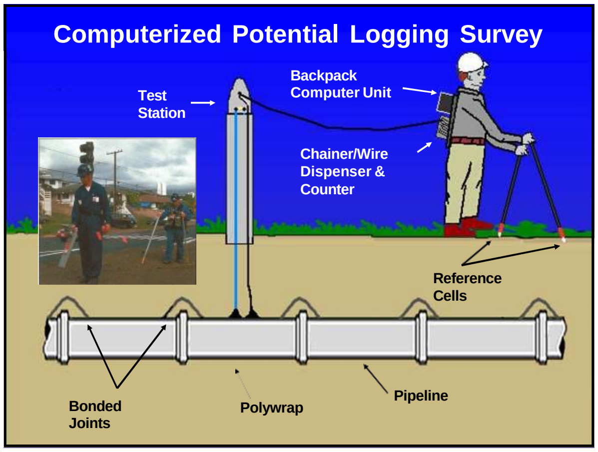

Proactive Anode Installation Options

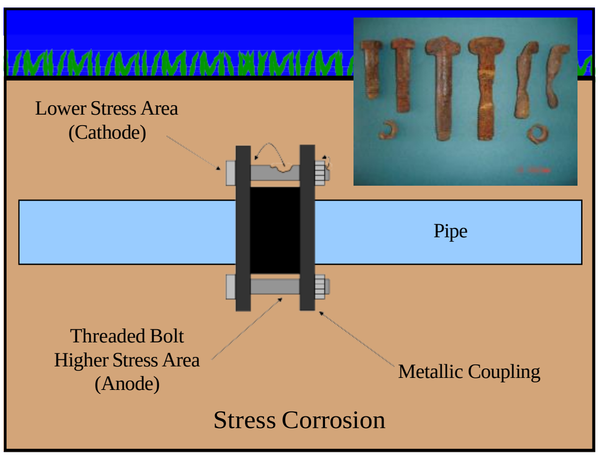

Anode Installation
Augered hole
Galvanic anode
Connection to piping

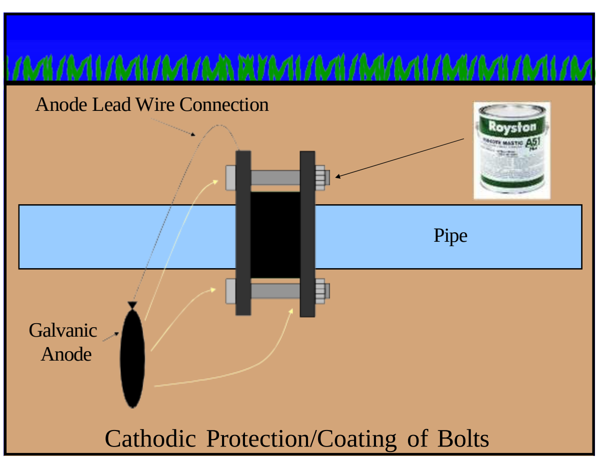

100 Breaks Prior to Cathodic Protection
3 Breaks After Cathodic Protection
Number of Breaks
0
5
10
15
20
25
C.P. Totals
Length Protected = 12,780 feet
74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95
Year
Break Records for Water Mains Cathodically Protected in 1988


94 Breaks Prior to Cathodic Protection
1 Breaks After Cathodic Protection
Number of Breaks
0
5
10
15
20
1993 C.P. Totals
Length Protected = 55,360 feet
74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95
Year
Break Records for Water Mains Cathodically Protected in 1993


Cathodic Protection Test Station
Test
Station
Magnesium
Anode
Structure

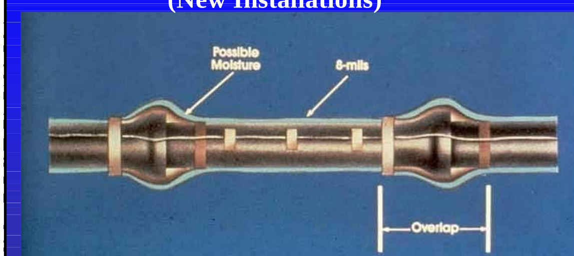

Computerized Potential Logging Survey
Backpack
Computer Unit
Test
Station
Chainer/Wire
Dispenser &
Counter
Reference
Cells
Bonded
Joints
Polywrap
Pipeline


Lower Stress Area
(Cathode)
Pipe
Threaded Bolt
Higher Stress Area
(Anode)
Metallic Coupling
Stress Corrosion

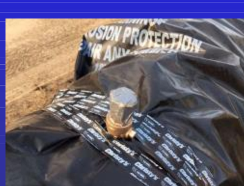

Anode Lead Wire Connection
Royston
Pipe
Galvanic
Anode
Cathodic Protection/Coating of Bolts

Anode Installed on Metallic Fitting

Polyethylene Encasement (New Installations)



- Follow manufacture's and AWWA recommendations to insure proper installation of polyethylene encasement.
- In extremely corrosive areas, additional methods (bonding of joints, cathodic protection, may be required).



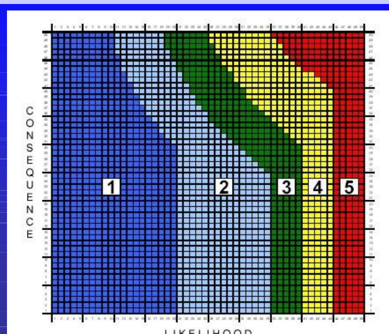
Investigative Structure (Existing)

Corrosion Assessment

- Review of General Characteristics of Water System
  - Age
  - Material Type
  - Wall Thickness
  - Construction Practices
- Review Break / Leak History
- Field Survey
  - Soil Conditions (Resistivity, Moisture Content, Chemical Analysis)
  - Electrical Test
- Data Analysis & Risk Management
- Priority Index (Identification of Opportunities to Reduce Replacement / Repair Costs)

Design Decision Model

For Ductile Iron Pipe



Summary

- Reducing corrosion rates on existing water distribution piping will result in a reduction of the number of breaks and also extend the operational life.
- Corrosion control measures should be considered during the design stage for any new metallic piping ans storage tank installations.

Cathodic Protection Application for Water and Wastewater Tanks

Michael Nordstrom, Corrpo Companies, Inc.

mnordstrom@aegion.com

Cathodic Protection Application for Water and Wastewater Tanks

Appalachian Underground Corrosion Short Course
Morgantown, West Virginia

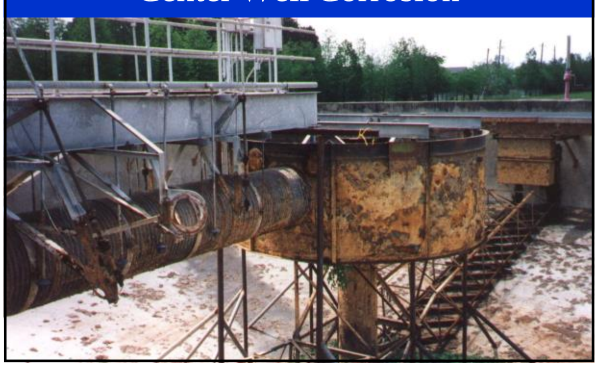
Water Storage Tanks


Water Treatment Equipment


Wastewater Treatment Equipment
(Pulp & Paper Mill)

Coating Deterioration
Treatment Unit

Wastewater Clarifier
Center Well Corrosion



The Environmental Protection Agency now mandates corrosion protection for all underground fuel storage tanks in the US

Magnesium anodes pre-packaged on underground fuel storage tanks

The Value of Using Cathodic Protection

- Economical initial cost of installation
- Economical to maintain
- Extends useful life of the coating
- Minimizes the need for coatings maintenance
- Minimizes the need for re-coating
- Minimizes metal repairs
- Minimizes the need for costly downtime
- Significantly lowers total cost of ownership

AWWA Standard D104

"Automatically Controlled Impressed-Current Cathodic protection for the Interior of Steel Water Tanks"

"The combination of coatings and cathodic protection may be more economical and effective than using coatings or cathodic protection alone"

NACE Standard Practice SP0388-2018

"Impressed Current Cathodic Protection of Internal Submerged Surfaces of Carbon Steel Water Storage Tanks"

"If the water is sufficiently corrosive to justify the use of coatings, then cathodic protection is also justified and provides a greater degree of protection than when either method is used alone"

National Fire Protection Association

NFPA Standard 25 "Inspection and Testing Of Water Storage Tanks for Fire Protection"

"The inspection interval for the interior surface areas shall be three (3 Years)"

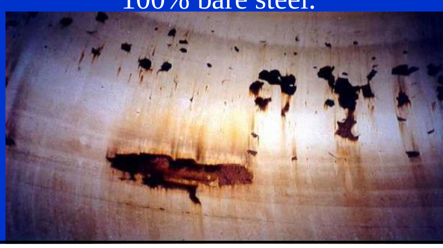
Exception 1: If corrosion control is utilized the inspection interval shall be five (5) years"

"Cathodic protection corrosion control system should be inspected annually"

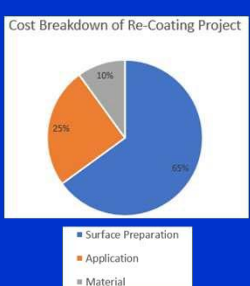
NSF 61
National Sanitation Foundation Standard 61

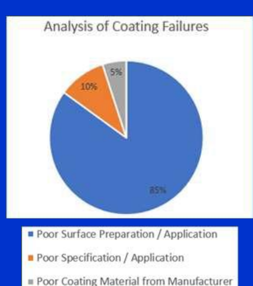
Anything that comes in contact with drinking water is tested and certified to be safe for the drinking water supply.

For stand-alone coating systems re-coating is typically recommended at 1-5% failure. A standard AWWA D104 anode system is designed to protect up to 20% bare for a **minimum** of 20 years. Systems can be designed to protect up to 100% bare steel.



Re-Coating Project

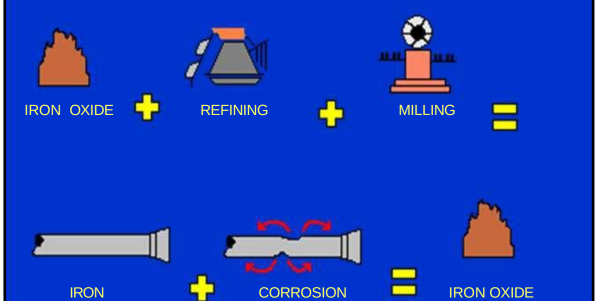




CORROSION IS DEFINED AS:

The deterioration of a substance (usually metal) due to a reaction with its environment

Corrosion - A Natural Process



Steel Mill Smelting Unit

1,200 degree steel coil

PRACTICAL GALVANIC SERIES

Material	Potential*
Pure Magnesium	-1.75
Magnesium Alloy	-1.60
Zinc	-1.10
Aluminum Alloy	-1.00
Cadmium	-0.80
Mild Steel (New)	-0.70
Mild Steel (Old)	-0.50
Cast Iron	-0.50
Stainless Steel	-0.50 to + 0.10
Copper, Brass, Bronze	-0.20
Titanium	-0.20
Gold	+0.20
Carbon, Graphite, Coke	+0.30

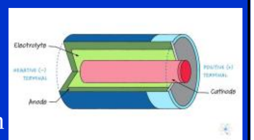
* Potentials With Respect to Saturated $Cu/CuSO_4$ Electrode

Water Storage Tanks and Treatment Facilities Possess the Four Requirements for Corrosion Cells to Form

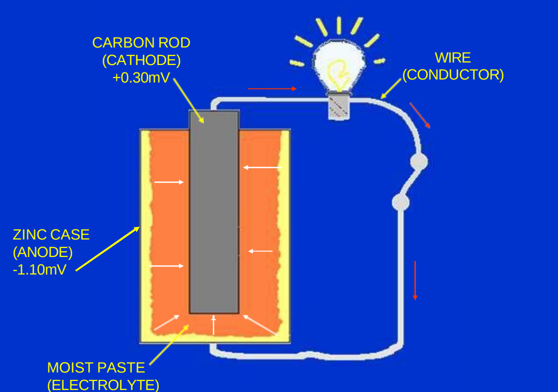
- Electrolyte: Water and/or Wastewater
- Conductor: Steel Tank or Equipment
- Anode: Metal in contact with the electrolyte
- Cathode: Metal in contact with the electrolyte

A Battery is an Example of a Corrosion Cell

- Electrolyte: chemical paste
- Anode: zinc container
- Cathode: carbon electrode
- Conductor: metal connection



The electrical energy of the corrosion process is measurable in the form of electric current



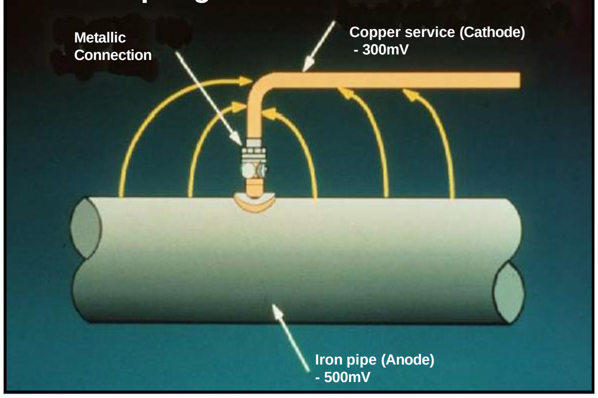
Metals Connected together can form a Corrosion Cell

ANODE (corrodes)		CATHODE (protected)
• New Steel	to	• Old Steel
• Steel	to	• Copper
• Galvanized Steel (ladders & safety climbs)	to	• Steel
• Steel	to	• Stainless Steel (ladders & safety climbs)
• Magnesium	to	• Steel
• Steel	to	• Reinforcing Steel

Galvanic Corrosion Induced by a Stainless Steel Ladder

Dissimilar metals

Coupling to Dissimilar Metals



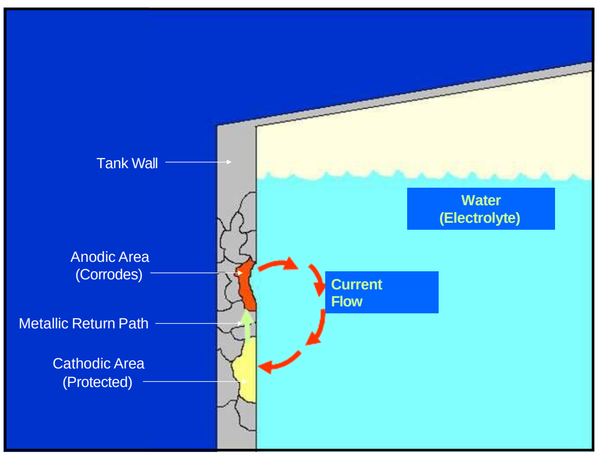
Corrosion of iron when coupled to copper service line.

Galvanic Corrosion reaction between steel and rebar in a treatment facility

The most common use of cathodic protection for water tanks

Homogeneous Metal Corrosion Example: Steel Plate or Iron Pipe

- Corrosion cells are created by different electrical levels in each grain of steel
- When in contact with an electrolyte (moisture) energy transfers between grains of steel
- Grains discharging energy corrode
- Grains accepting energy do not corrode

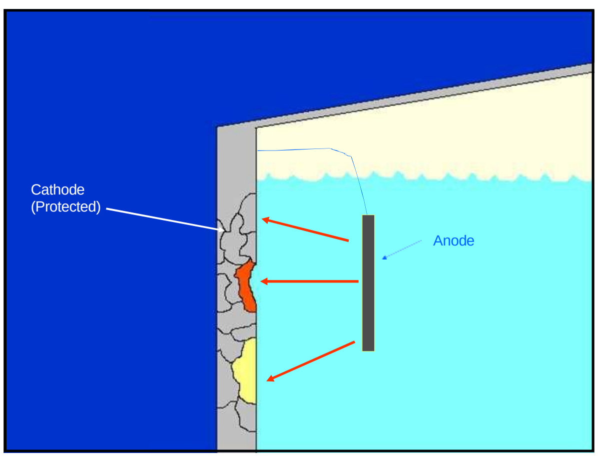


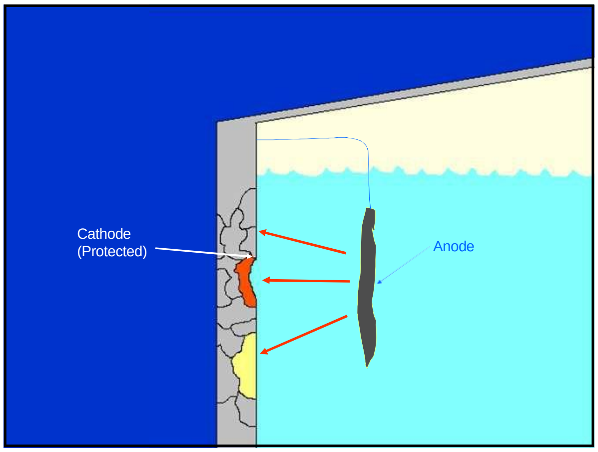
To Prevent Corrosion, one or more of the four requirements of a corrosion cell must be eliminated or minimized

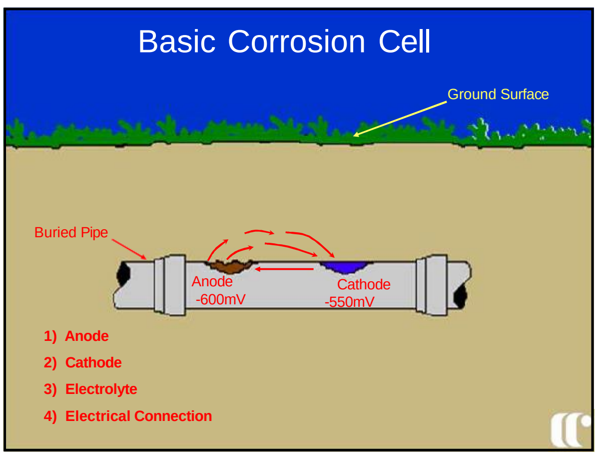
- Not practical to eliminate the electrolyte
  WATER
- Not practical to eliminate the conductor
  TANK OR EQUIPMENT

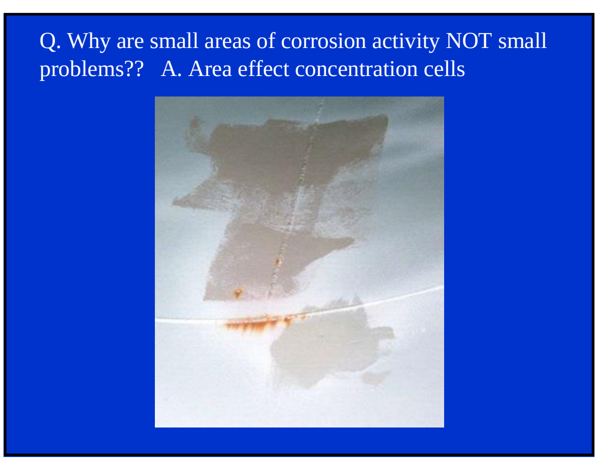
For Corrosion Control it is Practical to eliminate or minimize

- Exposed metals (anodes and cathodes) in contact with the electrolyte: **Protective Coating**
- Change all anodic metal areas (where corrosion occurs) to cathodic metal areas (where no corrosion occurs): **Cathodic Protection**

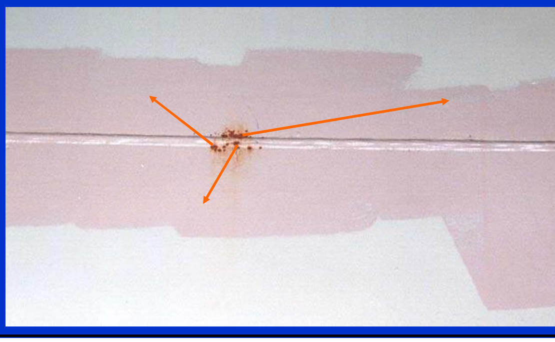



Cathode
(Protected)
Anode

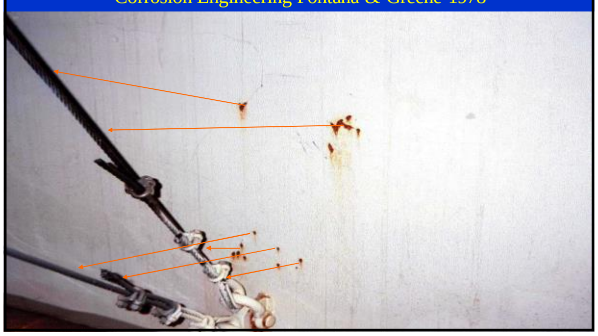

Basic Corrosion Cell
Ground Surface
Buried Pipe
Anode
-600mV
Cathode
-550mV
1) Anode
2) Cathode
3) Electrolyte
4) Electrical Connection


Q. Why are small areas of corrosion activity NOT small problems?? A. Area effect concentration cells

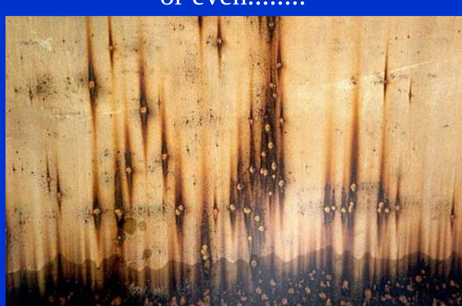
Continued active corrosion on a weld seam after two years in service and one attempted touch-up



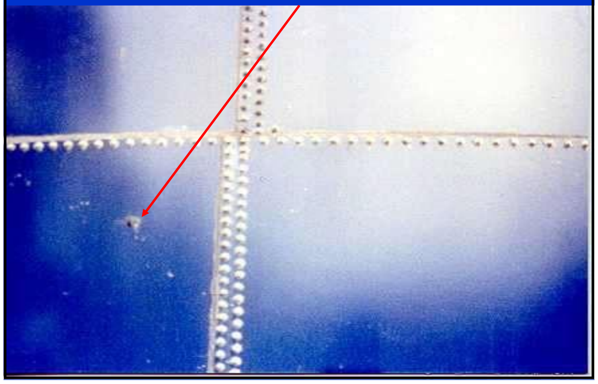
Area effect: "Corrosion of the anodic area may be 100 - 1000 times greater than if the anodic and cathodic areas were equal in size"
Corrosion Engineering Fontana & Greene 1978



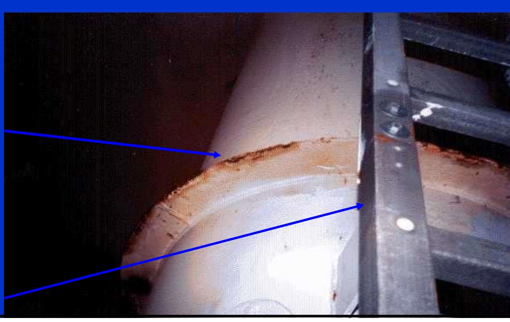
Pitting Corrosion can lead to costly welding repairs or the use of "pit fillers" or even........



A Corrosion Penetration Failure



A Cathodic Protection System will send a D.C. electrical "charge" through the water to both the metallic structures arresting galvanic corrosion



The same principal applies to Treatment Equipment

Impressed current cathodic protection
in a clarification basin

Calcareous deposits often form over “holidays”

Protection of holidays in coating along
the edges of the support column

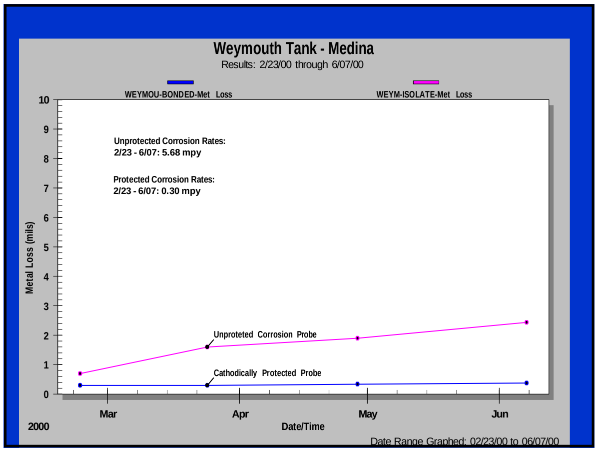
Exposed "holiday" with no active corrosion

AWWA Standard D104

- "Automatically controlled impressed current cathodic protection for the interior of steel water storage tanks"

Cathodic Protection is Effective When:

- Current distribution from anode to cathode meets "criteria for protection"
- "Criteria" is defined as a structure to water potential of -.850V to -1.050V relative to a copper-copper sulfate reference electrode
- Protective current is distributed over the entire submerged surface area
- Protective current is maintained continuously



In Reference to AWWA D104 the Major Components of a Cathodic Protection System Are:

- Automatically controlled rectifier
- Reference electrodes
- Anode
- Anode suspension system
- Hardware and wiring

Automatic Rectifiers

The purpose of an automatically controlled rectifier is to adjust the current output as conditions in the electrolyte change due to:

- Water Level
- Temperature
- Water Chemistry
- Water Turbulence
- Polarization

Properly Calibrated Automatic Potential Control Rectifier

This rectifier has achieved it’s protective potential level and has stopped applying current. The unit will *automatically* start up again when the potential drops below its “set point”

10 year old Automatic Rectifier with analog meters still in near perfect condition & operating properly to provide corrosion control within criteria for protection

Reference Electrodes

The purpose of long life reference electrodes is:

- To constantly monitor the protection levels in the system
- Transmits a signal to the automatic controller to adjust the current output as required

Copper-Copper Sulfate Reference Electrode

Waterworks Anodes

Long life anodes should have an average design life of ten to twenty (10 - 20) years.

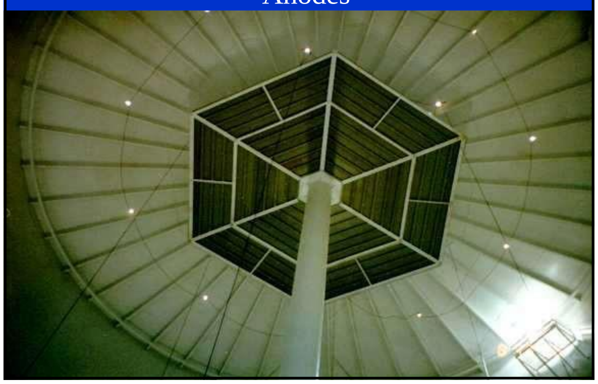
Anode Materials Typically Include:

- Titanium with precious metal oxide coating
- Platinized Niobium with a copper core

Anode Suspension Systems Vary Depending Upon Icing or Non-icing Conditions

- For icing conditions the standard design is a horizontally suspended anode system supported from the side wall or interior dry access column
- For non-icing conditions the standard design is a vertically suspended system from the roof of the tank

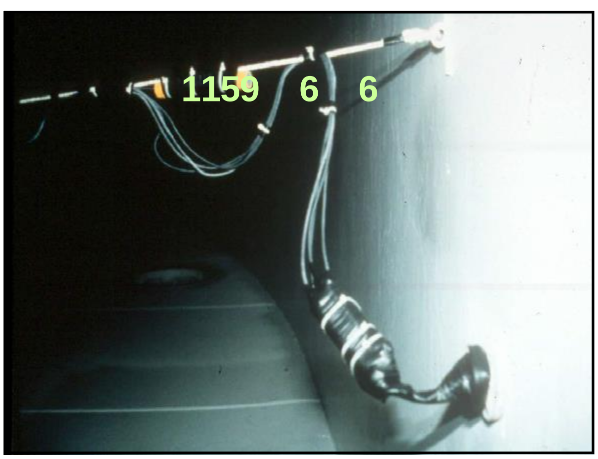
Vertically Suspended Mixed Metal Oxide Anodes

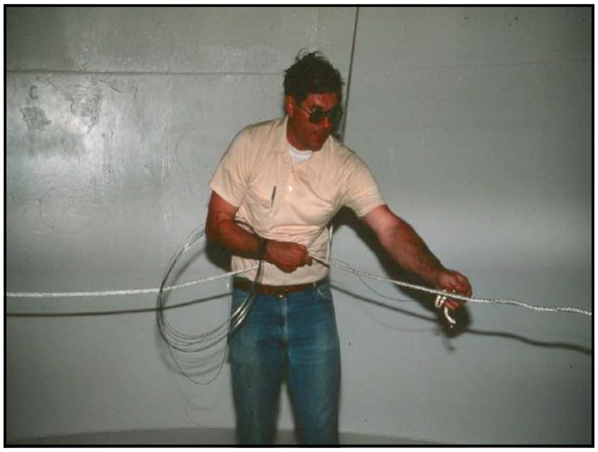


Advantages of the Vertical System

- Systems are easily installed without the need to drain the tank
- Systems can be completely serviced, upgraded, repaired and replaced without the need to drain the tank

Horizontally submerged anode system





Advantages of the Horizontal System

- Supported in the lower portion of the tank to avoid contact with ice
- Eliminates the need for seasonal anode replacement
- Eliminates build up of old anodes in the bottom of the tank

DESIGN
by a corrosion engineer

- Certified by NACE
  (National Association of Corrosion Engineers)
- Experienced in Cathodic Protection
- Experienced in Cathodic Protection of Waterworks Structures

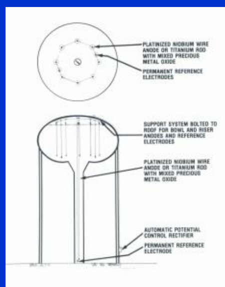
The Corrosion Engineer Determines

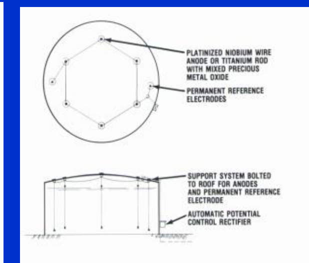
1. Total submerged surface area
2. Percentage bare
3. Current density
4. Resistivity of water
5. Consumption rate of anode material
6. Anode size, length and layout
7. Anode suspension system
8. Rectifier unit output
9. Number and location of reference cells
10. Number and type of electrical connections
11. Location of rectifier
12. A.C. requirements
13. National and local codes

Examples of System Designs

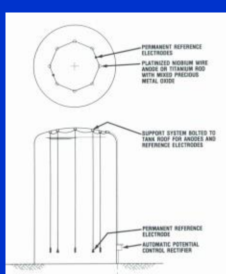
- System designs which are typically utilized for various styles of water storage tanks

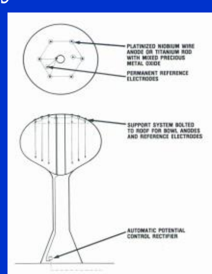
Typical Vertically Suspended Anode Systems



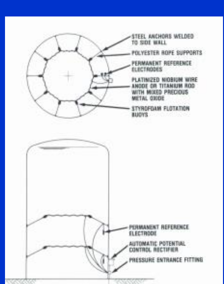


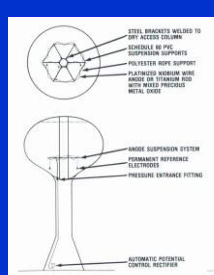
Typical Vertically Suspended Anode Systems



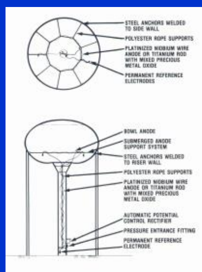


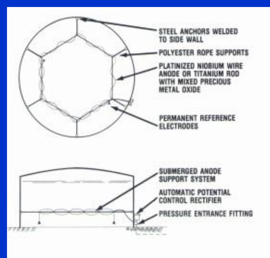
Typical Horizontally Suspended Anode Systems





Typical Horizontally Suspended Anode Systems





Start-up and Calibration

- Start-up service verifies the system is operating at optimum performance levels
- Calibration adjusts the system to perform within "Criteria for Protection"
- Independent tank-to-water potential profile verifies the systems output levels
- Complete written report with data and evaluation furnished to the owner

Annual Maintenance Services

- Complete system evaluation
- Potential testing to verify system performance
- Calibration to maintain corrosion control per AWWA & NACE criteria
- Written report with recommendations

Annual Service Inspection by a Qualified Technician is Recommended by AWWA-D104

The annual service visit includes:

- Complete electrical system check for continuity of anode and reference cell circuits
- Independent reference cell potential test to verify system performance
- Calibration and adjustment of the system to maintain corrosion control within “criteria”
- Written evaluation and recommendations

Service Visit

- Electrical measurements shall be conducted with a portable high impedance voltmeter and a calibrated copper-copper sulfate reference electrode
- Adjustments shall be made in accordance with “criteria for protection” for optimum corrosion control
- Data shall provide sufficient information to evaluate to evaluate the performance of he system relating to “Criteria for protection”
- If additional work is required a written report will be furnished with recommendations

Resistance readings verify electrical system continuity

Technician Recording the Readings During the Independent Cell Test

Technician Performing Visual Inspection of Vertical Anodes

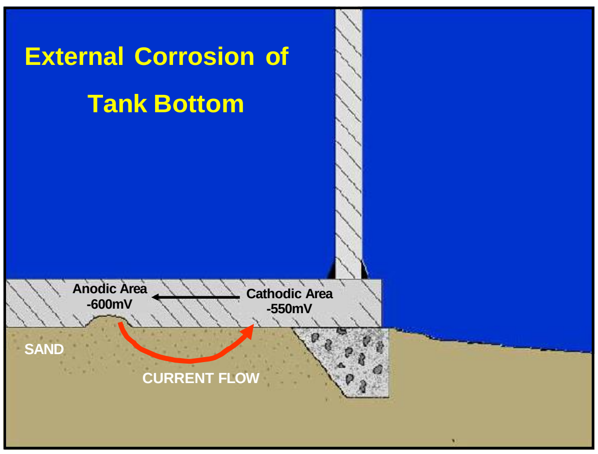
Independent cell tests verify the operating cells performance

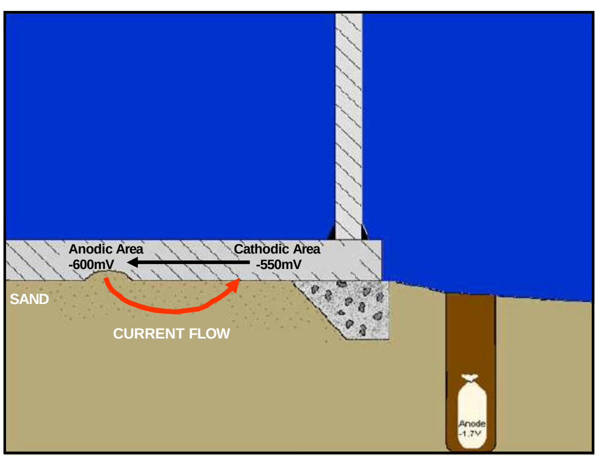
Continuing corrosion occurring at the initial "problem areas" at a 3 year inspection interval

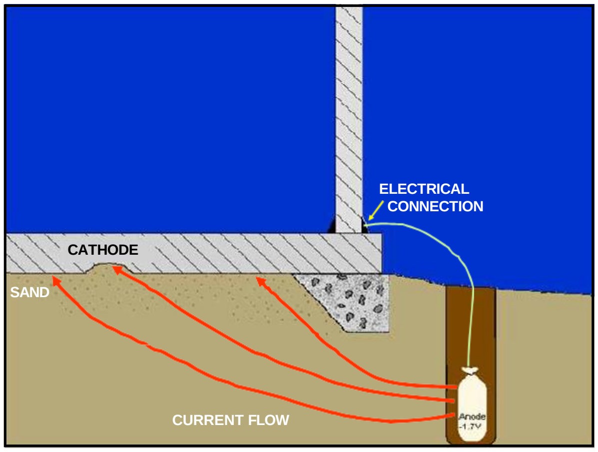
Impressed Current Cathodic Protection Installation

Continuing Maintenance

- Owner should check the meters on the rectifier at intervals not to exceed 60 days
- Compare the volts, amps and potential readings to set point and previous readings
- Remote Monitoring Technology is quickly evolving as an economical means of monitoring system performance

