Water and Wastewater Course

Appalachian Underground Corrosion Short Course
Morgantown, West Virginia

Day 1

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

Session 2: 10:40 AM – 11:40 AM: Corrosion and Its Control, Polyethylene Encasement (V-Bio®), for Ductile Iron Pipe
Allen Cox, Ductile Iron Pipe Research Association

Session 3: 1:30 PM – 2:30 PM: Linings and Coatings for Ductile Iron Pipe
Conor Madden, U.S. Pipe

Session 4: 2:40 PM – 3:40 PM: Mitigating Corrosion on Spiralwelded Steel Pipe
Kyle Couture, American

Session 5: 3:50 PM – 4:50 PM: Concrete Pipe and Corrosion Control Techniques
TBD, Thompson Pipe Group

Day 2

Session 6: 8:15 AM – 9:15 AM: Corrosion Control Installation Procedures for Water and Sewer Pipeline Infrastructure: Part 1 – Selection and Design Considerations
Joe Greulich, Washington Suburban Sanitary Commission

Session 7: 9:25 AM – 10:25 AM: Corrosion Control Installation Procedures for Water and Sewer Pipeline Infrastructure: Part 2 – Installation and Testing
Joe Greulich, Washington Suburban Sanitary Commission

Session 8: 10:35 AM – 11:35 AM: Developing a Corrosion Control Program for a Water Utility
Jacob Martin, Cleveland Water

Session 9: 1:30 PM – 2:30 PM: Stray Current and Ductile Iron Pipelines
Paul Hanson, Ductile Iron Pipe Research Association

Session 10: 2:40 PM – 3:40 PM: Installation of Cathodic Protection Systems in Water Towers
Adam Freeman, Freeman Industries, Inc.

Session 11: 3:50 PM – 4:50 PM: Linings, Wet Wells and Manholes: This is how we roll (and spray)
Steve Roetter, Sherwin Williams

Day 3

Session 12: 8:30 AM – 9:30 AM: Corrosion Control Training – GACP and ICCP Systems
Sasan Hosein, Pond Co.

Session 13: 9:45 AM – 10:45 AM: Design of CP for Water Systems
Andrew Fuller, Engineering Design Technologies

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

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.

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

"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

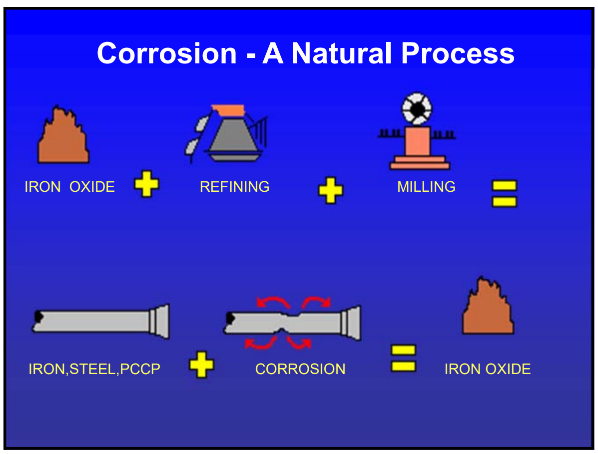
Water gushes from a broken main at W. 38th St., just south of Franklin Blvd. in Cleveland yesterday.

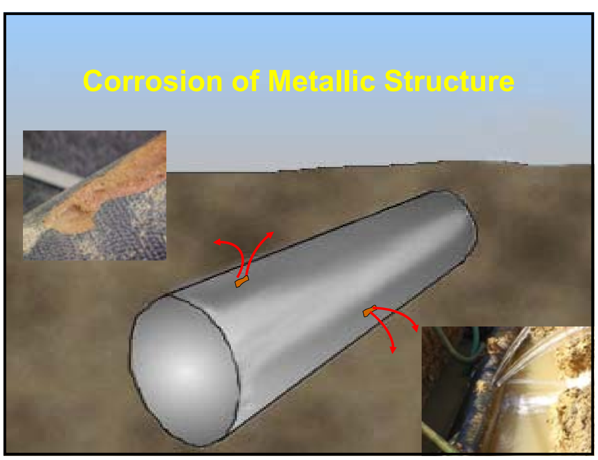

30" West 38th Street - 3/28/2001

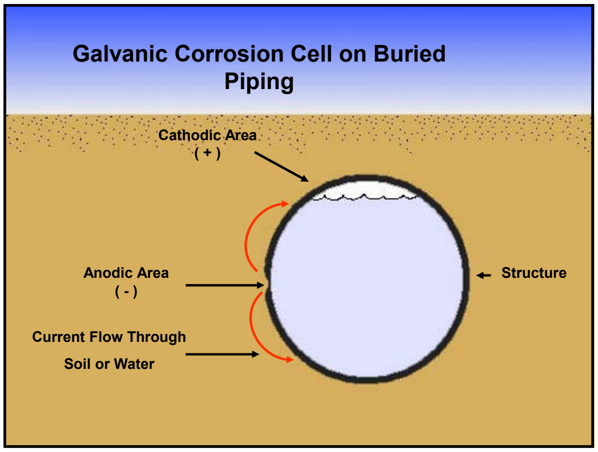

Traffic Disruptions
Water Loss
Fire Protection
Legal & Environmental Claims
Damages

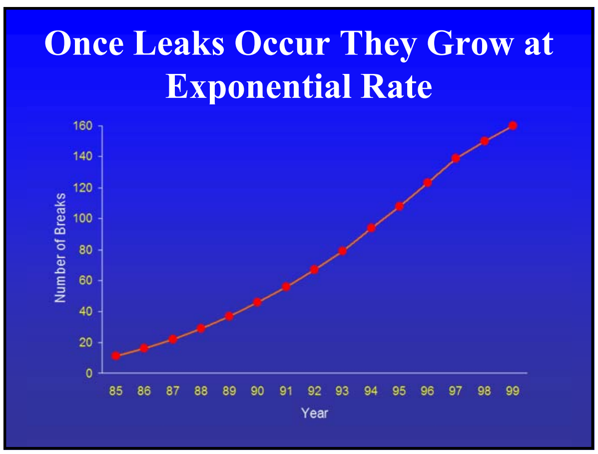

Corrosion


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
(-)
Current Flow Through
Soil or Water
Structure


Once Leaks Occur They Grow at Exponential Rate
Number of Breaks
160
140
120
100
80
60
40
20
0
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

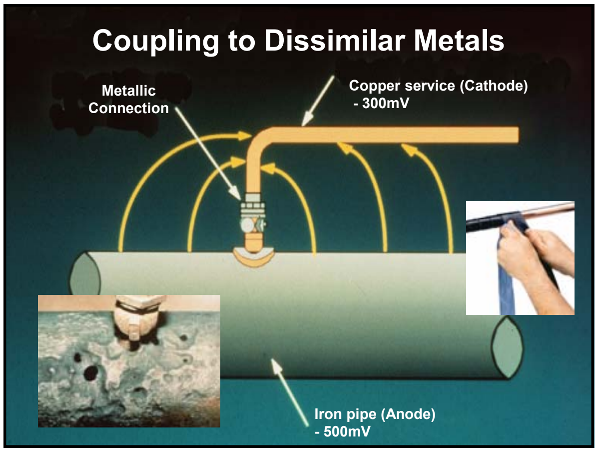
- Introduced in 1955 as an improvement to cast iron.
- Centrifugal casting process produces a thinner walled, lighter pipe which is stronger and more ductile than cast iron.

Cast (Grey) Iron

Graphitization leaves pipe brittle and weakened.

Ductile Iron

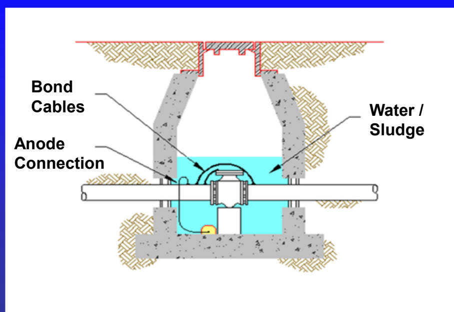
Pitting (concentrated) corrosion attack on ductile iron pipe.


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


Gate Valve Corrosion

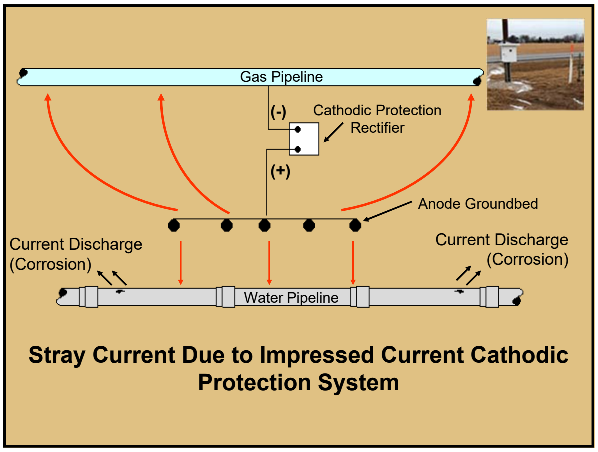

Meter Vault Corrosion
08/22/2007

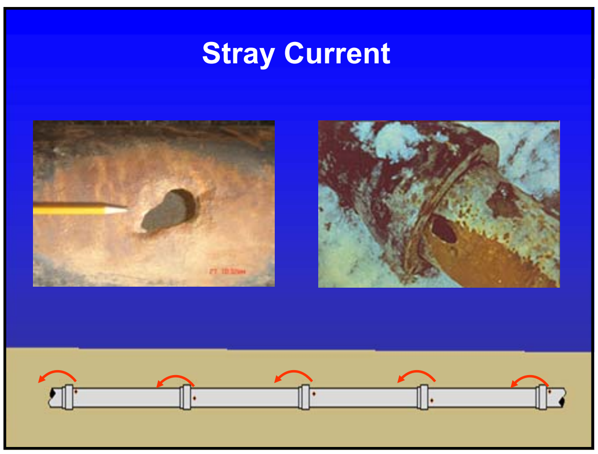
Meter Vault with Anode

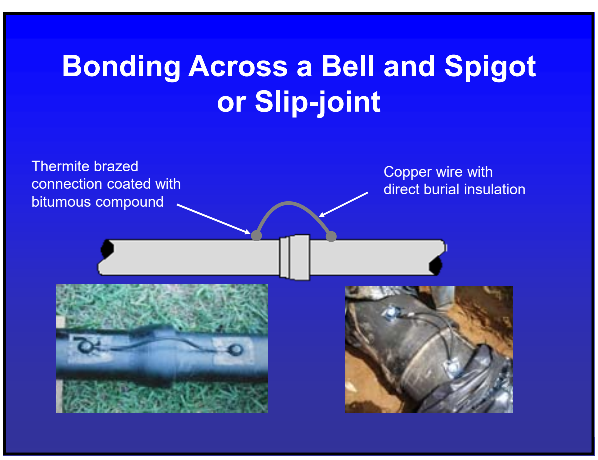


Stainless Steel Corrosion

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

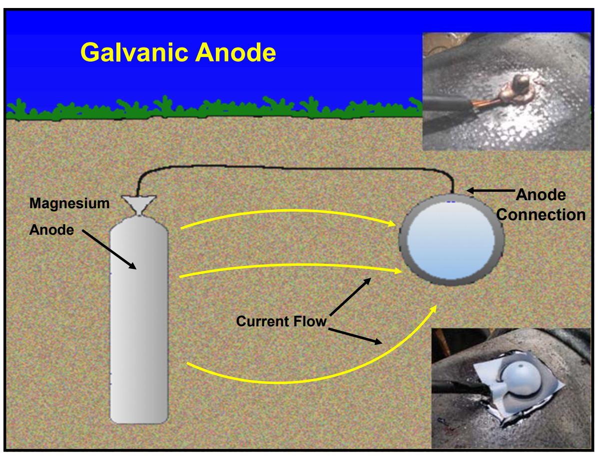

Stray Current

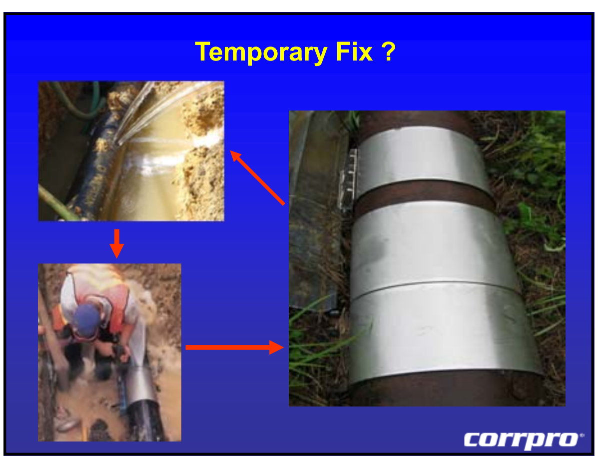

Bonding Across a Bell and Spigot or Slip-joint
Thermite brazed
connection coated with
bitumous compound
Copper wire with
direct burial insulation

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





Leak Repair Should Include Anode Installation

Incomplete

Complete

Water Municipality Anode Kit (Kept in Storeroom/Truck)

Includes:

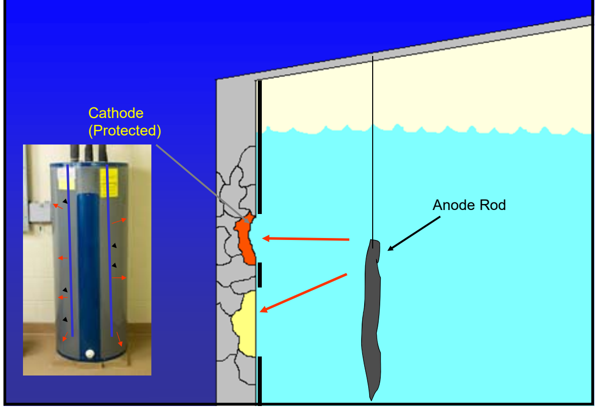
Installation instructions.