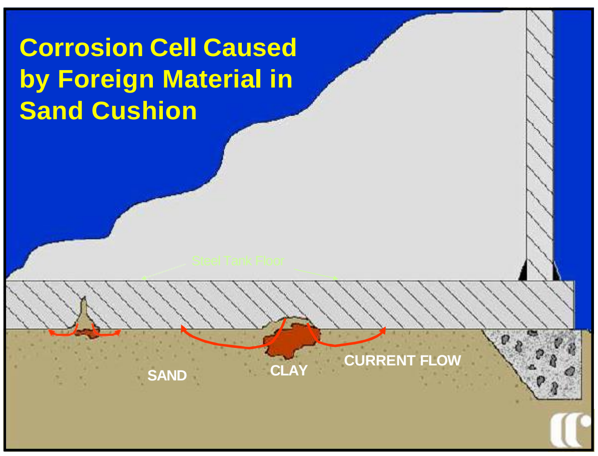

External Corrosion of
Tank Bottom
Anodic Area
-600mV
Cathodic Area
-550mV
SAND
CURRENT FLOW

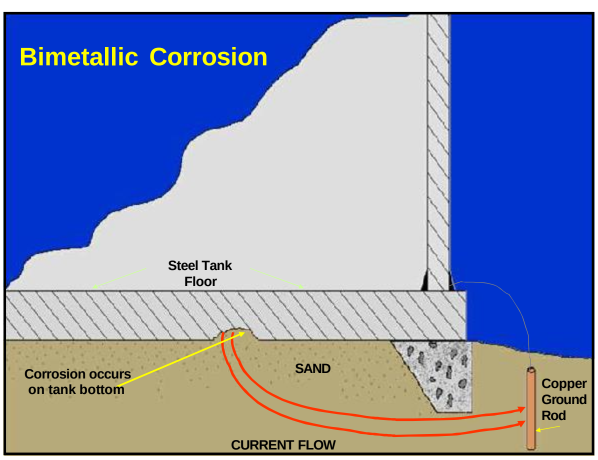

Anodic Area
-600mV
Cathodic Area
-550mV
SAND
CURRENT FLOW
Anode
-1.7V

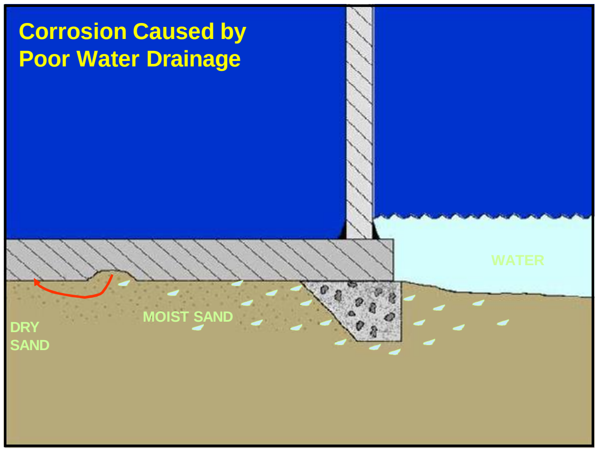


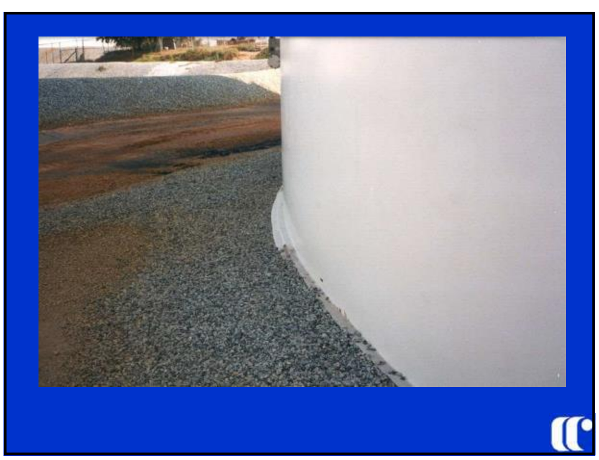
Remote Monitoring using low cost paging technology is now available in most areas of the US

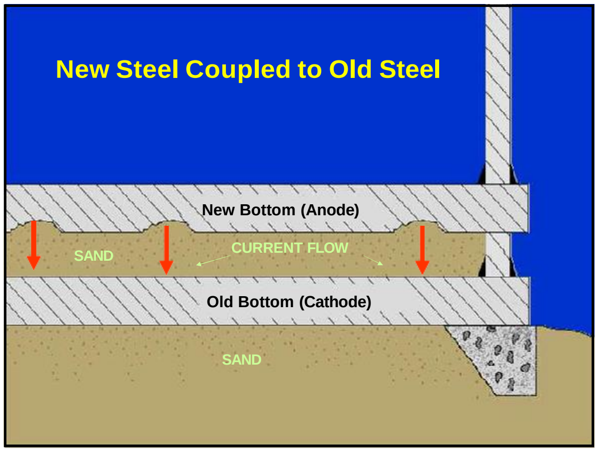

F.604
Tank to Soil Potential Measurements

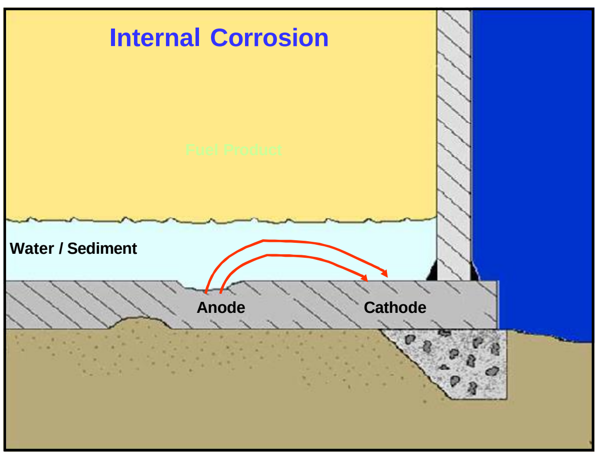

Corrosion Cell Caused by Foreign Material in Sand Cushion
SAND
CLAY
CURRENT FLOW

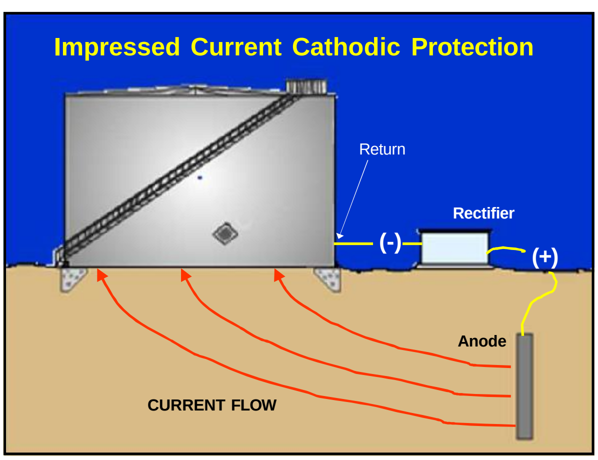

Bimetallic Corrosion
Steel Tank Floor
Corrosion occurs on tank bottom
SAND
Copper Ground Rod
CURRENT FLOW

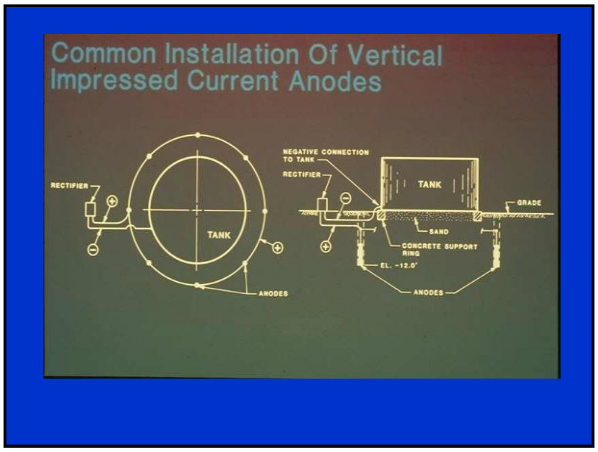

Corrosion Caused by
Poor Water Drainage
WATER
MOIST SAND
DRY
SAND



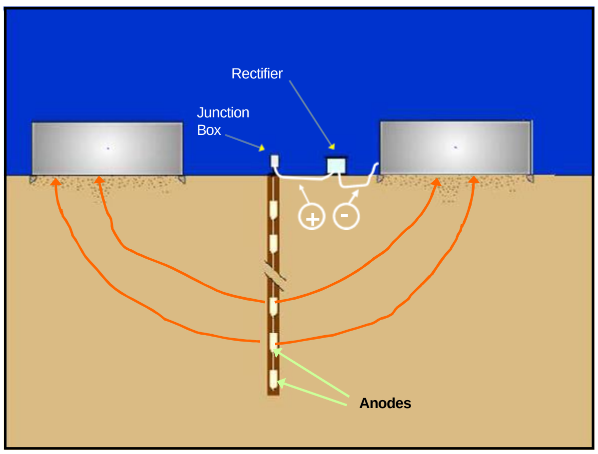

New Steel Coupled to Old Steel
New Bottom (Anode)
SAND
CURRENT FLOW
Old Bottom (Cathode)
SAND


Internal Corrosion
Water / Sediment
Anode
Cathode

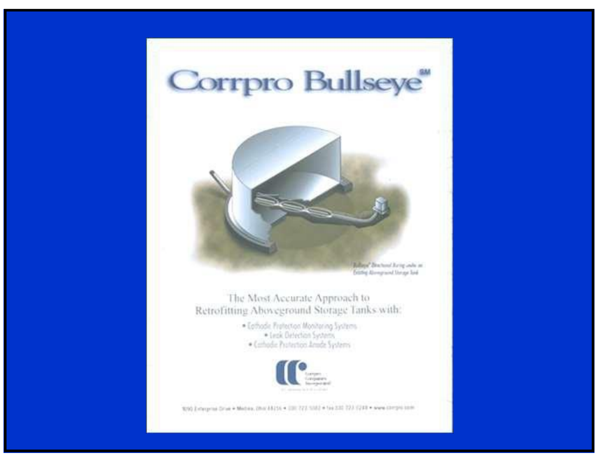

Impressed Current Cathodic Protection
Return
Rectifier
(-)
(+)
Anode
CURRENT FLOW



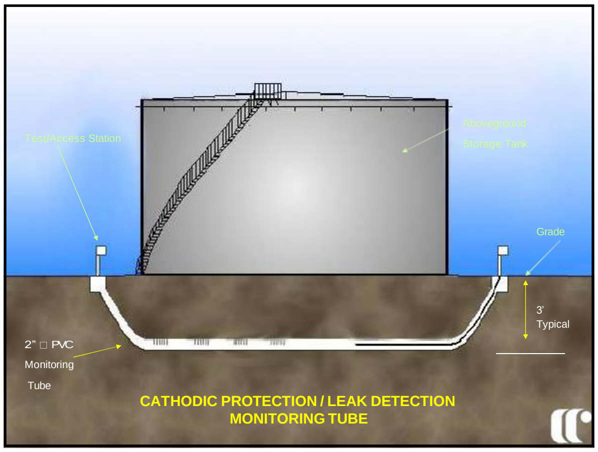
Common Installation Of Vertical Impressed Current Anodes
RECTIFIER
TANK
ANODES
NEGATIVE CONNECTION TO TANK
RECTIFIER
TANK
GRADE
SAND
CONCRETE SUPPORT RING
EL. -12.0'
ANODES

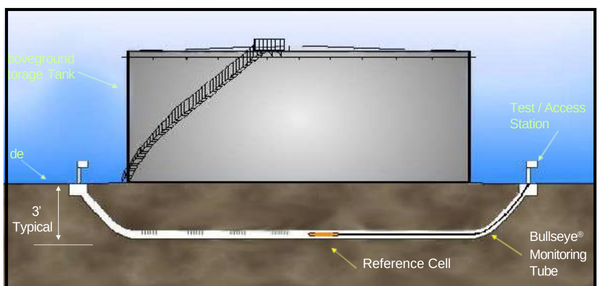


Rectifier
Junction Box
Anodes



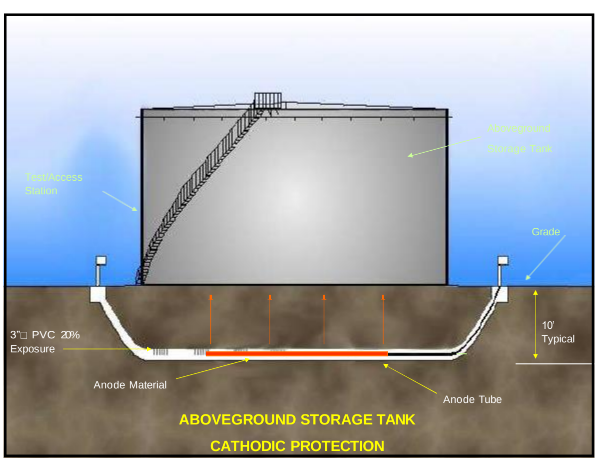
Corrpro Bullseye℠
The Most Accurate Approach to Retrofitting Aboveground Storage Tanks with:
• Cathodic Protection Monitoring Systems
• Leak Detection Systems
• Cathodic Protection Anode Systems

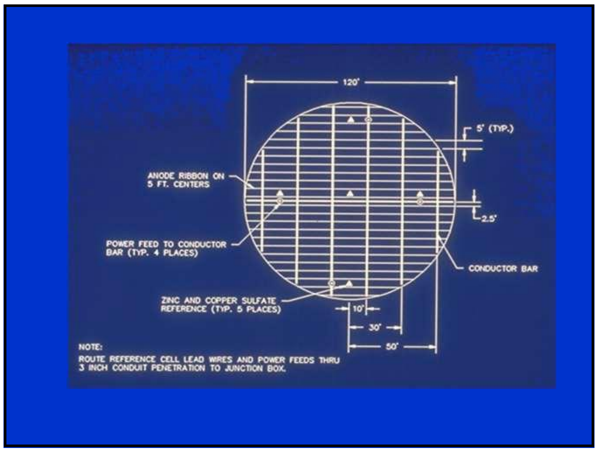




	Rim	25'	Center	55'	Rim
On	-1411	-698	-404	-601	-1455
Off	-902	-664	-402	-578	-911

Potentials (mV)




120'
5' (TYP.)
ANODE RIBBON ON
5 FT. CENTERS
2.5'
POWER FEED TO CONDUCTOR
BAR (TYP. 4 PLACES)
CONDUCTOR BAR
ZINC AND COPPER SULFATE
REFERENCE (TYP. 5 PLACES)
10'
30'
50'
NOTE:
ROUTE REFERENCE CELL LEAD WIRES AND POWER FEEDS THRU
3 INCH CONDUIT PENETRATION TO JUNCTION BOX.

Corrosion and Its Control, Polyethylene Encasement (V-Bio®), for Ductile Iron Pipe

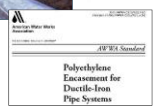
Allen Cox, Ductile Iron Pipe Research Association

acox@dipra.org

Corrosion and Its Control, Polyethylene Encasement (V-Bio®), for Ductile Iron Pipe

Appalachian Underground Corrosion Short Course

Morgantown, West Virginia
May 9-11, 2023


AWWA Standard

Polyethylene Encasement for Ductile-Iron Pipe Systems

AUCSC

(www.dipra.org)

dipra Ductile Iron Pipe Research Association

1

DIPRA Member Companies

- AMERICAN Ductile Iron Pipe
  Birmingham, AL
- Canada Pipe Company, LTD.
  Hamilton, Ontario
- McWane Ductile
  Coshocton, OH
- U. S. Pipe
  Birmingham, AL

AMERICAN DUCTILE IRON PIPE

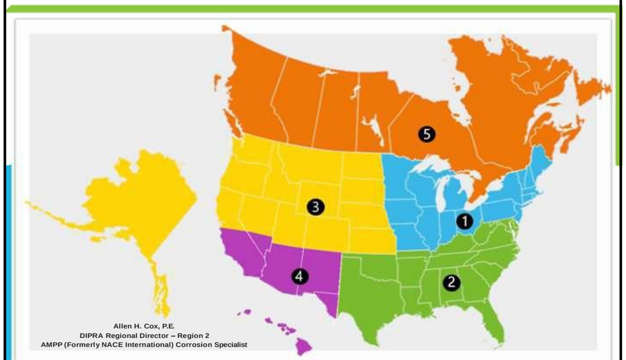
CANADA PIPE

US PIPE

McWANE DUCTILE

2

Regional Engineer Program



3

DIPRA Website
(www.dipra.org)

4

DIPRA Website
(www.dipra.org)

5

DIPRA Website
(www.dipra.org)

Corrosion Control

FILE TYPE	TITLE
	Cement Mortar Linings for Ductile Iron Pipe (English)
	Cement Mortar Linings for Ductile Iron Pipe (French)
	Charleston, SC Flow Test - First Cement-Mortar Lined Iron Pipe - 97 yrs
	Corrosion Control: Polyethylene Encasement (English)
	Corrosion Control: Polyethylene Encasement (French)
	Design Decision Model - Corrosion Control For Ductile Iron Pipe
	DIPRA Introduces: V-Bio
	Facts & Figures: Bonded Coatings vs. Polyethylene Encasement
	Facts & Figures: Polyethylene Encasement and Corrosion Control
	Facts & Figures: V-Bio® Enhanced Polyethylene Encasement and Corrosion Control
	Flow Test of 97-Year-Old Cement-Mortar Lined Pipe (English)
	Flow Test of 97-Year-Old Cement-Mortar Lined Pipe (French)
	Innovations Didn't Start Yesterday - Lafourche
	V-Bio® Enhanced Polyethylene Encasement
	V-Bio® Enhanced Polyethylene Encasement Chapter #1 Introduction
	V-Bio® Enhanced Polyethylene Encasement Chapter #2 Modified Method A
	V-Bio® Enhanced Polyethylene Encasement Chapter #3 Modified Method A Wet Conditions
	V-Bio® Enhanced Polyethylene Encasement Chapter #4 Method A
	V-Bio® Enhanced Polyethylene Encasement Chapter #6 Appurtenances
	V-Bio® Enhanced Polyethylene Encasement Chapter #7 Summary
	V-Bio® Enhanced Polyethylene Encasement for Ductile Iron Pipe Suggested Specifications
	V-Bio® Enhanced Polyethylene Encasement Installation

6

7

DIPRA Publications

8

Versailles, France

(Installed 1664)

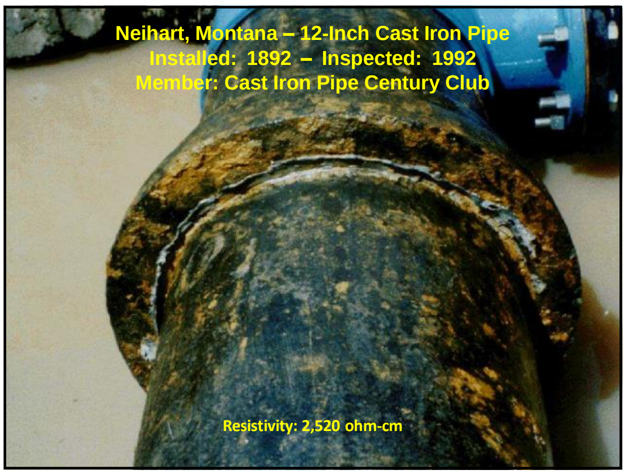
9

Century Club

- The Cast Iron Pipe Century Club recognizes water utilities with Cast Iron mains that have provided service for 100 years or more. 530 in US.

100 Years
CENTURY CLUB
dipra

10



11

Century Club
(West Virginia)

Location	Utility	Year Inducted	Oldest Pipe
Charleston	West Virginia-American Water Company	1994	1884
Clarksburg	Clarksburg Water Board	1989	1888
Huntington	West Virginia-American Water Company, Huntington Division	1987	1887
Wheeling	Water Department	1947	1839

100 Years
CENTURY CLUB
dipra

12

13

Sesquicentennial Club

- The Cast Iron Pipe Sesquicentennial Club recognizes water utilities with Cast Iron mains that have provided continuous service for 150 years or more. 21 In US.

150 Years
SESQUICENTENNIAL CLUB
dipra

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Sesquicentennial Club

Huntsville, AL	Troy, NY	York, PA
Mobile, AL	Utica, NY	Nashville, TN
Louisville, KY	Cincinnati, OH	Lynchburg, VA
Boston, MA	Allentown, PA	Richmond, VA
Detroit, MI	Columbia, PA	Winchester, VA
St. Louis, MO	Lancaster, PA	Halifax, NS
Albany, NY	Philadelphia, PA	Montreal, QC
Buffalo, NY	Pittsburgh, PA	Quebec City, QC

dc water is life BGMU SAVANNAH

15

Sesquicentennial Club

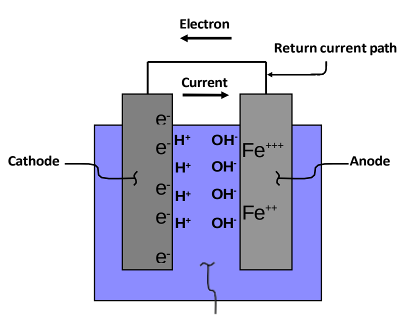
Louisville, KY - October 2010

16

External Soil Corrosion

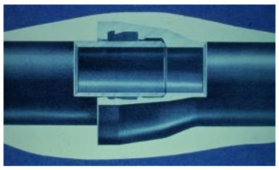
17

Galvanic Corrosion Cell

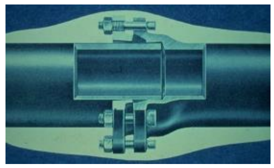


18

Ductile Iron Pipelines are Electrically Discontinuous



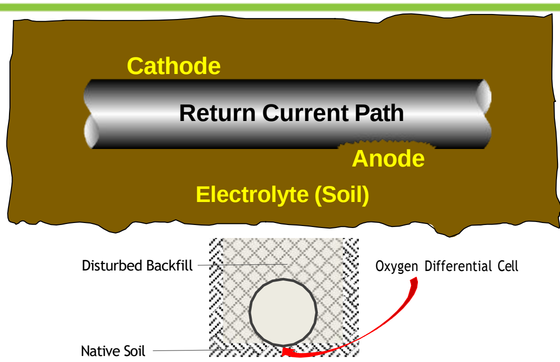
Push-on Joint



Mechanical Joint

19

The underground pipe corrosion cell . . .



20

ANSI/AWWA C105/A21.5

21

dipra
Ductile Iron Pipe Research Association

10-Point System

22

Soil Evaluation Parameters

- Resistivity
- Redox
- pH
- Sulfides
- Moisture

23

10-Point Soil Evaluation

Resistivity - ohm-cm (based on water-saturated soil box):		
< 1,500	10	
≥ 1,500 - 1,800	8	
> 1,800 - 2,100	5	
> 2,100 - 2,500	2	
> 2,500 - 3,000	1	
> 3,000	0	
pH:		
0 - 2	5	
2 - 4	3	
4 - 6.5	0	
6.5 - 7.5	0*	*3 points should be added if low or negative redox and sulfides are present
7.5 - 8.5	0	
> 8.5	3	
Redox potential:		
> +100 mV	0	
+50 to +100 mV	3.5	
0 to +50 mV	4	
Negative	5	
Sulfides:		
Positive	3.5	
Trace	2	
Negative	0	
Moisture:		
Poor drainage, continuously wet	2	
Fair drainage, generally moist	1	
Good drainage, generally dry	0	

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Corrosive Environments

- Coal
- Cinders
- Swamps
- Expansive Clays
- Peat Bogs
- Mine Wastes
- Landfill Areas
- Alkali Soils

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DIPRA Corrosion Research

- 1928 – Strength of Corrosion Products
- 1940 – Coatings
- 1949 – Bolt Corrosion
- 1952 – Coatings and Loose Polyethylene
- 1963 – Field Investigations (on-going)
- 1971 – Stray Current
- 1989 – Copper Service
- 1999 – Elevated Temperature
- 2000 – Effect of Chloramines on Gasket Materials
- 2002 – Rate of Corrosion

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DIPRA Test Sites

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DIPRA Test Sites

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DIPRA Test Site Data

LOCATION	RESISTIVITY	pH	SULFIDES	REDOX
Atlantic City, NJ	66	7.0	positive	-240
Birmingham, AL	400	7.0	------	------
Casper, WY	350	8.0	negative	+96
Everglades City, FL	150	7.2	positive	-150
Herrin, IL	4,440	4.7	negative	+205
Lombard, IL	2,500	7.3	trace	+90
Overton, NV	188	7.9	negative	+200
Raceland, LA	1,000	7.2	trace	+140
Spanish Fork, UT	720	7.5	negative	+140
Watsonville, CA	1,040	6.2	trace	+180
Wisconsin Rapids, WI	6,000	3.5	positive	+210

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DIPRA Research

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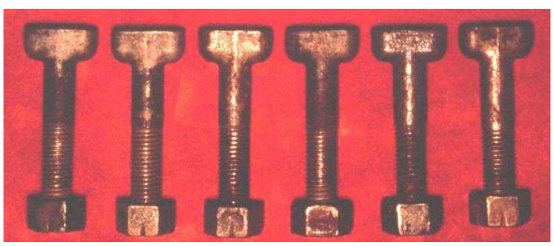
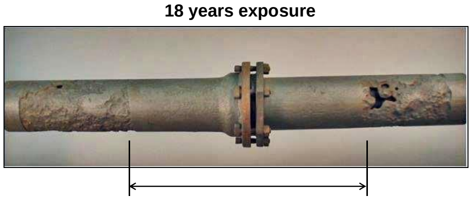
DIPRA – Bolt Study



32

CIPRA - 1952
Polyethylene Protection Study

Everglades City, FL - 6" Gray Cast iron
18 years exposure



4-mil polyethylene encased

Resistivity: 400 ohm-cm
Redox: - 35 mV
pH: 7.1
Sulfides: Positive
Soil Moisture: Saturated

33

A Solution – Both Economical and Effective

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Polyethylene Encasement

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Polyethylene Encasement

History of Development

1952 - Research initiated

1958 - First installation

1972 - First standard issued

20 years of research

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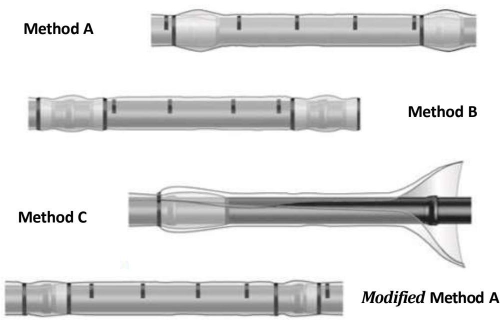
Polyethylene Encasement Installation



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Polyethylene Encasement Installation

Modified **Method A**

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Polyethylene Encasement (Wet Trench) Installation

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Installation Video

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Encasement of Appurtenances

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Casings

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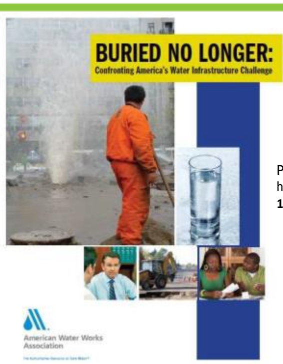
BURIED NO LONGER:

Confronting America's Water infrastructure Challenge



Properly designed and installed **Ductile Iron Pipelines** have an expected service life that ranges from **105** to **120** years - Average **110 years**

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Polyethylene Encasement

(V-Bio® Enhanced with Additional Colored Layer)

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Tapping

46

Tapping

47

Tapping

48

Tapping

49

Saddle Taps

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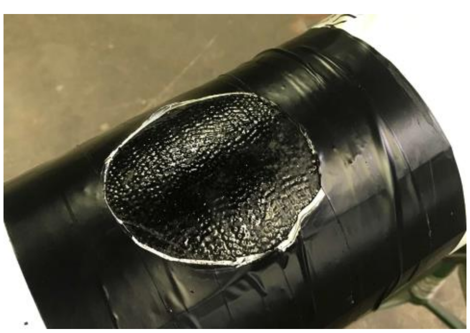
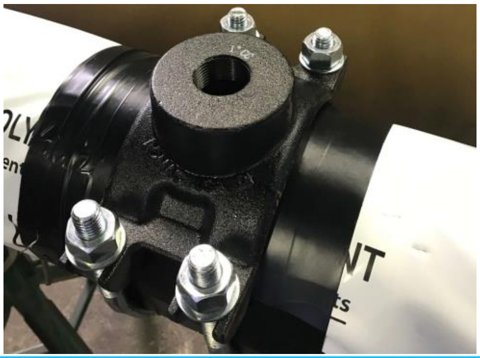
Saddle Taps



51

Saddle Taps



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Polyethylene Film Comparison

	Linear Low-Density	HDCL
Minimum Thickness (mil)	8	4
Dielectric Strength (V/mil)	800	800
Tensile Strength (psi)	3,600	6,300
Elongation (%)	800	100
Impact Resistance (g)	600	800
Tear Resistance (gf)	2,550	250

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Brochures & Guidelines

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Polyethylene Encasement Investigations

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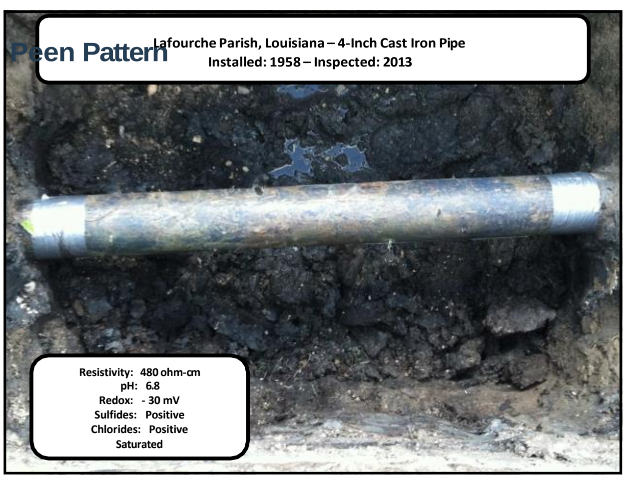

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Lafourche Parish, Louisiana
(Clear, Low Density (8-mil) Polyethylene)

Parameter	Tested	Min.*
Tensile Strength at Break (psi)	2,104	1,200
Elongation at Break (%)	518	300

* Minimum values as set forth in AWWA C105-72

Tested Values from 2013 Inspection

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Lafourche Parish, Louisiana
(Clear, Low Density (8-mil) Polyethylene)

61

Lafourche Parish, Louisiana
(Clear, Low Density (8-mil) Polyethylene)

62

Lafourche Parish, Louisiana
(Clear, Low Density (8-mil) Polyethylene)

63

Lafourche Parish, Louisiana
(Clear, Low Density (8-mil) Polyethylene)

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Polyethylene Encasement Investigations

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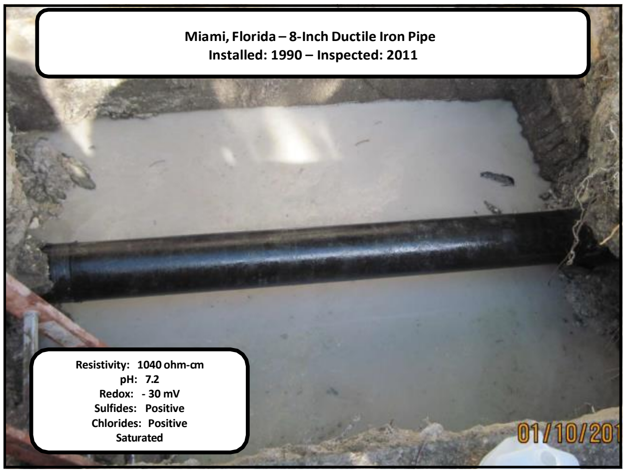
Miami, Florida – 8-Inch Ductile Iron Pipe
Installed: 1990 – Inspected: 2011
Resistivity: 1040 ohm-cm
pH: 7.2
Redox: - 30 mV
Sulfides: Positive
Chlorides: Positive
Saturated
01/10/201

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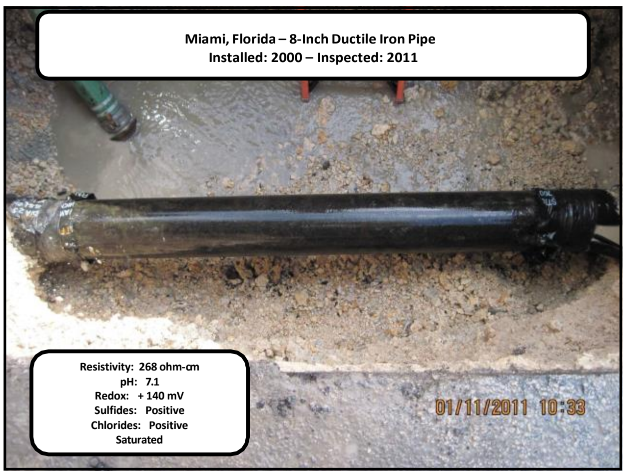
Miami, Florida – 8-Inch Ductile Iron Pipe
Installed: 2000 – Inspected: 2011
Resistivity: 268 ohm-cm
pH: 7.1
Redox: + 140 mV
Sulfides: Positive
Chlorides: Positive
Saturated
01/11/2011 10:33

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Indian Creek Village, Florida – 8-Inch Ductile Iron Pipe
Installed: 1985 – Inspected: 2014
Resistivity: 160
pH: 6.8
Redox: - 60 mV
Sulfides: Positive
Chlorides: Positive
Saturated

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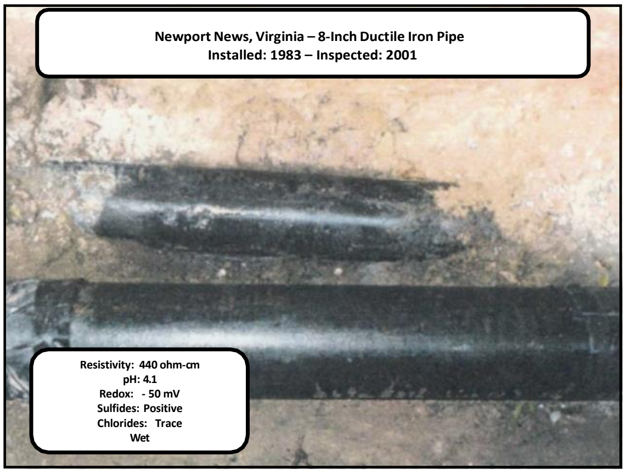

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Corrosion Probes

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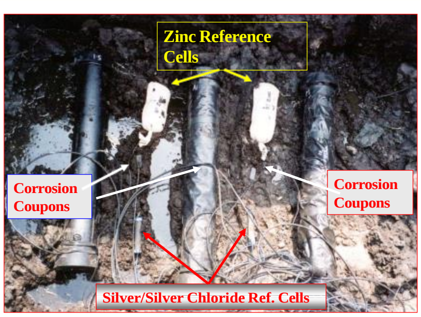
Florida Everglades Corrosion Testing
(above ground monitoring)



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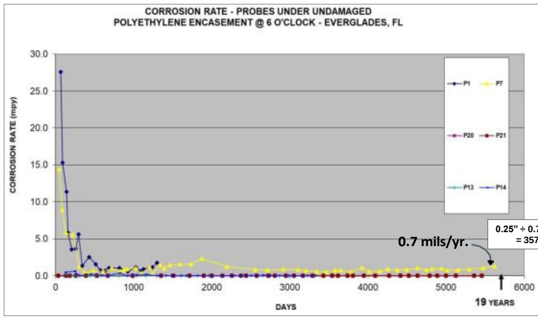
Corrosion Probes under Polyethylene Encasement



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RECOMMENDED ADDITIONAL RESEARCH

(Polyethylene Encasement with an Anti-microbial & Corrosion Inhibitor in film - V-BIO®)

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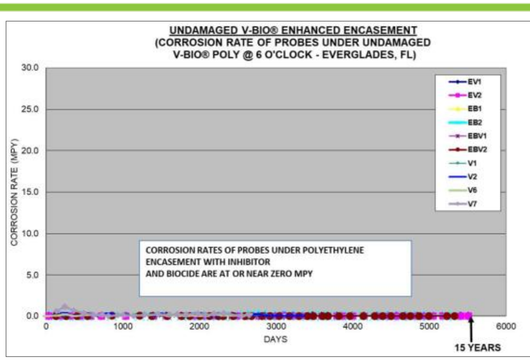
Corrosion Probes under *V-Bio*® Polyethylene Encasement



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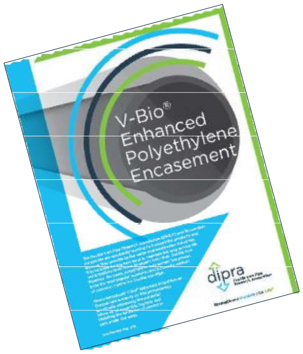
V-Bio® Polyethylene Encasement



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V-Bio® Polyethylene Encasement

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Design Decision Model (DDM®)

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The Design Decision Model (DDM®)

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Likelihood Factors

- Resistivity
- Redox
- pH
- Sulfides
- Moisture Content
- Known corrosive environs
- Chlorides
- Bi-metallic connections
- Ground water influence

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Consequence Factors

- Pipe Size
- Pipe Location
- Depth of Cover
- Alternative Water Supply?