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

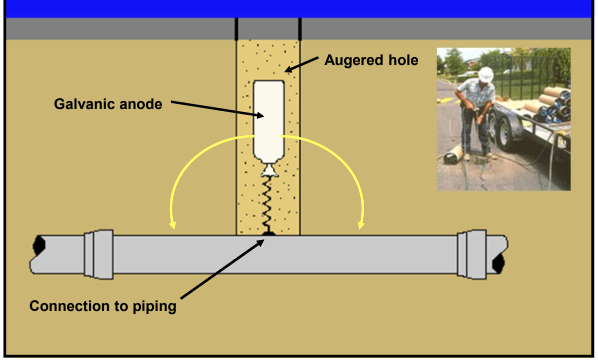


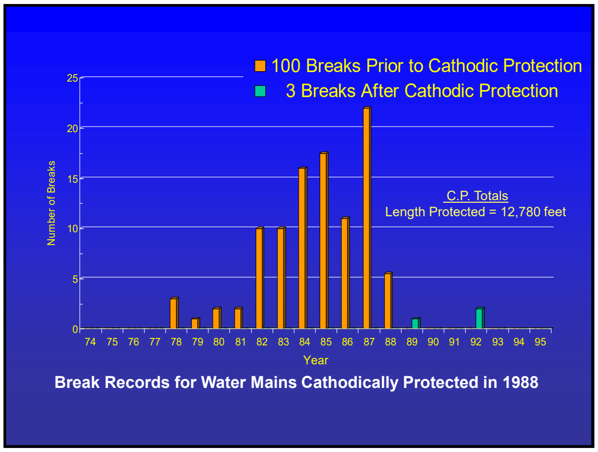
12" PIPING LEAK RATES/PRIORITIZATION PROGRAM

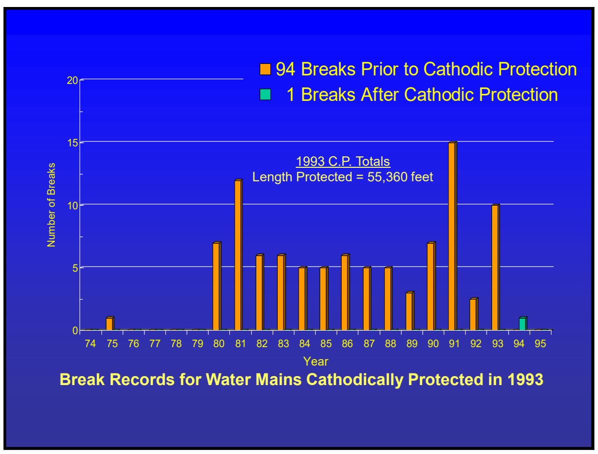
Red: High Leak Rate
Yellow: Growing Leaks
Green: Moderate/Low Leaks

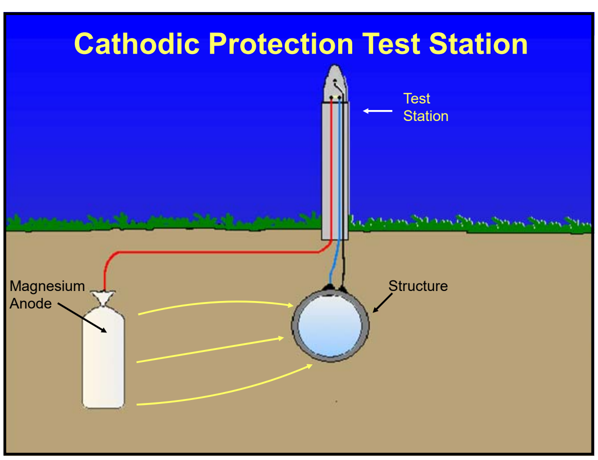
Proactive Anode Installation Options

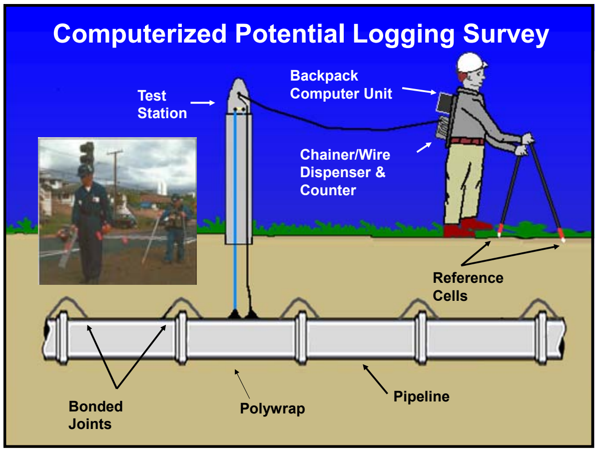
Anode Installation

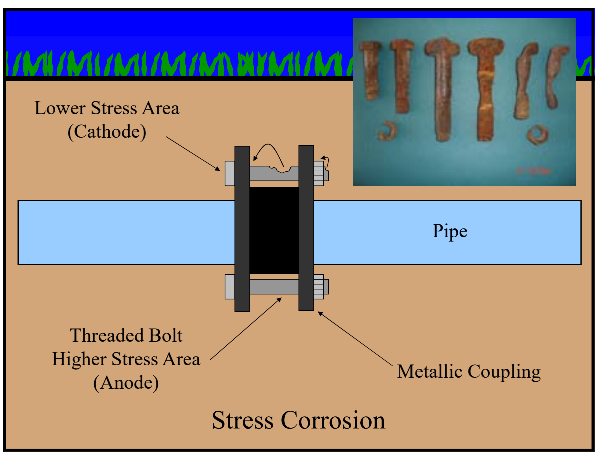


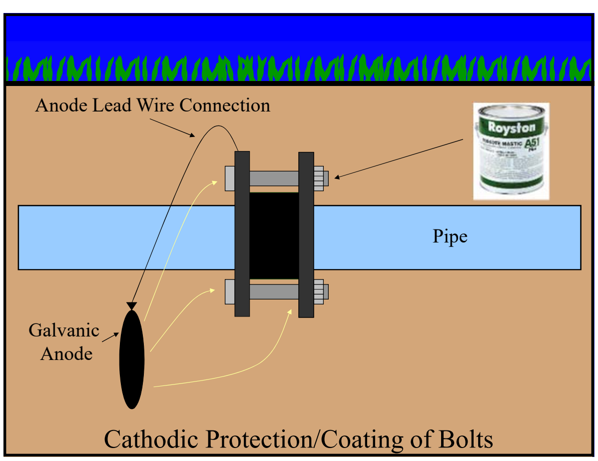

100 Breaks Prior to Cathodic Protection
3 Breaks After Cathodic Protection
Number of Breaks
C.P. Totals
Length Protected = 12,780 feet
Year
Break Records for Water Mains Cathodically Protected in 1988


94 Breaks Prior to Cathodic Protection
1 Breaks After Cathodic Protection
Number of Breaks
1993 C.P. Totals
Length Protected = 55,360 feet
Year
Break Records for Water Mains Cathodically Protected in 1993


Cathodic Protection Test Station
Test Station
Magnesium Anode
Structure

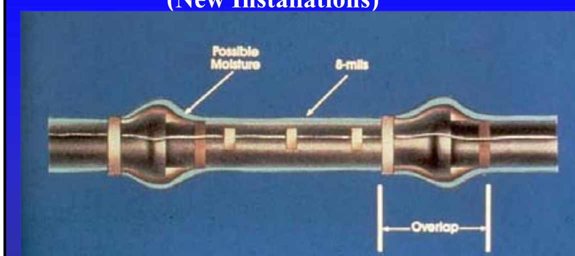

Computerized Potential Logging Survey
Test Station
Backpack Computer Unit
Chainer/Wire Dispenser & Counter
Reference Cells
Bonded Joints
Polywrap
Pipeline


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).

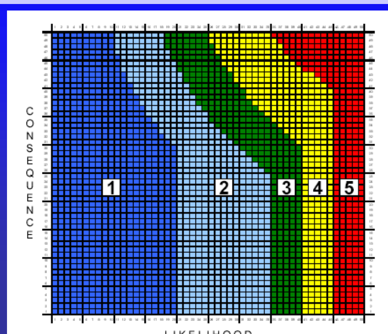
Investigative Structure (Existing)

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.

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

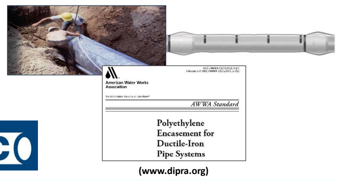
Allen Cox, Ductile Iron Pipe Research Association

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



AUCSC

(www.dipra.org)

dipra Ductile Iron Pipe Research Association

1

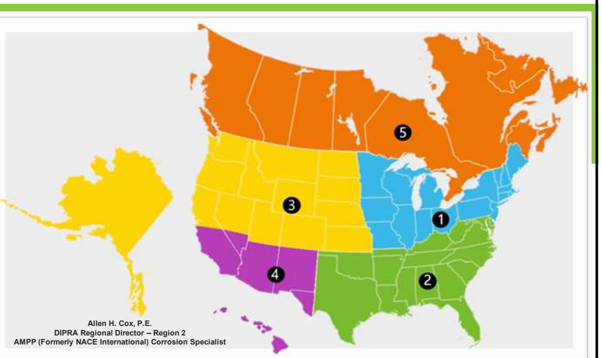
DIPRA Member Companies

- 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 — CP CANADA PIPE — US PIPE — MD McWANE DUCTILE

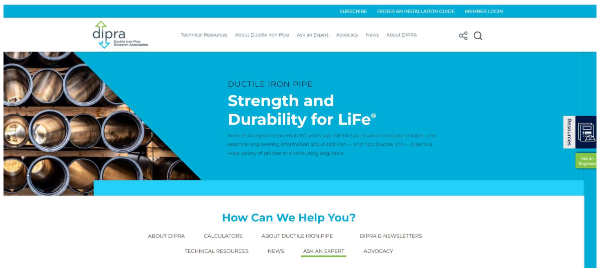
2

Regional Engineer Program



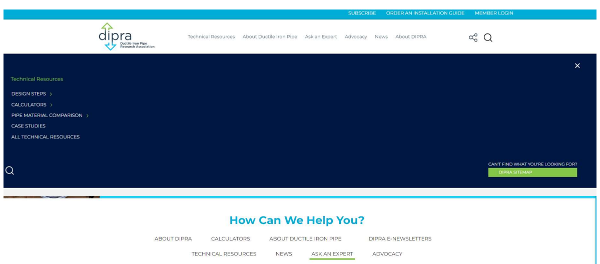
3

DIPRA Website
(www.dipra.org)



4

DIPRA Website
(www.dipra.org)



5

DIPRA Website
(www.dipra.org)

Corrosion Control

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

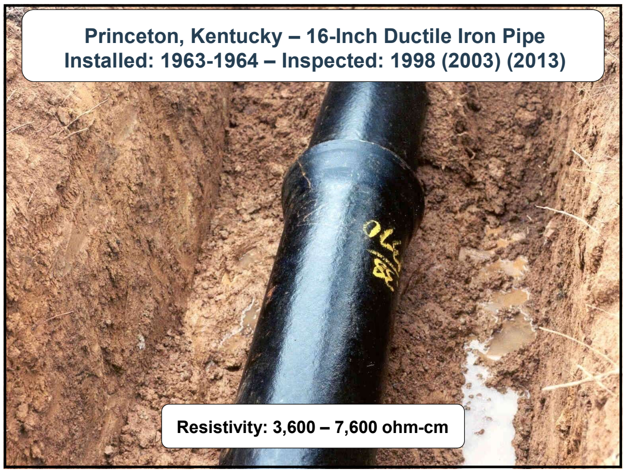
11

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.

14

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

15

Sesquicentennial Club

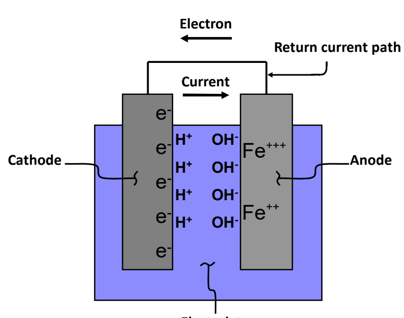
Louisville, KY - October 2010

16

External Soil Corrosion

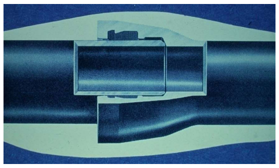
17

Galvanic Corrosion Cell

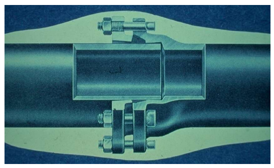


18

Ductile Iron Pipelines are Electrically Discontinuous



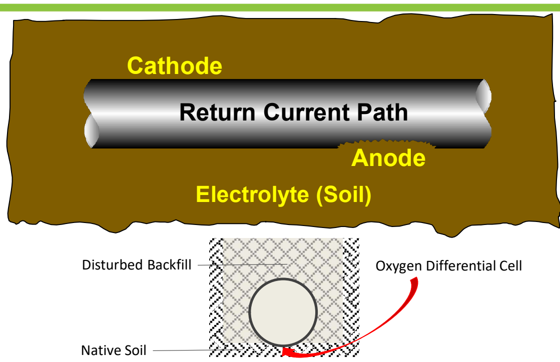
Push-on Joint



Mechanical Joint

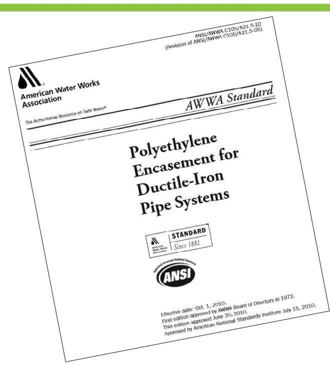
19

The underground pipe corrosion cell . . .



20

ANSI/AWWA C105/A21.5



American Water Works Association

AWWA Standard

Polyethylene Encasement for Ductile-Iron Pipe Systems

STANDARD

ANSI

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*
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

*3 points should be added if low or negative redox and sulfides are present

24

Corrosive Environments

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

25

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**

26

DIPRA Test Sites

27

DIPRA Test Sites

28

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

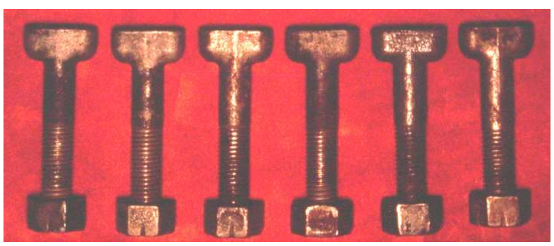
29

30

DIPRA Research

31

DIPRA – Bolt Study



32

CIPRA - 1952
Polyethylene Protection Study

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

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

33

A Solution – Both Economical and Effective

34

Polyethylene Encasement

35

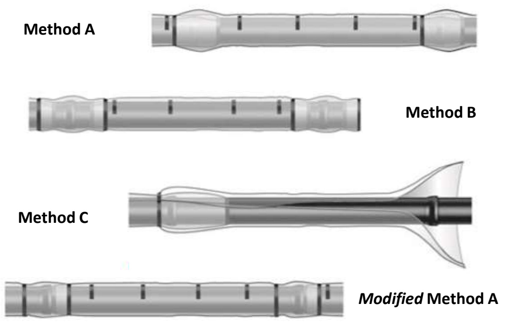
Polyethylene Encasement
History of Development

- 1952 - Research initiated
- 1958 - First installation
- 1972 - First standard issued

20 years of research

36

Polyethylene Encasement Installation



37

Polyethylene Encasement Installation

***Modified* Method A**

38

Polyethylene Encasement (Wet Trench) Installation

39

Installation Video

40

41

Encasement of Appurtenances

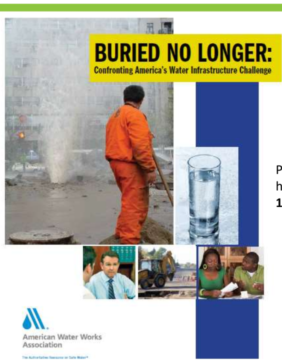
42

Casings

43

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**

44

Polyethylene Encasement

(V-Bio® Enhanced with Additional Colored Layer)