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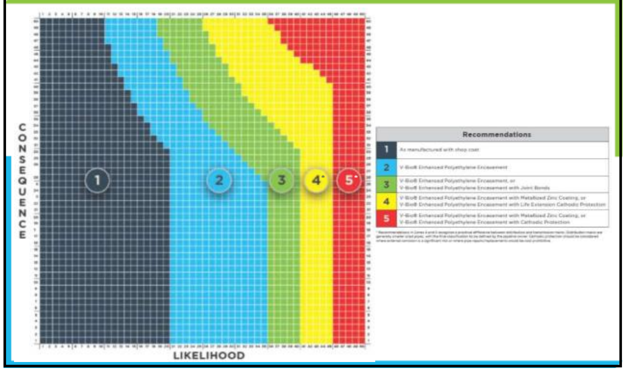
The Design Decision Model® (DDM®)



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Design Decision Model®

Recommendations	
1	As manufactured with shop coat
2	V-Bio® Enhanced Polyethylene Encasement
3	V-Bio® Enhanced Polyethylene Encasement, or V-Bio® Enhanced Polyethylene Encasement with Joint Bonds
4 *	V-Bio® Enhanced Polyethylene Encasement with Metallized Zinc Coating, or V-Bio® Enhanced Polyethylene Encasement with Life Extension Cathodic Protection
5 *	V-Bio® Enhanced Polyethylene Encasement with Metallized Zinc Coating, or V-Bio® Enhanced Polyethylene Encasement with Cathodic Protection

* Recommendations in Zones 4 and 5 recognize a practical difference between distribution and transmission mains. Distribution mains are generally smaller sized pipes, with the final classification to be defined by the pipeline owner. Cathodic protection should be considered where external corrosion is a significant risk or where pipe repairs/replacements would be cost prohibitive.

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Polywrapped DIP with CP

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75 Years of Research

Corrosion and corrosion control of iron pipe:

75 years of research

Iron was known to humans in prehistoric ages, and there is ample evidence of its use in early history. Human ability to cast pipe probably developed from or coincided with the manufacture of cannons, which occurred as early as 1313. There is an official record of cast-iron pipe manufactured at Siegerland, Germany, in 1455 for installation at the Dillenburg Castle.

In 1664, Louis XIV of France ordered the construction of a cast-iron main extending 15 mi (24 km) from a pumping station at Marly-on-Seine to Versailles to supply water for the town and its fountains. This cast-iron pipe provided continuous service for more than 330 years. Cast-iron pipe was first used in the United States around 1816 (AWWA, 2003).

Ductile-iron pipe was cast experimentally for the first time in 1948 and was introduced to the marketplace in 1955. Since 1965 ductile-iron pipe has been manufactured in accordance with the Standard for Ductile-Iron Pipe, Centrifugally Cast, for Water and Other Liquids (AWWA/ANSI, 2002), using centrifugal casting methods that have been commercially developed and refined since 1925.

POLYETHYLENE ENCASEMENT FOR CORROSION CONTROL

Corrosion protection of these early installations was virtually nonexistent until the mid-1990s. Still, this early pipe fared well in most soil environments, and its longevity is well demonstrated. More than 600 utilities in the United States and Canada have had cast-iron pipe that provided more than 100 years of continuous

85

75 Years of Research

TABLE 6 Mean deepest pitting rate of intentionally damaged polyethylene encasement and asphaltic shop-coated specimens

Everglades, Fla.		Overton, Nev.		Logandale, Nev.		Hughes, Ark.		Aurora, Colo.		Five Test Sites Combined	
Pipe Type* and Number of Specimens	Mean Pitting Rate *in. (mm) per year*	Pipe Type and Number of Specimens	Mean Pitting Rate *in. (mm) per year*	Pipe Type and Number of Specimens	Mean Pitting Rate *in. (mm) per year*	Pipe Type and Number of Specimens	Mean Pitting Rate *in. (mm) per year*	Pipe Type and Number of Specimens	Mean Pitting Rate *in. (mm) per year*	Pipe Type	Combined Mean Deepest Pitting Rate *in. (mm) per year*
DPE, 38	0.0121 (0.3025)	DPE, 3	0.0045 (0.1125)	DPE, 10	0.0206 (0.515)	DPE, 3	0.0058 (0.145)	DPE, 8	0.0000 (0.0000)	DPE	0.0112 (0.28)
ASC, 54	0.0320 (0.8)	ASC, 5	0.0205 (0.5125)	ASC, 12	0.0268 (0.67)	ASC, 12	0.0041 (0.1025)	ASC, 6	0.0000 (0.0000)	ASC	0.0247 (0.6175)

*DPE—damaged polyethylene encasement, ASC—asphaltic shop-coated

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Damaged Polyethylene
vs.
Damaged Bonded Coatings
(Conventional DIP)

– **3 test sites (Everglades, Nevada & Hughes)**
  - **Accelerated pitting on bonded coatings**
  - **Not accelerated for polyethylene encasement**

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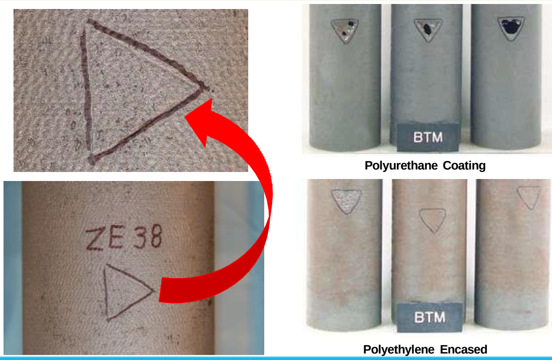
Everglades Test Site

(Zinc-coated Pipe & Damaged V-Bio®)



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V-Bio® Polyethylene Encasement

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Strength and Durability for LiFe®

Questions ?

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Thank you!

Allen H. Cox, PE
Regional Director

Ductile Iron Pipe Research Association
4405 Birdseye Court
Hermitage, TN 37076
205.790.6705
acox@dipra.org
www.dipra.org

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Linings and Coatings for Ductile Iron Pipe

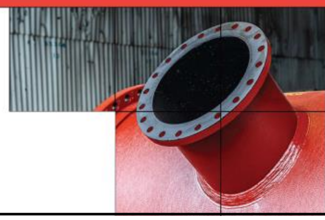
Conor Madden, U.S. Pipe

cmadden@uspipe.com

Linings and Coatings for Ductile Iron Pipe

Conor Madden
AUCSCO

Appalachian Underground Corrosion Short Course



US PIPE
A QUIKRETE® COMPANY

1

Summary

- Intro to Ductile Iron Pipe
- Internal Linings
  - Cement Mortar
  - Ceramic Epoxy
  - Glass (Porcelain Enamel)
- External Coatings
  - Thin Film Primers
  - Thick Film Coatings
  - Zinc and VBio® Enhanced Polyethylene Encasement

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2

Raw Material – Ferrous Scrap Metal

- Majority ferrous scrap metal
- Also added to ferrous scrap: limestone, silica, coke
- "The raw material for ductile iron shall have an average minimum content consisting of 90% recycled iron and steel. Ductile iron pipe shall be manufactured in the USA in accordance with ANSI/AWWA C151/A21.51."

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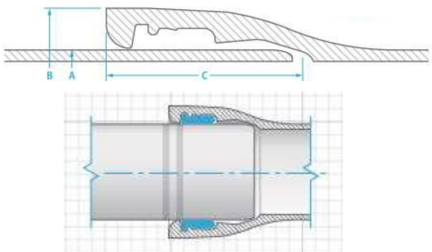
Standard Product - 3″ to 64″ Diameter

- Bell and Spigot Push-On Joint



4

Casting Machine Spigot End

5

Casting Machine Bell End

6

Sand Bell Cores

- Pipe is cast in one step
- Each pipe requires a sand core to form the bell joint type
- Manufacture and cast date are required in the casting per: ANSI/AWWA C151/A21.5, Ductile Iron Pipe, Centrifugally Cast for Water

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Centrifugally Cast Pipe Extraction

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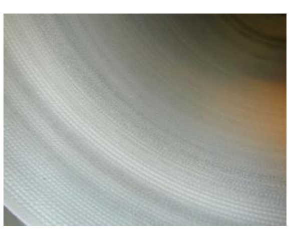
Peened Mold and Resulting Surface



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Annealing Oven

- Improves mechanical properties of ductile iron by relieving residual stresses – maximizes ductility and toughness

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Cement Lining Process

- Both the centrifugal process (top photo) and the projection method (bottom photo) of applying cement-mortar linings are used in modern practice

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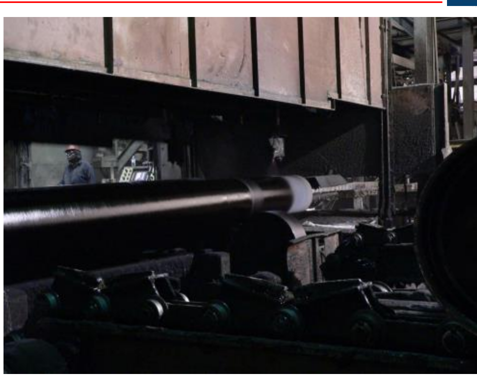
Asphaltic Paint



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Finished Product

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Interior Linings

- Overview
  - Cement Mortar
  - Ceramic Epoxy
  - Glass (Porcelain Enamel)

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Cement Mortar

- Covered by ANSI/AWWA C104/ A21.4 that was introduced in 1939
- First utilized in 1922 in Charleston S.C.
- Provided and maintained "C factor" for improved flow characteristics after 97+ years

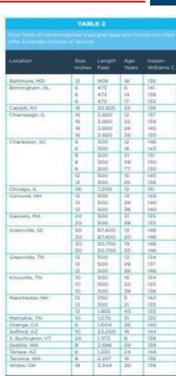

TABLE 2

[illegible]

Location	Size Inches	Length Feet	Age Years	Hazen-Williams C
Baltimore, MD	12	909	18	136
Birmingham, AL	6	475	6	141
	6	473	14	138
	6	475	17	133
Catskill, NY	16	30,825	25	136
Champaign, IL	16	3,920	12	137
	16	3,920	22	139
	16	3,920	29	145
	16	3,920	36	130
Charleston, SC	6	300	12	146
	6	300	16	143
	8	300	51	131
	8	300	59	130
	8	300	77	130
	12	500	15	145
	12	500	25	136
Chicago, IL	36	7,200	12	151
Concord, NH	12	500	13	143
	12	500	29	140
	12	500	36	140
Danvers, MA	20	500	31	135
	20	500	38	133
Greenville, SC	30	87,400	13	148
	30	87,400	20	146
	30	50,700	19	148
	30	50,700	25	146
Greenville, TN	12	500	13	134
	12	500	29	137
	12	500	36	146
Knoxville, TN	10	500	16	134
	10	500	32	135
	10	500	39	136
Manchester, NH	12	550	5	142
	12	550	21	135
	12	1,955	45	133
Memphis, TN	10	1,070	31	135
Orange, CA	6	1,004	26	140
Safford, AZ	10	23,200	16	144
S. Burlington, VT	24	1,373	8	138
Seattle, WA	8	2,686	29	139
Tempe, AZ	6	1,233	24	144
Tacoma, WA	8	2,257	16	136
Wister, OK	18	3,544	30	139

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Cement Mortar

- Eliminate tuberculation
- Improve disinfection problems
- Reduce color, odor, and taste complaints
- Improve flow characteristics of the pipeline (i.e., reduce pumping costs)
- Maintain flow characteristics with time

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Cement Mortar

- Tuberculation is an accumulation of corrosion products resulting from a combination of corrosion and bacterial activity
- Cement mortar lining prevents this from occurring

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Cement Mortar

In November 2019, with the cooperation of Charleston Water System in Charleston, SC, DIPRA conducted the fourth hydraulic flow test on the first cement-mortar lined iron pipe in the U.S., installed in 1922. The average result of five flow tests resulted in a C-factor of 140.1 for this iconic pipeline.

Test Results

Test Number	Time of Day	Flow Rate (gpm)	Velocity (fps)	Head Loss (in. of water)	Head Loss per Foot	C
Test 1	1:15 PM	330.4	2.3216	9.1444	0.0025	141.6
Test 2	1:30 PM	331.9	2.3321	9.8240	0.0027	136.8
Test 3	1:50 PM	329.8	2.3173	9.2161	0.0026	140.7
Test 4	2:05 PM	329.6	2.3159	9.1841	0.0025	140.9
Test 5	2:15 PM	329.7	2.3166	9.2395	0.0026	140.5
Average Results		330.3	2.3207	9.3216	0.00258	**140.1**

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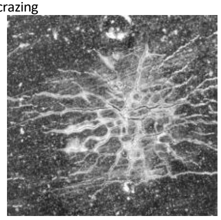
Autogenous Healing

Small surface cracks (left image) will be sealed (right image) when the pipe is filled with water. Note ANSI/AWWA C104/ A21.4 allows these surface crazing



Reference: Wagner, E.F., "Autogenous Healing of Cracks in Cement-Mortar Linings for Gray-Iron and Ductile Iron Water Pipe," Journal AWWA, June 1974

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NSF 61

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Cement Mortar Limitations

- With Sealcoat: ~150F
- Without Sealcoat: <212F
- Septic Sewage – Sewage with chemical and bacterial characteristics which will convert hydrogen sulfide gas to H2SO4 (sulfuric acid). Acidic pH values approaching zero have been documented on the crown of pipe in lines conveying septic sewage that only occurs in conditions where lines flowing partially full (i.e., gravity lines and non-full areas of force mains)
- Certain Industrial and Chemical waste , Glycol from hot/chilled water, aggressive water (pure distilled, boiler condensate, high sulfate waters, etc.)

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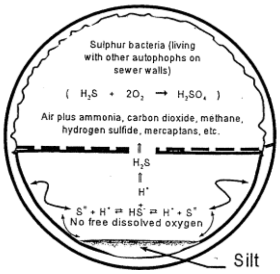
Septic Sewage Example



If improper lining is used, the above can result. Note proper lining depends on the application

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Ceramic Epoxy Lining

- Ceramic Novolac Epoxy
- Developed specifically as a deterrent to corrosion from sulfuric acid in sewer systems
- More than 40 years of successful service
- Used in over 50 million linear feet of pipe and related fittings

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Ceramic Epoxy – Sewer Only

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Ceramic Epoxy – Drinking Water

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Considerations for Epoxy Lining

- Chemical and abrasion resistance
- Lining must withstand septic sewer
- Resistance to undercutting and pressure washing
- Surface preparation
- Holiday testing
- Nominal thickness: 40 mils DFT

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Glass (Porcelain Enamel) Lining

- This glass lined piece (bottom photo) was installed in the same sludge system as the non-glass lined (top photo)
- There was no build-up on this glass lined piece after more than 6 months
- These pieces were installed at the same time as the piece

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Glass (Porcelain Enamel) Lining

- Typically used for in-plant process piping in wastewater and sewage treatment plants
- Used in high solids sludge, scum and grit applications where solids content exceeds 3 ½%
- Over 60 years of unsurpassed, continuous service in these otherwise problematic, very high maintenance piping areas
- U.S. Pipe Fab SG-14 has set the industry standard for glass lining
- ASTM B 1000-21 was established based on our standard specification and QC guidelines

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Exterior Coatings

- Overview
  - Thin film primer
  - Thick film “bonded coatings”
  - Metalized Zinc and VBio® Enhanced Polyethylene Encasement

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Exterior Coatings

PRIMERS

- Thin (< 20 mils)
- Minimal surface prep
- Used above ground (usually in treatment plants)
- Typically top coated after installation
- No holiday test required
- Examples
  - epoxy primer
  - alkyd primer
  - various zinc primers

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Asphalt Coating

<u>QUESTION:</u> CAN ASPHALT BE TOPCOATED OVER WITH ANY PRIMER OR OTHER COATING?

<u>ANSWER:</u> NO

ASPHALT CAN ONLY BE TOPCOATED WITH MORE ASPHALT

31

Thick Film Bonded Coatings for Buried Service

- Considerations
  - Surface Preparation
  - Holiday Testing
  - Joints/Dimensions
  - NSF-61 approval consideration
  - Fittings & Valves
  - Damage & Repair
  - Cathodic Protection

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Surface Preparation

- Most exterior bonded coatings like polyurethane, tapewrap, liquid epoxies, fusion bonded epoxies, etc. require a SSPC/NACE type near-white or white metal blast for immersion or buried service
- These surface prep standards were developed for steel surfaces
  - SSPC-SP5/NACE No. 1 ("White Metal")
  - SSPC-SP10/NACE No. 2 ("Near White")

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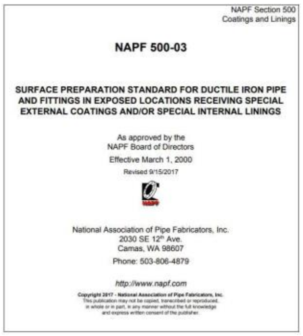
Ductile Iron Surface Prep


NAPF Section 500
Coatings and Linings

NAPF 500-03

SURFACE PREPARATION STANDARD FOR DUCTILE IRON PIPE AND FITTINGS IN EXPOSED LOCATIONS RECEIVING SPECIAL EXTERNAL COATINGS AND/OR SPECIAL INTERNAL LININGS

As approved by the
NAPF Board of Directors
Effective March 1, 2000
Revised 9/15/2017

National Association of Pipe Fabricators, Inc.
2030 SE 12th Ave.
Camas, WA 98607
Phone: 503-806-4879

http://www.napf.com

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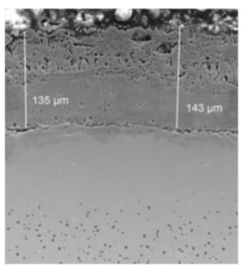
Annealing Oxide



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Damage to DIP from Over Blasting

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Holiday Testing

- Low Voltage Testing
  - Also called “wet sponge” testing used for coatings less than 20 mils DFT
- Hight Voltage Testing
  - Also called “spark” testing and typically used for coatings 20 mils or greater DFT
  - Can damage coating if excess voltage, follow recommendation from coating manufacture for proper testing voltage

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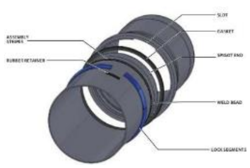
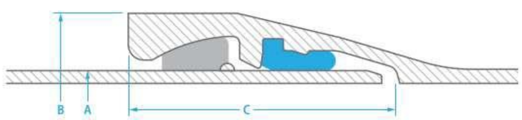
Ductile Iron Pipe Specific

- Joint tolerances for gasket sealing
  - Coating on spigot end cannot be ~ >10mils DFT





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Ductile Iron Fittings

- Fitting require special attention due to edges, bolts & nuts, corners, welds, and tight curvature
- Note annealing oxide is absent and can be blasted more aggressively

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Damage and Repair

- Damage to coatings is possible at some point prior to service so field repair is necessary according to manufacturers recommendations
- DIP is often cut in the field, so repair at cut ends it necessary prior to service
- Environmental considerations during repair process

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Cathodic Protection

- Cathodic protection is typically required if a thick film bonded coating is used in buried service
- Without CP, accelerated pitting corrosion at damage or holidays can occur
- Coatings need to be compatible with CP, therefor, cathodic disbondment testing is needed
- Joint bonding is needed when CP is used with DIP

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Bonded Coatings – Liquid Epoxy

- Normally applied by outside applicator at 25 mils
- ~100% solids liquid epoxy
- Requires special plural component spray equipment
- Available in all pipe diameters & for fittings

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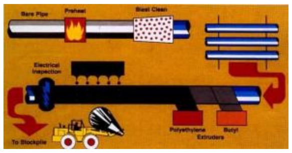
Bonded Coatings – Extruded Polyethylene

- Extruded polyethylene 50-70 mils thick
- Not available for diameters > 48”
- Not available for fittings



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Fusion Bonded Epoxy (FBE)

- **FBE – not recommended for septic sewer linings**
  - **Part is heated to 400 to 450 deg F and then dipped in an epoxy powder in a fluidized bed or applied with electrostatic spray**
  - **If dipped, then both ID and OD will be coated**
  - **Not recommended for full length DIP due to surface texture and holidays**
  - **Used for**
    - **Ductile iron fittings, short flange pipe (AWWA C116)**
    - **Steel pipe and fittings (AWWA C213)**
  - **NSF61 approved ≥4” pipe & ftg.**

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Summary

- Thick film bonded coatings for buried service are not typically used for ductile iron pipe due to reasons previously discussed
- <1% of DIP is supplied with thick film bonded coatings in buried service
- Corrosion protection method normally specified is polyethylene encasement per ANSI/AWWA C105/A21.5-10 and utilizing the Design Decision Model® (DDM®)

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US Pipe Corrosion Studies – Everglades, FL

- **1957** – US Pipe established New Jersey test site
- **2001** – US Pipe established Florida Everglades test site





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Everglades, FL - Bare pipe 60+ mpy corrosion rate

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Field Testing - Zinc

- **Intentional damage on zinc-coated DIP after ~5.5 years**

SOIL (control)	~ 10 mpy
AWWA C105 Polyethylene Encasement	~ 1 mpy
Enhanced Polyethylene Encasement	~ 0. 1 mpy
Enhanced Polyethylene Encasement + Zinc coating	~ 0 mpy
Poly Encasement with 15% damage + Zinc coating	~ 0 mpy

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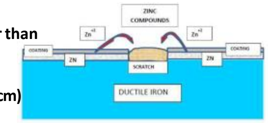
Metalized Zinc

Not recommended <u>alone</u> for:
- **soils with pH below 4.5 or greater than 9, peat soil, contaminated soil**
- **areas of stray DC currents**
- **corrosive soils (i.e., < 1,500 ohm-cm)**
- **for areas of flowing water**



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Field Testing

- Result demonstrates that concentrated pitting corrosion at damaged bonded coating is greater than damaged at polyethylene encasement

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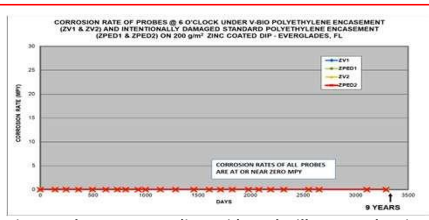
Zinc and VBio® Summary



- **Zinc supplements annealing oxide and will protect the pipe at areas of damage to the encasement**
- **VBio® Enhanced Polyethylene Encasement will extend the life of the zinc and enhance the development of zinc corrosion products as the zinc sacrifices itself**
- **Combination creates a homogeneous environment around pipe with antimicrobial characteristics**

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Questions?

Conor Madden
cmadden@uspipe.com
U.S. Pipe & Foundry Co.

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DIPRA Cement-Mortar Flow Test

- Cement Mortar Flow Test Video:
- https://youtu.be/hVFIzzt4dSE
- 2020 Water Finance & Management "Research Tests Show Consistently Strong Energy Efficiency Flows in First U.S. Cement-Mortar Lined Iron Pipe – At 97-Years-Old" By L. Gregg Horn

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Design Decision Model (DDM®)

The DDM® provided the first two-dimensional risk-based model for corrosion control of Ductile iron pipe – one that balances the likelihood of a corrosion-related concern against the consequences of such an occurrence.

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DDM Parameters

TABLE 3

Consequence Score Sheet

CONSEQUENCE FACTOR		POINTS	MAXIMUM POSSIBLE POINTS
PIPE SERVICE	3" to 24" 30" to 36" 42" to 48" 54" to 64"	0 8 12 22	22
LOCATION: Construction-Repair Considerations	Routine (Fair to good access, minimal traffic/other utility consideration, etc.)	0	20
	Moderate (Typical business/residential areas, some right of way limitations, etc.)	8	
	Difficult (Subaqueous crossings, downtown metropolitan business areas, multiple utilities congestion, swamps, etc.)	20	
DEPTH OF COVER CONSIDERATIONS	0 to 10 feet depth > 10 to 20 feet depth > 20 feet depth	0 3 5	5
ALTERNATE WATER SUPPLY	Alternate supply available - no Alternate supply available - yes	3 0	3
	TOTAL POSSIBLE POINTS		50

TABLE 2

Likelihood Score Sheet

LIKELIHOOD FACTOR		POINTS	MAXIMUM POSSIBLE POINTS
RESISTIVITY	< 500 ohm-cm ≥ 500 - 1000 ohm-cm > 1000 - 1500 ohm-cm > 1500 - 2000 ohm-cm > 2000 - 3000 ohm-cm > 3000 - 5000 ohm-cm > 5000 ohm-cm	30 25 22 19 10 5 0	30
CHLORIDES	> 100 ppm = positive 50 - 100 ppm = trace < 50 ppm = negative	8 3 0	8
MOISTURE CONTENT	> 15% = Wet 5 - 15% = Moist < 5% = Dry	5 2.5 0	5
GROUND WATER INFLUENCE	Pipe below the water table at any time	5	5
pH	pH 0 - 4 pH > 4 - 6 pH 6 - 8, with sulfides and low or negative redox pH > 8	4 1 4 0	4
SULFIDE IONS	positive (≥1 ppm) trace (> 0 and < 1 ppm) negative (0 ppm)	4 1.5 0	4
REDOX POTENTIAL	= negative = positive 0 - 100 mv = positive > 100 mv	2 1 0	2
BI-METALLIC CONSIDERATIONS	Connected to noble metals (e.g. copper) - yes Connected to noble metals (e.g. copper) - no	2 0	2
	TOTAL POSSIBLE POINTS		60
Known Corrosive Environments	Cinders, Mine Waste, Peat Bog, Landfill, Fly Ash, Coal		21

* Soils with Known Corrosive Environments shall be assigned 21 points or the total of points for Likelihood Factors, whichever is greater.

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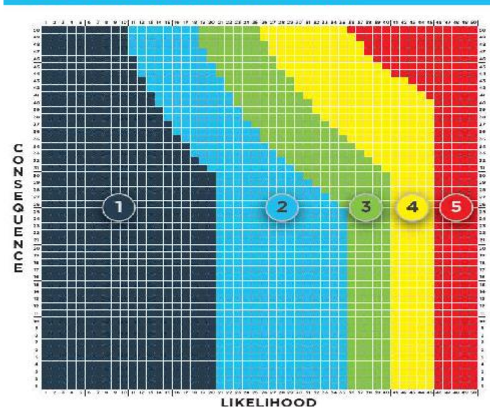
DDM® Two-Dimensional Matrix



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DDM Recommendations

Design Decision Model® (DDM®)

	Recommendations
1	As manufactured with shop coat
2	V-Bio® Enhanced Polyethylene Encasement
3	V-Bio® Enhanced Polyethylene Encasement, or V-Bio® Enhanced Polyethylene Encasement with Joint Bonds
4	V-Bio® Enhanced Polyethylene Encasement with Metallized Zinc Coating, or V-Bio® Enhanced Polyethylene Encasement with Life Extension Cathodic Protection
5	V-Bio® Enhanced Polyethylene Encasement with Metallized Zinc Coating, or V-Bio® Enhanced Polyethylene Encasement with Cathodic Protection

* Recommendations in Zones 4 and 5 recognize a practical difference between distribution and transmission mains. Distribution mains are generally smaller sized pipes, with the final classificiation to be defined by the pipeline owner. Cathodic protection should be considered where external corrosion is a significant risk or where pipe repairs/replacements would be cost prohibitive.

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DIPRA Modified Method A

- Link: https://www.youtube.com/watch?v=MroK7QgqMqM

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ASTM Document – Poly with CP

Designation: G218 – 19

Standard Guide for
External Corrosion Protection of Ductile Iron Pipe Utilizing Polyethylene Encasement Supplemented by Cathodic Protection[1]

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References

- 2014 ASCE paper "Zinc Metallizing for External Corrosion Control of Ductile Iron Pipe"
- 2017 ASCE paper "Synergistic Corrosion Protection of Ductile Iron Pipe Utilizing Metallic Zinc Coating in Combination with Enhanced Polyethylene Encasement"
- 2022 ASCE paper "Polyethylene Encasement Film Technologies History and Field Use for Corrosion Control of Ductile Iron Pipe"

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Mitigating Corrosion on Spiralwelded Steel Pipe

Anooj Kothari, American

akothari@american-usa.com

Mitigating Corrosion on Spiralwelded Steel Pipe

A MANUFACTURER'S PERSPECTIVE

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Territory Manager
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AMERICAN
THE RIGHT WAY

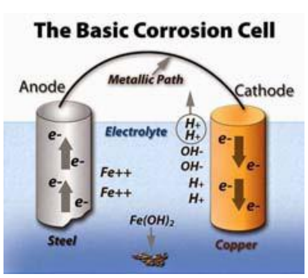
Corrosion Theory

AWWA Manual M11 Definition:

- Corrosion: The deterioration of a substance (usually a metal) or its properties as a result of a reaction with its environment.

Corrosion Theory

- Four basic components for corrosion to occur
  - Anode - Low potential metal
  - Cathode - High potential metal
  - Electrolyte - Ionized, electrically conductive substance
  - Return Path - Provides current flow from the cathode to the anode
- Common types of corrosion
  - Galvanic corrosion
  - Concentration cells
  - Electrolytic corrosion



Types of Corrosion

Galvanic Corrosion

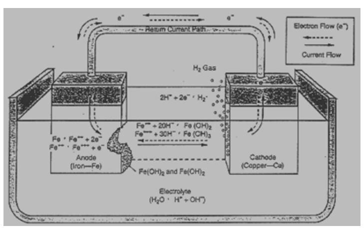
- Two dissimilar metals immersed in a single, uniform electrolyte

or

- Similar metals immersed in a solid electrolyte of uneven composition
- Four components must be present
  (anode, cathode, electrolyte, return path)

Galvanic Corrosion

Galvanic Cell



Galvanic Corrosion

Galvanic Series

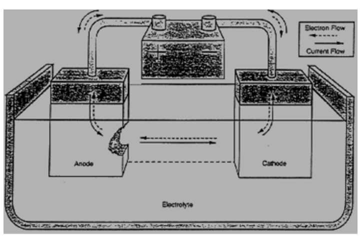
Anodic, Active (Read Down)	
	Manganese bronze
Magnesium	Nickel
Magnesium Alloys	Yellow brass
Zinc	Aluminum bronze
Aluminum 4S	Red brass
Aluminum 3S	Copper
Aluminum 2S	Silicon bronze
Cadmium	Ambrac - 5%Zn, 20%Ni, 75%Cu
Aluminum 17S-T	Nickel (passive)
Mild Steel	Monel - 70%Ni, 30%Cu
Wrought Iron	Titanium
Gray and Ductile Cast Iron	Silver
13% Cr stainless steel	Graphite
50-50 lead-tin solder	Gold
18-8 stainless steel	Platinum
Lead	
Tin	**Cathodic, Noble** (Read Up)

Electrolytic Corrosion

- Similar to galvanic corrosion in that the four components must be present
- Electrical current is supplied by a direct current source
- Corrosion reaction is driven by the direct current source

Electrolytic Corrosion

Electrolytic Cell



Electrolytic Corrosion

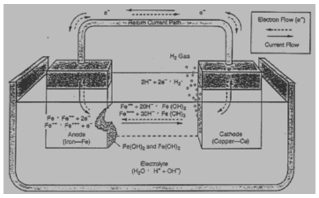
Causes of electrolytic corrosion

- Cathodic protection systems
- Electric transit systems and electric welding equipment ground to underground utilities

Usually more severe than other types of corrosion

Rate of Corrosion

Directly proportional to the amount of current leaving the metal at the anode.



Rate of Corrosion

What controls the magnitude of the current?

- Magnitude of the potential difference between anode and cathode
- Relative size of anode and cathode areas
- Thermodynamic characteristics at the metal-electrolyte interfaces
- Electrical resistance of the various current paths

Corrosion Prevention

- **Isolate and electrically insulate pipe**
- **Cathodic Protection**
- **Environmental Alteration**

Cathodic Protection

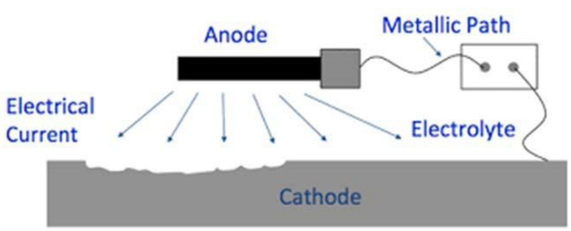
Theory

- Makes the entire pipeline the cathode of a galvanic or electrolytic corrosion cell

Two types of cathodic protection systems

- Sacrificial anode system, with anodes installed to purposefully corrode and thereby protecting the pipeline
- Impressed current system

Cathodic Protection-How it works



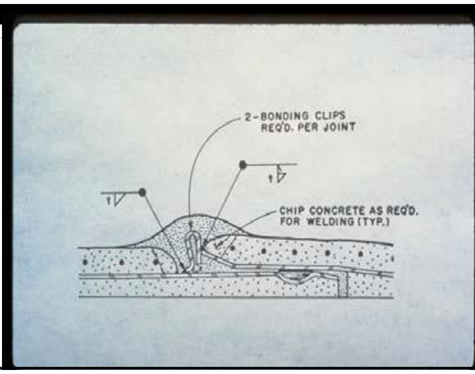
Cathodic Protection can be applied to both new and existing pipelines

Cathodic Protection-Test Stations

- **Can be used to simply monitor corrosion without the use of an anode**
- **Intervals determined by cathodic protection design**
- **Anode Bags (Magnesium, Zinc) can be added to proactively protect against corrosion**

Cathodic Protection

- Design and installation costs are relatively high
- Continuous monitoring and maintenance required by qualified personnel
- The location of buried anodes must be known, and anodes must be replaced as they are consumed (can be very difficult requirements)
- May increase corrosion in nearby pipelines that are not included in the system



What are corrosion concerns?

- Leak
- Catastrophic failure

What do steel pipe manufacturers recommend?

- **Bonded coatings**
- **Electrically continuous joints**
- **Monitoring stations**
- **Corrosion engineering**

What is the background for our recommendations?

- Oil and Gas Industry
  - Prime provider
- Required to provide bonded coating
- Required to cathodically protect

Why?

Because in Gas & Oil lines there is no minor leak

- Environmental damage
- Human life

But we are here to discuss Water/ Wastewater

- External corrosion
- Internal corrosion
- Risk factor

Manufacturing

- **Cylinder**
- **Joints**
- **Hydrostatic test**
- **Lining**
- **Coating**
- **Fittings**

Design Resources

Steel Pipe

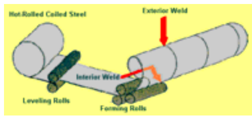
- **AWWA C200 – Steel Water Pipe, 6 in. and Larger**
- **AWWA M11 – Steel Pipe – A Guide for Design and Installation**

ASTM A139 Grade C

Physical	**Minimums**
Tensile	**60,000 psi**
Yield	**42,000 psi**
Elongation	**25%**

ASWP Manufacturing - Process

Spiral welded steel pipe is fabricated in a continuous process whereby coiled steel is formed into a cylinder with a spiral seam that is welded using a double submerged arc welding procedure.