45

Tapping

46

Tapping

47

Tapping

48

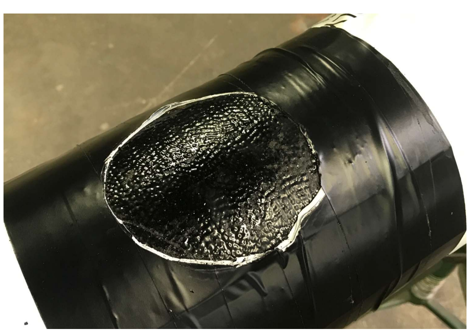
Tapping

49

Saddle Taps

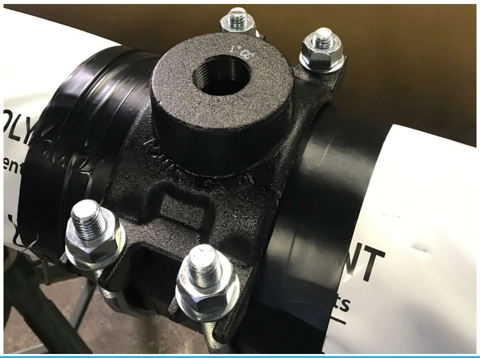
50

Saddle Taps



51

Saddle Taps



52

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

53

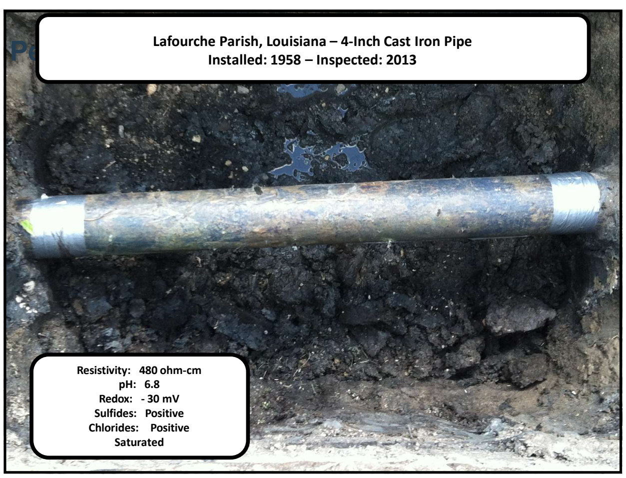
Brochures & Guidelines

54

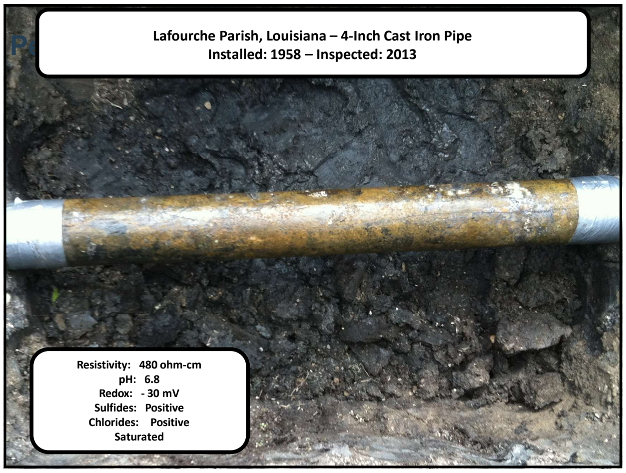
Polyethylene Encasement Investigations

55

56



57



58

59

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

60

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

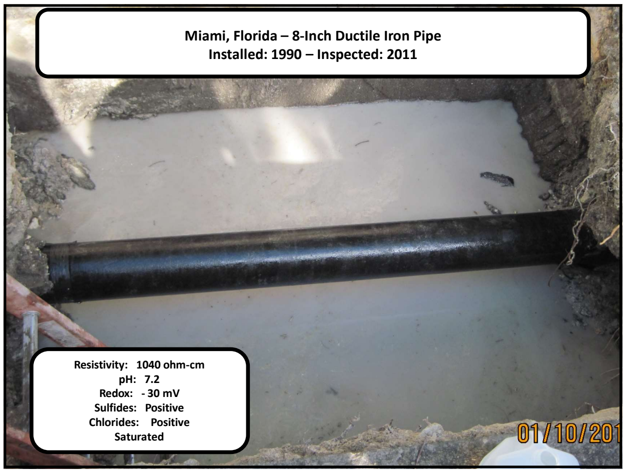
Lafourche Parish, Louisiana
(Clear, Low Density (8-mil) Polyethylene)

64

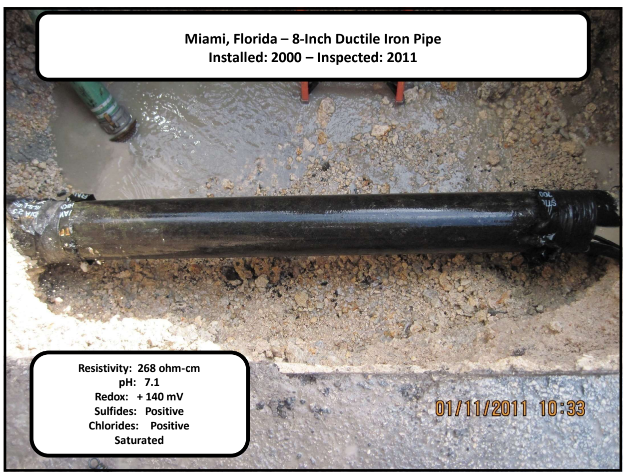
Polyethylene Encasement Investigations

65

66


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

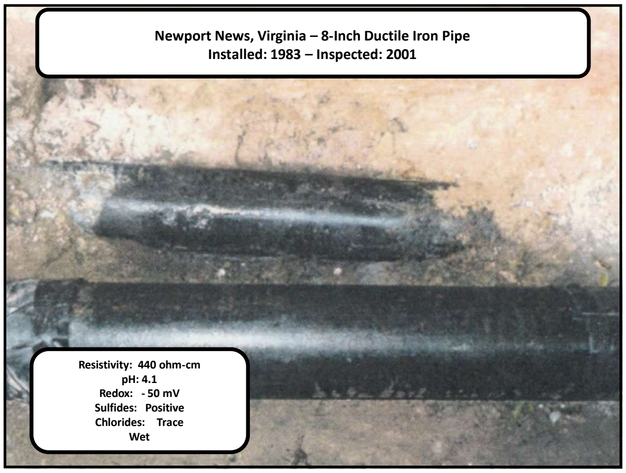
67


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

68


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

69

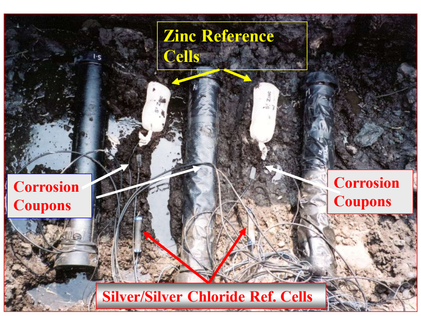


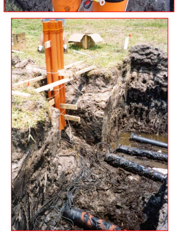
70

Corrosion Probes

71

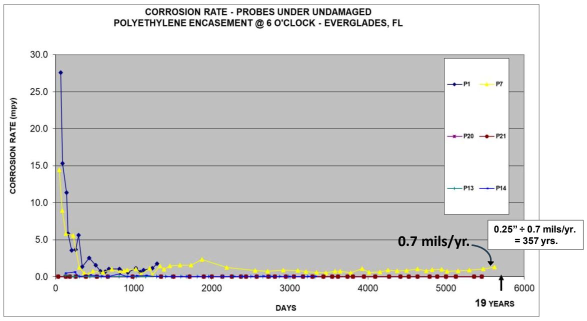
Florida Everglades Corrosion Testing
(above ground monitoring)





72

Corrosion Probes under Polyethylene Encasement



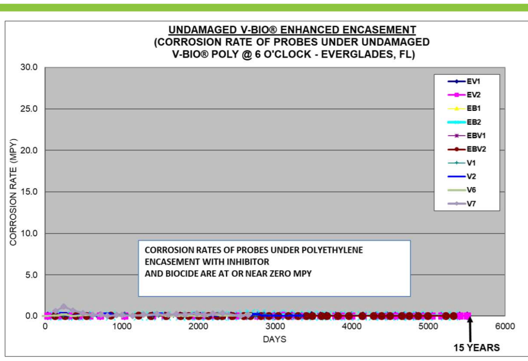
73

RECOMMENDED ADDITIONAL RESEARCH

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

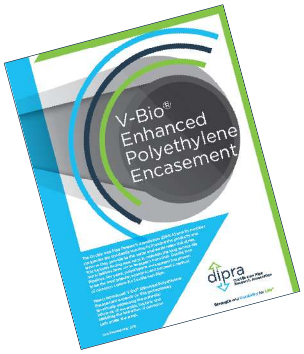
74

Corrosion Probes under *V-Bio*® Polyethylene Encasement



75

V-Bio® Polyethylene Encasement



76

V-Bio® Polyethylene Encasement

77

Design Decision Model (DDM®)

78

The Design Decision Model (DDM®)

79

Likelihood Factors

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

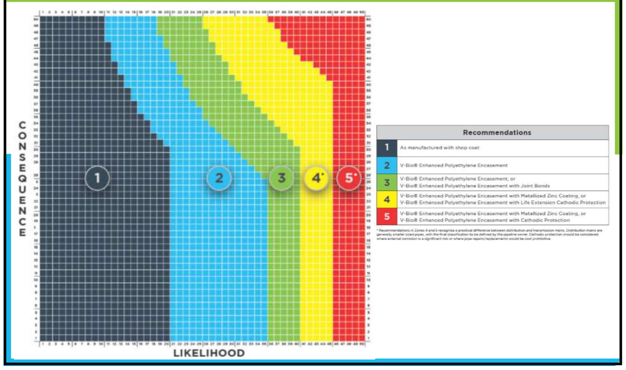
80

Consequence Factors

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

81

The Design Decision Model® (DDM®)



82

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.

83

Polywrapped DIP with CP

84

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

88 JUNE 2005 | JOURNAL AWWA • 97:6 | PEER-REVIEWED | BONDS ET AL

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

86

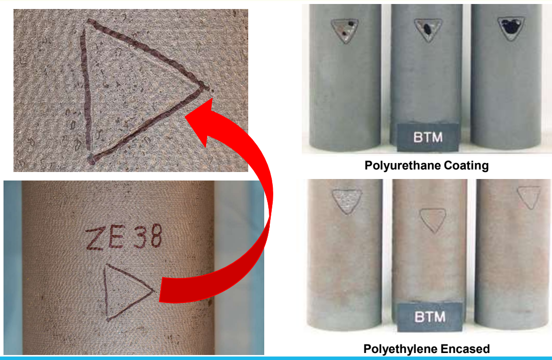
Damaged Polyethylene
vs.
Damaged Bonded Coatings
(Conventional DIP)

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

87

Everglades Test Site

(Zinc-coated Pipe & Damaged V-Bio®)



88

V-Bio® Polyethylene Encasement

89

Strength and Durability for LiFe®

Questions ?

90

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

91

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

U.S. PIPE
A QUIKRETE® COMPANY

1

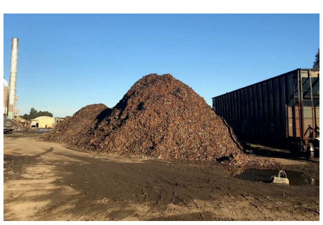
Summary

- 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

4/5/2023 2

2

Raw Material – Ferrous Scrap Metal



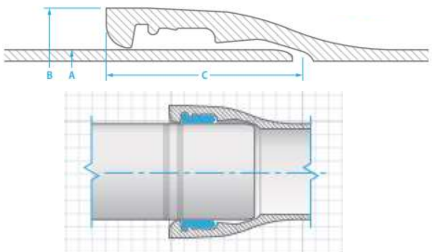
- Majority ferrous scrap metal
- Also added to ferrous scrap: limestone, silica, coke
- "The raw material for ductile iron shall have an average minimum content consisting of 90% recycled iron and steel. Ductile iron pipe shall be manufactured in the USA in accordance with ANSI/AWWA C151/A21.51."

4/5/2023 3

3

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

4/5/2023 7

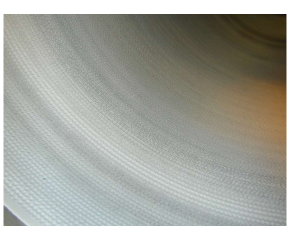
7

Centrifugally Cast Pipe Extraction

4/5/2023 8

8

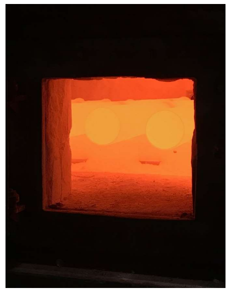
Peened Mold and Resulting Surface



4/5/2023 9

9

Annealing Oven



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

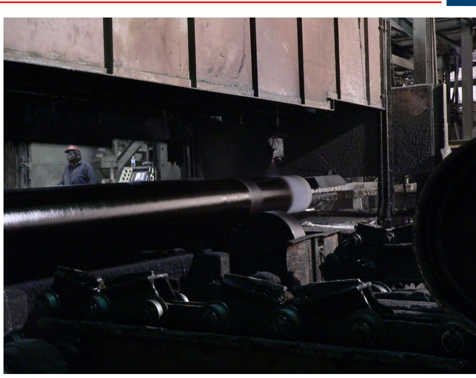
10

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

11

Asphaltic Paint



12

Finished Product

13

Interior Linings

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

14

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

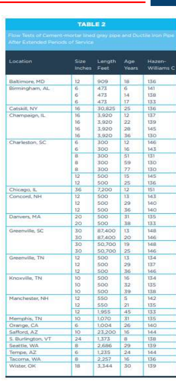


TABLE 2

Flow Tests of Cement-mortar lined gray pipe and Ductile Iron Pipe After Extended Periods of Service

Location	Size Inches	Length Feet	Age Years	Hazen-Williams C
Baltimore, MD	12	909	18	136
Birmingham, AL	6	473	6	141
	6	473	14	138
	6	473	17	133
Catskill, NY	16	30,825	25	136
Champaign, IL	16	3,920	12	137
	16	3,920	22	139
	16	3,920	28	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	138
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	1,235	24	144
Tacoma, WA	8	2,257	16	136
Wister, OK	18	3,344	30	139

15

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

16

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

17

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.