Coil Steel

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Spiral Welded Pipe Mills

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Hydraulic Expander

Hydrostatic Tester

Cement Mortar Lining

Polyurethane Coating

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Fabrications

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Steel Pipe Linings & Coatings

- AWWA C205 – Cement Mortar Lining
- AWWA C222 – Polyurethane Coating
- AWWA C216 – Heat Shrink Sleeves

Polyurethane

- **Highly impermeable**
- **Excellent adhesion**
  - 1500 psi minimum
- **Abrasion and impact resistant**
  - Minimum of 25 mils
- **Holiday free**
- **Good flexibility**

Repairs

Concrete Pipe and Corrosion Control Techniques

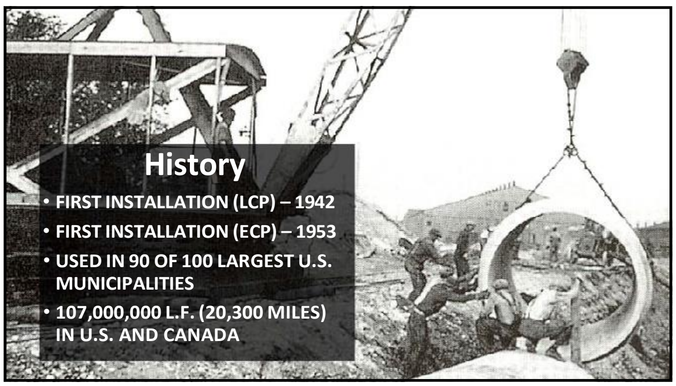
Jeff LeBlanc, Thompson Pipe Group

jleblanc@thompsonpipegroup.com

AUCSC

Corrosion Protection for Concrete Pressure Pipe

Jeff LeBlanc, P.E.
THOMPSON PIPE GROUP



History

- FIRST INSTALLATION (LCP) – 1942
- FIRST INSTALLATION (ECP) – 1953
- USED IN 90 OF 100 LARGEST U.S. MUNICIPALITIES
- 107,000,000 L.F. (20,300 MILES) IN U.S. AND CANADA

Concrete Pressure Pipe History

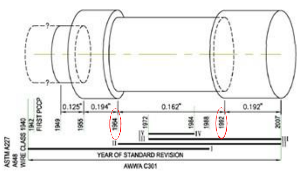
- 1899 – Harry S. Price, Sr. formed Price Brothers as a construction company in Michigan.
- 1998 – Gifford-Hill-American purchased by major pipe manufacturer, Hanson.
- 2000 – Price Brothers purchases Cretex facility in South Beloit, Illinois.
- 2007 – Hanson acquires Price Brothers.
- 2015 – Hanson is sold and name is changed to Forterra.
- 2016 – Forterra acquires U.S. Pipe
- 2017 – Thompson Pipe Group purchases the U.S pressure pipe assets from Forterra.

Failure of Prestressed Concrete Cylinder Pipe (PCCP) - 2008

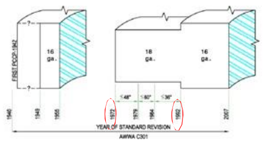
Table 3.1
Sample populations

Partition	Category 1 Failures	Categories 2 and 3 Failures
All samples	393	24,822
pre-1955	32	10
1955–63	40	2,381
1964–67	31	63
1968–71	60	46
1972–78 (all)	194	15,158
1972–78 (Interpace)	152	4,349
1972–78 (non-Interpace)	14	2,586
1979–91	35	5,864
1992–2007	1	1,299

16.5 % reduction in wire thickness



20 % reduction in cylinder thickness



Concrete Pressure Pipe Standards Improvements

Prestessing Wire Improvements

- Minimum Diameter Increased to 0.192
- Eliminated Class IV Wire & set upper tensile limit
- Maximum wire drawing temperature
- Torsion Testing
- Reduction of Area Testing
- Hydrogen Embrittlement testing
- Minimum Wire spacing increased
- Decrease allowable fluctuation in wrapping stress

Steel Cylinder Improvements

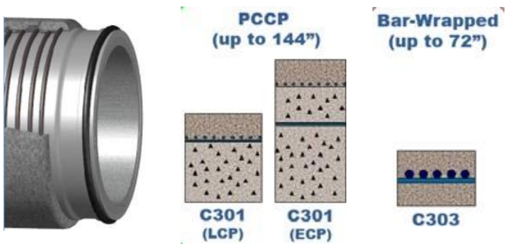
- Minimum Cylinder Thickness Increased to 16 ga
- All Welders Qualified
- Additional Cylinder Steel & Weld Testing

Mortar Coating Improvements

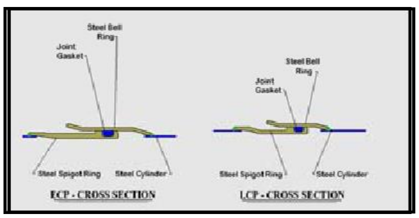
- Minimum coating thickness increased
- Minimum compressive strength added
- Minimum Moisture Content
- Absorption Testing
- Soundness & Bond Check Requirements
- Strength Qualification Tests

> “PCCP estimated service life is 75 to 100 years.
>
> - American Water Works Association (2015) Buried No Longer: Confronting America’s Water Infrastructure Challenge”

Concrete Pressure Pipe



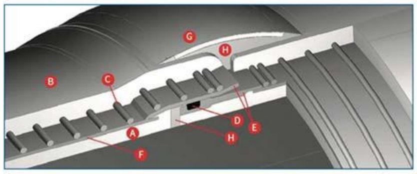
Prestressed Concrete Cylinder Pipe



C301
Prestressed Concrete Cylinder Pipe
(PCCP)

AMERICAN
Concrete Pressure Pipe
ASSOCIATION

Bar-Wrapped (C303) Pipe Components



- A Concrete or Cement Mortar Lining
- B Dense Cement Mortar Coating
- C Bar-wrapped Reinforcement
- D Round Rubber Gasket
- E Steel Joint Rings
- F Steel Cylinder
- G Polyethylene Foam-lined Grout Band
- H Field-applied Cement Mortar

C303 Bar-Wrapped Concrete Cylinder Pipe

AMERICAN Concrete Pressure Pipe ASSOCIATION

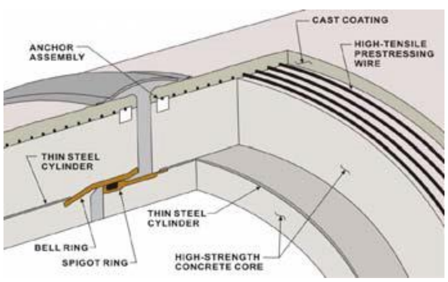
Cement Mortar Coating

Mortar-Coated Pressure Pipe

Excellent Track Record

- Resistant to external corrosion/ deterioration in most soil/groundwater
- Understand Damaging Mechanisms
  - Know when supplemental protection needed
  - Know appropriate form of supplemental protection
- Assure quality construction

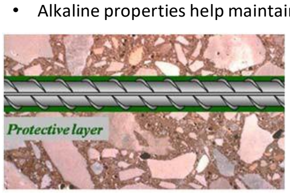
Mortar-Coated Pressure Pipe

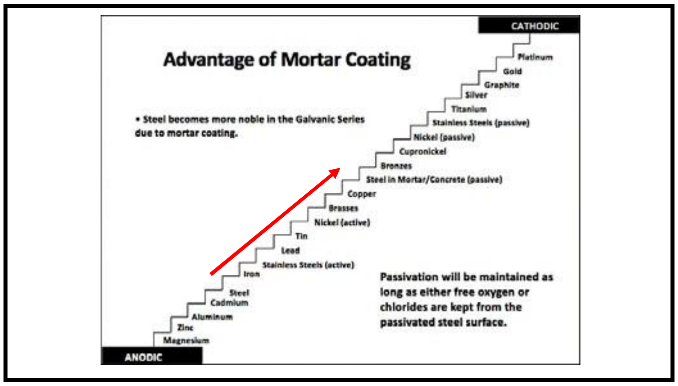


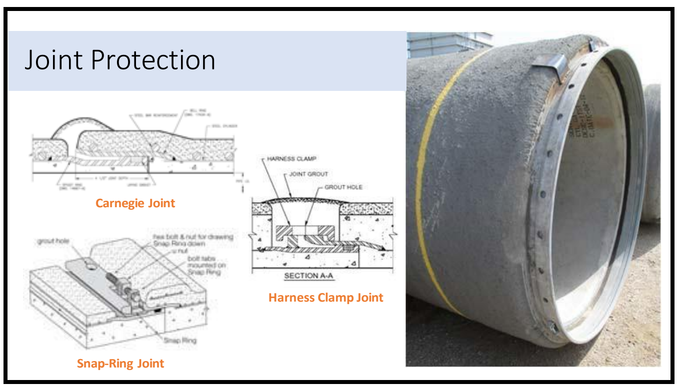
Mortar Protection

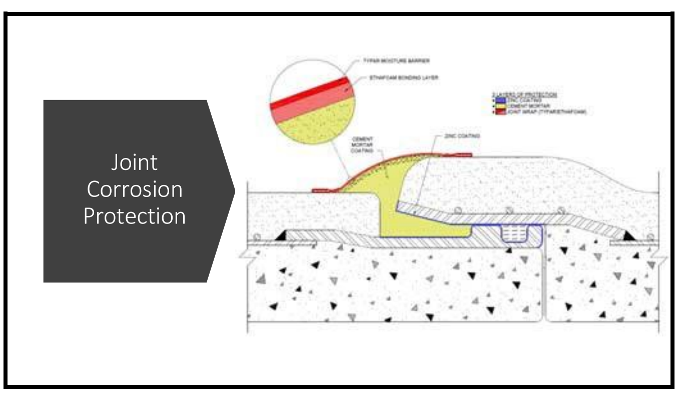
Steel Component Protection

- CM barrier to corrosion
- Alkaline properties help maintain passivity of steel components




CATHODIC
Advantage of Mortar Coating
• Steel becomes more noble in the Galvanic Series due to mortar coating.
Platinum
Gold
Graphite
Silver
Titanium
Stainless Steels (passive)
Nickel (passive)
Cupronickel
Bronzes
Steel in Mortar/Concrete (passive)
Copper
Brasses
Nickel (active)
Tin
Lead
Stainless Steels (active)
Iron
Steel
Cadmium
Aluminum
Zinc
Magnesium
Passivation will be maintained as long as either free oxygen or chlorides are kept from the passivated steel surface.
ANODIC


Joint Protection
Carnegie Joint
HARNESS CLAMP
JOINT GROUT
GROUT HOLE
SECTION A-A
Harness Clamp Joint
grout hole
Snap-Ring Joint


Joint Corrosion Protection
TYPAR MOISTURE BARRIER
ETHAFOAM BONDING LAYER
CEMENT MORTAR COATING
ZINC COATING

MOST COMMON CORROSION DAMAGE MECHANISMS FOR CONCRETE PRESSURE PIPE

Most Common Corrosion

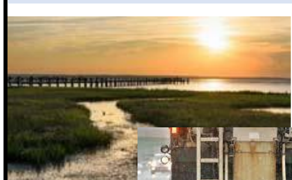
- High Chloride Soils
- High Sulfate Soils
- Acid Soils
- Stray Current

Most Common Corrosion

Sulfate Attack

- Sulfate reacts with C_3A; more in wet/dry
- Partially buried pipe – Salt concentration distress; sulfates build up through capillary action in pores in CM coating; cause expansive sulfate reactions
- Fully buried pipe – high-sulfate groundwater results in chemical sulfate attack of CM
- Exposes wires to corrosive groundwater/soil

Most Common Corrosion

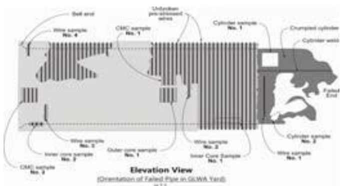


- **Chloride Corrosion of Steel**
  - High chloride concentration in soil/groundwater penetrates mortar coating – promotes active prestressed wire corrosion
  - Needs water, oxygen

Most Common Corrosion

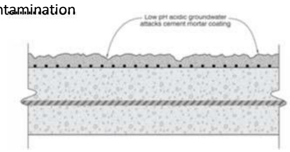
48" PCCP Water Main

- Water, chloride, oxygen intrusion
- HE of prestressing wire



Most Common Corrosion

- **Acidic Attack**
  - Low-pH soil/groundwater exposure breaks down cement mortar coating and promotes active wire corrosion
  - Soil contamination



Most Common Corrosion

- **Poor External Joint Grouting**
  - Exposes joint rings to corrosive soils/groundwater, leads to joint ring corrosion, concrete cracking and prestressed wire corrosion.

Most Common Corrosion

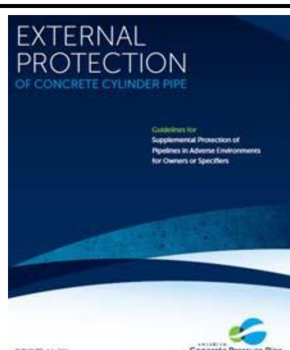
Damage to CM Coating During Construction

- Exposes pre-stressing wires, cylinder

PROVEN PREVENTION METHODS

Supplemental Protection for Adverse Environments

- Coating
- Barriers
- Cement
- Backfill
- Bonded Joints
- Cathodic Protection



Sulfate Attack Prevention

Criteria for Supplemental Protection:
- SO 2- < 2000 ppm

Solutions:
- ACPPA recommends Type II portland cement (lower C_3A)

Criteria for Supplemental Protection:
- SO 2- < 2000 ppm

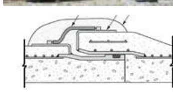
Solutions:
- Use Type V (<5% C_3A) portland cement, or apply external coal tar epoxy coating


Chloride Intrusion Prevention

Criteria for Supplemental Protection:
- < 1500 Ω-cm and Cl- > 400 ppm and unsubmerged

Solutions:
- Install moisture barrier around pipe
- Add silica fume to CM mixture; enhances density, slows rate of attack (temporary)
- Bond joints, install test stations to monitor for future CP





Acidic Attack Prevention

Criteria for Supplemental Protection:
- In granular soils, pH < 5, and total acidity > 25 meq per 100 grams soil

Solutions:
- Apply coal-tar epoxy coating over CM coating
- Install PE or other plastic membrane around pipe
- Backfill with clay or calcareous aggregate (sourcing issues; temporary)
- Add silica fume to CM mixture; enhances density, slows rate of attack (temporary)



Acidic Attack Prevention

Criteria for Supplemental Protection:

- pH < 4

Solutions:

- Apply coal-tar epoxy coating over CM coating
- Install PE or other plastic membrane around pipe
- Backfill with clay or calcareous aggregate (sourcing issues; temporary)

Proven Prevention from Acidic Attack

Middlesex Water Company, Iselin, NJ

- 42" PCCP, 45 years old
- Exposed to low-pH soils
- CTE coating
- Has performed without leakage

Analytical Test Results-Soil

Soil Description		Dark brown, very dense fine particles
Resistivity	as-received (Ω-cm)	57,000
Resistivity	soil/water paste (Ω-cm)	15,000
Water Content (%)		18
Total Hardness* (ppm)		49
pH		5.3
Alkalinity (mval/kg)		1
Acidity (mval/kg)		3.6
Redox (mV, platinum vs. Ag/AgCl)		+103
Chloride (mg/kg)		15
Sulfate (mg/kg)		5.5
Sulfide (yes/trace/no)		yes
Particle Size Analysis		
% Sand		40.4
% Clay		25.3
% Silt		34.3
Soil Classification		Loam

Table 1

Location	1	2	3	4	5	6	7	8	9	[illegible]	[illegible]	[illegible]
Station	0+00	18+00	50+00	48+09	76+75	110+25	122+58	126+33	135+07	[illegible]	[illegible]	[illegible]
Resistivity (Ohm-cm)												
20'	2872	1723	1532	1915	1915	5745	114	19	3064	[illegible]	[illegible]	[illegible]
15'	4596	5.75	1723	2010	2010	17235	201	25	2585	[illegible]	[illegible]	[illegible]
10'	6798	3638	2872	4021	1915	7660	76	24	11	[illegible]	[illegible]	[illegible]
5'	9048	3649	5266	6606	2585	9766	75	32	8	957	7947	161
Pipe To Soil Potential (mV)												
AC	289	195	8	26	6	65	11.5	25.8	74	9	1.7	2.8
DC	-458	-527	-303	-630	-540	-350	-430	-370	-296	-548	-660	-711
Soil pH												
pH	4.5	7	6.5	6.5	7	7	6.5	6.5	4.7	6.5	6.5	6.5

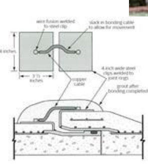
Stray Currents

Criteria for Supplemental Protection:

- Anticipated or Expected Stray Currents

Solutions:

- Supplemental Dielectric Coating
- Bond and Monitor Joints
- Active or Passive Cathodic Protection Systems



CATHODIC PROTECTION

Cathodic Protection

Design

- Current requirement generally low (μA/ft^2)
- Avoid impressed current CP – susceptible to over-protection, HE of wires
  - If high-resistivity soils, use barrier coating instead
  - If high current requirement, need better isolation

Cathodic Protection

Design

- Use sacrificial anode CP, keep pipe-to-soil potentials to less negative than -1,000 mV vs. $Cu/CuSO_4$ to avoid HE of wires
- -850 mV criterion (NACE SP0169) is too close to -1,000 mV
- Use minimum 100-mV shift criterion when designing
- Doesn't have to be entire pipeline; isolate sections in corrosive soils and use SACP

Cathodic Protection

Anodes

- Mg (high-potential) – 1,800 mV
- Mg (standard) – 1,500 mV
- Zinc – 1,100 mV
- Zinc can passivate in some soils, so install in special backfill:
  - Gypsum – pulls in moisture
  - Bentonite clay – low resistivity
  - Sodium sulfate – keeps anode from passivating

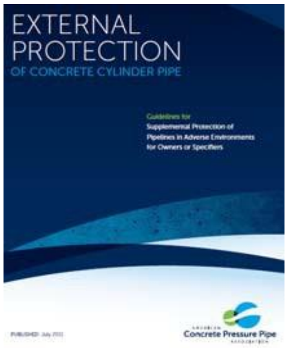
SEGMENTAL CORROSION PROTECTION METHODOLOGY

Segmental Corrosion Protection

If segments of pipeline intersect especially “hot” soils, add CTE over CM coating or install sacrificial anode cathodic protection and isolate the pipe electrically well back into non-aggressive soils.

Adverse Environments and Supplemental Protection

- High Chloride Soils
- High Sulfate Soils
- Acidic Soils
- Stray Current



Questions

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Corrosion Control Installation Procedures for Water and Sewer Pipeline Infrastructure

Joe Greulich, Washington Suburban Sanitary Commission

Joe.greulich@wsscwater.com

Corrosion Control Installation Procedures For Water and Sewer Pipeline Infrastructure WSSC Engineering and Environmental Services Division

WSSC WATER
DELIVERING THE ESSENTIAL

Joe Greulich
Principal Corrosion Engineer

May 10, 2023

About WSSC Water

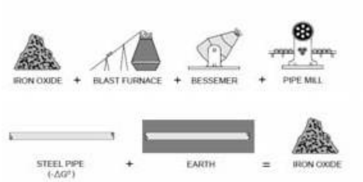
The Need for Corrosion Control

- **Corrosion control extends the service of pipelines and can be installed for a fraction of the cost of pipe replacement.**
- **Some large diameter pipes are so critical to WSSC operations that they can not be taken out of service for replacement, or there is no space to install new pipe.**

- **The 84 IN line had a corrosion control system installed for approximately $ 750,000.00**

The Need for Corrosion Control

- Corrosion control is needed because common metals such as iron and aluminum are found naturally in their corroded state. Iron ore as referred to in mining is corroded iron.
- Gold is one metal found in a relatively pure state.
- After the iron ore is processed into ductile iron or steel the metal when buried wants to return to its natural state.
- Metal loss occurs at location of corrosion, weakening structure. Corrosion can eventually lead to full loss of wall causing leaks.



- Processing of iron ore into steel

WSSC Corrosion Control Decision Process:

- WSSC classifies water pipelines according to the following criteria:
  - Distribution - less than or equal to 12 inch diameter.
  - Transmission - greater than or equal to 16 inch diameter.
- WSSC uses the following materials for pipelines:
  - PCCP (Prestressed Concrete Cylinder Pipe) - mostly existing water greater than 36 inch, not used for new construction.
  - PVC – for water less than or equal to 12 inch under certain conditions, primarily used for sewer gravity flow lines.
  - Ductile iron – primary pipe material used for water lines up to 54 inch diameter. Also used for sewer in certain cases.
    - Class 54 is standard class used. Due to current supply chain issues, Class 52 is allowed in certain limited cases.
    - Some relocations with State Highway Administration requires use of Class 56 which can eliminate the need for a casing.
  - Steel – for pipelines in excess of 54 inch diameter, coated pipe with cathodic protection is required for steel, regardless of conditions.
  - Copper – for Water House Connections (WHCs) up to 2 inches. WHCs larger than 3 inches use ductile iron.
  - Water pipes receive an internal cement mortar lining per AWWA, sewer also receives an internal lining, typically a ceramic epoxy.

WSSC Corrosion Control Decision Process:

- Engineering and Environmental Services Division (EESD) reviews projects for Corrosion Control requirements from three different internal WSSC groups:
  - Pipeline Design Division (PDD) – Replacement of existing water and sewer lines.
  - Development Services Division (DSD) – Installation of new water and sewer lines, primarily distribution.
  - Facility Design & Construction Division (FDCD) – Upgrades to water filtration and sewer treatment plants, pumping stations, and storage tanks. Have also begun overseeing design and installation of some new transmission water and sewer pipelines.
- Section C28 of WSSC Pipeline Design Manual details the multistage review process for how required Corrosion Control on projects is determined.
- Once a corrosion control system is installed, EESD oversees the testing and maintenance of the systems.

Corrosion Survey Checklist

- To be included in the first submittal.
- Identify existing conditions:
  - Corrosion control present on existing pipe
  - Dissimilar pipe material at connections.
  - Stray current sources within 2000 ft of the project site
  - Soil conditions (from testing of soil samples)
- Determine if stray current or soil testing is required.
- If no corrosive conditions are identified and additional testing is not required, the design can proceed using zinc coated DIP with V-BIO polyethylene encasement.

Stray Current Test

- One hour recording of potential readings using portable reference cell to structure.
- Connect to existing pipe not guardrails or guy wires.
- If stray current source is electric powered mass transit rail, testing is required to be conducted between 6-10 am or 3-7 pm. Trains are typically more frequent or longer during these periods increasing power demand.
- No testing is required if there are no stray current sources identified within 2000 feet
- If 200 feet from an electrified rail line, design for severe stray current exposure.

TABLE "32"
Stray Current Analysis

Exposure Level to Stray Currents	Pre-Construction Survey and Test Results
SEVERE EXPOSURE	• Continual stray current that results in more than 50 mV potential variation (any source). • WMATA Metrorail electrified AMTRAK, or Maryland Transit Administration (MTA) lines, or Maryland Transit Administration (MTA) Traction Power Substation (TPSS) that are within 200 feet of the pipeline. • Future proposed extension of WMATA Metrorail lines, electrified AMTRAK, Maryland Transit Administration (MTA) lines, or Maryland Transit Administration (MTA) Traction Power Substation (TPSS) within 500 feet of the pipeline. • Cathodically protected foreign buried pipes or cables that cross or come within 100 feet of the pipeline and have a ground bed within 2000 feet.
MODERATE EXPOSURE	• Moderate or sporadic stray current that results in 50 mV or less potential variation (any source). • WMATA Metrorail, electrified AMTRAK, Maryland Transit Administration (MTA) lines, or Maryland Transit Administration (MTA) Traction Power Substation (TPSS) that is within 200 to 500 feet of the pipeline. • Cathodically protected foreign buried pipes or cables that are within 100 to 500 feet of the pipeline and have a ground bed within 2000 feet or that cross the pipeline and have a ground bed over 2000 feet away.
NO EXPOSURE	• No stray current detected during testing. • WMATA Metrorail electrified AMTRAK and Maryland Transit Administration (MTA) lines or Maryland Transit Administration (MTA) Traction Power Substation (TPSS) beyond 500 feet away from the pipeline. • Cathodically protected foreign utility buried pipes and cables are more than 500 feet away from the pipeline.

Soil Condition Analysis

- Required for all 16-inch and larger water pipelines.
- Also required for pipelines less than 16-inch if project is adjacent to farm, golf courses or other areas with significant landscaping treatment. Soil chemistry can be significantly different than native soil in these areas.
- A minimum of at least 2 soil samples per pipeline alignment, taken at the pipeline depth.
- Soil sampling intervals should not exceed 1000 ft unless pipeline is less than 2000 ft in length, then the sample interval should not exceed 700 ft.
- Laboratory or field test for pH, chloride content, redox potential, soil resistivity, and soil description. Table 30 and 31 determines the overall corrosivity of the soil.

TABLE "30"
Soil Condition Analysis

ANALYSIS TYPE	ANALYSIS RANGE	POINTS	ANALYSIS TYPE	ANALYSIS RANGE	POINTS
PH	0 - 2	5	Soil Description	Clay (Blue-Gray)	10
	2 - 4	3		Clay Stone	5
	4 - 8.5	0		Clay	3
	> 8.5	3		Silt	2
Chloride Content	> 1000 ppm	10		Clean Sand	0
	500 - 1000 ppm	6		—	-
	200 - 500 ppm	4	Soil Resistivity	< 1,000 ohm-cm	10
	50 - 200 ppm	2		1,000 - 1,500 ohm-cm	8
	0 - 50 ppm	0		1,500 - 2,500 ohm-cm	6
Redox Potential	Negative	5		2,500 - 5,000 ohm-cm	4
	0 - 100 mV	4		5,000 - 10,000 ohm-cm	2
				> 10,000 ohm-cm	0
	> 100 mV	0		—	-

TABLE "31"
Overall Corrosivity Rating

SOIL CORROSIVITY	TOTAL POINTS
Severe	> 15.5
Appreciable	10.0 - 15.5
Moderate	5.0 - 9.5
Mild	0 - 4.5

Decision Process

- The field testing results and the existing pipe analysis are used with Charts C and D to determine the recommended corrosion control.

Form B Corrosion Documentation

- **To be included in the second submittal with the results of any required testing.**
- **Summary of testing results and corrosion control requirements**

WSSC Corrosion Control Methods

- **WSSC uses the following corrosion control methods for pipelines:**
  - **Ductile iron with zinc coating and V-BIO polyethylene encasement – this is the minimum requirement when review determines that there is minimal risk of corrosion.**
  - **If the minimum requirements are not sufficient the following methods are used:**
    - **PVC pipe – allowed up to 12 inches for water. Requires a fluid pressure analysis to determine if working pressure is within acceptable limits, detailed in Part I Sections 4 and 5 of WSSC Pipeline Design Manual.**
    - **Coated pipe with cathodic protection. Ductile iron has a factory applied tape coating (PRITEC™).**
    - **Steel will either be tape coated or spray applied.**

Pipe with polyethylene encasement and encasement before placement on pipe

WSSC Corrosion Control Methods

Zinc coated Pipe before installation of polyethylene encasement, and manufacturer information on zinc coating.

WSSC Corrosion Control Methods

PRITEC Coated ductile iron pipe. Two top pictures are bell and spigot ends of lower left. Variation in coating color due to shade/sunlight. Lower right has casing spacers for road crossing.

WSSC Corrosion Control Methods

Manufacturer spray applied Polyurethane coated steel pipe, 66 inch installed in 2022. Manufacture information (bottom left), joint before welding (bottom center), field coating of welded joint (bottom right)

WSSC Corrosion Control Methods

Tape Coated 84 inch steel pipe, installed in 1989 designed on Contract 1988-7629A. Right picture shows possible separation between layers of tape. Three layer tape system with a trade name of YG-III.

WSSC Corrosion Control Methods

Internal cement mortar lining for water (left). This is interior of pipe shown in previous slide. Right side shows internal sewer lining for 48 inch ductile iron. Lining is ceramic epoxy with trade name of Protecto 401™.

WSSC Corrosion Control Methods

Internal lining for sewer is different because sewer produces Hydrogen Sulfide gas which breaks down the cement mortar lining, which allows the gas to contact the metal. Hydrogen Sulfide gas is corrosive to iron. Since Hydrogen Sulfide is a gas, corrosion will occur at crown (top) of pipe as shown in picture below.

WSSC Corrosion Control Methods
Lining Damage Due to Improper Handling

Internal cement mortar lining damage due to pipe being dropped (left) and use of forklift on interior of pipe (right).
After forklift incident, WSSC Standard Specifications were modified to prohibit handling of pipes by placing forks in interior of pipe.


Components of A Cathodic Protection System

- For both galvanic and impressed current systems:
  - Test stations to monitor effectiveness of systems, use flush mount and post mount types, see WSSC Standard Details C4.0 and C4.2. Effectiveness is measured by reading a pipe to soil potential, which is the DC voltage difference between the pipe and soil. Criteria per NACE SP-0169.
  - Test stations require excavation to pipe depth for attachment of test lead wires via thermite welding. Also installed below pipe is permanent reference cell to measure pipe to soil potentials.

Components of Cathodic Protection Systems

Typical installations of flush mount test stations, and test lead wires attached to terminal board

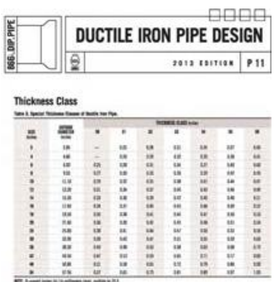



Components of Cathodic Protection Systems

Typical installations of post mount test stations, and test lead wires attached to terminal board. Upper location shows a test station with magnesium anodes installed.

Components of A Cathodic Protection System

- When designing a cathodic protection system, it as assumed that a certain percentage of the external surface of the coated pipe will be bare due to manufacturing defects and/or handling damage. A surface area (= π *x length x diameter*) calculation is performed.
  - The estimated bare area is then multiplied by a current density (amperes/ ft^2) to estimate current required.
  - When pipe sizes are discussed it is typically the INNER diameter that is referenced since that is what carries the fluid of interest.
  - However, for cathodic protection system design it is the OUTER diameter that is of concern since it is contact with the soil.
  - For steel pipe OUTER = INNER + (2 x wall thickness). Ductile iron has predetermined outer diameters as shown in chart.
  - There can be a significant difference in the calculated surface area depending on whether inner or outer diameter is used especially on long lengths of large diameter pipe. Wall thickness on large diameter steel can be as much as one inch.
  - This difference will affect the amount of current required, the number of anodes, and possibly whether galvanic or impressed current cathodic protection is installed.

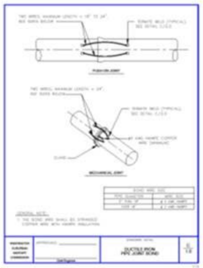

666. DIP PIPE
DUCTILE IRON PIPE DESIGN
2013 EDITION
P 11

Thickness Class

Components of A Cathodic Protection System

- Effective cathodic protection systems require the pipe to be electrically continuous. This is achieved by welding bond wires across pipe joints (STD Detail C 1.0) for new pipe construction. The bonding is required due to the use of the bell and spigot configuration which allows pipe sections to be pushed together.
- There is a rubber gasket placed in bell that the spigot end rests on when pipe is pushed together. The gasket and cement mortar prevent metallic contact between pipe sections.
- This is different than the use of plain end steel pipe, which is welded together. The weld creates one continuous pipe so joint bonding is not required.
- At connections between new and existing pipe Insulating Joints (IJs) are installed to isolate sections of pipelines. IJs are also installed on Water House Connections (WHCs) 3 inch or larger, since these are ductile iron. Insulating joints ensure that cathodic protection system works on only pipeline system was designed for.
- Section VI of WSSC Standard Detail Manual show other instances of where bonding around pipe joints is required, including valve vaults, mechanical joints and fittings. All other corrosion related standard details are located here.
- When an impressed current system is installed, a structure negative lead wire must be attached to pipeline via thermite weld. Structure negative lead is then routed to rectifier connected to DC NEGATIVE terminal.

Components of A Cathodic Protection System



Joint bonding detail
for ductile iron pipe

Plain end steel pipe
before joint welding

Installation of Push on Joint Pipe

Attachment of Test Leads, Structure Negatives, and Joint Bond Wires Via Thermite Weld

Coating
removal

Grinding to
bare metal

Pipe surface
after grinding

Wire attachment
via thermite weld

Attachment of Test Leads, Structure Negatives, and Joint Bond Wires Via Thermite Weld

Pictures of bond wires and tape coating of joint




Attachment of test leads via pin brazing and tape coating of joints

Pin brazing

Tape coating

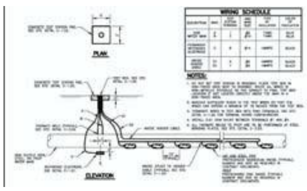

Components of A Cathodic Protection System

- For galvanic systems:
  - Magnesium or zinc anodes are installed in a trench parallel to pipeline.
    Anodes are usually installed horizontally in one continuous trench. Anodes may also be installed vertically in individual drilled holes.
  - Minimum depth is pipe invert depth preferably at least 2 feet below to ensure adequate coverage to underside of pipe.
  - Anodes come in a prepackaged bag surrounded by a specialized backfill which improves performance of anode. Anode remains in bag for installation. A 32 lb anode will have a packaged weight of 68 lbs.
  - Anodes are soaked in water prior to installation to activate special backfill. Backfill is mixture of 75% gypsum, 20% bentonite, 5% sodium sulphate.
  - Anodes have a lead wire attached at manufacturer.
  - Lead wires are spliced to a continuous header cable which terminates at test station. At test station, header cable is connected to one of the pipe test leads. The connection completes the circuit and allows the protective current to flow.
  - Anode current is measured through a shunt, which is installed in test station.
  - In certain applications on existing pipelines, anodes are directly connected to pipelines. This is to extend service life to slow corrosion rate of ductile iron.
  - WSSC uses zinc anodes in the following instances:
    - At ductile iron to PCCP connections. Anode is directly connected to ductile iron via thermite weld.
    - On water main replacements where adequate separation from PCCP cannot be achieved. The prestressed wires in PCCP can become brittle if subjected to excessive voltages. Zinc operates at a lower voltage than magnesium.
  - Anodes usually have a service life of 20 - 25 years and can be replaced when service ends.

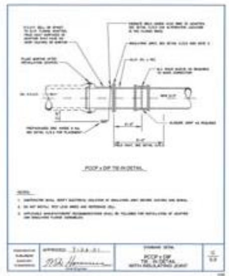
Magnesium anodes before placement in bag with special backfill

Galvanic Anode Cathodic Protection System

Typical installation of magnesium or zinc anodes



WSSC Standard Detail for PCCP x DIP adapter



Galvanic Anode Cathodic Protection System

Installation of magnesium anodes for water main service life extension

Galvanic Anode Cathodic Protection System

Installation of magnesium anodes for water main service life extension

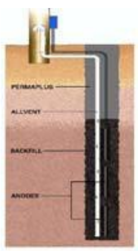
Impressed Current Cathodic Protection System

- For impressed current systems:
  - Need to attach a structure negative lead to pipeline. This is one continuous lead without splices placed in trench terminated at rectifier.
  - Anodes are typically installed vertically in one well known as a deep well. Deep well depths are usually 150 to 200 ft in depth.
  - Anodes may also be placed in individual vertical wells or laid horizontally in trench. Minimum depth is pipe invert depth preferably at least 2 feet below to ensure adequate coverage to underside of pipe.
  - Anodes have a lead wire attached at manufacturer connected to core of anode. Each anode lead wire is brought in one continuous run to an anode junction box. Anodes are terminated at individual terminals with shunts to measure current output. An anode header cable connects the junction box to the rectifier.
  - The area between the anode and the well wall is filled with a special backfill known as coke breeze. This is a solid material that is pumped into well as a slurry.
  - Also installed in the well is a anode vent pipe which is terminated just below the surface. The anodes emit a gas as they are consumed, vent allows this gas to escape to atmosphere.
  - Well is terminated at grade with a flush mount well cap with drilled holes to allow gas to go into atmosphere.
  - Present anode material is High Silicon Cast Iron(HSCI), Mixed Metal Oxide (MMO) can also be used which uses a titanium core. MMO anodes are smaller and lighter.

Impressed Current Cathodic Protection System

Structure negative lead trench to rectifier

Anode well



Impressed Current Cathodic Protection System

High Silicon Cast Iron Anodes – Left center wire connection, Center: with lead wires (Black) and lowering rope (yellow), Right: with centralizers attached holds anode in place in well.

Impressed Current Cathodic Protection System

Drilling of anode well

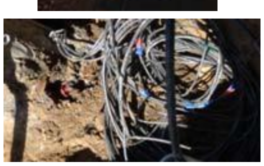
Anode well casing typically installed in first 50 ft of well

Impressed Current Cathodic Protection System

Installation of anode vent

Impressed Current Cathodic Protection System

Anode lead wires at top of well and top of vent



Anode well with vent cap attached, and anode leads in conduit for placement in junction box

Impressed Current Cathodic Protection System

Anode well with vent cap attached, and anode leads in conduit for placement in junction box. Small conduit is for anode header cable. Single wire in background is negative connection.