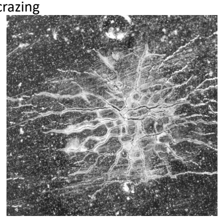
Test Results

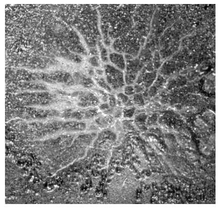
Test Number	Time of Day	Flow Rate (gpm)	Velocity (fps)	Head Loss (in. of water)	Head Loss per Foot	C
Test 1	1:15 PM	330.4	2.3216	9.1444	0.0025	141.6
Test 2	1:30 PM	331.9	2.3321	9.8240	0.0027	136.8
Test 3	1:50 PM	329.8	2.3173	9.2161	0.0026	140.7
Test 4	2:05 PM	329.6	2.3159	9.1841	0.0025	140.9
Test 5	2:15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

18

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

4/5/2023 19

19

NSF 61

4/5/2023 20

20

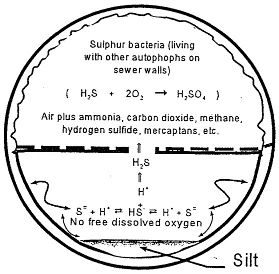
Cement Mortar Limitations

- 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.)

4/5/2023 21

21

Septic Sewage Example



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

4/5/2023 22

22

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

4/5/2023 23

23

Ceramic Epoxy – Sewer Only

4/5/2023 24

24

Ceramic Epoxy – Drinking Water

4/5/2023 25

25

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

4/5/2023 26

26

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

4/5/2023 27

27

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

4/5/2023 28

28

Exterior Coatings

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

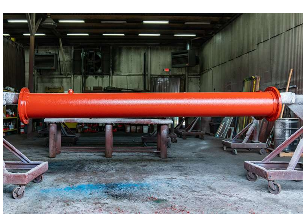
4/5/2023 29

29

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



4/5/2023 30

30

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

4/5/2023 32

32

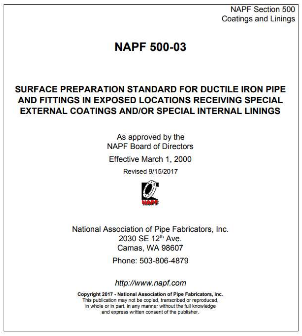
Surface Preparation

- 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")

4/5/2023 33

33

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

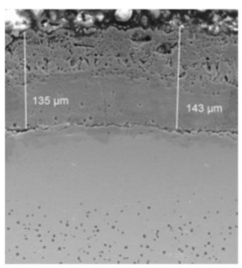
National Association of Pipe Fabricators, Inc.
2030 SE 12th Ave.
Camas, WA 98607
Phone: 503-806-4879

http://www.napf.com

4/5/2023 34

34

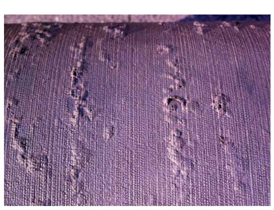
Annealing Oxide



4/5/2023 35

35

Damage to DIP from Over Blasting



4/5/2023 36

36

Holiday Testing

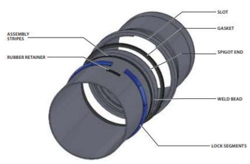
- Low Voltage Testing
  - Also called "wet sponge" testing used for coatings less than 20 mils DFT
- Hight Voltage Testing
  - Also called "spark" testing and typically used for coatings 20 mils or greater DFT
  - Can damage coating if excess voltage, follow recommendation from coating manufacture for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

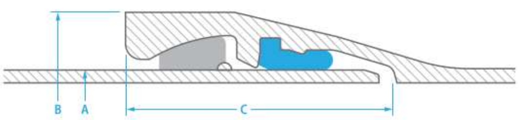
4/5/2023 37

37

Ductile Iron Pipe Specific

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





4/5/2023 38

38

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

4/5/2023 39

39

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

4/5/2023 40

40

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

4/5/2023 41

41

Bonded Coatings – Liquid Epoxy

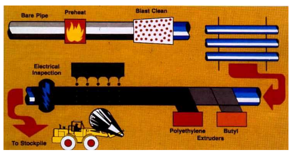
- Normally applied by outside applicator at 25 mils
- ~100% solids liquid epoxy
- Requires special plural component spray equipment
- Available in all pipe diameters & for fittings

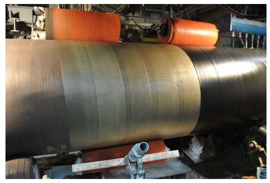
4/5/2023 42

42

Bonded Coatings – Extruded Polyethylene

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





4/5/2023 43

43

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.**

44

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®)

4/5/2023 45

45

US Pipe Corrosion Studies – Everglades, FL

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





4/5/2023 46

46

Everglades, FL - Bare pipe 60+ mpy corrosion rate

47

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

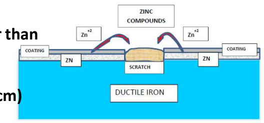
4/5/2023 48

48

Metalized Zinc

Not recommended alone 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**



4/5/2023 49

49

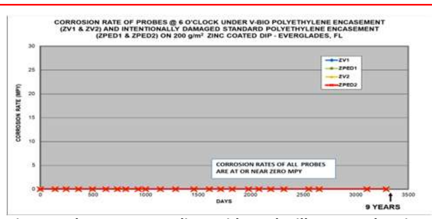
Field Testing

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

4/5/2023 50

50

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**

4/5/2023 51

51

Questions?

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

52

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

53

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.

54

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

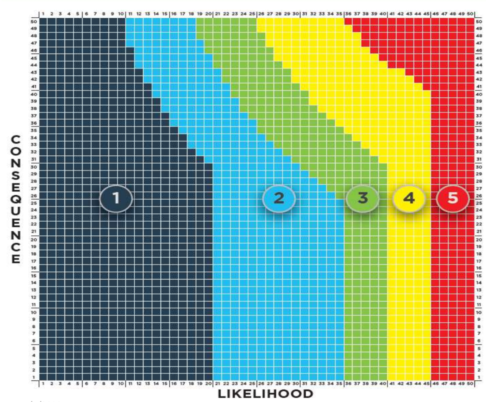
LIKELIHOOD FACTOR		POINTS	MAXIMUM POSSIBLE POINTS
RESISTIVITY	< 500 ohm-cm ≥ 500 - 1000 ohm-cm > 1000 - 1500 ohm-cm > 1500 - 2000 ohm-cm > 2000 - 3000 ohm-cm > 3000 - 5000 ohm-cm > 5000 ohm-cm	30 25 22 19 10 5 0	**30**
CHLORIDES	> 100 ppm = positive 50 - 100 ppm = trace < 50 ppm = negative	8 3 0	**8**
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 > 6	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.

4/5/2023 55

55

DDM® Two-Dimensional Matrix



4/5/2023 56

56

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.

4/5/2023 57

57

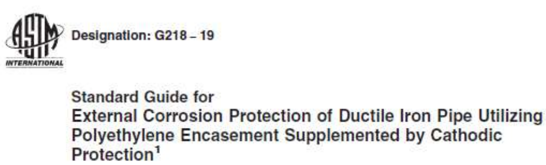
DIPRA Modified Method A

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

4/5/2023 58

58

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]

4/5/2023 59

59

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*"

4/5/2023 60

60

Mitigating Corrosion on Spiralwelded Steel Pipe

Kyle Couture, American

kcouture@american-usa.com

Mitigating Corrosion on Spiral Welded Steel Pipe

A Manufacturer's Perspective

Kyle Couture, P.E.
Sr. Territory Manager
205-215-0220
kcouture@american-usa.com

AMERICAN

AUCSC
MAY 7-9, 2024

Why Steel Pipe?

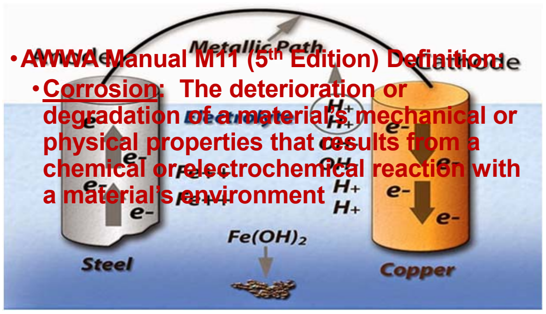
Steel Pipe Advantages

- **Long, Proven History**
  - Use dates back to 1860's
- **Simple, Comprehensive Design Criteria**
  - Flexible Conduit Design
- **Single Component Material**
- **Factory Testing**
  - Hydro test to 75% of yield
- **Bonded Coatings with Dielectric Properties**
- **Competitive Pipe Material in the Marketplace**

Outline

- **Basic Corrosion Principles**
- **Steel Pipe Manufacturing Process**
- **Steel Pipe Lining/Coating Options**

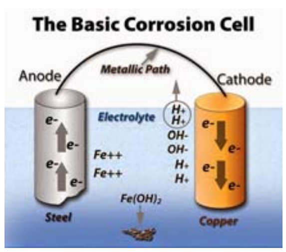
Corrosion Theory



- AWWA Manual M11 (5th Edition) Definition:
  - Corrosion: The deterioration or degradation of a material's mechanical or physical properties that results from a chemical or electrochemical reaction with a material's 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
  - Electrolytic corrosion



Environmental Influences

- **Can change the rate of corrosion by increase or decrease based on type of chemical reaction**
- **Factors include:**
  - Microbiological influence
  - Concentration Cells
  - Temperature change
  - Velocity effects

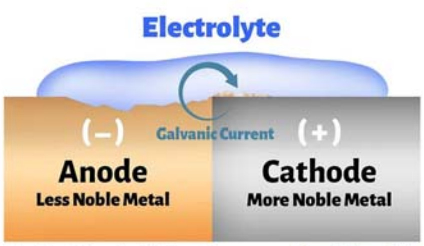
Types of Corrosion

- **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



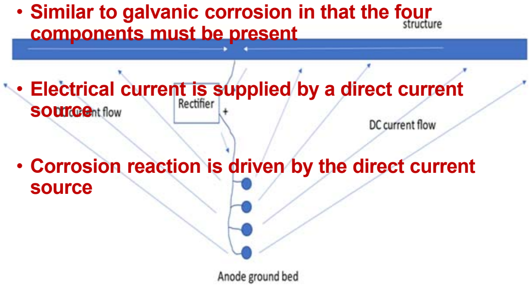
Galvanic/Bimetallic Corrosion of dissimilar metals. © Poma Architectural Metals

Galvanic Corrosion

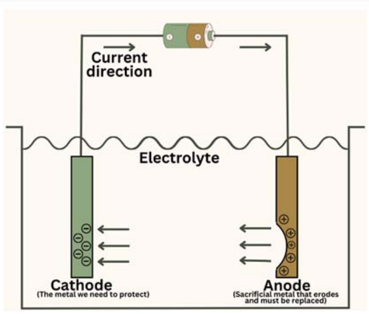
Anodic, Active (Read Down)	
	Manganese bronze
Magnesium	Nickel
Magnesium Alloys	Yellow brass
Zinc	Aluminum bronze
Aluminum 4S	Red brass
Aluminum 3S	Copper
Aluminum 2S	Silicon bronze
Cadmium	Ambrac - 5%Zn, 20%Ni, 75%Cu
Aluminum 17S-T	Nickel (passive)
Mild Steel	Monel - 70%Ni, 30%Cu
Wrought Iron	Titanium
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 Corrosion

- **Causes of electrolytic corrosion**
  - Cathodic protection systems
  - Electric transit systems and electric welding equipment ground to underground utilities

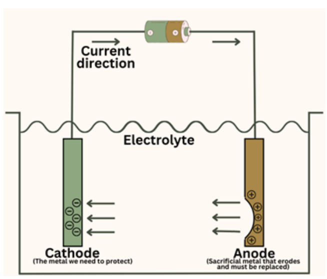
Usually more severe than other types of corrosion

Corrosivity Assessment

- **Prior to any pipeline project**
- **Corrosion Surveys**
  - Field soil resistivity testing
  - Chemical-physical analyses of soil samples
  - Identification of stray current sources
  - Analysis of surrounding area
- **NACE SP0169 or NACE SP0100 are good resources when determining level of corrosion protection needed for your pipeline**

Rate of Corrosion

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

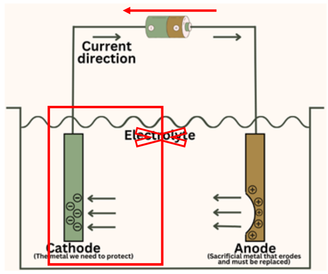


Rate of Corrosion

- **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
  - Various pipe coatings
- Cathodic Protection
- Environmental Alteration

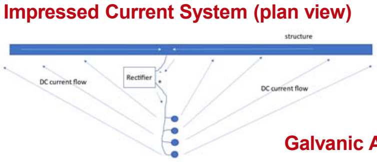


Cathodic Protection

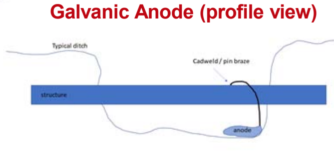
- Theory
  - Makes the entire pipeline the cathode of a galvanic or electrolytic corrosion cell
- Two types of cathodic protection systems
  - Sacrificial anode system, with anodes installed to purposefully corrode and thereby protecting the pipeline
  - Impressed current system

Cathodic Protection

Impressed Current System (plan view)



Galvanic Anode (profile view)



CP - Components

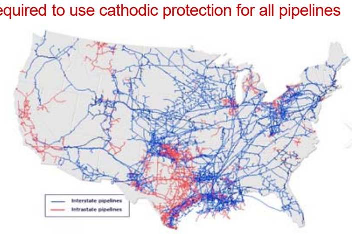
- Bonding of all non-welded or gasketed pipe joints
- Measure stray current, current flow rate, etc
- Electrical isolation
- Can be used to simply monitor corrosion without the use of an anode
- Intervals determined by cathodic protection design
- Anode Bags (Magnesium, Zinc) can be added to proactively protect against corrosion

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
- Past industrial history
  - Required to provide bonded coating
  - Required to use cathodic protection for all pipelines

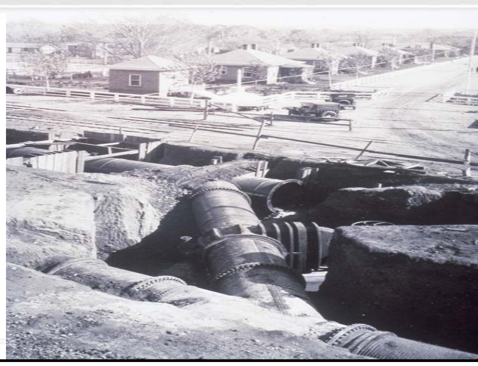


Why?