Anode wells for site

Impressed Current Cathodic Protection System

- For impressed current systems:
  - Impressed current systems are powered by a rectifier which converts incoming AC power to DC to power the circuit.
  - Location of AC power is a determining factor for placement of impressed current systems.
  - At the DC terminals of rectifier, the anode header cable is connected to the DC positive terminal, and structure lead is connected to the DC negative terminal.
    - It is a critical step that these connections are properly made. Severe rapid corrosion of pipeline will result if connections are reversed. Full pipe wall penetration is possible.
    - WSSC specifications require anode header cable to be marked to differentiate it from structure negative lead.
  - Rectifiers can be either air cooled or oil cooled. Oiled cooled units are used in hazardous atmospheres or enclosed spaces where there is limited air movement.
  - Rectifiers have a Remote Monitoring Unit (RMU) connected to them, which allows output of rectifiers to be checked without visiting site.
  - While a galvanic system has a fixed output, an impressed current system has adjustable output that can be varied over time. Pipeline coatings can deteriorate over time exposing more metal to soil, increasing current requirements. Changes in soil conditions can also increase current requirements.

Impressed Current Cathodic Protection System

Completed installation of rectifier, anode junction box, and RMU. Anode well cap in pad.

Impressed Current Cathodic Protection System

Anode junction box with individual anode leads (red and yellow tape). Single wire on left is anode header cable.

Rectifier close up with anode header cable (red tape) and structure negative lead.

Impressed Current Cathodic Protection System

Front panel of rectifier showing DC output terminals.

Front panel of rectifier showing Tap settings which control output, volt and ammeter, on and off switch.

Impressed Current Cathodic Protection System

RECTIFIER INFORMATION, USUALLY PLACED ON INSIDE OF DOOR, OR ON FRONT OF DOOR. TYPICALLY CONTAINS AC AND DC RATINGS, MODEL AND SERIAL NUMBER, AND NAME OF MAUNFACTURER.

Figure 117 - Rectifier label, north side of High Zone Pumping Station, Contract 94-1597B

Impressed Current Cathodic Protection System

Figure 116 – Rectifier panel, north side of High Zone Pumping Station, Contract 94-1597B

Impressed Current Cathodic Protection System

Close up of RMU and connections to rectifier.

Damaged Test Stations

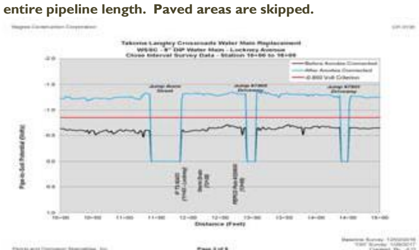
Test stations that cannot be located.

Damaged Test Stations

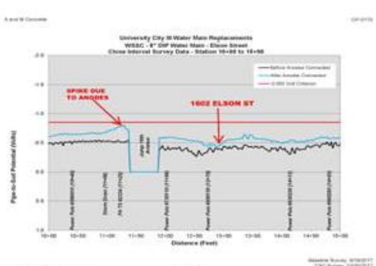
Test stations that have been damaged.

Testing of cathodic protection systems

- **After construction is complete, cathodic protection system is tested to assess its effectiveness.**
- **Testing can reveal issues with design or construction.**
- **One test performed is known as Close Interval Survey (CIS) which measures the effectiveness along the entire pipeline length. Paved areas are skipped.**



Testing of cathodic protection systems



Sample CIS graph showing ineffective cathodic protection

Testing of cathodic protection systems

Map showing location of projects from previous two graphs.

Testing of cathodic protection systems

- The University City III moved the water main from one side of the gas main to the other. This meant that the copper WHCs now cross gas main.
- Washington Gas was contacted, they indicated issues with their cathodic protection system.
- Washington Gas indicated the presence of a possible contact through testing they conducted.

Contact between copper WHC and steel gas main

Testing of cathodic protection systems

Paint markings showing crossing of WHC and gas main.

Clearing of contact by placing plastic between WHC and gas main

Links to documents

- [Pipeline Construction Conditions & Standards | WSSC Water]
- Specifications:

https://app.ebuilder.net/public/publicLanding.aspx?QS=6feb735b8b9b46beadfd776a1a5ed800

https://www.wsscwater.com/work-us/codes-standards-policies-and-procedures/standard-details-construction-2021

- www.wsscwater.com

Questions

Joe Greulich
Joe.Greulich@wsscwater.com
240-338-6444

Thank you

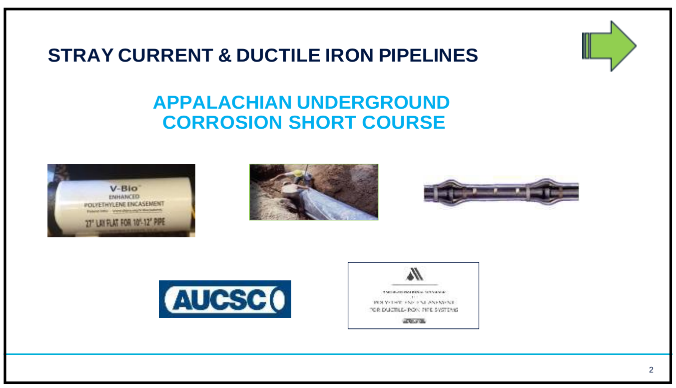
Stray Current and Ductile Iron Pipelines

Paul Hanson, Ductile Iron Pipe Research Association

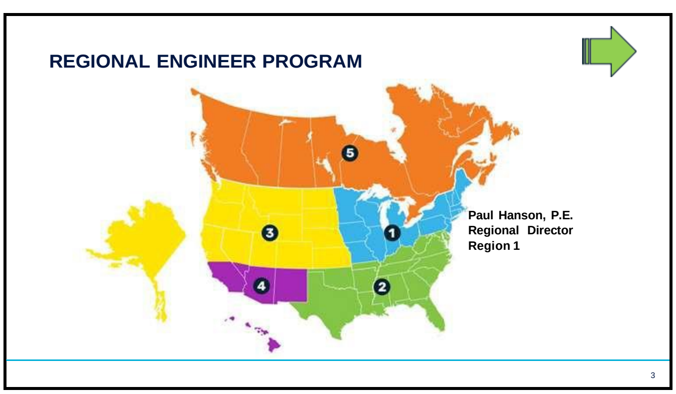
phanson@dipra.org


PRESENTATION TO….
APPALACHIAN UNDERGROUND CORROSION SHORT COURSE
April 10, 2023

1


STRAY CURRENT & DUCTILE IRON PIPELINES
APPALACHIAN UNDERGROUND CORROSION SHORT COURSE
V-Bio
AUCSC
2

2


REGIONAL ENGINEER PROGRAM
Paul Hanson, P.E.
Regional Director
Region 1
1
2
3
4
5
3

3

Ductile Iron Pipe

Strength and Durability for Life

4

DIPRA MEMBER COMPANIES

- AMERICAN Ductile Iron Pipe
  Birmingham, AL
- Canada Pipe Company, LTD.
  Hamilton, Ontario
- McWane Ductile
  Coshocton, OH
- United States Pipe and Foundry Company
  Birmingham, AL

5

5

C104/A21.4
Cement-Mortar Linings

C105/A21.5
Polyethylene Encasement

C110/A21.10
Ductile-Iron and Gray-Iron Fittings

C111/A21.11
Rubber-Gasket Joints

C115/A21.15
Flanged Ductile-Iron Pipe

C116/A21.16
Fusion-Bonded Coatings for Fittings

C150/A21.50
Thickness Design

C151/A21.51
Ductile-Iron Pipe, Centrifugally Cast

C153/A21.53
Ductile-Iron Compact Fittings

C600
Installation of Ductile-Iron Water Mains

6

6

LEARNING OBJECTIVES

- Pipe Joints – Discontinuous
- Stray Direct Current
- DIPRA Research
- Examples, field work
- Polyethylene Encasement, VBio™
- Installation: Modified Method A
- DDM Update, CP

7

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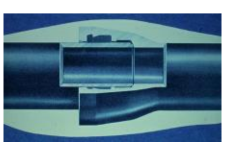
DUCTILE IRON PIPELINES ARE ELECTRICALLY DISCONTINUOUS



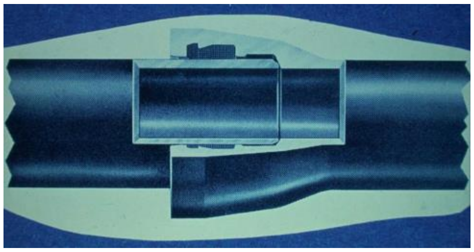
Push-on Joint

Mechanical Joint

9

9

PUSH-ON JOINT



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PUSH-ON JOINT ASSEMBLY

STEP 1: Clean Joint Assembly

STEP 2: Insert Gasket

STEP 3: Apply Lubricant

11

11

PUSH-ON JOINT ASSEMBLY

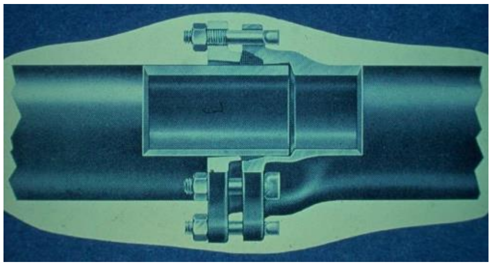
STEP 4: Push Home

STEP 5: Completed Assembly

12

12

MECHANICAL JOINT



13

MECHANICAL JOINT ASSEMBLY

STEP 1: Clean Joint Assembly

STEP 2: Lubricate Joint with Soapy Water

14

MECHANICAL JOINT ASSEMBLY

STEP 3: Connect and Tighten

STEP 4: Completed Assembly

Joint Size (in.)	Bolt Size (in.)	Range of Torque (ft.-lb.)
3	⅝	45-60
4-24	¾	75-90
30-36	1	100-120
42-48	1 ¼	120-150

15

JOINT RESISTANCE MEASUREMENTS EXISTING 12" DUCTILE IRON PIPELINE NEW BRAUNFELS, TEXAS

45 joints tested

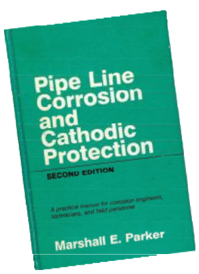
9 were shorted

Resistance: 2.3 to 23.0 ohms

16

16

STRAY CURRENT INTERFERENCE



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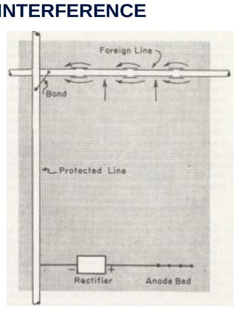
STRAY CURRENT INTERFERENCE



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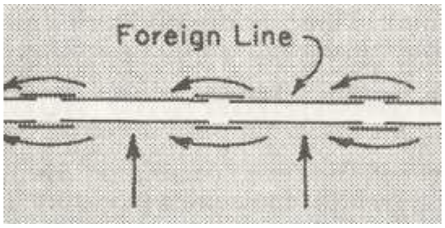
STRAY CURRENT INTERFERENCE



19

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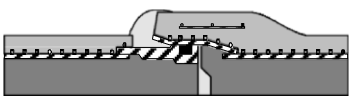
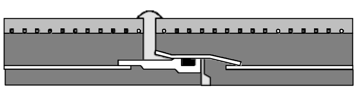
PRESTRESSED CONCRETE CYLINDER PIPE
(AWWA C-301)



Lined Cylinder Pipe

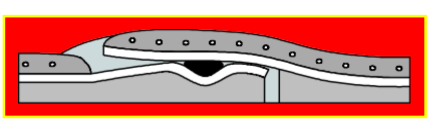


Embedded Cylinder Pipe

20

20

CEMENT-COATED STEEL PIPE
(AWWA C-200)



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Stray (Direct) Current Corrosion

22

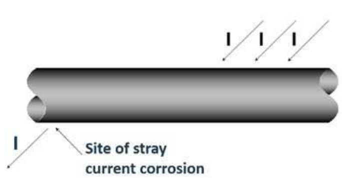
STRAY CURRENT CORROSION

Corrosion resulting from direct current flow through paths other than the intended circuit

23

23

STRAY CURRENT CORROSION



24

24

SOURCES OF STRAY DIRECT CURRENT

- Impressed current cathodic protection systems
- Electric transit systems
- Arc-welding equipment
- Direct current transmission systems
- Grounding electrical systems to pipe

25

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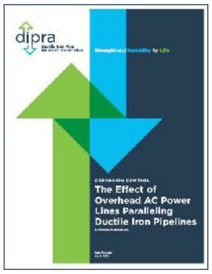
AC OVERHEAD POWER LINE RIGHT-OF-WAYS

26

26

EFFECT OF OVERHEAD AC POWER LINES



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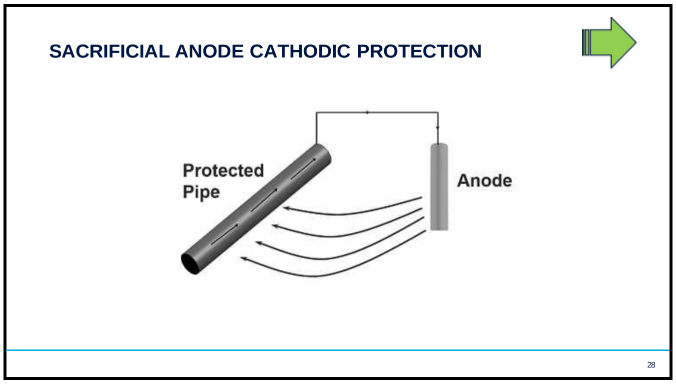
SACRIFICIAL ANODE CATHODIC PROTECTION
Protected Pipe
Anode
28

28


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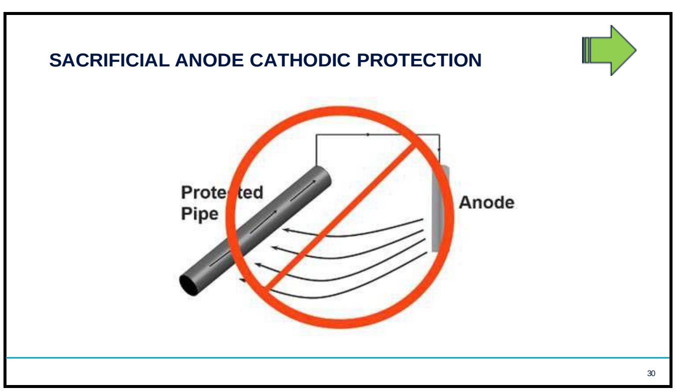
SACRIFICIAL ANODE CATHODIC PROTECTION
Prote ted Pipe
Anode
30

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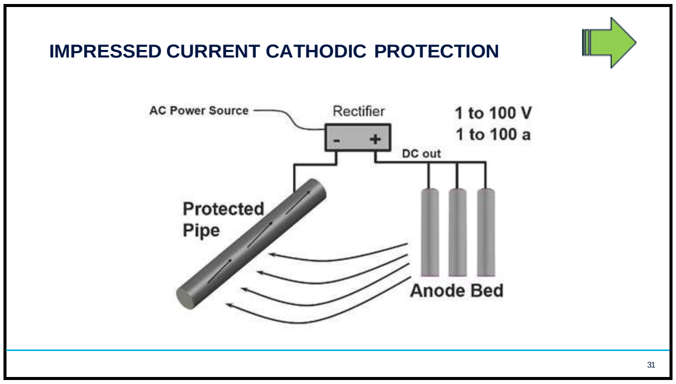
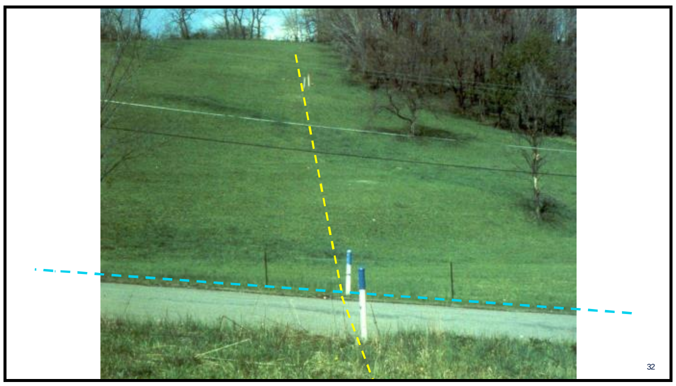

IMPRESSED CURRENT CATHODIC PROTECTION
AC Power Source
Rectifier
- +
1 to 100 V
1 to 100 a
DC out
Protected Pipe
Anode Bed
31

31


32

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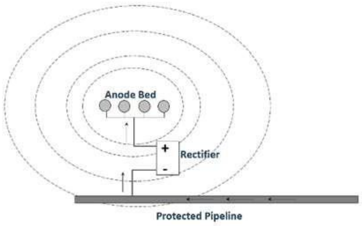
TYPICAL STRAY CURRENT ENVIRONMENT



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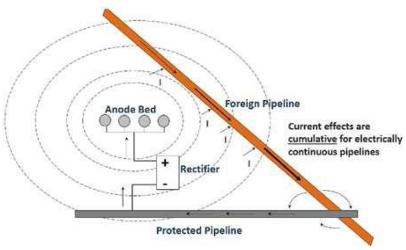
TYPICAL STRAY CURRENT ENVIRONMENT



35

35

OHM'S LAW

The magnitude of the current is directly proportional to the driving potential and inversely proportional to the circuit resistance.

$$I = \frac{E}{R}$$

$$\text{Current} = \frac{\text{Driving Potential}}{\text{Circuit Resistance}}$$

36

36

FARADAY'S LAW

The weight of metal lost to corrosion is proportional to the magnitude of the corrosion current and the time the current flows.

$$W = w_e \cdot I \cdot t$$

Weight Loss $= w_e \cdot$ Direct Current $\cdot$ Time

37

37

FARADAY'S LAW

Weight Loss per Ampere-Year at 100% Corrosion Efficiency

Lead	74.7 lbs.
Zinc	23.6 lbs.
Copper	22.9 lbs.
Iron	20.1 lbs.
Magnesium	8.8 lbs.
Aluminum	6.5 lbs.

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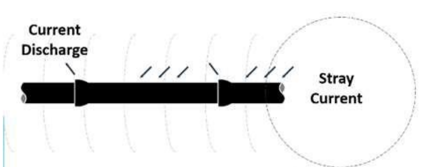
DISCONTINUOUS JOINT



Current does not accumulate on <u>electrically discontinuous</u> piping systems.

39

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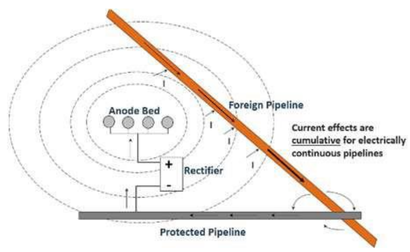
TYPICAL STRAY CURRENT ENVIRONMENT



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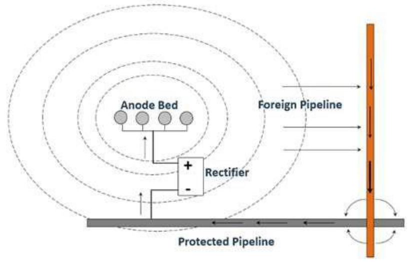
TYPICAL STARY CURRENT ENVIRONMENT



41

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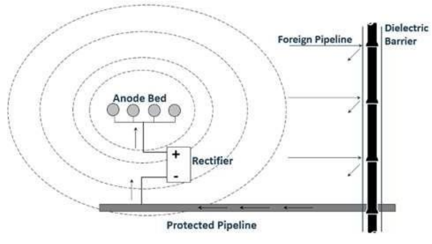
DISCONTINUOUS JOINT EFFECTS



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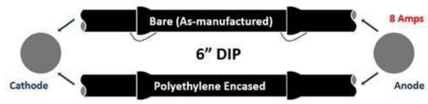
DIPRA STRAY CURRENT STUDY



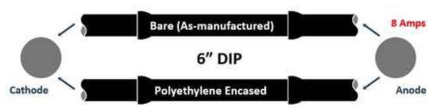
Current Pick-Up

	Bonded
Bare	1,650.0 ma

43

43

DIPRA STRAY CURRENT STUDY



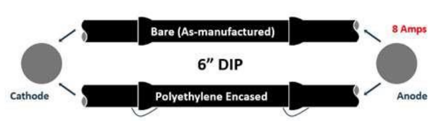
Current Pick-Up

	Bonded	Unbonded
Bare	1,650.0 ma	538.0 ma

44

44

DIPRA STRAY CURRENT STUDY



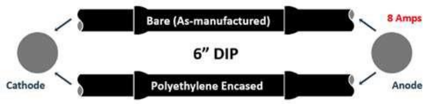
Current Pick-Up

	Bonded	Unbonded
Bare	1,650.0 ma	538.0 ma
Polyethylene	4.3 ma	

45

45

DIPRA STRAY CURRENT STUDY



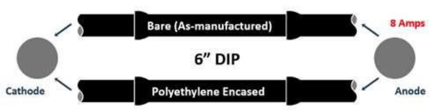
Current Pick-Up

	Bonded	Unbonded
Bare	1,650.0 ma	538.0 ma
Polyethylene	4.3 ma	1.5 ma

46

46

DIPRA STRAY CURRENT STUDY



Current Pick-Up

	Bonded	Unbonded
Bare	1,650.0 ma	538.0 ma
Polyethylene	4.3 ma	1.5 ma

Bare/Bonded to Poly/Unbonded → 1,100 times less current

47

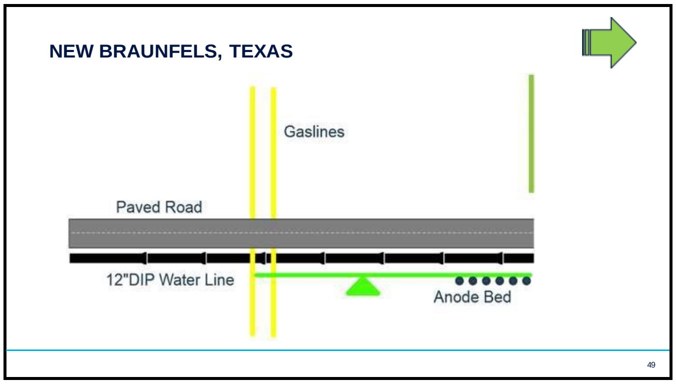
47

STRAY CURRENT INTERFERENCE IS DEPENDENT ON:

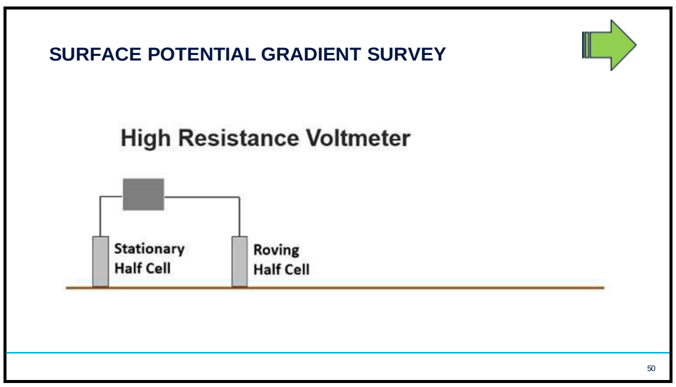
- Pipeline geometry
- Soil resistivity
- Water table
- Pipe sizes
- Pipeline coating
- Rectifier output

48

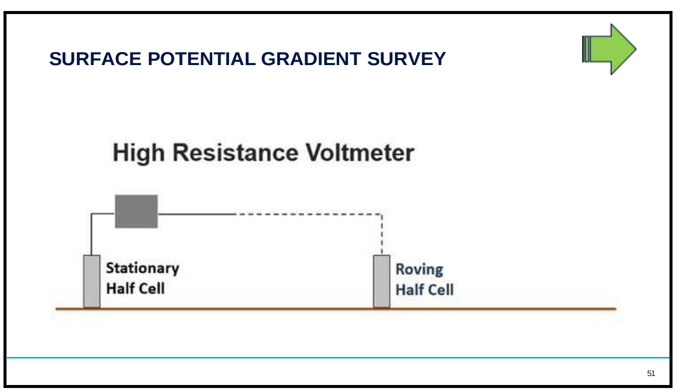
48


NEW BRAUNFELS, TEXAS
Gaslines
Paved Road
12"DIP Water Line
Anode Bed
49

49


SURFACE POTENTIAL GRADIENT SURVEY
High Resistance Voltmeter
Stationary Half Cell
Roving Half Cell
50

50


SURFACE POTENTIAL GRADIENT SURVEY
High Resistance Voltmeter
Stationary Half Cell
Roving Half Cell
51

51

SURFACE POTENTIAL GRADIENT SURVEY

High Resistance Voltmeter

52

52

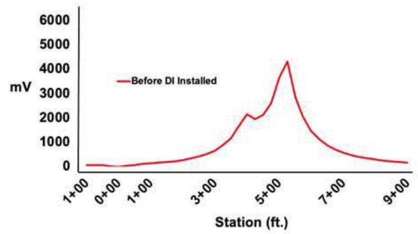
53

53

54

54

POTENTIAL PROFILE COMPARISON NEW BRAUNFELS, TEXAS



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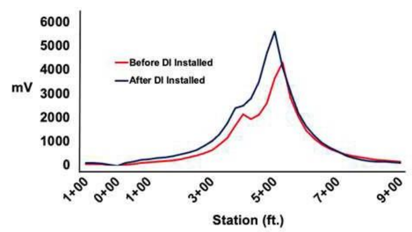
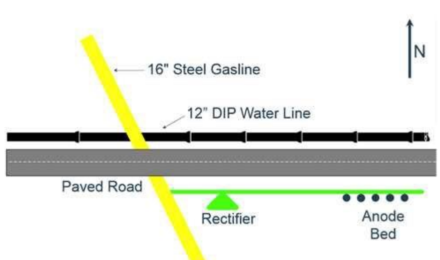
POTENTIAL PROFILE COMPARISON NEW BRAUNFELS, TEXAS



56

56

SAN ANTONIO, TEXAS



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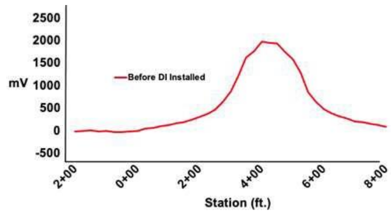
57

POTENTIAL PROFILE COMPARISON SAN ANTONIO, TEXAS



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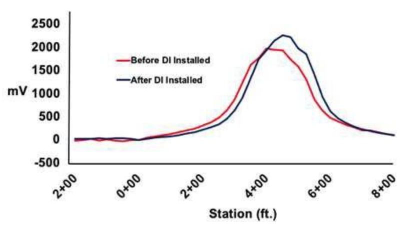
POTENTIAL PROFILE COMPARISON SAN ANTONIO, TEXAS



59

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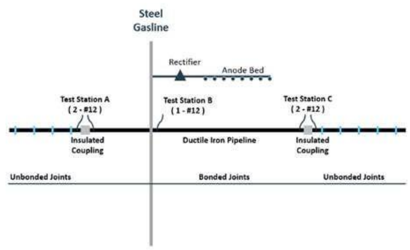
STRAT CURRENT RCOMMENDATION CRITERIA

- **Severe Stray Current Environment:**
  - Polyethylene encasement recommended for the affected area
  - Bonded joints recommended through the area indicated by the profile results
  - Electrical isolation of the bonded section
  - Install appropriate test leads and “current drain”

60

60

TYPICAL DUCTILE IRON PIPE BONDED SECTION FOR THE MITIGATION OF STRAY CURRENT INTERFERENCE



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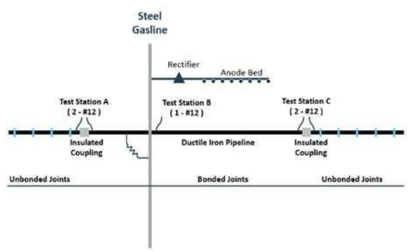
TYPICAL DUCTILE IRON PIPE BONDED SECTION FOR THE MITIGATION OF STRAY CURRENT INTERFERENCE



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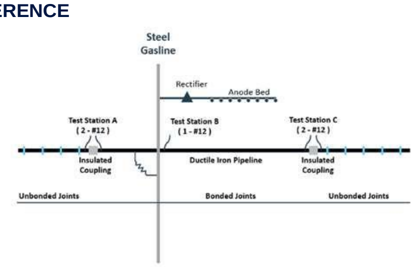
TYPICAL DUCTILE IRON PIPE BONDED SECTION FOR THE MITIGATION OF STRAY CURRENT INTERFERENCE



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BONDING DUCTILE IRON PIPE JOINTS

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BONDING DUCTILE IRON PIPE JOINTS

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BONDING DUCTILE IRON PIPE JOINTS

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BONDING DUCTILE IRON PIPE JOINTS

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BONDING DUCTILE IRON PIPE JOINTS

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BONDING DUCTILE IRON PIPE JOINTS

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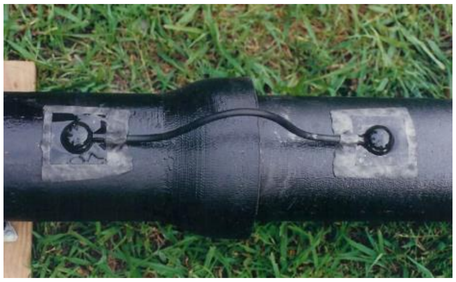
BONDING DUCTILE IRON PIPE JOINTS



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BONDING DUCTILE IRON PIPE JOINTS

Table 1
Suitable Conductor Sizes for Joint Bonding of Ductile Iron Pipe

Pipe Size (inch)	Quantity – Size of Bond Cable
3 to 14	2 - #8
16 to 36	2 - #4
42 to 64	2 - #2

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STRAY CURRENT RECOMMENDATION CRITERIA

- **Moderate Stray Current Environment:**
  - Polyethylene encasement recommended as indicated by the stray current profile results
  - Double polyethylene encasement generally recommended

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STRAY CURRENT RECOMMENDATION CRITERIA

- **Minimal Stray Current Environment:**
  - Polyethylene encasement recommended for a minimum of 20 feet perpendicular distance on either side of the crossing and any installation laid parallel to and within 10 feet of any cathodically protected pipelines

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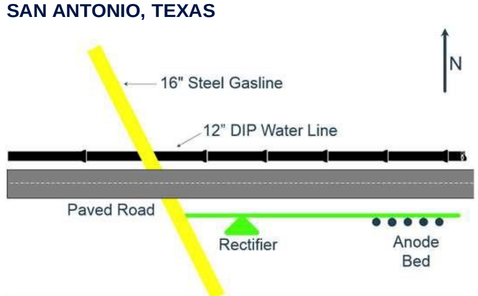
SAN ANTONIO, TEXAS



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PIPE-TO-SOIL POTENTIALS (INSTANT OFF) SAN ANTONIO, TEXAS

	Rectifier Off (mV)	Rectifier On (mV)	Voltage Change (mV)
East End	-430	-260	+170
Middle	-450	-610	-160
West End	-450	340	100

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MITIGATION DATA (INSTANT OFF) SAN ANTONIO, TEXAS

	P/S Normal (mV)	P/S with Interference (mV)	P/S with Direct Bond (mV)	P/S with 50 ohm Bond (mV)
East End	430	-260	-1,620	-900
Middle	-450	-610	-1,900	-980
West End	-450	-310	-1,650	-850

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CP CURRENT REQUIREMENTS
POLYETHYLENE ENCASED

- Operating Water Systems (DIPRA Tests) – 24 µa/ft²
- DIPRA Research – 23µa /ft²
- Others - 11 to 39 µa/ft²

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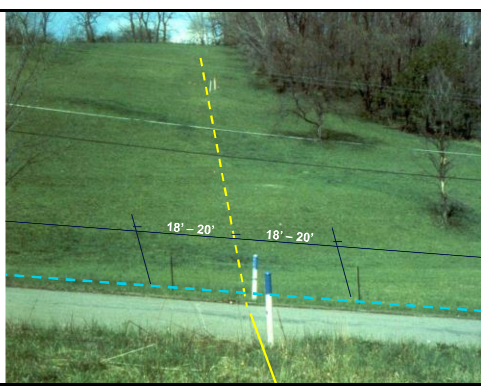

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GAS LINE CROSSING
CALL GAS MAIN OWNER…

- Is the line cathodicly protected?
- Galvanic anodes or rectified?
  - Anodes – wrap at crossing
- Where is rectifier/anode bed in relation to proposed WM
- Remote – wrap at crossing
- Closer than ½ mile - Call DIPRA for further investigation
  - Deep well, output, geometry etc.
- Field work and recommendations as needed

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SUMMARY . . .

- Sources
- Typical stray current environment
- Electrically continuous vs. discontinuous systems
- Shielding effect of dielectric barrier
- Very few problems have ever been reported to DIPRA
- Contact DIPRA if you suspect possible stray current problems

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SUMMARY . . .

- Water and Regulated Utilities work together to avoid problems
- Locations of impressed current systems
- Education of consulting engineers
- Address concerns in design instead of after installation

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TO ACHIEVE A CENTURY OF SERVICE FROM YOUR DI PIPE…

- Design
- Installation
- Corrosion Control
- O & M

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THANK YOU!

Paul H. Hanson, PE
Regional Director

Ductile Iron Pipe Research Association
10271 Normandy Ct.
Fishers, IN 46040
205.790.6704
phanson@dipra.org
www.dipra.org

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CIS and DCVG Survey over Pipelines

Sasan Hosein, Pond & Company

hoseins@pondco.com

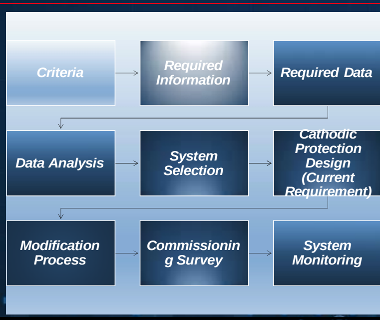
AUCSC

POND

AUCSC Corrosion Control
CIS & DCVG Survey over Pipeline

POND

Cathodic Protection System Survey Process

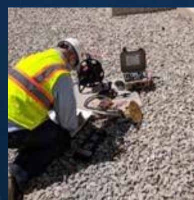


Corrosion Control Monitoring

- As an Operator, you must have an accurate pipeline location map with depth of cover information.
- All systems should provide the ability to test the cathodic protection system (i.e. test stations). "Adequate" number of test points required for regulatory compliance.
- Impressed Current Rectifiers must be inspected at least once every sixty days.
- Cathodic Protection Systems must be surveyed and evaluated at least once a year.
  - Criteria for protection is published in NACE SP-0169, "Control of External Corrosion on Underground or Submerged Metallic Piping Systems".
- The bottom line is to demonstrate corrosion control over the entire pipeline surface.

Acceptance (Annual) CP Services

- Surveys should be performed under direction of a Corrosion or Cathodic Protection Specialist.
- Surveys should include:
  - Rectifier operation
  - Electrical Continuity testing
  - Potential survey (CIP & DCVG)
  - System Adjustment
  - Design Survey
  - Dynamic and Static Interference testing
  - Soil Corrosivity Survey
  - Troubleshooting and Modification



Cathodic Protection Criteria

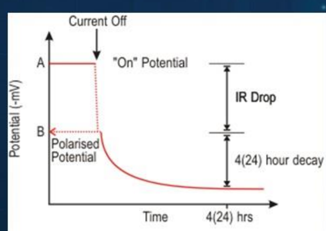
NACE International certified Corrosion Specialist or Cathodic Protection Specialist to Confirm Compliance Criteria:

- -850 mV Structure to Soil Potential

  Potential measured with a copper/copper sulfate reference cell and voltmeter. Measurement must allow for IR Drop.

- 100 mV Polarization

  Requires record of potential of structure prior to application of cathodic protection



What are Indirect Surveys?

- Over the line survey methods where data can be collected without directly exposing the pipeline. The survey data between multiple "tools" can then be aligned by GPS and/or pipeline station to identify direct assessment (DA) dig locations.
- Indirect survey method examples:
  - Close Interval Survey (CIS)
  - Direct Current Voltage Gradient (DCVG)
  - AC Current Attenuation (PCM)
  - Alternating Current Voltage Gradient (ACVG)
  - Soil Resistivity

Close Interval Potential Survey

Close Interval Potential Survey (CIPS)

- The principle of a close-interval potential survey (CIPS or CIS) is to record the pipe-to-soil (P/S) potential profile of a pipeline over its entire length by measuring potentials at intervals that do not significantly exceed the depth of the pipe (often ~1 m).
- The actual survey typically involves three distinct tasks:
  - Locating and marking the pipeline with stakes or flags inserted at regular intervals, based on tape measurements or chaining;
  - Data collection, including P/S potentials and notation of physical features along the right-of-way with global positioning system (GPS) coordinates collected separately for these features; and
  - Clearing the right-of-way of survey wire and other materials.

Close Interval Potential Survey (CIPS)

- Because the potential of interest is at the structure-electrolyte boundary, it is important to consider possible voltage (IR) drop errors that result from the flow of current through the earth between the pipe surface and the reference electrode(s).
  - Used technique includes the synchronized interruption of cathodic protection (CP) current sources.
  - It is a good practice to obtain potential waveforms at the start of a day's survey and throughout the day to confirm that interrupters remain synchronized and that no uninterrupted current sources influence the pipeline.

CIS Survey – Pipeline Integrity Evaluation

- Determine the effectiveness of cathodic protection
- Assess compliance with cathodic protection criteria
- Locate coating defects and/or areas of coating deterioration
- Detect AC and/or DC interference
- Identify areas of electrical or geologic current shielding
- Evaluate current attenuation
- Identify foreign contacts
- Detect areas of localized corrosion

CIS Survey – Equipment

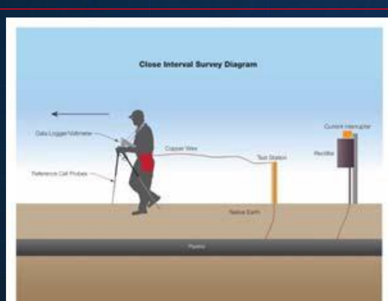
- Datalogger
- GPS antenna
- Survey Poles with Reference Electrodes
- Hip Pack with Light Wire
- Pipe Locator
- GPS Synchronizable Current Interrupters





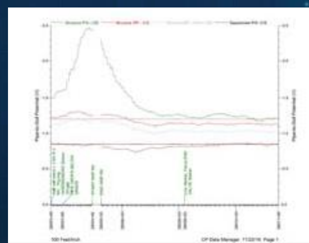


Methodology of CIS



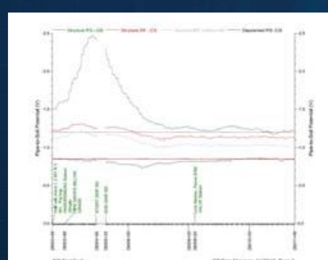
CIS Survey Advantage

- The CIS technique provides a complete P/S potential profile, indicating the status of CP levels.
- The most useful graphical presentation of CIS data is to plot the “on” and “off ” potentials together as separate profiles vs. distance.
- This condition must be explained or investigated.:
  - Localized dips in the potential profiles (to less negative values) may indicate the presence of a poor-quality coating or low-resistivity soils.
  - The difference between the “on” and “off ” potential values should also be noted. A reduction in this potential shift may also indicate a decrease in local P/S resistance or a problem with the distribution of protective current.



CIS Survey Advantage

- It may also be useful to complement the interrupted CIS with a “native” (depolarized) CIS; these data provides the opportunity to evaluate the 100 mV polarization CP criterion.
- The “native” survey may be conducted prior to the initial activation of the CP system for a new pipeline; however, the polarization criterion is more commonly applied for older piping with deteriorated coating.
- Other applications and variations of the CIS technique are presented in NACE SP0207-2007, “Performing Close-Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines.”



CIS Survey Advantage

- Potential Mapping of Entire Pipeline
- Potential Readings Between Test Points
- Coating Quality Information
- Identifying Critical Locations Along the Pipeline
- Providing Information for Pro-active Approach
- Prioritizing the Corrective Actions Schedule (Soil Corrosivity)
- Cost Efficiency and Saving for Maintenance and Minimizing Emergency System Interruptions

Direct Current Voltage Gradient (DCVG) Survey

What is DCVG?

- DCVG stands for Direct Current Voltage Gradient
- First developed in 1970's by John Mulvaney in Australia
- First used to locate insulation faults on telecom cable
- Successfully used worldwide for pipeline diagnostics
- Measuring the DC voltage gradient along the pipeline.
- Variety of techniques – often combined, and sometimes confused with close interval potential CP survey.
- Requires interruption of DC influences with a minimum of 100mv shift on the pipeline; pulsing on / off cycles.

Direct Current Voltage Gradient (DCVG) Survey

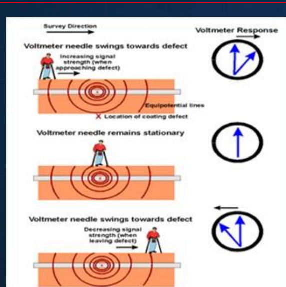
Direct Current Voltage Gradient (DCVG)

- Advantages
  - Extremely detailed coating assessment
  - Single operator
  - Relative sizing and location on pipe
  - Coating anomaly location physically marked on pipeline ROW
- Disadvantages
  - Manual recording or manual entry of data into datalogger
  - Heavily dependent on operator interpretations
  - Does not adequately assess CP effectiveness
  - Slow and tedious process on poorly coated pipeline
  - Can miss some coating defects on older pipelines with effective CP due to calcareous deposit buildup (can act as a dielectric barrier)

Direct Current Voltage Gradient (DCVG)

- DCVG can be effectively utilized to assess and prioritize coating condition on small discrete segments of pipeline.
- Coating defects can be sized
- Data can be recorded electronically and plotted for analysis
- Sensitive – Can detect and size small coating defects
- Single Operator (usually part of team)
- Equipment required: Zero centered voltmeter, data logger, GPS receiver

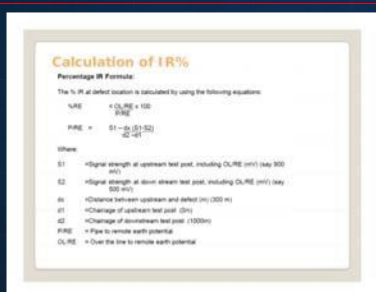
Direct Current Voltage Gradient (DCVG) Survey



Test Station and Indication Measurements

- Technician needs to collect shift calculations at upstream test lead and downstream test lead.
- IR drop measurements at each test station. This measurement is added to total shift for that T/S.
- Measurement of indications is collected by totaling the amount of mV IR drop at the indication site out to remote earth, perpendicular to the pipeline. (Crabbing out)

DCVG – IR% Calculation



Calculation of IR%

Percentage IR Formula:

The % IR at defect location is calculated by using the following equations:

$$\%IR = \frac{OL/RE \times 100}{P/RE}$$

$$P/RE = S1 - \frac{dx\,(S1-S2)}{d2-d1}$$

Where:

S1	=Signal strength at upstream test post, including OL/RE (mV) (say 900 mV)
S2	=Signal strength at down stream test post, including OL/RE (mV) (say 500 mV)
dx	=Distance between upstream and defect (m) (300 m)
d1	=Chainage of upstream test post (0m)
d2	=Chainage of downstream test post (1000m)
P/RE	= Pipe to remote earth potential
OL/RE	= Over the line to remote earth potential

Size categories of DCVG indications

Defect Assessment: DCVG survey indications are often prioritized, based on approximate size. Defects are graded based on %IR, which is based on voltage gradients measured and signal strength between (2) known test points:

- Category 1: 1 to 15% IR - Holidays in this category are often considered of low importance, and repair is not required.
- Category 2: 16 to 35% IR - Holidays in this category may be recommended for repair, based on proximity to groundbeds or other structures of importance.
- Category 3: 36 to 60% IR - Holidays in this category are generally considered worthy of repair.
- Category 4: 61 to 100% IR – Holidays in this category are generally recommended for immediate repair.

CIS & DCVG – Combined Integrity Assessment

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CIS & DCVG Data analysis

- There are several advantages to undertaking a combined CIPS and DCVG survey.
  - Same time by the same surveyors,
  - Same climatic and soil conditions without spatial errors.
- Digital survey equipment, each reading is stored along with the time, date and GPS coordinates; thus defects can easily be located if excavation is required.
- When two surveyors are utilized walking over top of the pipeline, the resultant measurement of a coating defect recorded over top of the pipeline appears as a sinusoidal waveform making for easy recognition of the defect.
- NACE Standard SP0207-2017.

CIS & DCVG Case Study

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CIP and DCVG Surveys

Anomaly Located During CIP & DCVG Surveys

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CIP and DCVG Surveys at Eielson

In 2021, the pipeline was exposed.

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CIP and DCVG Surveys

A broken cable was found. The cable is most likely from the local anodes installed for interference mitigation.

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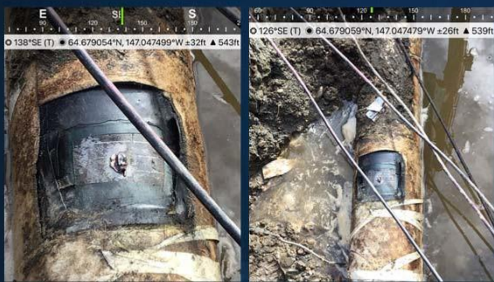
CIP and DCVG Surveys



CIP and DCVG Surveys

Corrosion Failures in Water & Wastewater Facilities, Parts 1 & 2

Anil Kumar Chikkam, Matergenics

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CORROSION FAILURES IN WATER & WASTEWATER FACILITIES (PART I)

ANIL KUMAR CHIKKAM, C.Eng, A.M.I.E
Lead – Metallurgy & Corrosion Laboratory
NACE CP II (66218)
API 571 Corrosion & Materials Professional (65994)
API 577 Welding Inspection & Metallurgy Professional (96519)
API 580 Risk Based Inspection Professional (93026)

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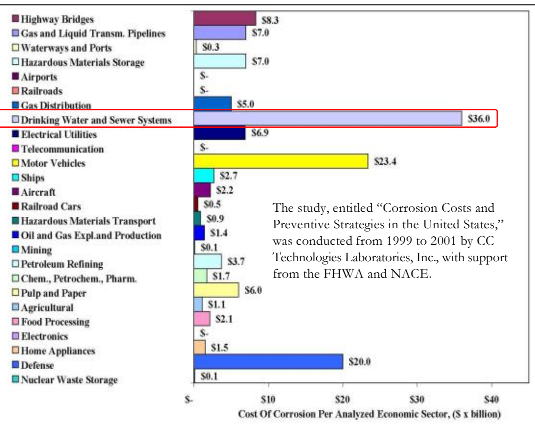

https://higherlogicdownload.s3.amazonaws.com/NACE/cedda8a4-c3c0-4583-b1b6-3b248e6eb1f2/UploadedImages/Resources/pdf/cost_corrosion.ppt

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Definition of Corrosion

"Corrosion: the deterioration of a material, usually a metal, by reaction with the environment."

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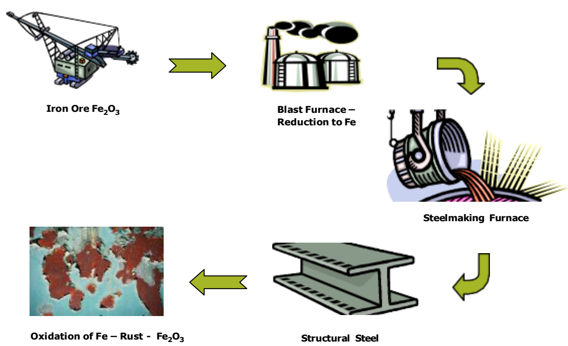
Corrosion Cycle



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Strategy

Identify corrosion mechanisms through failure analysis

↓

Determine likely causes

↓

Identify necessary remedial actions

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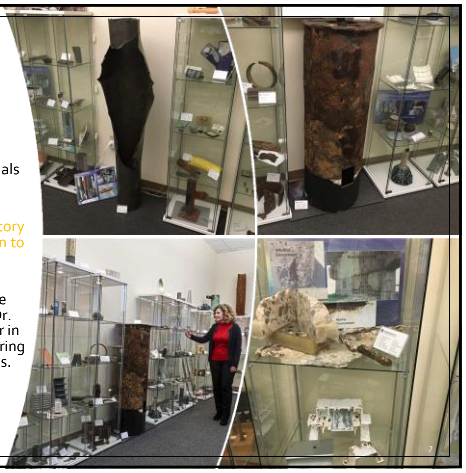
Failure Analysis

Failure: Negative Term

Failure Analysis: Very Positive

6

- Don't blame the metal, blame the human, and other lessons from a museum of materials failure.
- Each item has a story to tell and a lesson to impart.
- The museum is the accumulation of Dr. Zee's entire career in corrosion engineering and failure analysis.



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Failure Definition

1. Any change in the component which prevents the satisfactory performance of its intended function.
2. Failure as a human act and is defined as : Omission of occurrence or performance, non-performance, cessation of proper functioning or performance.
3. When expectations (specifications) are not met.
4. Collapse, Fracture and Catastrophic Events.

8

Causes of Failure....

Materials do not fail. They follow laws of physics and chemistry perfectly. All failures are due to human error.

There are three basic types of human errors:

a) Errors of knowledge

Insufficient knowledge, education, training, and experience

b) Errors of performance (negligence)

Include errors in calculations and detailing, incorrect reading of drawing, specifications, and defective manufacturing and workmanship. There are errors of execution, and are the result of lack of care

c) Errors of intent (greed)

Is an error of intent which is done with full knowledge

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What is Failure Analysis?

- Failure analysis is the process of collecting and analyzing data to determine the cause of a failure and how to prevent it from recurring.
- It is important in any industry to identify the primary cause of failure to avoid similar failures in the future or explosions.

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The code of Hammurabi

First Construction Code in History

- **Building failures resulting in death to the homeowner = death to builder**
- **Son for a son**
- **Slave for a slave**
- **At builder's expense**

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The South Wall Frieze

Supreme Court of the United States

http://nathanielsegal.mysite.com/TenCommandments/10SupremeCourtBuilding.html

12

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Just the facts…

- ✓ What happened? How did it fail? Mode of failure…
- ✓ Why did it happen? Root Cause Analysis
- ✓ Who was responsible? Designers, Contractors, Inspectors…
- ✓ Who should have done what? Codes, Standards…
- ✓ Reports, Technical Conclusions
- ✓ Engineering Solutions: Repair, Replacement, Inspection Frequency
- ✓ Legal Issues

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What is Water Main?

- Water main is a primary underground pipe in a municipal water distribution system.
- Water mains take clean water from a city's water treatment plant to homes, properties and businesses.

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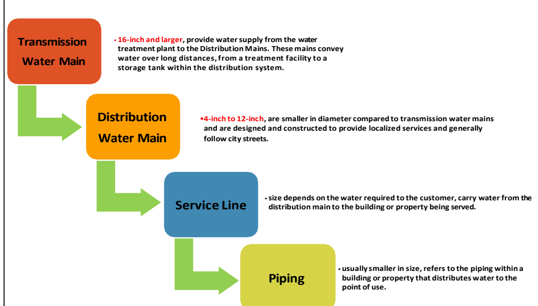
Type of Pipelines in Water Industry



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Background

- Cisterns — Water delivered through conduits made of stones and bricks.
- Cisterns — Water delivered through Aqueducts and Canals. 312 B.C.
- Reservoirs — Water delivered through Aqueducts and lead pipes. 100 – 300 A.D.
- River Thames — Water delivered through lead or baked clay pipelines. A.D. 1236
- New River Company — Water was delivered to every home in the city of London for the first time in 1619.

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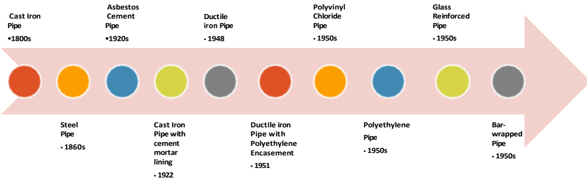
History - Types of Pipe for Water Main Construction



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Applications - Types of Pipe for Water Main Construction (Adopted from: Najafi, 2010)

Pipe Material	Applications
Cast iron pipe	1. Mainly Potable water distribution 2. Few sewer systems
Ductile iron pipe	1. Mainly Potable water distribution 2. Few sewer systems
Steel pipe	1. Transports fluids such as natural gas, crude oil 2. Potable water transmission
Asbestos cement pipe	1. Water systems 2. Sewer systems
Reinforced concrete pipe	1. Non-pressure applications 2. Low-pressure applications
Prestressed concrete cylinder pipe	1. High pressure applications 2. Sewer systems 3. Industrial cooling systems
Polyvinyl chloride pipe	1. Water systems 2. Sewer systems
Polyethylene pipe	1. Gas distribution 2. Water systems 3. Sewer systems 4. Nuclear and industrial process piping 5. Electrical and communication duct
Bar-wrapped steel-cylinder concrete pipe	1. Pressure applications 2. Treatment plants
Glass reinforced pipe	1. Water systems 2. Sewer systems

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Cast Iron - Classification

- White Cast Iron (combined carbon Fe_3C)
- Malleable Cast Iron (free carbon as irregular particles)
- Chilled Cast Iron (white cast iron at the surface and gray cast iron at the interior)
- Grey Cast Iron (Flake Graphite)
- Spheroidal Graphite (SG) / Ductile Cast Iron / Nodular Cast Iron (free carbon as spheroids)

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Cast Iron Pipe - Background

- In the United States, the first cast iron pipe installations (which was imported from England and Scotland) was at Bethlehem, Pennsylvania, where it replaced deteriorated wooden mains.
- In 1819, production began at several charcoal furnace plants in New Jersey.
- At about the same time, a foundry located at West Point, New York, also produced limited amounts of cast iron pipe.

Reference: Cast Iron Soil Pipe And Fittings Handbook, Twelfth Printing 2006

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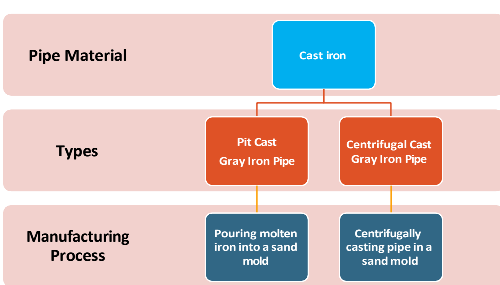
Cast Iron Pipe – Types and Manufacturing Process



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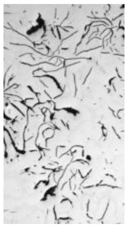

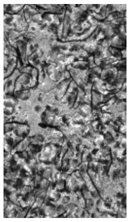

Cast Iron Pipe - Microstructure

- Distribution of graphite flakes in the iron matrix.
- The matrix could be pearlitic or pearlitic-ferritic or ferritic-pearlitic or ferritic.

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Ductile Iron (DI) Pipe - Background

- In 1948, the first ductile iron pipe was produced experimentally.
- In 1960s, US began using DI pipes for water and wastewater system.
- The nominal composition in mass fraction for unalloyed ductile iron is 3.1 to 3.9 percent carbon, 2.1 to 2.8 percent silicon, and less than 1 percent of other elements (chromium, nickel, molybdenum, and others) with the balance iron.
- Adding the magnesium (Mg) alloy results in a remarkable change in the microstructure by causing the carbon in the iron to assume a spheroidal or nodular shape which is different than the flake form of graphite observed in cast iron pipe.

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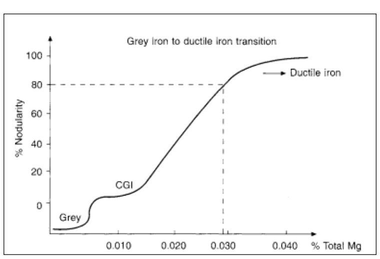
Ductile Iron (DI) Pipe - Background



The effect of Mg content on the transformation of graphite morphology from flake to compacted and ultimately to spheroidal graphite.

Reference: Foseco Ferrous Foundryman's Handbook

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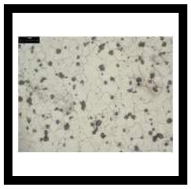
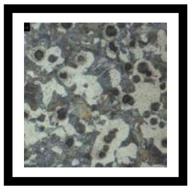
DI Pipe - Microstructure

- normally consists of pearlite or pearlite and ferrite with graphite nodules surrounded with ferrite.
- DI family: ferritic, ferritic pearlitic, Pearlitic, Martensitic, Bainitic, austenitic and Austempered Ductile Iron (ADI).





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What is water main break?

Prior to failure, pipe appears sound, so failures are not often recognized as corrosion but are usually referred to merely as "main breaks".

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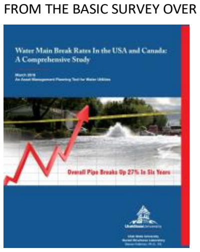
	Length	Failures	2018 Break Rate	2012 Break Rate	% Change
AC	21,589	2,240	10.4	7.1	46%
CI	48,471	16,864	34.8	24.4	43%
CSC	4,940	152	3.1	5.4	-43%
DI	47,595	2,627	5.5	4.9	13%
PVC	37,704	878	2.3	2.6	-10%
Steel	4,765	362	7.6	13.5	-44%
Other	5,506	680	12.4	21	-41%
Total	170,569	23,803	14.0	11	27%

SUMMARY OF FAILURE DATA FROM THE BASIC SURVEY OVER A 12-MONTH PERIOD



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Departments

Material Matters

Water Main Breaks: Case Studies and Analysis

The costs associated with broken water mains are rising. As this infrastructure ages, the investment necessary for repairs and replacements increases. It is estimated that the U.S. should spend over $1 trillion on underground water infrastructure work over the next 25 years, and $1.7 trillion over the next 40 years. Water main breaks lead to extensive costs and make up a significant portion of municipal budgets due to repair costs, flood damage, loss of revenue for those companies impacted, and the disruption to essential public services like health care or fire protection.

Figure 1: Photograph of the broken water main in Case Study 1.

Issues arise when ductile iron (DI) pipe makers claim a 100+ year lifespan, yet research indicates the average lifespan to be about 50 years. To make matters worse, in several water main projects conducted by researchers Mehrooz Zamanzadeh, Edward Larkin, Peyman Taheri, Alyson Chur, Aaron Ulmer, Erik Lahti, and Anil Kumar Chikkam with Matergenics Inc. (Pittsburgh, Pennsylvania, USA), service life was a mere 20 to 30 years.

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Causes of Water Main Breaks

- Some of the causes of water main breaks are:
  1. Inadequate design
  2. Improper installation
  3. Surge or water hammer
  4. Soil movement
  5. Internal corrosion
  6. External corrosion
  7. Temperature differential
  8. Manufacturing defects
  9. Impact

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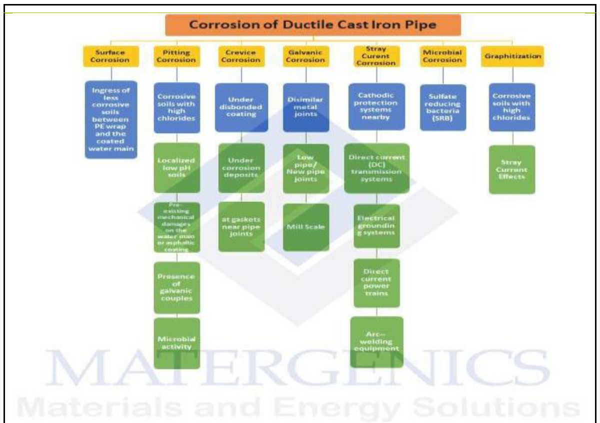

Note: Possibilities of external corrosion of DI pipe

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Graphitic Corrosion

- In water industry, graphitic corrosion and graphitization are interchangeably used. However, they are different forms of corrosion.
- **graphitic corrosion**—deterioration of cast iron wherein the metallic constituents are selectively leached or converted to corrosion products, leaving the graphitic particles intact.
- **graphitization**—the formation of graphite in iron or steel, usually from decomposition of iron carbide at elevated temperatures.
- "*When in Rome, do as the Romans do*". So let us consider that both graphitic corrosion and graphitization are same, keeping water utility in mind.

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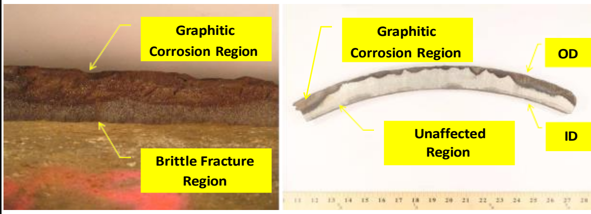
Graphitic Corrosion



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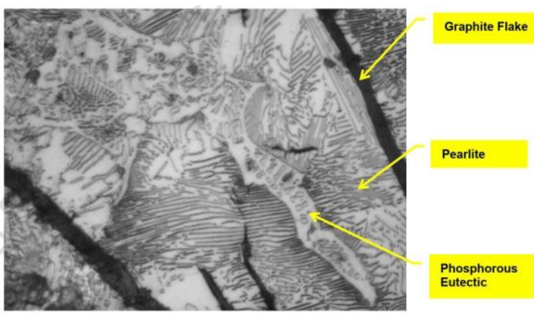

Photograph at 1000x showing the large phosphorous eutectics within the microstructure of the pipe. Etched with 2% Nital.

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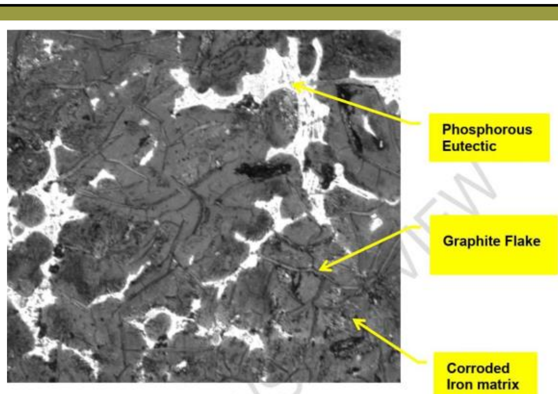

Photograph at 200x showing the graphitic corrosion products and non-corroded phosphorous eutectics. Etched with 2% Nital.

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Types of Graphitic Corrosion

- Surface-type graphitization is not detrimental to the cast iron pipe as it results only in a thin graphite film on the pipe. Eventually corrosion ceases and the iron beneath the film remains intact.
- However, plug-type graphitization results in the formation of plugs of graphite through the pipe wall thickness and weaken the pipe at these regions.
- In Complete graphitization, iron constituents will be corroded and only a graphite shell remains. In service, an increase in external stresses, water pressure and water hammer will result in the pipe break at these plugged/ weakened areas.
- Reference: **Corrosion as a Primary Cause of Cast-Iron Main Breaks**, John H. Fitzgerald, A contribution to the JOURNAL, submitted on Apr. 1, 1968, by John H. Fitzgerald III, Vice P·res., The Hinchman cs., Detroit.

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Trend in Wall Thickness

Year of Installation	Material	Wall Thickness (in.)
1908	Cast iron	1.58
1952	Cast iron	1.22
1957	Cast iron	0.94
1965	Ductile iron	0.58
1976	Ductile iron	0.43
1991	Ductile iron	0.38

Change in Wall Thickness Specifications (permitted under AWWA recommendations) for a 36-in. Pipe Operating at 150 psi

Note: The corrosion resistance of ductile iron pipe is equal to cast iron pipe

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Graphitic Corrosion – Important Observation

- The graphitic corrosion products of ductile-iron specimens had the same general characteristics and adhesive properties as were observed on corroded specimens of plain cast iron. Hence, it appears that ductile cast iron and plain cast iron not only corrode at about the same rate in the same soil but that the pattern of corrosion and the nature of the corrosion products are also similar in the same.

- Reference: **Exterior Corrosion of Cast-Iron Pipe** - A paper presented on Jun. 4, 1964, at the Annual Conference, Toronto,Ont., by Melvin Romanoff, Physical Chemist, National Bureau of Standards, Corrosion Sec., US Dept. of Commerce, Washington, D.C.

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Galvanic Corrosion

- Corrosion may result because of contact between dissimilar metals or because of local differences in the packing of the soil, which may produce oxygen-concentration cells; the regions with less oxygen are anodic with respect to those with more.

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Galvanic Corrosion

- This older pipe section is typically cathodic to a newer pipe, even when the composition of the older and newer pipe is identical. When a section of DIP is replaced, the new section in contact with the older, passivated iron surface can locally corrode galvanically in the soil environment.
- Areas on the pipe covered with the oxide scale are cathodic to areas of bare metal, so galvanic corrosion of the bare metal can occur in the soil environment

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Corrosion due to Microbial Activity

- Buried ductile iron and grey cast iron pipe are susceptible to microbiologically influenced corrosion (MIC).
- Sulfate-reducing bacteria (SRB) is responsible for anaerobic corrosion of buried iron structures.

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Stray Current Corrosion

- Stray current corrosion is caused by the discharge of stray direct current from the surface of a buried metal.
- Stray currents may emanate from welding or plating operations, electrified railways, cathodic protection systems, and other sources of direct current.
- In travelling through the earth, these currents frequently are picked up by the water main at one point (cathode) and discharged at another (anode).

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AUCSCO

CORROSION FAILURES IN WATER & WASTEWATER FACILITIES (PART II)

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CASE STUDIES

46

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Case History 1: GRAPHITIZATION OF CAST IRON WATER MAIN

- A 36-inch (91.44 cm) diameter cast iron (CI) water main failed catastrophically. Water from the leak covered many blocks.
- The CI pipe was reported to be approximately 90 years old.
- The broken sections of the pipe are shown in Figure 2.

Figure 2: Photographs showing the pieces of the broken water main.

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Case History 1: Field Testing (Visual Examination)

- Conditions within the trench is shown in the Figure 3.
- Visual examination indicated that the initial failure of the pipe had resulted in a large window section having broken out.
- The window section was measured to be 36 inches (91.44 cm) long and 18 inches (45.72 cm) wide.

Figure 3: Photograph showing the conditions within the excavation trench. Remainder of failed pipe in background. Note wood railroad ties at right.

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Case History 1: (On-Site Soil Resistivity Measurements)

Location	A at failed location, along pipe	B close to failed location, 3 feet from pipe	C 10 feet from failed location, 3 feet from pipe	D 10 feet from failed location, 3 feet from pipe	E 50 feet from failed location, 3 feet from pipe	F 100 feet from failed location, 3 feet from pipe
Pin Spacing	**Soil Resistivity Results from Field Testing (ohm-cm)**					
2 feet	460	3830	3256	7660	53,623	16,853
4 feet	245	4903	3600	3677	44,431	19,917
6 feet	115	3792	2873	125,248	25,279	14,938
8 feet		1992	1272	735	19,917	8426
10 feet		1341	1417	1341	12,257	3064
Layer Depth	**Soil Layers Resistivity (ohm-cm) by Barnes Layer Calculation**					
0 – 2 feet	460	3830	3256	7660	53,623	16,853
2 – 4 feet	167	6809	4027	2419	37,929	24,343
4 – 6 feet	56	2609	2046	1923	13,576	9959
6 – 8 feet		822	476	185	12,172	3651
8 – 10 feet		581	2614	585	4828	864

Table 1: Soil Resistivity (ohm-cm) Analysis from Field Measurements as per ASTM G57

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Case History 1: Soil Analysis

- On-site soil resistivity measurements revealed that soil around the pipeline is corrosive as per Table 2.

Resistivity Range (ohm-cm)	Corrosivity
0 - 1000	Very severe
1,001 – 2,000	Severe
2,001 – 5,000	Moderate
5,001 – 10,000	Mild
>10,000	Very mild

Table 2: Classification of Soil Corrosivity Based on Resistivity

- Five soil samples were collected from the excavation trench near the failed pipe.

Test	Specification
Soil Resistivity	ASTM G57
Moisture Content	ASTM D2216
pH	ASTM G51
Sulfates	ASTM C1580, AASHTO T290
Sulfides	Colorimetric
Chlorides	ASTM D512, AASHTO T291
Redox Potential	ASTM G200
LPR Corrosion Rate	ASTM G102

Table 3: Soil Test Specifications

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Case History 1: Laboratory Investigation (Soil Analysis)

Test	Soil Sample No. 1	Soil Sample No. 2	Soil Sample No. 3	Soil Sample No. 4	Soil Sample No. 5
Location of Sample	top of pipe	3 feet from North side of pipe, 4 feet from surface	3 feet from North side of pipe, from surface	bottom, in contact with pipe	3 feet from South side of pipe, 6 feet from surface
Soil Resistivity (ohmcm) As Received	1738	246	1488	1730	2356
Moisture Content (wt%) As Received	14	27	20	18	18
Saturated Soil Resistivity (ohmcm)	1098	98	1415	1496	2270
pH	5.99	7.06	7.8	3.32	7.13
Sulfates (ppm)	740	773	61	290	118
Sulfides (mg/l)	0.06	0.57	0.10	0.05	<0.04
Chlorides (ppm)	94.10	78.47	185.00	160.00	31.20
Redox Potential (mV)	556.8	719.3	667.4	578.6	560.4
LPR Corrosion Rate (mpy)	6.34	>40.00	3.19	10.62	5.57

Table 4: Laboratory Soil Analysis Results

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Case History 1:
Laboratory Investigation
(SEM/EDS Analysis of Soil Samples)

Figure 4: Photograph showing soil sample no. 2 which had the lowest measured resistivity value.

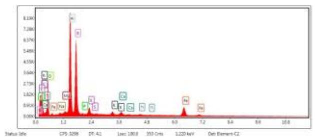

Figure 5: EDS spectrum of the soil sample no. 2 which had the lowest measured resistivity value.

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Case History 1:
Laboratory Investigation
(XRD Analysis of Soil Samples)

Compound	Formula	Sample No. 1	Sample No. 2	Sample No. 3	Sample No. 4	Sample No. 5
Silica	SiO_2	73.9	34.7	61.6	63.0	68.7
Muscovite	$KAl_2(AlSi_3O_{10})(F,OH)_2$	13.3	4.1	11.4	19.5	22.0
Kaolinite	$Al_2Si_2O_5(OH)_4$	3.6	1.7	3.4	6.1	2.0
Microcline	$KAlSi_3O_8$	3.4	---	2.3	1.3	1.6
Albite	$NaAlSi_3O_8$	3.0	---	---	2.7	3.6
Clinochlore	$(Mg_5Al)(AlSi_3)O_{10}(OH_8)$	1.8	---	2.7	6.1	1.9
Hematite	Fe_2O_3	0.7	---	2.5	1.3	0.2
Calcite	$CaCO_3$	0.3	---	4.6	---	---
Mullite	$Al_6Si_2O_{13}$	---	49.0	9.3	---	---
Magnetite	Fe_3O_4	---	6.3	2.2	---	---
Gehlenite	$Ca_2Al(AlSiO_7)$	---	4.2	---	---	---
Goethite	FeO(OH)	---	---	---	---	---
Akaganeite	FeO(OH,Cl)	---	---	---	---	---
Schreibersite	Fe_3P	---	---	---	---	---
Siderite	$FeCO_3$	---	---	---	---	---

Table 5: X-Ray Diffraction Results for Soil Samples.

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Case History 1:
Laboratory Investigation
(Microbiological Testing of Soil)

- All five soil samples tested positive for each of the five types of bacteria.

Bacteria Type	Positive/Negative
Low Nutrient Bacteria	Positive
Iron Related Bacteria	Positive
Anaerobic Bacteria	Positive
Acid Producing Bacteria	Positive
Sulfate Reducing Bacteria	Positive

Table 6: Microbiological Analysis Test Results

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Case History 1: Laboratory Investigation (Visual Examination of the Failed Pipe)

- Along one of the fractured edges of the window and the cross-section extracted from the pipe, the depth of corrosion can be seen as shown in Figure 6.

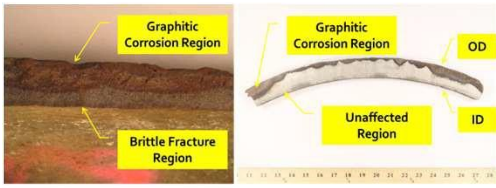

Figure 6: Photographs showing the depth of corrosion.

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Case History 1: Laboratory Investigation (Chemical Analysis of Pipe)

- A quantitative chemical analysis of the failed cast iron pipe is shown in the Table 7 and compared the test data with ASTM A74 chemical requirements.