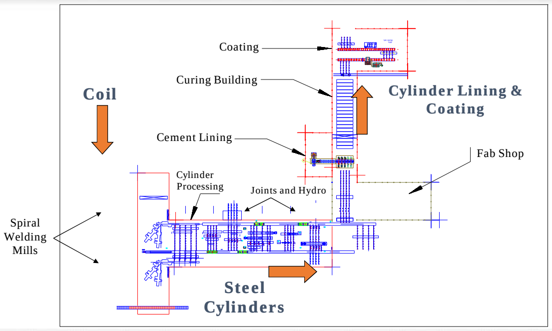
- Because in Gas & Oil lines there is no minor leak
  - Environmental damage
  - Huge monetary consequences
  - Human life

But we are here to discuss Water/ Wastewater

- External corrosion
- Internal corrosion
- Risk factor



Manufacturing Process



Design & Manufacturing

Steel Pipe

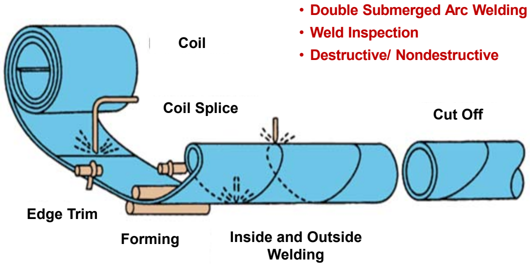
- AWWA C200 – Steel Water Pipe, 6 in. and Larger
- AWWA M11 – Steel Pipe – A Guide for Design and Installation

ASTM A139 Grade C

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

Spiral Welding Mills

- Double Submerged Arc Welding
- Weld Inspection
- Destructive/ Nondestructive



Manufacturing Photos

Steel Pipe Linings & Coatings

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

Manufacturing Photos

Internal Corrosion Protection

- Depends on corrosivity of water or wastewater carried
- More likely to occur in pipelines that change flow rate or are not flowing full
  - Tuberculation
- Cement-mortar lining is most used since 1930s
- Newer linings have been developed and continue to develop for wastewater and forcemain applications

Manufacturing Photos

External Corrosion Protection

- Apply dielectric pipe coating at a minimum for protection
- Use fully welded system
  - Electrically continuous- no joint bonding needed
- Corrosion monitoring system includes:
  - Important this system does not affect a future CP system if discovered to be needed later
- CP System
  - Discuss with your corrosion expert to design

Polyurethane

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

Fittings and Appurtenances

- **Variety of Fittings**
  - **Tee's**
  - **Elbows**
  - **Wye's**
  - **Crosses**

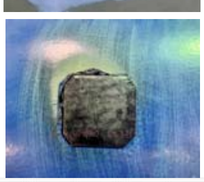
- **Appurtenances**
  - **Man Holes**
  - **Thrust Collars**
  - **Blow Offs**

Repairs

Shrink Sleeve

Polyurethane Repair Kit

CRP Patch



Keys to Remember:

- Iron and Steel Pipe have been used for over 100 years
- History of reliability
- Technology continues to advance
- Use your resources
- Consult a corrosion expert
- Discuss past experiences with your cities, contractors, and manufacturers
- Increasing wall thickness does not mean more corrosion protection

Questions?

Kyle Couture, P.E.
East Sr. Territory Manager
kcouture@american-usa.com
205-215-0220

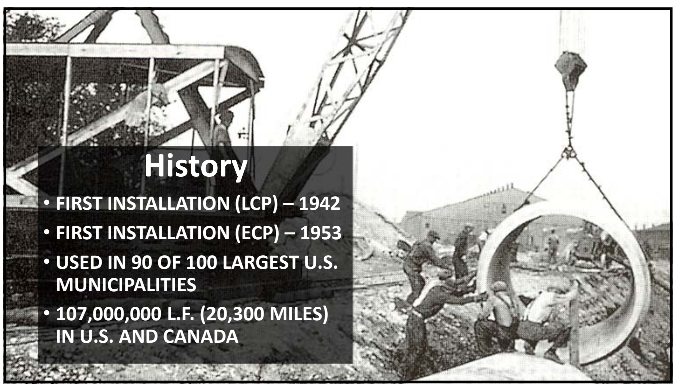
Concrete Pipe and Corrosion Control Techniques

Thompson Pipe Group

AUCSC

Corrosion Protection for Concrete Pressure Pipe

THOMPSON PIPE GROUP



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.

Awwa Research Foundation
Advancing the Science of Water

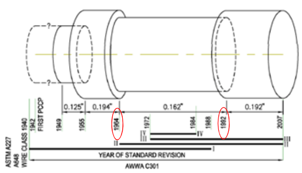
EPA

Failure of Prestressed Concrete Cylinder Pipe (PCCP) - 2008

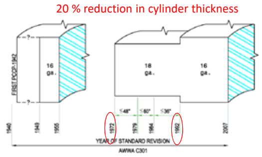
Table 3.1
Sample populations

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

Prestressing 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

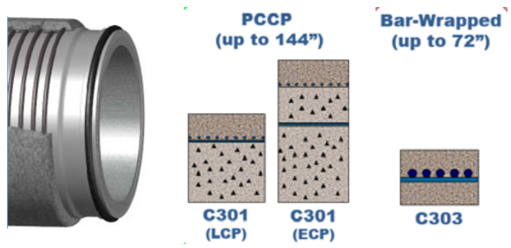
- Minimum Cylinder Thickness Increased to 16 ga
- All Welders Qualified
- Additional Cylinder Steel & Weld Testing

Mortar Coating Improvements

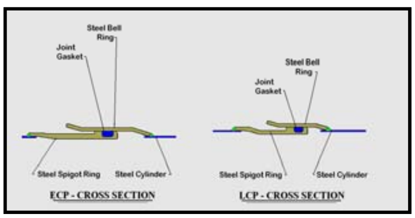
- Minimum coating thickness increased
- Minimum compressive strength added
- Minimum Moisture Content
- Absorption Testing
- Soundness & Bond Check Requirements
- Strength Qualification Tests

> “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



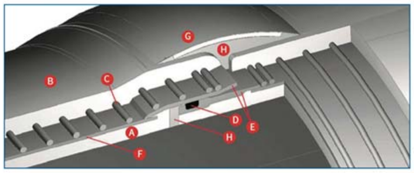
Prestressed Concrete Cylinder Pipe



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

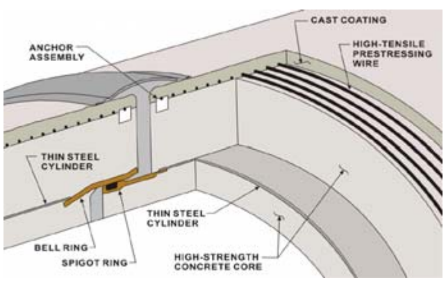
Cement Mortar Coating

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

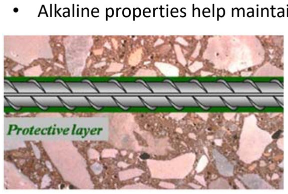
Mortar-Coated Pressure Pipe

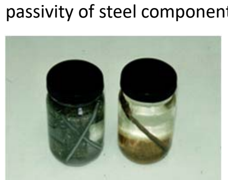


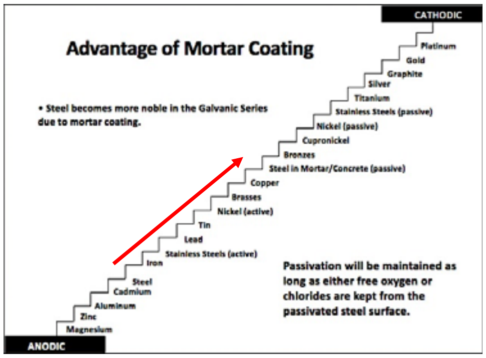
Mortar Protection

Steel Component Protection

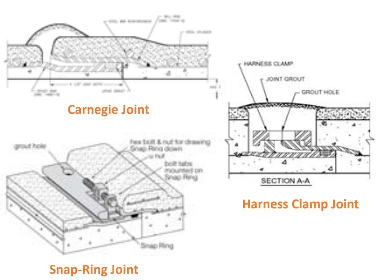
- CM barrier to corrosion
- Alkaline properties help maintain passivity of steel components



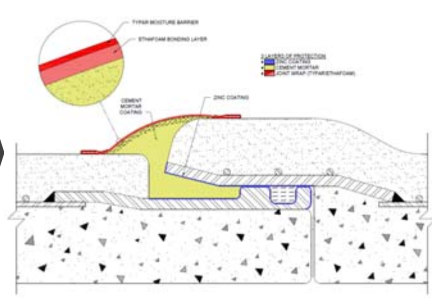




Joint Protection



Joint Corrosion Protection



MOST COMMON CORROSION DAMAGE MECHANISMS FOR CONCRETE PRESSURE PIPE

Most Common Corrosion

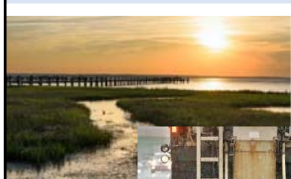
- High Chloride Soils
- High Sulfate Soils
- Acid Soils
- Stray Current

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

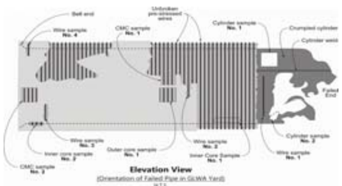


- **Chloride Corrosion of Steel**
  - High chloride concentration in soil/groundwater penetrates mortar coating – promotes active prestressed wire corrosion
  - Needs water, oxygen

Most Common Corrosion

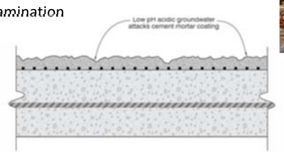
48” PCCP Water Main

- 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

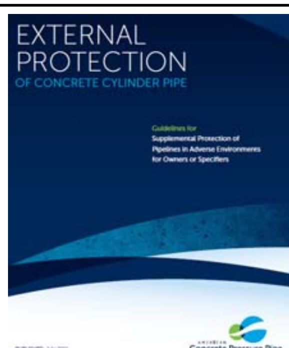
Damage to CM Coating During Construction

- 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)

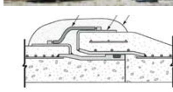
Criteria for Supplemental Protection:
- SO 2- < 2000 ppm

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

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	5649	5266	6606	2585	9766	75	32	8	957	7947	181
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

Analytical Test Results-Soil

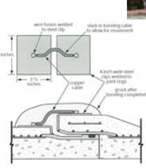
Soil Description		Dark brown, very dense fine particles
Resistivity	as-received (Ω-cm)	57,000
Resistivity	soil/water paste (Ω-cm)	15,000
Water Content (%)		18
Total Hardness* (ppm)		49
pH		5.3
Alkalinity (mva1/kg)		1
Acidity (mva1/kg)		3.6
Redox (mV, platinum vs. Ag/AgCl)		+103
Chloride (mg/kg)		15
Sulfate (mg/kg)		5.5
Sulfide (yes/trace/no)		yes
Particle Size Analysis		
% Sand		40.4
% Clay		25.3
% Silt		34.3
Soil Classification		Loam

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

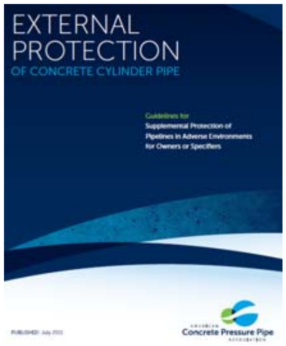
SEGMENTAL CORROSION PROTECTION METHODOLOGY

Segmental Corrosion Protection

If segments of pipeline intersect especially "hot" soils, add CTE over CM coating <u>or</u> 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



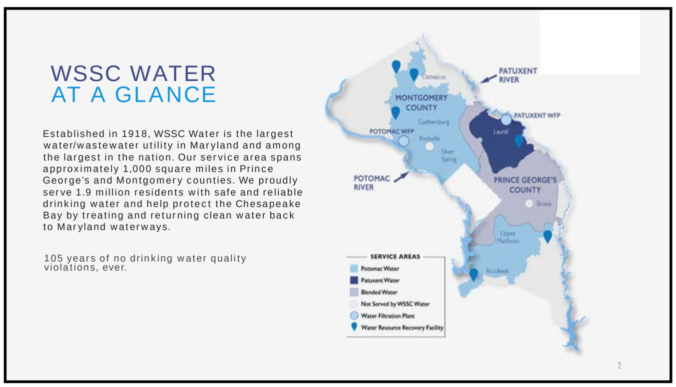
Questions

Corrosion Control Installation Procedures for Water and Sewer Pipeline Infrastructure - Selection and Design Considerations

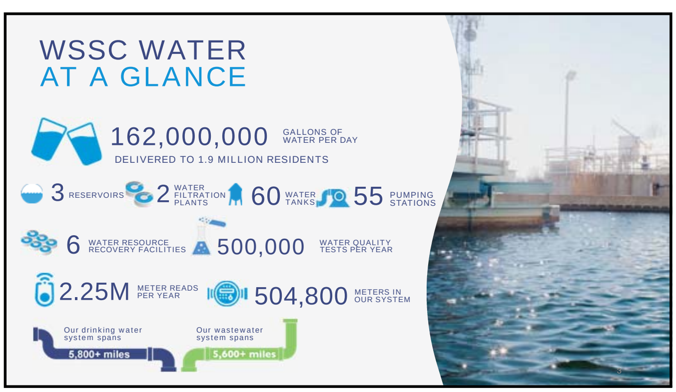
Joe Greulich, Washington Suburban Sanitary Commission

Joe.greulich@wsscwater.com

Corrosion Control Procedures For Water and Sewer Pipeline Infrastructure
Part One – Selection and Design Considerations
WSSC WATER
DELIVERING THE ESSENTIAL
Joe Greulich
Principal Corrosion Engineer
WSSC Engineering and
Environmental Services Division
May 7, 2024



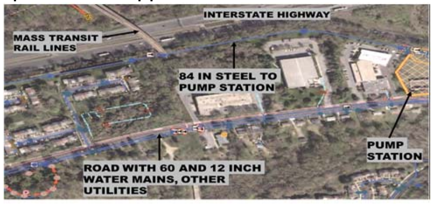
WSSC WATER
AT A GLANCE
Established in 1918, WSSC Water is the largest water/wastewater utility in Maryland and among the largest in the nation. Our service area spans approximately 1,000 square miles in Prince George's and Montgomery counties. We proudly serve 1.9 million residents with safe and reliable drinking water and help protect the Chesapeake Bay by treating and returning clean water back to Maryland waterways.
105 years of no drinking water quality violations, ever.
PATUXENT RIVER
MONTGOMERY COUNTY
PATUXENT WFP
POTOMAC WFP
POTOMAC RIVER
PRINCE GEORGE'S COUNTY
SERVICE AREAS
Potomac Water
Patuxent Water
Blended Water
Not Served by WSSC Water
Water Filtration Plant
Water Resource Recovery Facility
2



WSSC WATER
AT A GLANCE
162,000,000 GALLONS OF WATER PER DAY
DELIVERED TO 1.9 MILLION RESIDENTS
3 RESERVOIRS
2 WATER FILTRATION PLANTS
60 WATER TANKS
55 PUMPING STATIONS
6 WATER RESOURCE RECOVERY FACILITIES
500,000 WATER QUALITY TESTS PER YEAR
2.25M METER READS PER YEAR
504,800 METERS IN OUR SYSTEM
Our drinking water system spans
5,800+ miles
Our wastewater system spans
5,600+ miles

The Need for Corrosion Control

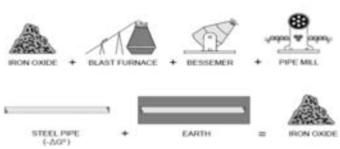
- Corrosion control extends the service of pipelines and can be installed for a fraction of the cost of pipe replacement.
- Some large diameter pipes are so critical to operations that they can not be taken out of service for replacement, or there is no space to install new pipe.