Element	Failed Pipe	ASTM A74
Total Carbon	3.61	
Graphitic Carbon	1.87	
Manganese	0.28	---
Phosphorus	0.48	0.38 Maximum
Sulfur	0.12	0.15 Maximum
Silicon	1.22	---
Chromium	0.25	0.50 Maximum
Nickel	0.10	---
Molybdenum	0.013	---
Aluminum	0.004	0.50 Maximum
Titanium	0.061	0.10 Maximum
Lead	0.018	0.015 Maximum
Copper	0.22	---
Carbon Equivalent	4.177	4.10 Minimum

Table 7: Chemical Analysis (wt%)

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Case History 1: Laboratory Investigation (Metallographic Examination)

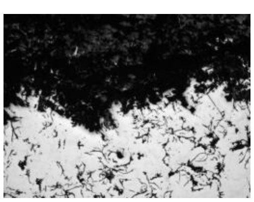

Figure 7: Photograph at 50x showing the graphite flake morphology and corrosion of the pipe at the OD surface. As polished.

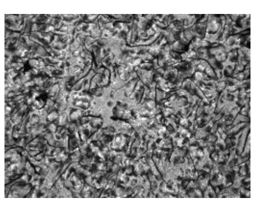

Figure 8: Photograph at 50x showing the microstructure near the OD surface. 2% Nital.

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Case History 1: Summary of Findings

- **Primary Cause** – Graphitization had reduced the wall thickness of the pipe effectively by up to 70% at some locations. In graphitization, the iron is removed from the cast iron by corrosion, leaving behind corrosion products and graphite, which is very brittle.
- **Root Cause** – The soil chemistry in contact with the pipe was very corrosive in the area of the failure. This promotes graphitization and loss of wall thickness in service.

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Case History 2:

STRAY CURRENT CORROSION OF DUCTILE IRON WATER MAIN

- Failed 8- inch (20.32 cm) DI water main crosses under the 30-inch (76.2cm) cast iron gas pipeline on a 45 degree angle. The water pressure within this area is around150 psi.

Figure 9: Photograph showing the failed water main pipe under the gas pipeline.

Figure 10: Photograph showing that the failed pipe is removed, and two (2) new pipe sections are installed.

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Case History 2: Field Testing

Figure 11: Photograph showing presence of stray current (0.612A).

Figure 12: Photograph showing installation of anodes.

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Case History 2: Soil Analysis

Soil Sample No.	Location Description
1	Below the failed pipe section (at leak)
2	Bottom of old pipe section that is intact
3	Top of old pipe section that is intact

Table 8: Soil Sample Location Description

Test	Soil Sample No. 1	Soil Sample No. 2	Soil Sample No. 3
As Received Soil Resistivity (ohm-cm)	1690	7610	4839
As Received Moisture Content (wt%)	14	10	10
Saturated Soil Resistivity (ohm-cm)	1576 (8)	5910	3689 (0)
pH	8.57 (3)	8.40 (0)	9.40 (3)
Sulfates (ppm)	425	124	780
Sulfides(mg/l)	<0.04 (0)	0.06 (2)	0.11 (2)
Chlorides (ppm)	216	41.8	122
Redox Potential (mv)	397.8 (0)	459.8 (0)	370.6 (0)
LPR Corrosion Rate (mpy)	3.59	2.84	2.31
Total Points	**(11)**	**(2)**	**(5)**

Table 9: Laboratory Soil Analysis Results (Points as per Appendix A of AWWA C105/ANSI A21.5).

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Soil Test Evaluation for Ductile Iron Pipe
10-Point System as described in Appendix A of ANSI/AWWA C105/A21.5

Soil Characteristics	Points*
Resistivity (ohm-cm)	
< 1,500	10
≥ 1,500–1,800	8
> 1,800—2,100	5
> 2,100—2,500	2
> 2,500—3,000	1
> 3,000	0
pH	
0–2	5
2–4	3
4–6.5	0
6.5–7.5	0**
7.5–8.5	0
> 8.5	3
Redox Potential	
> + 100 mv	0
≥ 50 to +100 mv	3.5
0 to +50 mv	4
Negative	5
Sulfides	
Positive	3.5
Trace	2
Negative	0
Moisture	
Poor drainage, continuously wet	2
Fair drainage, generally moist	1
Good drainage, generally dry	0

Ductile Iron Pipe Research Association (DIPRA) 10 point system

- Ten points or greater indicates that soil is corrosive to Ductile Iron Pipe.
- ** If sulfides are present and low (<100 mv) or negative redox-potential results are obtained, 3 points should be given for this range

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Case History 2: Laboratory Investigation (SEM/EDS Analysis of Corrosion Products)

- Elemental composition of the corrosion products from the perforation area of the failed pipe is shown in Figure 13.
- Chlorine as a corrosive species was found in the corrosion products. The semi-quantitative elemental results are given in the Table 10.

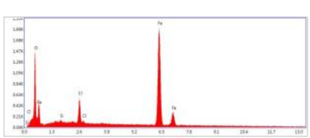

Figure 13: EDS spectrum of the corrosion products. Note chlorine peak.

Element	Wt%
Oxygen	17.58
Aluminum	---
Silicon	0.26
Chlorine	4.95
Calcium	---
Iron	77.21

Table 10: EDS Elemental Results of Corrosion Products (wt%)

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Case History 2: Laboratory Investigation (Visual Examination of the Failed Pipe)

Figure 14: Photograph showing the three holes in the DI pipe.

Figure 15: Photograph showing the distribution of graphitic corrosion in ring section extracted at the leak area. Through wall graphitization can be clearly seen at the leak area.

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Case History 2: Summary of Findings

- **Primary Cause** – The 8-inch (20.32 cm) DI water main failed as a result of graphitic corrosion of the outside diameter bottom surface.
- **Root Cause** – Graphitic corrosion was due to stray current effects, corrosive soil, which contained high chlorides and sulfates, and a synergistic effect of those two corrosion mechanisms. Because it is such a steep road, it is likely that winter deicing salt applications are exceptionally high, adding significantly to the corrosiveness of the soil.

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Case History 3:

GALVANIC CORROSION OF DUCTILE IRON WATER MAIN

- During the process of fixing the leak described in case history 2, three more leaks were observed on the same water main in the same street at different locations.

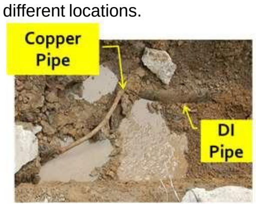

Figure 16: Photograph shows the condition within the trench. The failure of the pipe occurred as a result of a hole in the top side of the pipe (12 O'clock position).

Figure 17: Photograph showing the pipe section cut from the failed location of the failed water main pipe. The perforation of the pipe is close to the copper service line connection.

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Case History 3: Soil Analysis

Soil Sample No.	Location Description
1	Backfill
2	Next to leak
3	On top of gas pipe
4	At the leak
5	Below the pipe

Table 11: Soil Sample Location Description

Test	Soil Sample No. 1	Soil Sample No. 2	Soil Sample No. 3	Soil Sample No. 4	Soil Sample No. 5
As Received Soil Resistivity (ohm-cm)	5410	16,160	524	11,300	380
As Received Moisture Content (wt%)	5	6	17	9	17
Saturated Soil Resistivity (ohm-cm)	1610 (8)	4676 (0)	449 (10)	3912 (0)	411 (10)
pH	6.59 (0)	8.33 (0)	6.51 (0)	9.14 (3)	7.91 (0)
Sulfates (ppm)	920	170	890	114	38
Sulfides(mg/l)	<0.04 (0)	0.08 (2)	0.06 (2)	0.08 (2)	0.72 (3.5)
Chlorides (ppm)	80.5	210	1751	61.4	908
Redox Potential (mv)	445.1 (0)	402.8 (0)	178.1 (0)	420.6 (0)	421.9 (0)
LPR Corrosion Rate (mpy)	3.44	2.65	5.09	2.79	7.28
Total Points	**(8)**	**(2)**	**(12)**	**(5)**	**(13.5)**

Table 12: Laboratory Soil Analysis Results (Points as per Appendix A of AWWA C105/ANSI A21.5).

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Case History 3: Laboratory Investigation

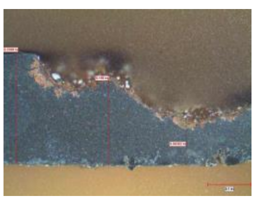

Figure 18: Stereoscope image showing the profile of the cross-section extracted from the corroded area next to perforation. Metal loss due to corrosion attack can be clearly seen. Mag. 7X.

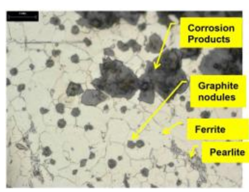

Figure 19: Photomicrograph of the inner surface shows nodules of graphite, pearlite (dark islands) and ferrite (light background) which indicates that the material of the water main is ductile iron. Mag. 400X. Etched with 2% Nital.

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Case History 3: Summary of Findings

- **Primary Cause** – The 8-inch (20.32 cm) ductile iron water main failed as a result of galvanic corrosion. Corrosion was observed only around the copper service line that was connected to DI pipe without insulation. The perforation was close to the tapping ferrule.
- **Root Cause –** The failure is most likely due to the mechanical damage of PE sheet at copper service line, and then galvanic corrosion between uninsulated copper service line and DI pipe.

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Conclusion

From the above case studies and the experience of field testing of more than 28 water main breaks, the following conclusions are made:

- The corrosion resistance of ductile iron pipe is equal to cast iron pipe. However, the longevity of cast iron pipe is primarily due to wall thickness.
- PE encasement or PE wrap reduces but not eliminate the external corrosion of DI pipe.

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Conclusion

- Damage of PE encasement or PE wrap is obvious during the installation. CP might prevent corrosion at the PE wrap damaged areas but not the other areas of the pipe under the PE wrap that is in contact with the soil or water.
- Ten-point system specified in AWWA C105 A21.5 is conservative and does not provide the accurate information on the corrosivity of soil towards DI pipe.

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Recommendation for Remediation

- Mill applied (or shop coated) asphalt coating on the exterior surface of the cast iron pipe was ≈1 mil thick and it could be only for aesthetic purpose. In our opinion, it does not offer any significant long-term protection against corrosion attack by aggressive soils.
- Selective backfill is often specified where pipe is to be laid in very corrosive soil. However, selective backfill alone is not considered adequate corrosion control.

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Recommendation for Remediation

- PE encasement is an easy option for gray cast iron and ductile iron pipe in most environments. However, if PE sheet is damaged, existing corrosive soil or contaminated new selective backfill could get in contact with pipe and result in localized corrosion attack with time.
- CP can be applied in conjunction with PE encasement. PE wrap will shield CP current from reaching the pipe surface. However, at the areas where PE sheet is damaged, CP current can reach the pipe surface.

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Corrosion Program as a Fail-Safe System

Overall approach to corrosion risk assessment and corrosion mitigation of a water main could be as follows:

1. Pre-assessment stage
2. Indirect assessment stage
3. Direct assessment stage

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Pre-Assessment Stage

- Desk study of soil types (USGS data) in the area. Mapping the existing data into a GIS to create a corrosion map (soil corrosivity map) so that the assets that are most at risk can be easily identified, inspected, and protected.
- Figure 20 below shows the soil corrosivity map for steel in USA.

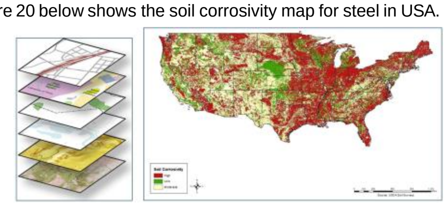

Figure 20

75

75

Indirect Assessment Stage

- On-site soil resistivity measurement.
- Collection of soil samples and chemical and corrosivity analysis of soil samples in Matergenics soils lab and modeling for remaining life.
- Electrochemical potential measurements.
- Look for correlations among the above data to identify susceptible areas of pipe corrosion for the direct assessment stage.

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Direct Assessment Stage - Sensor Device

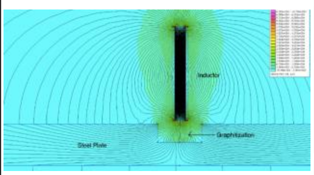

Figure 21: Photograph showing the working principle of the sensor.

Figure 21 (Cont.): Photograph showing the sensor.

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Test	Soil Sample from Virginia Ave Leak	Soil Sample from Lillian St. Leak	Soil Sample from 1145 Ridgeland Ave Leak	Soil Sample from 16th street Leak	Soil Sample from 2800 Block Eccles Street Leak
As-Received Soil Resistivity (ohm-cm)	636	1900	3768	13240	--
As-Received Moisture Content (wt.%)	17	21	10	7	22
Saturated Soil Resistivity (ohm-cm)	458 (10)	1627 (8)	1798 (8)	6130 (0)	1282 (10)
pH	6.75	7.01	6.62	10.84 (3)	7.26
Sulfates (ppm)	460	480	800	84	860
Sulfides (mg/L)	1.60	<0.04	<0.04	<0.04	7.00
Chlorides (ppm)	421	166	24.10	153	193
Redox Potential (mV)	485.5	420.8	468.4	395.9	499.4
LPR Corrosion Rate (mils per year) [Note: 1 mil = 0.001-inch]	15.02	4.25	5.49	1.65	8.64
Sulfides (SRB Test)	Positive (3.5)	Positive (3.5)	Positive (3.5)	Positive (3.5)	Positive (3.5)
Total Points as per Appendix A of AWWA C105/ANSI A21.5	13.5	11.5	11.5	6.5	13.5

Table 13: Soil Analysis Results (Points)

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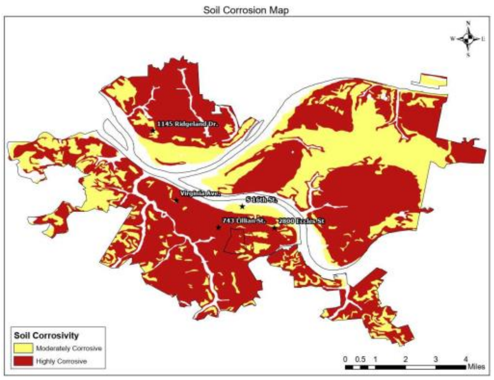

Figure 22: Pittsburgh Soil Corrosivity Map

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Questions?

Thank you for your attention!

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Installation of Cathodic Protection Systems in Water Towers

Adam Freeman, Freeman Industries, Inc.

adam.freeman@freemanindustriesinc.com

Installation of Cathodic Protection Systems in Water Towers

Freeman Industries, Inc.
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(440) 858-2600
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CP System Components

- Rectifier
  - Automatic potentially controlled circuit
  - Single or multiple circuits
- Anode
  - Material and configuration of anode system
- Control Cell
  - $Cu/CuSO_4$
- DC Wiring
  - Anode and structure ground feeds and Control wires

Rectifier

- Most modern CP systems in water towers use automatic potentially controlled rectifiers
- Various capacities available
- Some water towers require multiple circuits
  - Independent circuits for bowl and riser

Anode Material

- Platinum-niobium wire on polyester rope
  - Long lifetime
  - Lightweight
- Mixed metal oxide
  - Titanium substrate
  - Niobium substrate

Anode Configuration

- Vertical systems
  - Anodes hung from the roof of the tank
- Submerged system
  - Anodes and wiring under water line
- Ice resistant systems
  - No anchors on outer wall of tank

Control Cell

- $Cu/CuSO_4$ cell
  - Desirable to have a cell accessible
  - No bridging between membrane and structure
  - Long life cell where not accessible

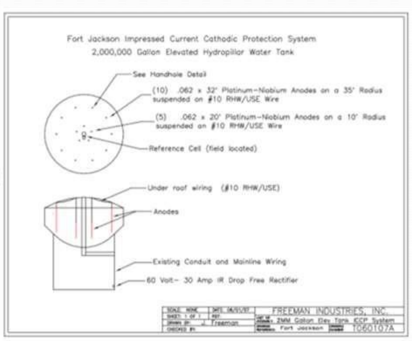
DC Wiring

- Pressure entrance fitting
  - Submerged systems
- Conduit to top of tank
  - Vertical systems

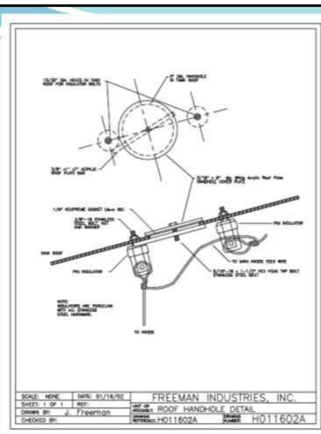
Choosing the Anode Configuration

- Is ice a factor?
- Can the tank be drained to install the CP system

Vertical CP System



Hand Hole

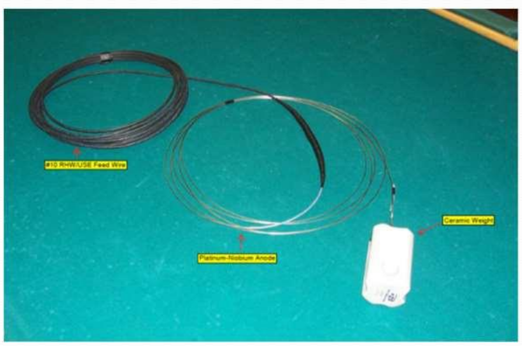


Rectifier

Rectifier

Anode

Anode



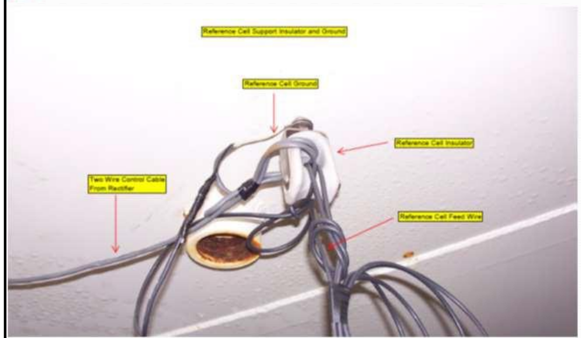
Reference Cell

Anodes on Tank

Old Anodes

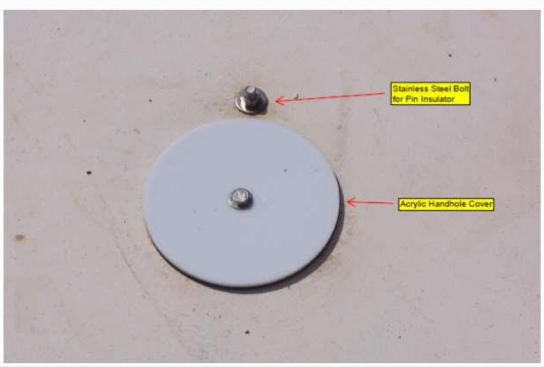
Tank Roof

Reference Cell Insulator

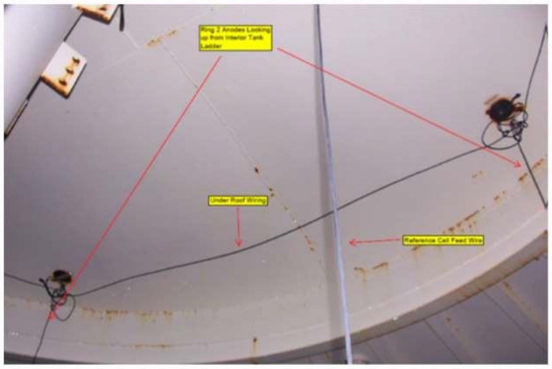


Rectifier Ground

Hand Hole



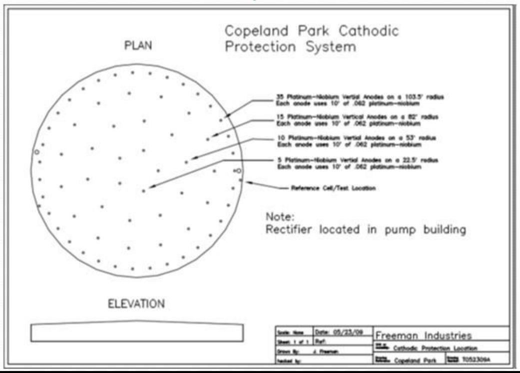
Anode Feed Wires



Anode Insulator

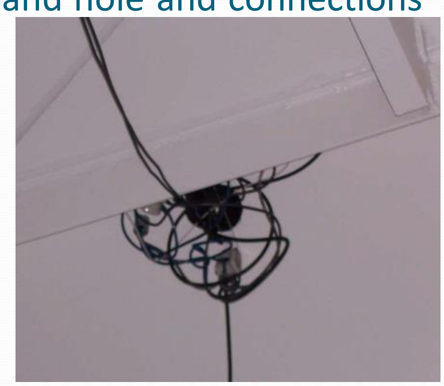
Vertical Anodes

Vertical Anode System

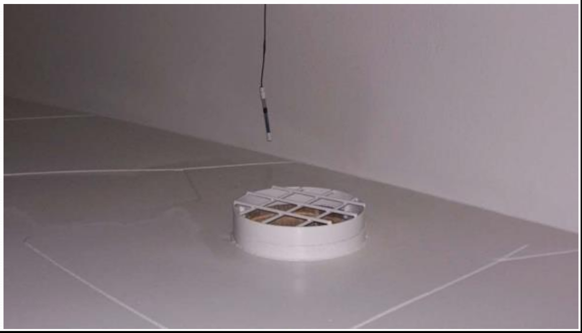


Inside tank

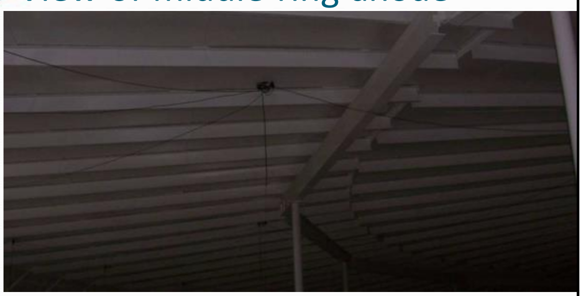
Hand hole and connections



Cell and fill pipe



View of middle ring anode

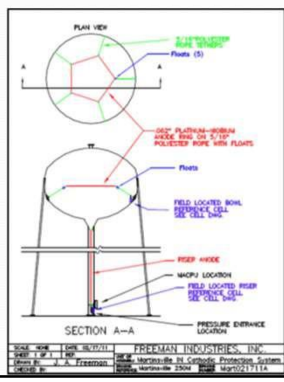


- Note the radial wiring

Single anode in outer ring

Inner ring anodes

Submerged 2 Circuit Anode System



Tank

Anode Float

Feed wire connection to anode

Bowl cell

Strain relief for feed wires

Riser anode and feed wires

Riser grate

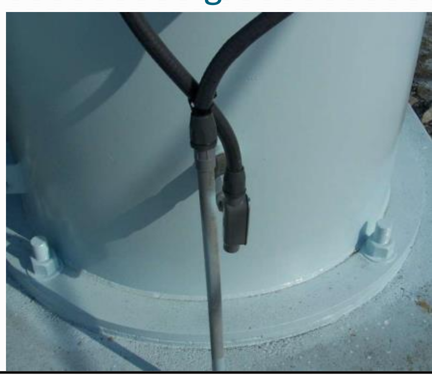
Bowl anode

Riser

Rectifier

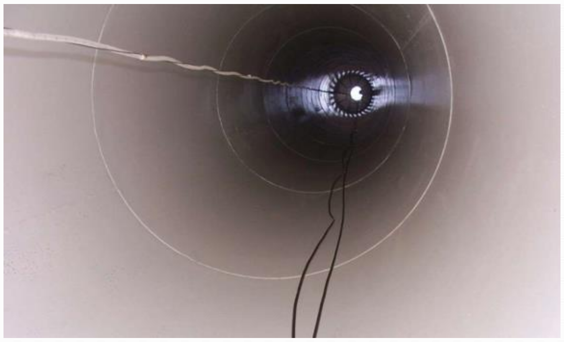
Stainless steel pressure entrance

AC and DC wiring



Pressure entrance fitting

View looking up the riser

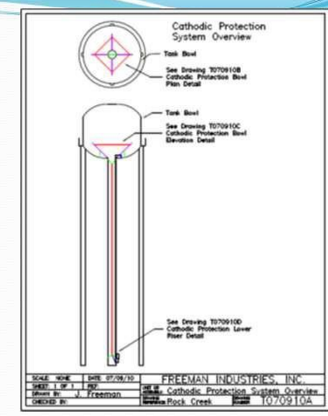


Strain relief for feed wires

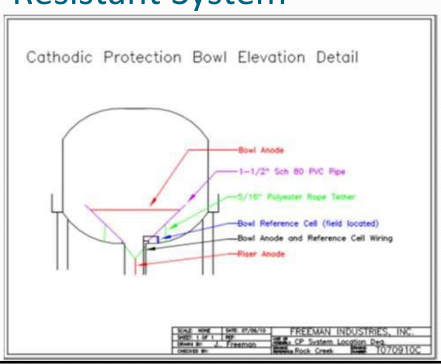
Inside view of pressure entrance fitting and reference cell

Fill pipe, pressure entrance fitting, and reference cell

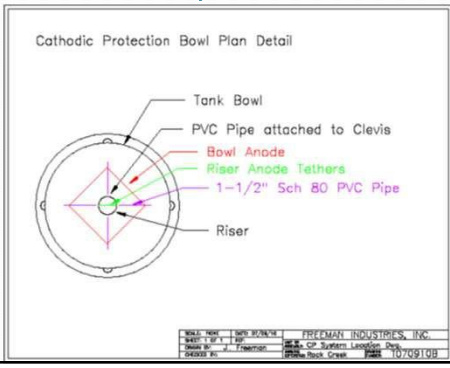
Ice Resistant System



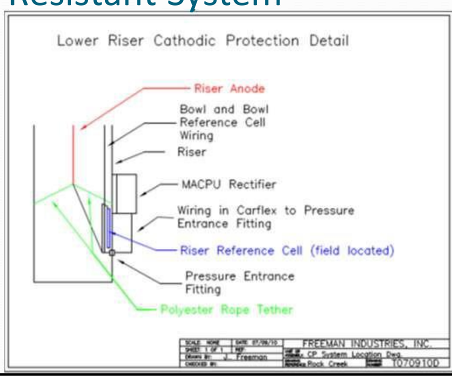
Ice Resistant System



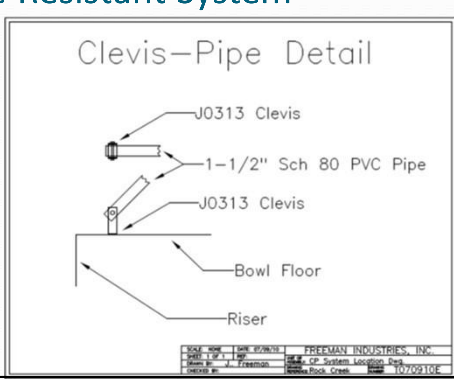
Ice Resistant System



Ice Resistant System



Ice Resistant System



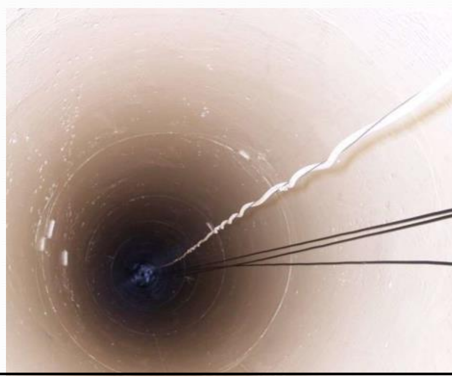
Riser Anode

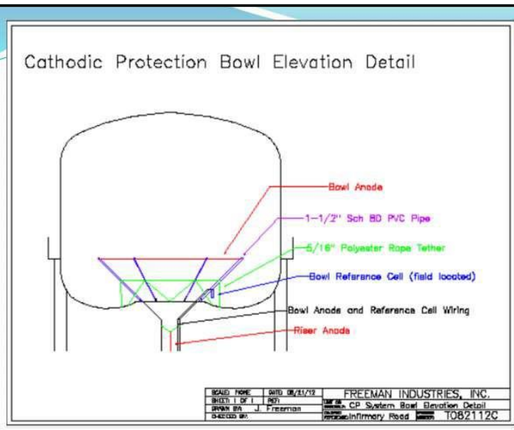
Clevis

Bowl anode

Riser Cell

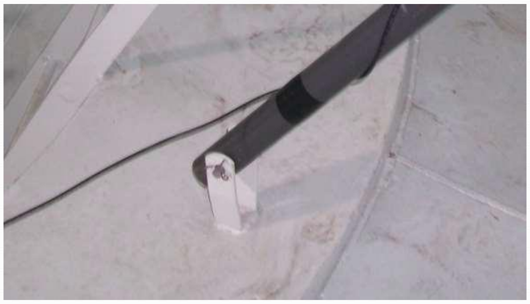
Riser Anode and Feed Wires

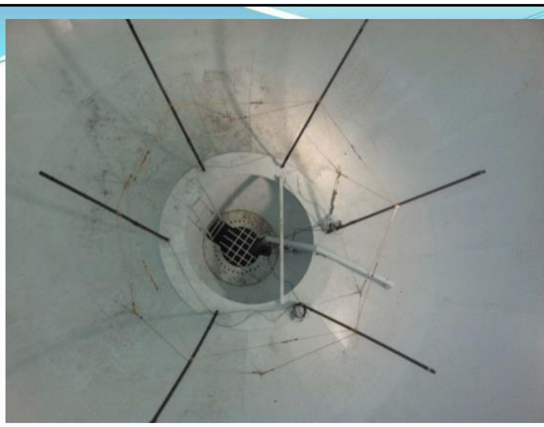


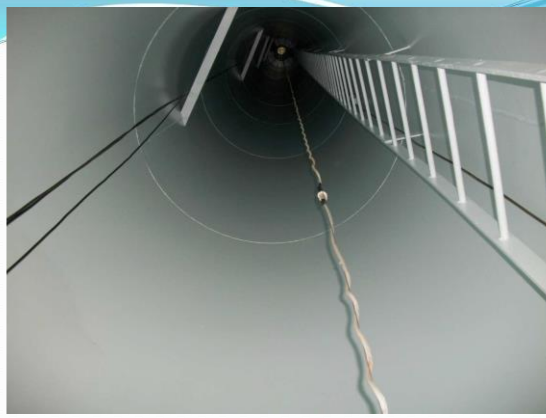


Tie down

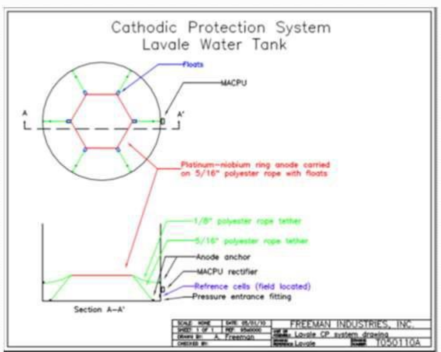
Clevis







Submerged CP System



Rectifier and Pressure Entrance Fitting

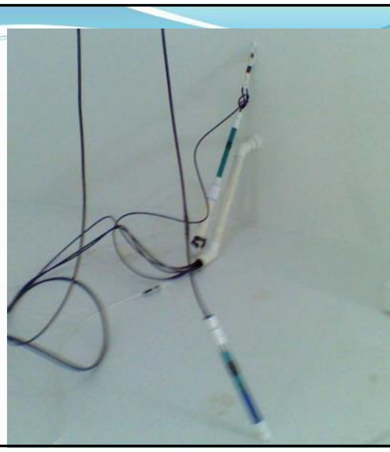
Solid State Rectifier module and feed wires

Anode

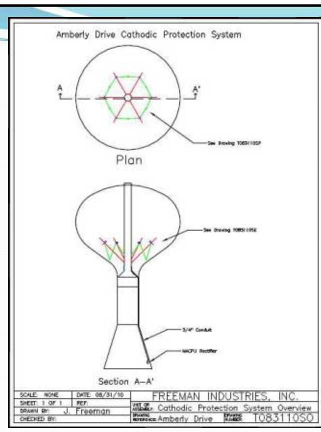
Anode

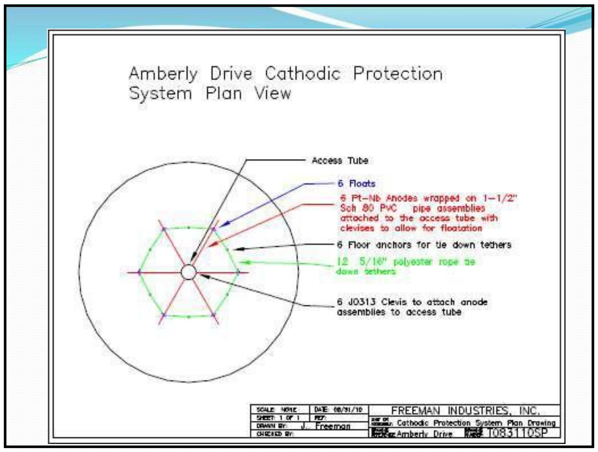
Control Cells

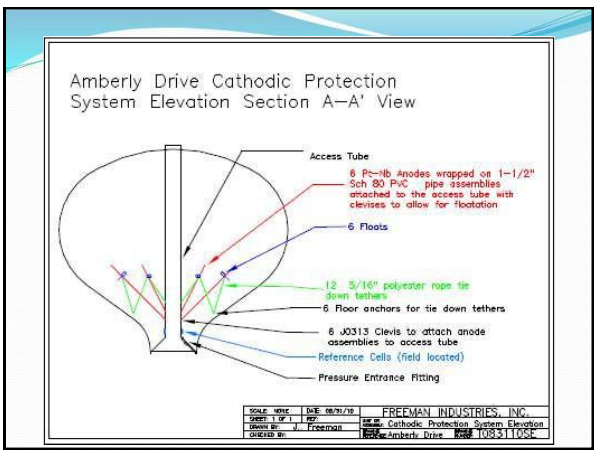
Control Cells

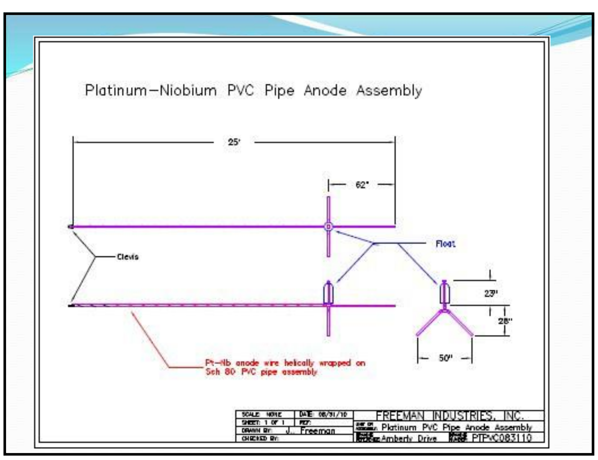


CP System




Amberly Drive Cathodic Protection
System Plan View
Access Tube
6 Floats
6 Pt-Nb Anodes wrapped on 1-1/2" Sch 80 PVC pipe assemblies attached to the access tube with clevises to allow for floatation
6 Floor anchors for tie down tethers
12 5/16" polyester rope tie down tethers
6 J0313 Clevis to attach anode assemblies to access tube
SCALE: NONE
DATE: 08/31/10
SHEET: 1 OF 1
REF:
DRAWN BY: J. Freeman
CHECKED BY:
FREEMAN INDUSTRIES, INC.
Cathodic Protection System Plan Drawing
Amberly Drive
T083110SP


Amberly Drive Cathodic Protection
System Elevation Section A-A' View
Access Tube
6 Pt-Nb Anodes wrapped on 1-1/2" Sch 80 PVC pipe assemblies attached to the access tube with clevises to allow for floatation
6 Floats
12 5/16" polyester rope tie down tethers
6 Floor anchors for tie down tethers
6 J0313 Clevis to attach anode assemblies to access tube
Reference Cells (field located)
Pressure Entrance Fitting
SCALE: NONE
DATE: 08/31/10
SHEET: 1 OF 1
REF:
DRAWN BY: J. Freeman
CHECKED BY:
FREEMAN INDUSTRIES, INC.
Cathodic Protection System Elevation
Amberly Drive
T083110SE