- 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.
  - Existing pipe more accurately reflects expected conditions
- If stray current source is electric powered mass transit rail
  - Testing required to be conducted between 6-10 am or 3-7 pm.
  - Trains are typically more frequent or longer increasing power demand
- No testing is required if there are no stray current sources identified within 2000 feet
- Within 200 feet of 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 and sewer pipelines.
- Also required for pipelines less than 16-inch if project adjacent to or on :
  - Former 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
  - Sampling intervals should not exceed 1000 ft
  - if length less than 2000 ft sample interval should not exceed 700 ft
- Laboratory or field test for pH, chloride content, redox potential, soil resistivity, and soil description.
- Soil Description obtained from boring logs
- Tables 30 and 31 (shown on next slide) determines the overall corrosivity of the soil

Soil Condition Analysis

- Table 30 lists five properties that determine overall soil corrosivity:
  - pH, chloride content, redox potential, soil resistivity, and soil description
  - Soil Description obtained from geotechnical boring logs
  - Laboratory or field tests determine the values of the other properties
  - Based on test results, each property is assigned a point value as shown in Table 30
- The individual point values are added to determine overall corrosivity of the soil as shown in Table 31

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	1		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 are used with Charts C and D to determine the recommended corrosion control.
- Chart C also considers stray current exposure and presence of groundwater to influence decision.

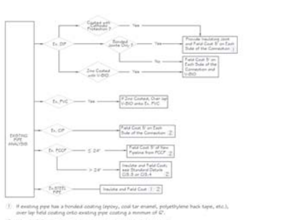


CHART "D"

CHART "C"

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


FORM "B"
Corrosion Documentation

1. Job Description:

2. Site Evaluation

3. Corrosion Control Requirements (based on results of Stray Current Analysis and Soil Condition Analysis):

WSSC Corrosion Control Methods

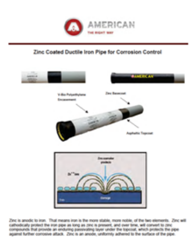
- **WSSC** uses the following corrosion control methods for pipelines:
  - Ductile iron with zinc coating and V-BIO polyethylene encasement – this is the minimum requirement when review determines that there is minimal risk of corrosion.
  - If the minimum requirements are not sufficient the following 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.
      - o Ductile iron has a factory applied tape coating
      - o Steel will either have a tape or spray applied coating

Pipe with polyethylene encasement and encasement before placement on pipe

WSSC Corrosion Control Methods

Zinc coated Pipe before installation of polyethylene encasement

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 spiral weld, 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, picture approximately 2015. 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. Interior of pipe shown in previous slide.

Internal lining for 48 inch ductile iron sewer. Lining is ceramic epoxy with trade name of Protecto 401™.

WSSC Corrosion Control Methods

Ductile iron sewer with green stripe near bell

Ductile iron sewer with exterior of pipe marked to indicate internal lining

Sticker placed near bell showing manufacturing information

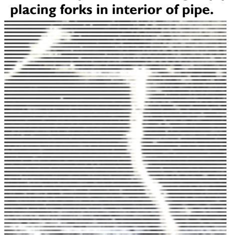
WSSC Corrosion Control Methods

- **Internal lining for sewer is different because sewer produces Hydrogen Sulfide gas.**
- **Gas 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
Internal Lining Damage Due to Improper Handling

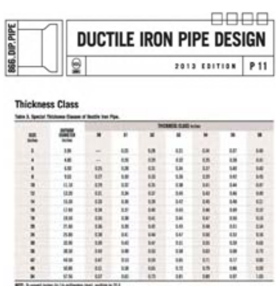
Internal cement mortar lining damage due to pipe being dropped

Damage due use of forklift on interior of pipe. After incident, WSSC Standard Specifications were modified to prohibit handling of pipes by placing forks in interior of pipe.



Design of A Cathodic Protection System

- Selection of a galvanic or impressed current cathodic protection is determined by current required which is affected by some or all of the following:
  - Bare surface area of pipe
  - Soil resistivity
  - Stray current
  - Presence of groundwater
- Assume that a certain percentage of the externally coated pipe surface will be bare due to:
  - Manufacturing process
  - Damage due to handling during shipping and construction
  - Number of fittings, connections to other pipes and/or service connections
  - Pipe geometry - bell and spigot or plain end
  - Length of time pipe has been in service
- To determine required current:
  - Calculate surface area = $\pi \; x \; length \; x \; diameter$
  - Current = *surface area (ft^2) x percent bare (as decimal) x current density (amperes/ ft^2)*
  - Current density is determined by industry guidelines based on soil conditions



Design of A Cathodic Protection System

- Note the following for surface area calculation:
  - Pipe sizes typically refer to the INNER diameter 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 in contact with the soil.
  - For steel pipe: OUTER = INNER + (2 x wall thickness)
  - Steel wall thickness is determined by AWWA M 11
  - Ductile iron has predetermined outer diameters as shown in chart on previous slide
- 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.
- Difference will affect:
  - Amount of current required
  - Number of anodes
  - Whether galvanic or impressed current is installed
- When performing design calculations, always round **UP** the amount of current or anodes required.

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

Corrosion Control Installation Procedures for Water and Sewer Pipeline Infrastructure - Installation and Testing

Joe Greulich, Washington Suburban Sanitary Commission

Joe.greulich@wsscwater.com

Corrosion Control Procedures For Water and Sewer Pipeline Infrastructure
Part Two – Installation and Testing

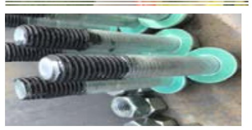
WSSC WATER
DELIVERING THE ESSENTIAL

Joe Greulich
Principal Corrosion Engineer
WSSC Engineering and
Environmental Services Division

May 7, 2024

Components of A Cathodic Protection System

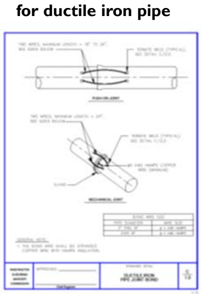
- Effective cathodic protection systems require the pipe to be electrically continuous.
  - A rubber gasket is placed between the spigot end and bell end, gasket and cement mortar lining prevents metallic contact between pipe sections.
  - Bond wires are welded across pipe joints (WSSC Standard
    Detail C 1.0) to provide electrical continuity.
  - Plain end steel pipe is welded together. The weld creates one continuous pipe so joint bonding is not required.
- Insulating Joints (IJs) are installed at connections between new and existing pipe
  - IJs electrically 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 Six 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.



42 inch insulating joint, bolts with non metallic washers and sleeves

Components of A Cathodic Protection System

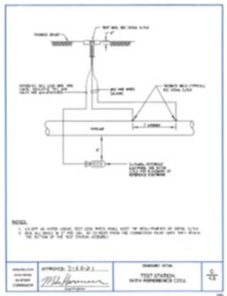
Joint bonding detail for ductile iron pipe



Plain end steel pipe before joint welding

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 AMPP (formerly 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.

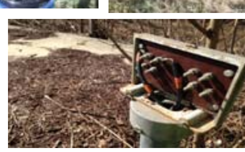


Components of Cathodic Protection Systems

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.



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 via pin brazing and tape coating of joints

Pin brazing

Tape coating

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

Pictures of bond wires and tape coating of joint



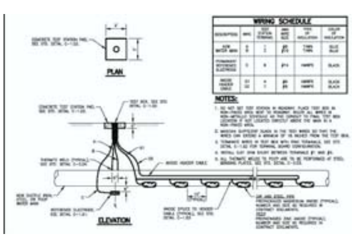

Galvanic Cathodic Protection System

- Magnesium or zinc anodes are installed :
  - Horizontally in one continuous trench parallel to pipeline
  - 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 to improve performance
  - Backfill is mixture of 75% gypsum, 20% bentonite, 5% sodium sulphate.
  - A 32 lb anode will have a packaged weight of 68 lbs.
  - Anode remains in bag for installation and are soaked in water prior to installation to activate special backfill.
  - 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, completing the circuit allowing 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. Anode lead can also be routed to test station with test leads.
    - 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 life ends.
  - End of service life indicated by little or no anode current, or low anode potential.
  - Anodes are also available in a ribbon which can be laid along pipe length to improve current distribution.

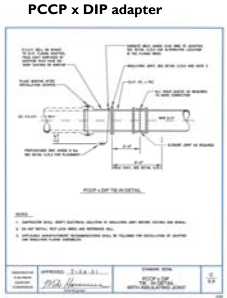
Magnesium anodes before placement in bag with special backfill

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

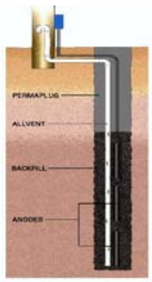
- **A galvanic system has a fixed output with limited current and voltage. An impressed current system has adjustable output that can be varied over time.**
- **Current requirements can increase over time due to some or all of the following:**
  - Deterioration of pipeline coatings
  - Changes in soil conditions
  - Stray current conditions change
- **Three main components:**
  - Structure negative lead
  - Anodes
  - Rectifier which converts incoming AC to DC
- **Structure negative lead:**
  - Attached to pipeline via thermite weld
  - Typical wire used is # 2 AWG HMWPE
  - Routed to rectifier in trench as one continuous lead without splices
  - Connected to DC NEGATIVE terminal of rectifier

Structure negative lead trench to rectifier

Impressed Current Cathodic Protection System

- Anodes
  - Typically installed vertically in one well known as a deep well, depths are usually 150 to 200 ft
    - Area between the anode and the well wall is filled with a special backfill known as coke breeze, a solid material that is pumped into well as a slurry.
    - Also installed in the well is a vent pipe which is terminated just below the surface. Anodes emit a gas as they are consumed, vent allows this gas to reach grade.
    - Well is terminated at grade with a flush mount well cap with drilled holes to allow gas to vent
  - 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.
  - Lead wire attached at manufacturer connected to core of anode.
    - Each lead wire is brought in one continuous run to an anode junction box.
    - Connected to individual terminals with shunts to measure current output.
  - An anode header cable connects the junction box to the rectifier.
    - Header cable connected to **DC POSITIVE** terminal of rectifier
  - Present anode material is High Silicon Cast Iron (HSCI), Mixed Metal Oxide (MMO) can also be used which has a titanium core. MMO anodes are smaller and lighter.
  - Anodes are also available in a ribbon which can be laid along pipe length to improve current distribution.

Anode well



Impressed Current Cathodic Protection System

High Silicon Cast Iron Anodes

Center wire connection

lead wires (Black) and lowering rope (yellow),

Centralizers attached holds anode in place in well.

Impressed Current Cathodic Protection System

Drilling of anode well

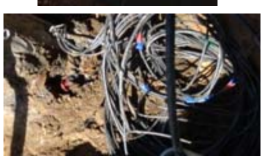
Anode well casing typically installed in first 50 ft of well

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.

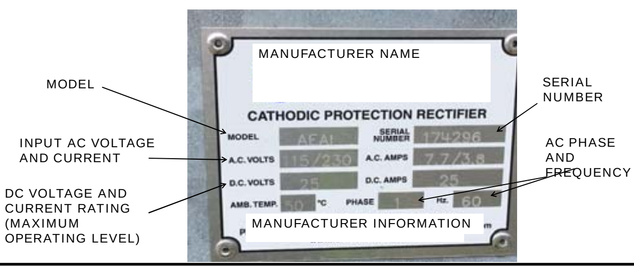
Anode wells for site.
Had to drill two shorter wells due to rock

Impressed Current Cathodic Protection System

- Rectifiers:
  - 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:
    - Anode header cable connected to the DC POSITIVE terminal
    - Structure negative lead connected to the DC NEGATIVE terminal
    - Critical step that these connections are properly made
    - Improper connections will reverse polarity of circuit, and pipe will act as anode.
    - Severe rapid corrosion of pipeline will result. Full pipe wall penetration is possible.
    - WSSC specifications require anode header cable to be marked to differentiate it from structure negative lead.
  - Either air cooled or oil cooled.
    - Oiled cooled units are typically used in hazardous atmospheres, enclosed spaces with limited air movement, or very high current demand.
  - Potential controlled units have a permanent reference cell installed to continuously monitor pipe to soil potentials.
    - If pipe to soil potential changes, rectifier output will automatically adjust
    - Typically used for stray current mitigation or to minimize stray current effects on other pipelines.
    - Also used for water tank interiors.
  - Rectifiers have a Remote Monitoring Unit (RMU) connected to them, which allows output of rectifiers to be checked without visiting site.

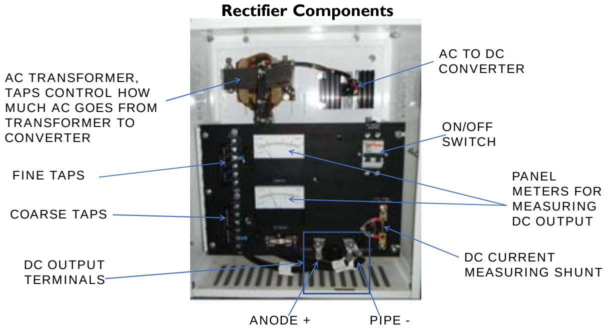
Impressed Current Cathodic Protection System

Rectifier Information panel, typically on front door or inside of front door



Impressed Current Cathodic Protection System

Rectifier Components



Impressed Current Cathodic Protection System

AC buss bar for 115 or 230 V AC service

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

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

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

Impressed Current Cathodic Protection System

Close up of RMU and connections to rectifier.


Impressed Current Cathodic Protection System

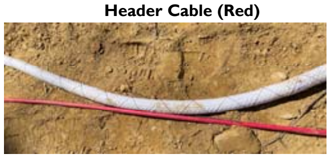
Oil cooled Rectifier




Impressed Current Cathodic Protection System

Potential Controlled Rectifier

Ribbon Anode and Header Cable (Red)



Damaged Test Stations

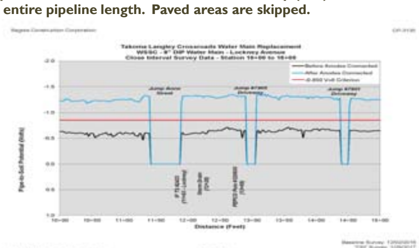
Test stations that cannot be located.

Damaged Test Stations

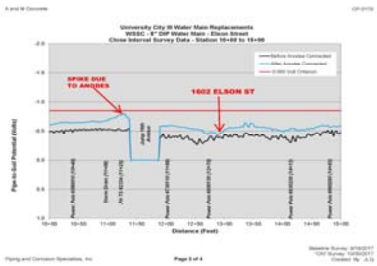
Test stations that have been damaged.