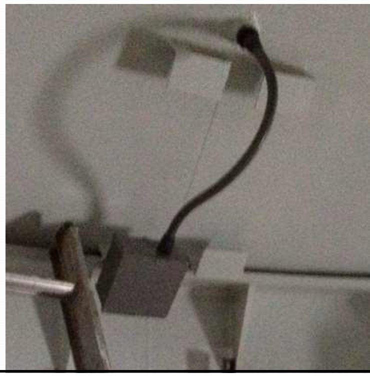

Platinum-Niobium PVC Pipe Anode Assembly
25'
62"
Float
Clevis
23"
28"
50"
Pt-Nb anode wire helically wrapped on Sch 80 PVC pipe assembly
SCALE: NONE
DATE: 08/31/10
SHEET: 1 OF 1
REF:
DRAWN BY: J. Freeman
CHECKED BY:
FREEMAN INDUSTRIES, INC.
Platinum PVC Pipe Anode Assembly
Amberly Drive
PTPVC083110

Anode support arm

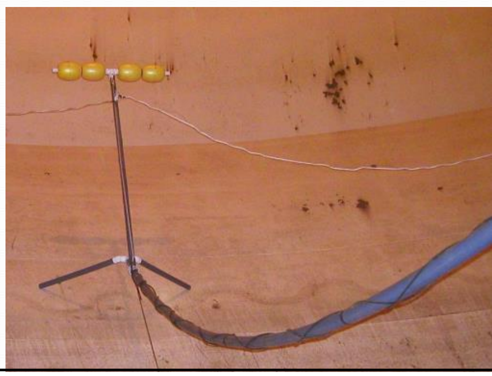
View from top

Reference Cell

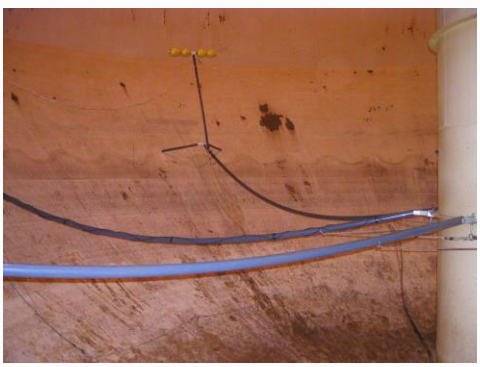
DC Junction Box and PE



Anode support arm



Anode



Anode

Reference Cell

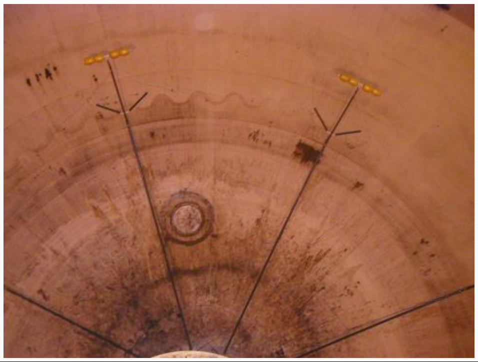
Support Arm

Reference Cell

Tie Down

Top View

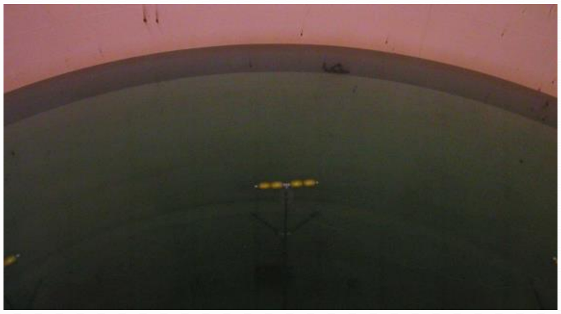
View from Top

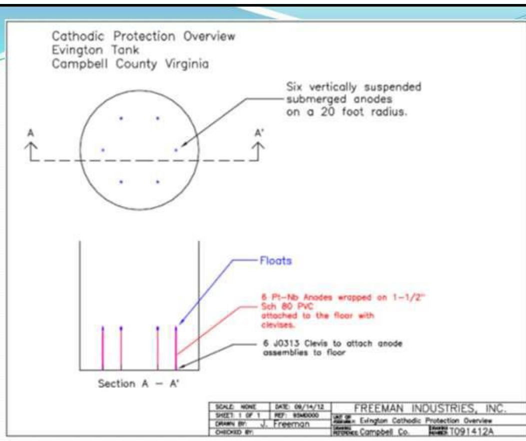


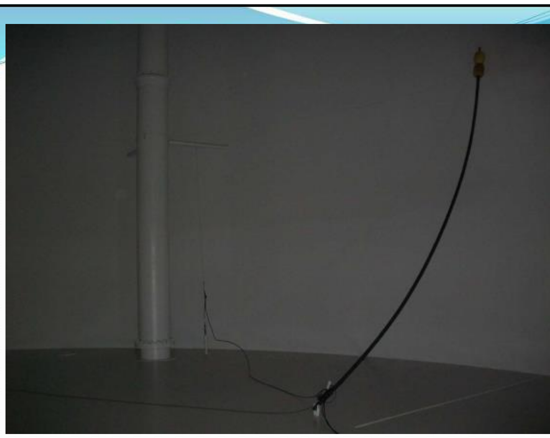
Filling Tank

Filling Tank

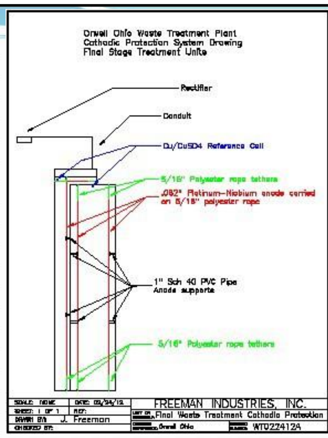
Filling Tank







CP System

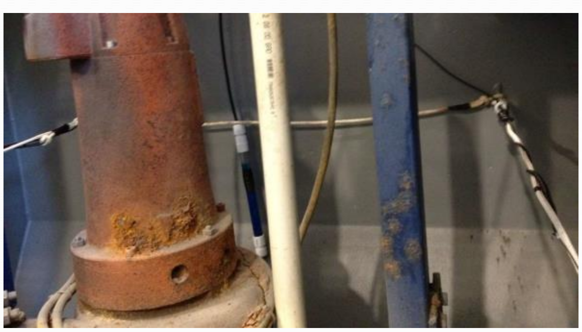


Anode

Anode

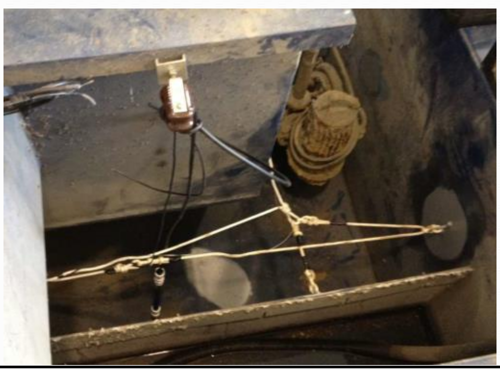
Anode

Anode and Cell



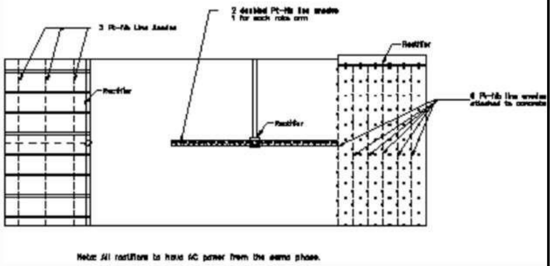
Anode

Anode and Cell



Anode

Cathodic Protection Overview

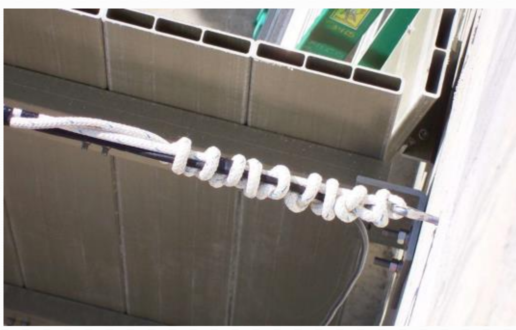


Flocculator Anodes

Flocculator Anode

Flocculator Anode

Anode Tie-off

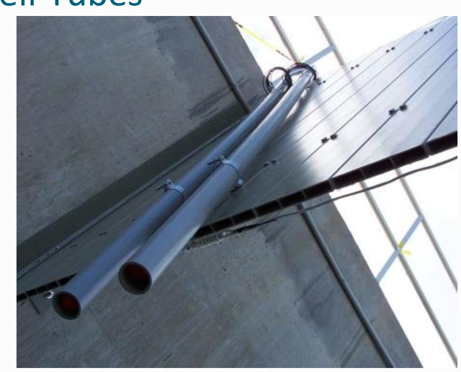


Grounding Wires

Current Collector

Current Collector

Cell Tubes



Anode Feed

Clarifier Basin

Clarifier Basin

Clarifier Anode

Clarifier Anode

Clarifier Anode

Clarifier Anode

Zn Anodes on Extension Arm

Current Collector

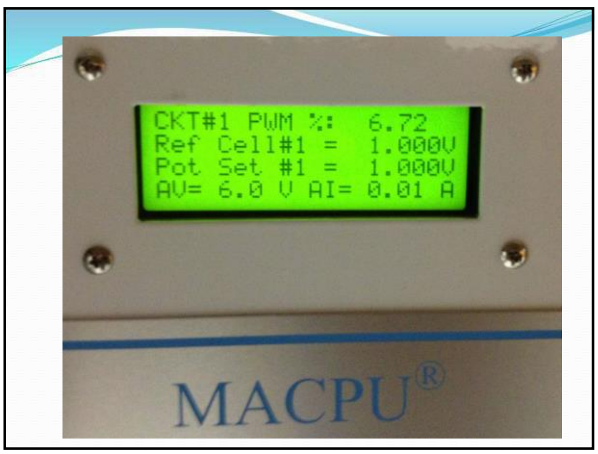
Launder Basin

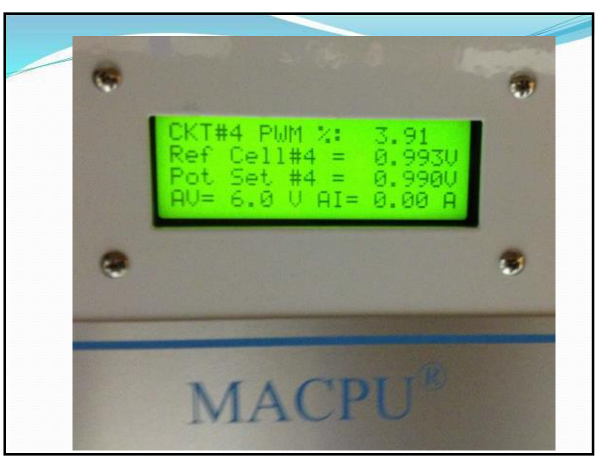
Launder Anodes

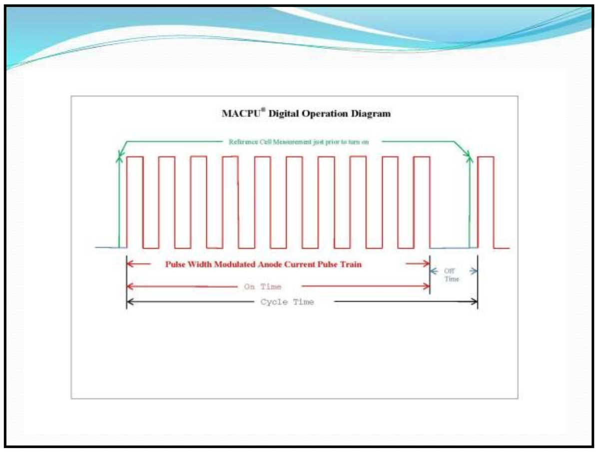
Launder Anodes

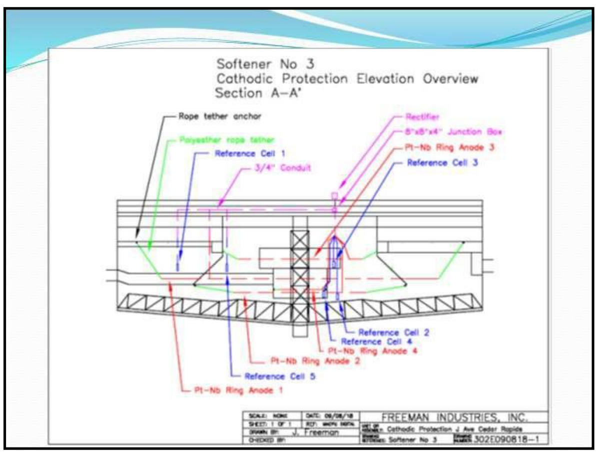
Uncoated Stainless Steel Inside a Water Tank

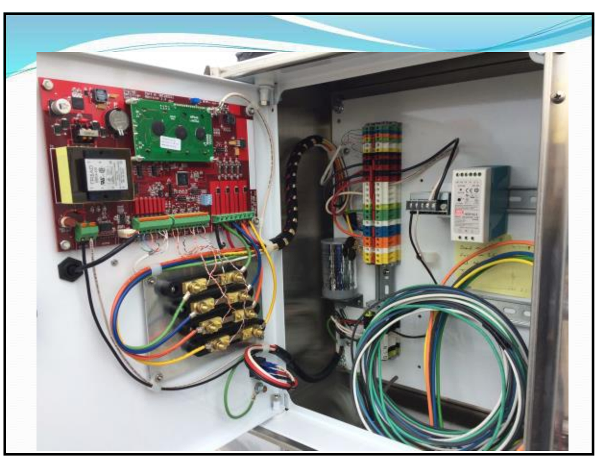
Digitally Controlled Rectifier

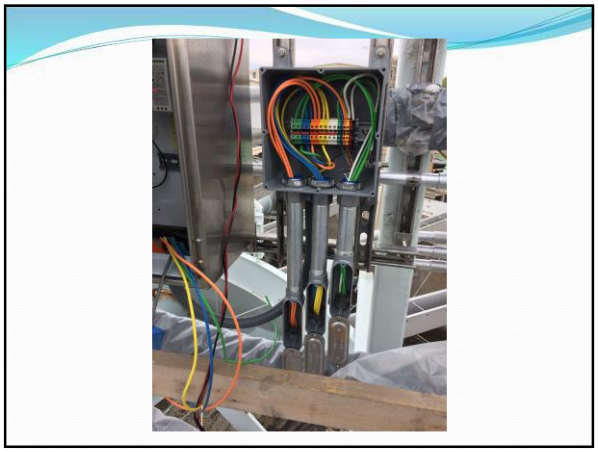

CKT#1 PWM %: 6.72
Ref Cell#1 = 1.000V
Pot Set #1 = 1.000V
AV= 6.0 V AI= 0.01 A
MACPU®

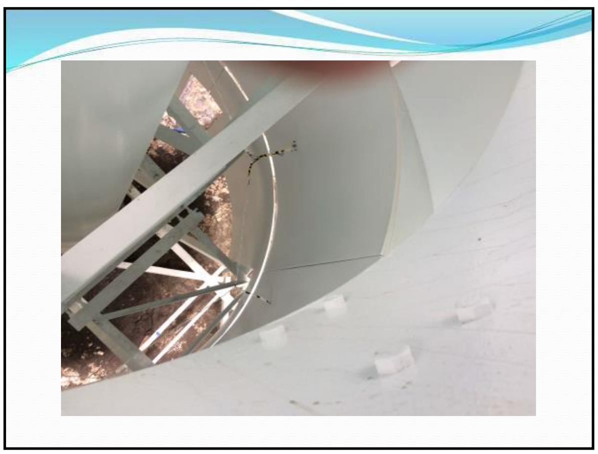

CKT#4 PWM %: 3.91
Ref Cell#4 = 0.993V
Pot Set #4 = 0.990V
AV= 6.0 V AI= 0.00 A
MACPU®


MACPU® Digital Operation Diagram
Reference Cell Measurement just prior to turn on
Pulse Width Modulated Anode Current Pulse Train
Off Time
On Time
Cycle Time


Softener No 3
Cathodic Protection Elevation Overview
Section A–A'
Rope tether anchor
Polyester rope tether
Reference Cell 1
3/4" Conduit
Rectifier
8"x8"x4" Junction Box
Pt-Nb Ring Anode 3
Reference Cell 3
Reference Cell 2
Reference Cell 4
Pt-Nb Ring Anode 4
Pt-Nb Ring Anode 2
Reference Cell 5
Pt-Nb Ring Anode 1
FREEMAN INDUSTRIES, INC.
J. Freeman
Cathodic Protection J Ave Cedar Rapids
Softener No 3
302E090818-1







Linings, Wet Wells and Manholes: This is how we roll (and spray)

Steve Roetter, Sherwin Williams

steven.p.roetter@sherwin.com

Linings, Wet Wells and Manholes
This is how we roll (and spray)

Steve Roetter, PE – Market Segment Manager,
Water & Wastewater, Sherwin-Williams

AUCSC
SHERWIN-WILLIAMS.

1

Steve Roetter, PE
Water/Wastewater Market Manager

- **26 Years with Tank Industry Consultants President/Managing Principal**
  - Potable Water Tanks – evaluation, coating rehabilitation, construction
  - Steel Structures
- **4 Years Corrpro/Ocean City Research**
  - Corrosion Research Projects
  - Coating, Corrosion and Metallurgical Consulting
  - Cathodic Protection
- **5 Years Corrosion Probe, Inc.**
  - Concrete and Steel Coating Specifications
  - Condition Assessment of Clarifiers, Digesters, Tanks and Vessels
  - General Corrosion and Metallurgical Consulting
  - Expert Witness

36 Years Consulting Experience
BSCE Rose-Hulman Institute of Technology
Indiana Professional Engineer
SSPC Protective Coating Specialist
NACE Level 2 Certified Coating Inspector
SSPC Past President/Board of Governors

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Question

SHERWIN WILLIAMS.

How do linings and secondary containment systems differ from the application of standard high-performance coatings that are used for atmospheric exposure ?

(IE epoxies, zincs, urethanes, etc.)

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Answer

Linings and secondary containment require increased attention regarding:

- surface preparation
  - contamination
  - surface cleanliness
  - surface profile
- environmental conditions (temperature, humidity, material & substrate temperatures)

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Surface Preparation

The cleaning or treating of a substrate to insure the best possible bond between the substrate and the coating.

The service and life expectancy of a coating is directly proportional to the degree of surface preparation done prior to that coating's application

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Surface Preparation

- Surface preparation is the <u>most important factor</u> affecting coating system performance
- Surface conditions affecting coating life:
  - Presence of oil/grease
  - Presence of salts or other chemicals
  - Presence of dust/dirt
  - Presence of corrosion products
  - Presence of old paint
- Surface preparation should match both the demands of the coating and environment and should be in the specification.

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Process of Surface Preparation for Metal and Concrete

- Decontamination
  - Dirt, oils, efflorescence, laitance
  - Metal (SSPC-SP 1)
  - Concrete substrates (ASTM D4258 + NACE6/SSPC-SP 13)
- Removal of surface defects
  - Weld spatter, pits, eggshells, protrusions – Steel
  - Filling of bugholes, voids, honeycombs, etc - Concrete
- Abrasive blast cleaning
  - Steel substrates (NACE/SSPC Cleanliness Standards)
  - Concrete substrates (ASTM D4259 & NACE 6/SSPC-SP 13)

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Surface Preparation Standards

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- SSPC-SP1 Solvent Cleaning
- SSPC-SP2 Hand Tool Cleaning
- SSPC-SP3 Power Tool Cleaning
- NACE 1/SSPC-SP5 White Metal Blast Cleaning
- NACE 2/SSPC-SP 10 Near White Metal Blast Cleaning
- NACE 3/SSPC-SP6 Commercial Blast Cleaning
- NACE 4/SSPC-SP7 Brush Off Blast Cleaning
- SSPC-SP8 Pickling
- SSPC-SP11 Power Tool Cleaning to Bare Metal
- SSPC-SP WJ-1/NACE WJ-1, SSPC-SP WJ-2/NACE WJ-2, SSPC-SP WJ-3/NACE WJ-3, and SSPC-SP WJ-4/NACE WJ-4
- NACE 6/SSPC-SP13 Surface Preparation of Concrete
- NACE 8/SSPC-SP14 Industrial Blast Cleaning
- SSPC-SP15 Commercial Grade Power Tool Cleaning
- SSPC SP 16 "Brush-off Blast Cleaning of Coated and Uncoated Galvanized Steel, Stainless Steels, and Non-ferrous Metals"

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Cleanliness Standards

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Tools Used to Measure Surface Cleanliness

- Establish a project-specific surface cleanliness standard. Best and typical of NACE and/or SSPC Written Standards.
- Ensure removal of abrasive and dust from surface prior to primer application
- Visual references are available.

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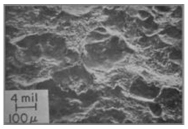
Why do we Blast Metal and Concrete

To Achieve a Surface Profile



- Measurement of the roughness of a surface which results from abrasive blast cleaning
- Measured from the bottom of the lowest valley to the top of the highest peak
- Achieving proper surface profile improves the mechanical bonding of a coating to the substrate.

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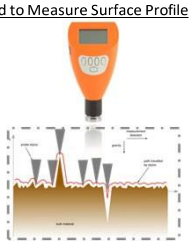
Surface Profile

Tools Used to Measure Surface Profile

ICRI 310.2R Replica Stamps
(For Concrete Surface Profile – CSP)



Depth Micrometer (Steel)

Replica Tape and
Anville Micrometer (Steel)

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Concrete Surface Preparation

Bugholes, Voids & Honeycombs

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Secondary Containment

SECONDARY CONTAINMENT Generally, means that the lining system must be able to withstand the chemical environment for 72 hours

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Secondary Containment

Coating Design Parameters

- Chemical Name
- Concentration Level
- Stored at Ambient or Elevated Temperatures?
- If elevated, what's temperature of chemical?
- If elevated - does it cycle? HOW MUCH & HOW OFTEN?
- In case of rupture, will chemicals mingle? Or separate containment areas?
- Interior or Exterior Application?
- Traffic Concerns? truck loading area associated?
- Expansion joints? If yes, how far apart?
- Existing Coating?

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Secondary Containment

There are a few different resin systems that are used to protect concrete in secondary containment scenarios ….. and they always depend on the chemical environment.

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Secondary Containment

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Resins

- No such thing as "good better best"
- Polyamine Epoxy
- Novolac Epoxy for water, alkali, solvent,fatty acid resistance & outstanding heat resistance
- Vinyl Esters for sodium hypo, sodium permanganate, Hydrofluorosilicic Acid
- Advanced Technology Novolac Epoxy

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Tank Linings

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Linings are also referred to as
PRIMARY CONTAINMENT

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Tank Linings

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MAIN FACTORS RESPONSIBLE FOR GREATER H_2S LEVELS IN U.S. WASTEWATER SYSTEMS

Pretreatment of metals
- Clean water act

Building large regional systems:
- Longer transport times
- Longer detention times
- More force mains… 360^{O} slime layer
- Odor control & covered structures

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Tank Linings

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REVIEW OF H2S GAS GENERATION

- Sewerage - high in sulfates (SO4)
- Slime formation on sewer surfaces
- Anaerobic condition sulfate reducing bacteria (srb):
  - Sulfide ion - s=
  - S= + h - hs- (bisulfide)
  - Aqueous h2s (dissolved)

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Tank Linings

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DYNAMIC CHEMICAL EQUALIBRIUM

- Turbulence - H_2S stripped out of solution
- Dissolved H_2S replaced by HS^- converted to aqueous H_2S
- HS^- replaced by $S^=$ converted to HS^-
- H_2S gas – absorbed into condensation on concrete or coating surface

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Tank Linings

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SULFURIC ACID PRODUCTION

- pH reduction at aerated surfaces by the sulfuric acid and carbonic acid, etc.
- When ph = 9.5 or lower, sulfuric oxidizing bacteria (SOB) can thrive
- SOB colonize and use dissolved O_2 to metabolize H_2S and other sulfides
- H_2S oxidized to form H_2SO_4
- Acidic attack of cement paste

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Tank Linings

SULFATE ATTACK
(occurs below the acid reaction zone)

- SO_4 ion react with calcium hydroxide
- Form gypsum (caso$_4$)
- $CaSO_4 + C_3A$---------------->
- Yields much larger compounds
- Expansive forces cause microcracking & disintegration

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Tank Linings

BIOGENIC SULFIDE CORROSION/VAPOR PHASE

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Tank Linings

BIOGENIC SULFIDE CORROSION/VAPOR PHASE

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Tank Linings

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BIOGENIC SULFIDE CORROSION/VAPOR PHASE

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Tank Linings

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Manholes, Wet Wells and Concrete Basins

- Dura-Plate 2300
- Sher-Glass FF
- Dura-Plate 6000
- Dura-Plate 6100
- Poly-Cote 115

Water Tank Linings

- Sherplate 600
- Macropoxy 5500
- Sher-Plate PW
- Dura-Plate UHS

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Tank Linings

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Dura-Plate 2300

DURA-PLATE 2300 is a three component, epoxy modified cementitious resurfacer containing Portland Cement, hydrophobic thixotropes, fiber reinforcement, graded silica sand and other abrasion resistant aggregates.

DURA-PLATE 2300 is used for resurfacing, patching and filling voids (bugholes) in concrete and masonry structures.

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Tank Linings

SHERWIN WILLIAMS.

Sher-Glass FF

- 76% Solids Amine-Cured Flake Filled Coating
- Reinforced with Micaceous Iron Oxide
- Can be used on Steel & Concrete
- Can be applied directly to blasted steel or concrete
- Cures fully in 7 days at 77 deg F + 50% Rel Humidity
- Is applied up to 20.0 mils dry film thickness per coat with typical film build between 8.0 – 20 mils dry film thickness per coat.
- Optional Heat Cure - 8 hours @ ambient, then 16 hours @ 140°F (60°C)

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Tank Linings

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Sher-Glass FF
High Performance Epoxy Uses

- Lift stations
- Concrete pipe
- Wet wells
- Steel pipe
- Manholes
- Sumps
- Digesters
- Trenches
- Clarifiers
- Sluice ways
- Basins
- Influent chambers

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Tank Linings

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Dura-Plate 6000 High Performance Epoxy

- NSF Approved 61/600
- 100% Solids, Reinforced Amine Cured Epoxy, Capable of being applied up to 125.0 mils DFT in a single coat. It IS approved for potable water.
- Maybe applied to a Surface Saturated Dry (SSD) Substrate
- Resistant to high H2S service & Sulfuric Acid.
- Airless or Heated Plural Application – 1:1 Ratio

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Tank Linings

SHERWIN WILLIAMS.

Dura-Plate 6000 High Performance Epoxy Uses

- Structures requiring NSF approval
- Lift stations
- Concrete pipe
- Wet wells
- Steel pipe
- Manholes
- Sumps
- Digesters
- Trenches
- Clarifiers
- Sluice ways
- Basins
- Influent chambers

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Tank Linings

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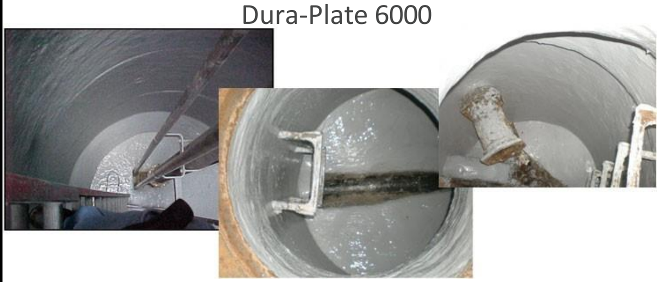
Dura-Plate 6000



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Tank Linings

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Dura-Plate 6100 High Performance Epoxy

- 100% Solids, Amine Cured Epoxy, Capable of being applied @ 12.0 – 125.0 mils DFT in a single coat.
- Maybe applied to a Surface Saturated Dry (SSD) Substrate.
- The product offers high physical performance characteristics (compressive strength: 15,000 psi, tensile Strength 5,600 psi, and water vapor trans: 3.0 grams/sq.m per 24 hrs.).
- Resistant to High H2S service, Sulfuric Acid 75%
- Dry to Recoat in *15 min. (min) / Dry to Handle in *2 Hrs.
- Fast Cure to Service in 6 Hrs.
- Reduced Touch-up due to Fewer Pinholes.
- Highest Light Reflectance Value – white
- Heated Plural Component Application – 2:1 Ratio

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Tank Linings

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Dura-Plate 6100

High Performance Epoxy Uses

- Lift stations
- Concrete pipe
- Wet wells
- Steel pipe
- Manholes
- Sumps
- Digesters
- Trenches
- Clarifiers
- Sluice ways
- Basins
- Influent chambers

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Tank Linings

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Tank Linings

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Poly-Cote 115

Elastomeric Polyurethane

- 100% Solids, Elastomeric Polyurethane, Capable of being applied @ 20 – >500 mils DFT in a single coat.
- NSF 61/600 approved.
- Resistant to High H2S service, Sulfuric Acid 75%
- ASTM G210 SWAT passed
- Dry to Handle in 12 Hrs.
- Fast Cure to Service in 12 Hrs. (72 hours for NSF)
- Heated Plural Component Application – 3:1 Ratio

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Tank Linings

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Poly-Cote 115

Elastomeric Polyurethane Uses

- Water Tanks
- Lift stations
- Concrete pipe
- Wet wells
- Steel pipe
- Manholes
- Sumps
- Digesters
- Trenches
- Clarifiers
- Sluice ways
- Basins
- Influent chambers

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Tank Linings

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Poly-Cote 115

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Water Tank Linings

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Sherplate 600

- NSF 61/600 certified
- 89% volume solids Phenalkamide Epoxy
- High chemical resistance of amine epoxy and application characteristics of a polyamide epoxy
- 5.0 – 10.0 mils DFT per coat.
- Meets AWWA D102 ICS-1, 2 and 5
- Low temperature application (35° F)
- Airless Spray Equipment utilized.
- Low VOC / Low Odor

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Tank Linings

Sherplate 600 Uses

- Potable water structures
- Lift stations
- Concrete pipe
- Wet wells
- Steel pipe
- Sumps
- Clarifiers
- Basins

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Water Tank Linings

Macropoxy 5500

- NSF 61/600 certified
- 74% volume solids Polyamidoamine Epoxy
- Field or Shop Applications (3 mo. Recoat window)
- 2.0 – 6.0 mils DFT per coat.
- Meets AWWA D102 ICS-1, 2 and 5
- Airless Spray Equipment utilized.
- Low VOC / Low Odor

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Tank Linings

Macropoxy 5500 Uses

- Potable water structures
- Lift stations
- Concrete pipe
- Wet wells
- Steel pipe
- Sumps
- Clarifiers
- Basins

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Water Tank Linings

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Sherplate PW

- Ultra-High Solids Amine Epoxy – 100%
- Heated Plural Component Spray Rig
- Low VOC / Low Odor
- Greater than 70% edge build retention, MIL-PRF-23236
- NSF 61/600 approved
- Fast Return to Service – Walk on in 4 hours
- OPTI-CHECK OAP TECHNOLOGY
- 50.0 mils DFT per coat
- Heated Plural Spray – 1:1 Ratio
- Cures in 1 day at 70 deg & 50% RH
  - Cures down to 35% deg F

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Water Tank Linings

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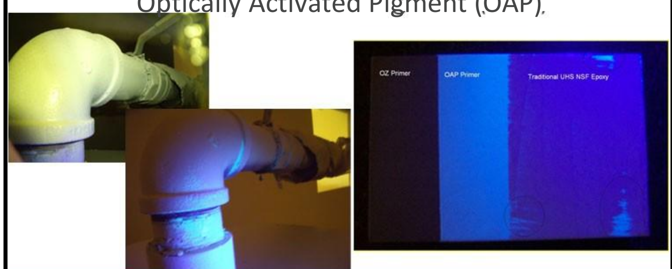
Optically Activated Pigment (OAP)



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Water Tank Linings

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Sherplate PW Uses

- Elevated & Ground Potable Water Storage Tanks
  - For tanks of 25 gallons or greater
- Potable Water Piping of 6" diameter or greater
- Quick Turnaround Projects – 1 day cure time
- Can be used on Concrete & Metal
- Abrasion Resistant - 21 grams/loss on ASTM D4060

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Water Tank Linings

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Sherplate PW

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Water Tank Linings

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Sherplate PW

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Water Tank Linings

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Dura-Plate UHS

- Ultra-High Solids Amine Epoxy – 98%
- NSF 61/600 approved
- Can be reduced 5% under NSF approval
- Airless or Heated Plural Component Spray Rig
- Low VOC / Low Odor
- Greater than 70% edge build retention, MIL-PRF-23236
- Cures in 4 days at 70 deg & 50% RH
- OPTI-CHECK OAP TECHNOLOGY
- 50.0 mils DFT per coat
- Highly chemical resistant
- Abrasion Resistant -20 grams/loss on ASTM D4060

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Water Tank Linings

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Dura-Plate UHS Uses

- Potable Water Ground & Elevated Tanks of 1000 gallons or greater
- NSF Piping – 30" or greater in diameter
- Ballast Tanks
- Oil Tanks
- Refined Fuel Storage Tanks
- Any Wastewater Treatment Immersion Scenario
  - Clarifiers, Digesters (Lids), Sludge Tanks
- Secondary Containment

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Water Tank Linings

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Dura-Plate UHS

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Tech Service

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PART OF WORKING WITH SHERWIN WILLIAMS INCLUDES INVOLEMENT FROM OUR

TECHNICAL SERVICE DEPARTMENT.

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Tech Service

Tech Service Role Defined

- Not a replacement for third party QA
- Assist sales reps and provide value to customer sales
- Assist with job start-ups for new products and new customers
- Provide assistance on application equipment sales and troubleshooting
- Evaluate and troubleshoot product issues with customers

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Tech Service

Capabilities and Equipment

- DFT gauge – checking dry film thickness on steel
- Vis 1 – abrasive blasting cleanliness on steel
- Testex Tape and Micrometer – abrasive blast profile
- Sling psychrometer with U.S. Weather Bureau Psychometric Tables – environmental conditions
- Tooke Gauge – paint layers and thickness
- Surface Temperature Gauge – surface temperature
- ICRI CSP Standards – concrete surface profile
- OAP light – holiday testing
- Adhesion tester – checking adhesion of the systems on substrate

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Tech Service

Coating Inspector's Tools of the Trade

Tools that are used by the painting contractor, the inspector or owner to ensure that the surface preparation and coating systems are performed per the specification.

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Tech Service

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- Ambient conditions
  - Air temp
  - Surface temp
  - Dew point

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Tech Service

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Visual Standards

ICRI Visual Standards

AMPP Visual Standards

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Tech Service

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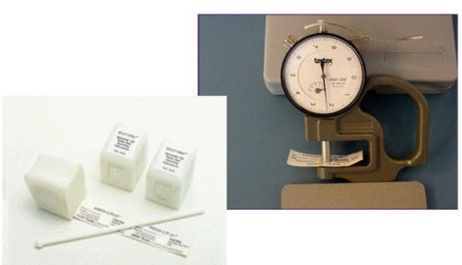
Steel Surface Profile



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Tech Service

Concrete Surface pH

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Tech Service

Coating thickness

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What if We Do Not Get it Right?

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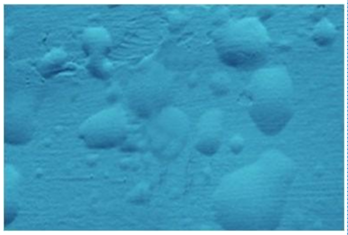
Consequences of Inadequate Selection/Application



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Consequences of Inadequate Selection/Application

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Consequences of Inadequate Selection/Application

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Thank You!

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Questions?

Visit our website to view archived webinars.

Contact swwater@sherwin.com regarding webinar questions.

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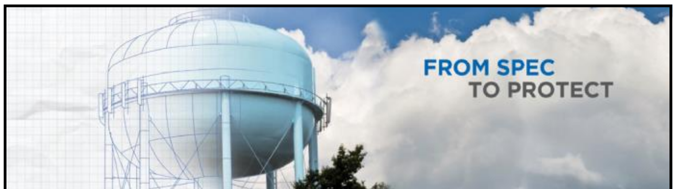

THANK YOU

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