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.**

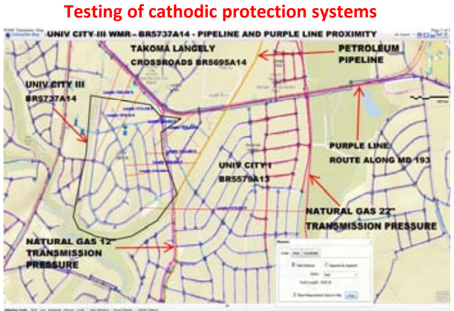


Testing of cathodic protection systems



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.**
- **Gas Utility was contacted, they indicated issues with their cathodic protection system.**
- **Gas Utility 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

Developing a Corrosion Control Program for a Water Utility

Jacob Martin, Cleveland Water

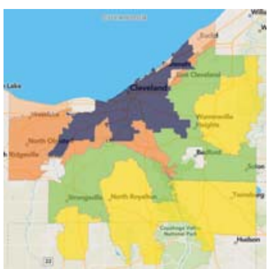
Jacob_martin@clevelandwater.com

Developing a Corrosion Control Program for a Water Utility

Jacob Martin – Corrosion Prevention and Control Program Manager

Cleveland Water

Cleveland Water Overview

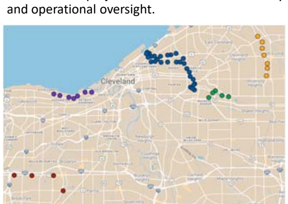


- 10th largest water utility in the U.S.
- Serves 1.5 million residents across 5 counties, including the City of Cleveland and 64 suburbs
- Infrastructure:
  - 5,500 miles of Water Mains
  - 4 Water Treatment Plants
  - 13 Pump Stations
  - 17 Water Storage Tanks/Towers

Corrosion Program History

CWD's corrosion program ranges from the 1970s to present with varying levels of robustness

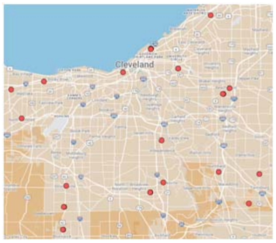
- ICCP systems on steel transmission mains were installed in the late 1970s and early 1990s with some rehabilitation projects in the late 2000s. These systems have generally gone without sufficient maintenance and operational oversight.



- Twin 60s: 11 miles of 48" and 60" steel/cast-iron main that runs from Kirtland Pump Station to Baldwin Treatment Plant.
- Brookpark Road: 4 miles of 36" steel transmission main.
- Lake Avenue: 4 miles of steel transmission main.
- North Park Boulevard: 3 miles of steel transmission main.
- South Belvoir Boulevard: 6 miles of steel transmission main.

Corrosion Program History

ICCP systems in 24 steel tanks including elevated tanks, surge tanks, and wash water tanks were primarily installed in the late 1970s.



Where did we start?

External Guidelines

- NACE SP21412-2016/SSPC-CPC 1, Corrosion Prevention and Control Planning
  - Standard intended to support future CPC improvements to national acquisition and sustainment of equipment, systems, facilities, and infrastructure at an acceptable cost.
- Review of the Bureau of Reclamation's Corrosion Prevention Standards for Ductile Iron Pipe
  - Addresses the corrosion performance issues associated with ductile iron pipe with polyethylene encasement and cathodic protection.
- State and Federal regulatory guidelines and compliance
- Washington Suburban Sanitary Commission Common Design Guidelines
- Water Research Foundation Project #4618: Retrofit and Management of Metallic Pipe with Cathodic Protection

Water Research Foundation Project #4618:

- Chapter 1: Introduction
- Chapter 2: Literature Review
  - Background information on corrosion, CP criteria, and methods of measuring CP effectiveness
- Chapter 3: Workshop Summaries
  - Covers various topics and includes input from workshop participants on the challenges and benefits of launching CP programs
- Chapter 4: Utility Decision Framework for Cathodic Protection
  - Discusses factors (other than pipe system properties) affecting a water utility's perspective and decision making in regard to CP programs
- Chapters 5 and 6: Case Studies
  - Contains numerical case studies based on failure (number of breaks) and qualitative case studies based on the administrative and planning side of launching a CP Program. The studies present CP program strategies based on the utilities' characteristics and asset management planning

Water Research Foundation Project #4618:

- Chapter 7: Hot Spot No Brainer
  - Discusses benefits of hot spotting as a procedure that should be exercised as part of the routine procedures in the event of failures
- Chapter 8: Financial Models
  - Presents charts and tables on savings that can be achieved by the implementation of CP retrofit programs
- Chapter 9: Best Practice Manual
  - Provides industry guidelines on the design and installation of CP retrofit and hot spot programs. Standard details and specification samples are provided as part of this chapter.
- Chapter 10: Conclusions and Future Work
- Appendix A: More on Soil Corrosivity Testing
- Appendix B: More on Stray Current and Grounding
- Appendix C: Record Keeping
- Appendix D: Standard Detail Drawings
- Appendix E: Sample Standard Specifications

Where did we start?

2001 Trunk Main Task Force

- Used to study and address the issues of Cleveland's aging water distribution system
  - Should CWD begin a systematic replacement of large diameter water mains? Prioritization method, replacement rate?
  - Should CWD embark on a program of non-destructive testing? Which mains, what techniques?
  - Should CWD embark on a program to extend life of large diameter mains? Which mains first, what techniques should be employed?
  - Are there modifications that CWD can make to extend the lifetime of mains?

2001 Trunk Main Task Force Recommendations

"Enhance CWD's Cathodic Protection Program"

- Retrofit other at-risk mains with cathodic protection
- Test bonded-joint pipe for corrosion conditions
- Initiate an Anode Replacement Program
- Formalize approach to cathodic protection
- Ensure stray current coordination with the cathodic protection systems of other utilities

2001 Trunk Main Task Force Recommendations

"Review CWD's Trunk Main Design Standards"

- Review trunk main design and installation standards for cathodic protection

"Enhance CWD's Trunk Main Program"

- Trunk main condition assessments
- Life extension of existing assets (through cathodic protection mitigation)
- Renewal of assets, as appropriate

Where did we start?

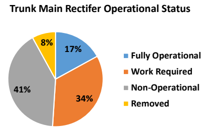
2018 ICCP Baseline Assessment

- Identify, quantify, and organize CWD's cathodic protection assets to determine their operational reliability
  - Inventory and field assessments were simultaneously conducted to quantify and qualify resources (field assets, test equipment, records, etc.) at all CWD facilities
  - Historical information was collated, digitized, and archived

2018 ICCP Baseline Assessment

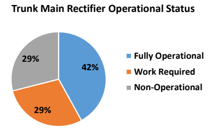
Trunk Mains

- 54 Total Rectifiers on 5 Steel Trunk Mains



Water Storage Tanks/Towers

- 24 Rectifiers – One for Each Tank/Tower



What Makes an Effective Corrosion Program?

Incorporating field operations and engineering components to create a cohesive program that successfully interfaces with all working groups

Engineering Staff
- Specification Development
- Development of and Updates to Standard Operating Procedures
- Corrosion Design and Project Review
- Failure Analysis
- Corrosion Education

Field Operations
- Inventory Control
- Asset Management
- System Monitoring
- Construction Inspection

Project Goals

External Corrosion Control Design Manual

- Update CWD's methodology for Corrosion Control including:
  - Design Specifications
  - Standard Details
  - Creation of a cathodic protection decision framework
  - Creation of a formal design submittal framework for cathodic protection design and implementation
- Lead to the development of consistent, unified practices and standard operation procedures

DOCUMENT OVERVIEW

The goal of this manual is to provide information for Cleveland Water (CWD) managers, operators, consultants, and contractors to select the best materials and practices for corrosion control.

Document Breakdown
- Corrosion Prevention Theory
- Corrosion Control Design Guidelines
- Asset Management Practices
- Cathodic Protection Specifications
- Standard Details
- Appendices
  - Design References
  - Submittal Forms

EXTERNAL CORROSION DESIGN MANUAL (ECCDM)

Provides information for CWD managers, operators, and contractors to select the best materials and practices for corrosion control

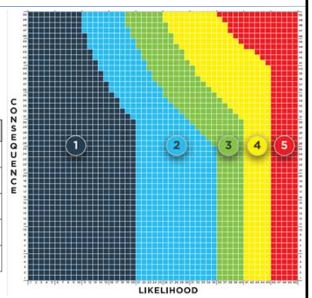
1. Corrosion Prevention Theory
   a) Causes of Corrosion
   b) Types of Corrosion
   c) Methods of Corrosion Control
   d) Failure Analysis
2. Corrosion Control Design Guidelines
   a) Soil Corrosivity Rating
   b) Soil Condition Analysis
   c) Stray Current Analysis
   d) Consequence of Failure (COF)
   e) Corrosion Control Decision Matrix (CCDM)
   f) Cathodic Protection Submittal and Design Guidelines
   g) Design Decision for Existing Water Mains
3. Asset Management Practices
4. Cathodic Protection Specifications
5. Standard Details

Corrosion Control Design Guidelines (DIPRA)

Corrosion Control Decision Matrix: Implements quantitative measures to provide consistent design guidelines for cathodic protection implementation:

1. *Likelihood of Corrosion (LoC)*
2. *Consequence of Failure (CoF)*

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



Likelihood of Corrosion

Soil Corrosivity Rating

- Point-rated scales for each parameter with total available points ranging 0-60
- Provides framework for uniform soil sampling and analysis
- ASTM Standardization

PARAMETER	RANGE	VALUE	PARAMETER	RANGE	VALUE
Soil Resistivity	<500 Ω-cm	30	Redox Potential	Negative	2
	≥500-1,000 Ω-cm	25		0-100 mV	1
	1,000-1,500 Ω-cm	22		>100 mV	0
	1,500-2,000 Ω-cm	19	Chloride Content	>100 ppm	8
	2,000-3,000 Ω-cm	10		50 - 100 ppm	3
	3,000-5,000 Ω-cm	5		< 50 ppm	0
	5,000-10,000 Ω-cm	3	Sulfide Content	> 1 ppm	4
	>10,000 Ω-cm	0		0 - 1 ppm	1.5
pH	0-2	6		0 ppm	0
	2-4	4	Moisture Content	> 15% = Wet	5
	> 4-6	2		5 - 15% = Moist	2.5
	6-8*	6		< 5% = Dry	0
	> 6	0	Pipe Location	Below Water Table at Any Time	5

***And** Contains sulfides **and** has a redox potential lower than 100 mV

ASTM Standards

Soil Corrosivity Rating

- Soil Resistivity (ASTM G57, ASTM G187)
  - Soil borings shall be collected nearest the proposed pipe depth
- pH (ASTM G51)
  - Measurements shall be collected by jar sampling nearest the proposed pipe depth
- Redox Potential (ASTM D1498)
  - Measurements shall be collected by jar sampling nearest the proposed pipe depth
- Chloride Content (ASTM D512)
  - Water soluble chloride content shall be determined by chloride ion extraction using acceptable industry methodology prior to testing.
- Sulfide Content (ASTM D4658)
  - Water soluble sulfide content shall be determined by sulfide ion extraction using acceptable industry methodology prior to testing
- Water Table (ASTM D4750)
  - The water table depth shall be determined via soil boring using acceptable industry methodology

Consequence of Failure

Consequence of Failure

- Critical factors relating to operational reliability, maintainability, and subsequent effects on the distribution system
- Point-rated scales for each parameter with total available points ranging 4-50

PARAMETER	RANGE	VALUE	PARAMETER	RANGE	VALUE
Pipe Diameter	36" to 60"	15	Reparability	Prohibitive	15
	28" to 32"	9		Difficult	9
	16" to 24"	5		Moderate	5
	3" to 12"	2		Routine	0
Secondary Water Supply	No Alternative Path	10	Customer Criticality	Severe	10
	Only Alternative Path is to Storage Tank/Tower	5		Moderate	6
	Alternative Path to Pump Station	0		Appreciable	2

Consequence of Failure: Reparability and Customer Criticality

PARAMETER	RANGE	VALUE
Reparability	Prohibitive	15
	Difficult	9
	Moderate	5
	Routine	0

Suggested Classifications for Reparability

Category	Requirements
Prohibitive	Primary roads, freeways, railroad crossing, river crossings
Difficult	Secondary roads, bridges
Moderate	Tertiary roads, sidewalks
Routine	Tree lawns, fields

PARAMETER	RANGE	VALUE
Customer Criticality	Severe	10
	Moderate	6
	Appreciable	2

Suggested Classifications for Customer Criticality

Category	Requirements
Severe	Industrial, Schools, Hospitals, High-density commercial, Wholesale customers
Moderate	Medium-density commercial and residential
Appreciable	Low-density commercial and residential

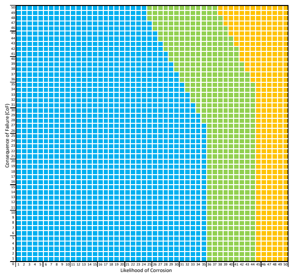
CWD Corrosion Control Decision Matrix

Corrosion Control Decision Matrix: Implements quantitative measures to provide consistent design guidelines for cathodic protection implementation:

1. *Likelihood of Corrosion (LoC)*
2. *Consequence of Failure (CoF)*

CATEGORY	REQUIREMENTS
1	V-Bio Enhanced Polyethylene Encasement
2	V-Bio Enhanced Polyethylene Encasement with Metallized Zinc Coating*
3	ICCP for diameters of 20" or larger. GACP for diameters less than 20".

*May include joint bonding at the discretion of CWD.



Design Submittal Process

CP Submittal II
(Due between 30% and 60% Design Submittals)

Submittal II

(1) All pipe sizes, submit the completed **Cathodic Protection Submittal II** form including:

i. Soil Condition Analysis
ii. Stray Current Analysis (if required)
iii. Existing Pipe Analysis
iv. Likelihood of Corrosion
v. External Corrosion Control Recommendation

Stray Current Corrosion Control Submittal
(Due with 60% Design Submittal, if required)

Stray Current Control Plan

(1) All pipe sizes, submit plans and specifications with corrosion control and stray current control measures.

CP Submittal 1
(Due with 30% Design Submittal)

Submittal I

(1) All pipe sizes, submit the completed **Cathodic Protection Submittal I** form along with:

i. Preliminary plans showing the pipeline alignment
ii. Proposed soil boring locations
iii. CWD will provide the CoF scores after Submittal I

CATHODIC PROTECTION SUBMITTAL I

SECTION I: PROJECT INFORMATION	
PROJECT NAME: ______________________	CONTRACT: ____________
PREPARER (PRINT): ______________________	TITLE: ____________
SIGNATURE OF PREPARER: ______________________	DATE: ____________

CATHODIC PROTECTION SUBMITTAL I

SECTION II: PROPOSED WATER MAIN INFORMATION

This section outlines information regarding the proposed water main. An additional page shall be attached, showing proposed soil sample and/or boring locations per the sampling requirements in **3.2 Soil Condition Analysis**.

Proposed Water Main Information

Job Type: ________ New Water Main ________ Relocation ________ Same Trench Replacement

Material: _____ DIP _____ PCCP _____ Steel _____ Other Size(s): ________

Water Main Type: _____ Distribution _____ Transmission _____ Express

CATHODIC PROTECTION SUBMITTAL I

SECTION III: STRAY CURRENT CONSIDERATIONS WITHIN 2000 FEET OF PROPOSED ALIGNMENT

This information is determined through OUPS tickets, geographical review, and/or contact with appropriate utilities. If any of the below result in *"Yes,"* a *Stray Current Corrosion Control* plan is **required**.

(1) Yes __ No __ Greater Cleveland Regional Transport Authority rapid transit lines

(2) Yes __ No __ Petroleum product, natural gas, or cryogenic liquid pipelines with impressed current cathodic protection systems

(3) Yes __ No __ Communication or power cables with impressed current cathodic Protection system

(4) Yes __ No __ An alignment perpendicular and/or parallel with an electrical transmission line corridor

CATHODIC PROTECTION SUBMITTAL I

SECTION IV: ADDITIONAL CORROSION CONSIDERATIONS

This information will be used for Cleveland Water Corrosion Prevention and Control internal purposes.

(1) Yes __ No __ Exposure to deicing salts

(2) Yes __ No __ Exposure to chemical or animal waste runoffs from nearby farms or golf courses

(3) Yes __ No __ Wetlands or sites containing significant deposits of organic soils, such as peat

(4) Yes __ No __ Pipe exposed to continually wet or submerged environments

(5) Yes __ No __ Cyclic wetting and drying due to fluctuating groundwater table

(6) Yes __ No __ Soil type generally corrosive to buried metals (i.e. acidic sulfate soils)

(7) Yes __ No __ Proximity to highly break or leak sensitive locations (dams, bridges, etc.)

CATHODIC PROTECTION SUBMITTAL II

SECTION I: PROJECT INFORMATION

PROJECT NAME: ______________________________ CONTRACT: ______________

PREPARER (PRINT): ____________________________ TITLE: ________________

SIGNATURE OF PREPARER: ________________________ DATE: ________________

CATHODIC PROTECTION SUBMITTAL II

SECTION II: EXISTING PIPE REVIEW

This section details necessary field work for tying into existing water main(s). CWD will provide additional data if existing cathodic protection conditions are unknown.

Size(s): ________

Existing Material:
- _____ CIP
- _____ DIP
- _____ PCCP
- _____ Steel
- _____ HDPE
- _____ Other

Existing Cathodic Protection:
- _____ None
- _____ Bonded Joints
- _____ Coated: Coating Type: ____________________
- _____ Cathodic Protection: Type: _____ Anodes
  - _____ Impressed Current

Corrosion Control Required per *Figure 14. Corrosion Control Decision Tree for Existing Mains*: ______________________________

CATHODIC PROTECTION SUBMITTAL II

SECTION III: STRAY CURRENT ANALYSIS *(IF APPLICABLE PER CP SUBMITTAL I)*

This information is determined through OUPS tickets, geographical review, and/or contact with appropriate utilities.

____ GCRTA Electrified Rail Line
- ____ Parallel (feet) and/or ____ Crossing(s)

_____ Cathodically Protected Petroleum Product, Natural Gas, or Cryogenic Liquid Pipeline(s)
- _____ Parallel (feet) and/or _____ Crossing(s)
  - _____ Impressed Current and/or _____ Galvanic Anode ______ Proximity of groundbed(s)

_____ Electrified Systems
- ___ Direct Buried Cable(s) ___ Overhead High-Voltage ____Pipe-Type Cables ____Communication

_____ Other *(detailed description)*:______________________________

Testing for stray current is mandatory when an existing stray current source is within two-thousand (2000) feet of a proposed water main. If stray current is detected within 2000 feet of the proposed alignment, field testing is required **per 7.3.2 Stray Current Testing.** This is to be conducted by a qualified cathodic protection firm.

CATHODIC PROTECTION SUBMITTAL II

SOIL CONDITION ANALYSIS: ALL PIPE SIZES

Please attach further soil boring and/or soil sample results on separate sheet(s).

Sample No. ___ Likelihood of Corrosion Total ___ Consequence of Failure Total ___ Rating: ___

Sample No. ___ Likelihood of Corrosion Total ___ Consequence of Failure Total ___ Rating: ___

Sample No. ___ Likelihood of Corrosion Total ___ Consequence of Failure Total ___ Rating: ___

Sample No. ___ Likelihood of Corrosion Total ___ Consequence of Failure Total ___ Rating: ___

CATHODIC PROTECTION SUBMITTAL II

RECOMMENDED CORROSION CONTROL REQUIREMENTS PER *CORROSION CONTROL DECISISON MATRIX AND STRAY CURRENT ANALYSIS*

V-Bio Enhanced Polyethylene Encasement _____

V-Bio Enhanced Polyethylene Encasement with Metallized Zinc Coating _____

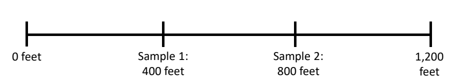
Impressed Current Cathodic Protection (ICCP) _____

Galvanic Anode Cathodic Protection (GACP) _____

The design guidelines are mandatory unless more stringent requirements are necessitated based on a qualified corrosion professional's analysis. CWD maintains ultimate authority for all cathodic protection design decisions. A NACE Certified Senior Corrosion Technologist, NACE Certified Cathodic Protection or Corrosion Specialist is required to oversee all design and construction work required under the cathodic protection design and submittal process.

Soil Testing Requirements

- If the alignment exceeds 2,000 feet:
  - Intervals of soil samples shall not exceed 1,000 feet. A minimum of two soil samples are required and samples shall be equidistant if possible.
- If the alignment is below 2,000 feet
  - Intervals of soil samples shall not exceed 700 feet. A minimum of two soil samples are required and samples shall be equidistance it possible.



Stray Current Testing Requirements

Testing for stray current is mandatory when an existing stray current source is within 2,000 feet of a proposed water main. Testing and results include:

- Potential Variations
- Amount of stray current detected (i.e., continual, sporadic, or none)
  - Surface potential gradient survey in the case that stray current is detected
- Proximity to GCRTA lines
- Proximity of cathodically protection foreign pipelines or cables
- Proximity of anode groundbeds
- System geometry (i.e. location of the pipeline relative to an anode groundbed and cathodically protected pipeline)

Cathodic Protection Specifications

CWD developed specifications for different types of cathodic protection system systems. These are further modified and specified for each project.

Specification Number	Specification Name
13 47 13.13	Cathodic Protection of Underground and Submerged Piping (ICCP)
13 47 13.14	Cathodic Protection of Underground and Submerged Piping (Galvanic)
13 47 13.16	Cathodic Protection of Steel Water Tanks, Internal
13 47 13.30	Cathodic Protection of Existing Underground Piping
13 47 13.50	Impressed Current Deep Well Anode Cathodic Protection
13 47 13.51	Impressed Current Deep Well Anode Replacement Cathodic Protection

Cathodic Protection Standard Details

CWD developed standard details for various Cathodic Protection cases to include in Plan Sets.

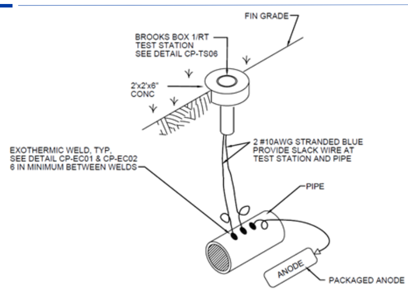
Detail Number	Detail Title 1	Detail Title 2
CP-AI01	Sacrificial Anode Installation	Retrofit Keyhole
CP-B01	Bonding	Mechanical/Ductile Iron Pipe Joint Bond
CP-B02	Bonding	Mechanical Coupling Joint Bond
CP-B03	Bonding	Bonding Group of Fittings
CP-B04	Bonding	Ductile Iron Mechanical Joint Valve
CP-B05	Bonding	Fire Hydrant Bonding
CP-B06	Bonding	Vault Bonding
CP-DA02	Deep Anode Systems	Replaceable Deep Anode System
CP-DA03	Deep Anode Systems	Junction Box/Rectifier Mounting
CP-DA04	Deep Anode Systems	Junction Box
CP-DA05	Deep Anode Systems	Centralizer
CP-EC01	Below Grade Electrical Connections	Pin Brazing
CP-EC02	Below Grade Electrical Connections	Exothermic Weld Wire Connection
CP-EC03	Below Grade Electrical Connections	Exothermic Weld Wire Splice

Cathodic Protection Standard Details

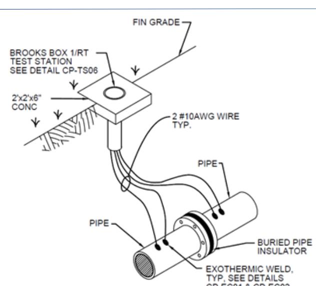
CWD developed standard details for various Cathodic Protection cases to include in Plan Sets.

Detail Number	Detail Title 1	Detail Title 2
CP-I01	Isolation	Insulated Flange Joint
CP-I08	Isolation	Copper Service Line
CP-I09	Isolation	Insulating Flexible Coupling
CP-PV01	PVC C-900	Fitting Galvanic CP
CP-ST01	Internal Steel Tank	Anode Support Rope at Hoop
CP-ST02	Internal Steel Tank	Anode Support Hooks
CP-ST03	Internal Steel Tank	Conductor Splicing
CP-ST04	Internal Steel Tank	Reference Electrode Mounting
CP-ST05	Internal Steel Tank	Rectifier/Junction Box
CP-ST06	Internal Steel Tank	Pressure Entrance Fitting
CP-TS01	Test Station (Plan/Elevation & Circuit Board)	Galvanic Test Station
CP-TS02	Test Station (Plan/Elevation & Circuit Board)	Test Station at Foreign Pipeline Crossing
CP-TS03	Test Station (Plan/Elevation & Circuit Board)	Test Station Pipe Casing
CP-TS04	Test Station (Plan/Elevation & Circuit Board)	Isolation Test Station
CP-TS05	Test Station (Plan/Elevation & Circuit Board)	IR Drop Test Station
CP-TS06	Test Station (Plan/Elevation & Circuit Board)	Test Station Circuit Board
CP-TS07	Test Station (Plan/Elevation & Circuit Board)	Vault Test Wires

CWD SAMPLE STANDARD DETAIL: GALVANIC TEST STATION



CWD SAMPLE STANDARD DETAIL: ISOLATION TEST STATION



Asset Management

References

- NACE SP0169-2007, Standard Practice, "Control of External Corrosion on Underground or Submerged Metallic Piping Systems" reaffirmed March 15, 2007, (NACE SP0169)
- ANSI/NACE SP0502-2010, Standard Practice, "Pipeline External Corrosion Direct Assessment Methodology," June 24, 2010, (NACE SP0502)
- NACE SP0102-2010, "Standard Practice, Inline Inspection of Pipelines" revised March 13, 2010, (NACE SP0102)
- NACE SP0207-2007, "Performing Close-Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines."

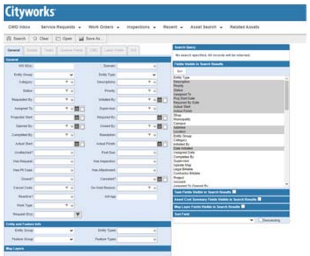
Asset Management: Pipelines

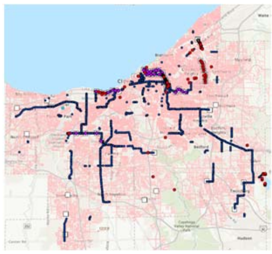
	System	Test Interval	Test	Qualifications
Pipelines	GACP	Every 3 years	• Pipe to Soil Potentials • Anode Current at each test station	CP Tester
	GACP – Stray Current	Every 6 months	• Pipe to Soil Potentials with stray current source interruption • Anode Current at each test station	CP Tester
	Bonds – Stray Current	Monthly	• Pipe to soil Potentials • Log voltage/current	CP Tester
	ICCP – Rectifiers/Test Stations	Every 2 months	• Voltage, current, system resistance log, make small adjustments to maintain steady current output, replace fuses and reset circuit breaker, as required	CP Tester
	ICCP – Rectifers/Test Stations	Annually	• Interrupt rectifier/Measure Pipe to Soil Potentials at each test station. Measure anode output in junction boxes, AC voltage, and current	CP Technician

Asset Management: Storage Tanks

	System	Test Interval	Test	Qualifications
Storage Tanks	ICCP	Monthly	• Voltage, current, system resistance log, make small adjustments to maintain steady current output, replace fuses and reset circuit breaker, as required. • Check rectifier for issues with theft or vandalism. Reinforce security fences and replace locks, if necessary.	CP Tester
	ICCP	Annually	• Interrupt rectifier/measure water to tank potential profile	CP Technician
	ICCP	Per tank draining	• Observe internal CP hardware/effectiveness of CPS • Perform coating inspection	CP Technician

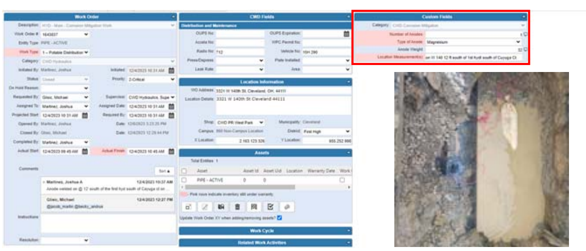
Asset Management: Cityworks and GIS





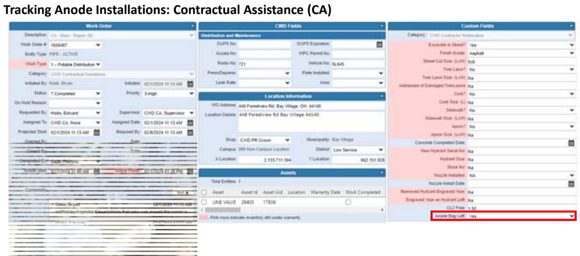
Asset Management: Cityworks

Tracking Anode Installations: Hydraulics



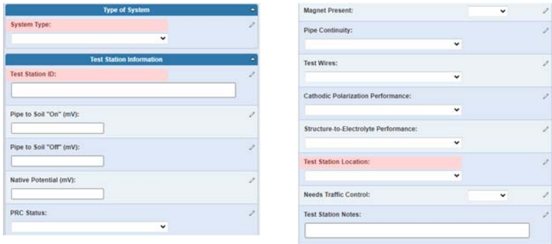
Asset Management: Cityworks

Tracking Anode Installations: Contractual Assistance (CA)



Asset Management: Cityworks

Test Station Inspection Form



Type of System

System Type:

Test Station Information

Test Station ID:

Pipe to Soil "On" (mV):

Pipe to Soil "Off" (mV):

Native Potential (mV):

PRC Status:

Magnet Present:

Pipe Continuity:

Test Wires:

Cathodic Polarization Performance:

Structure-to-Electrolyte Performance:

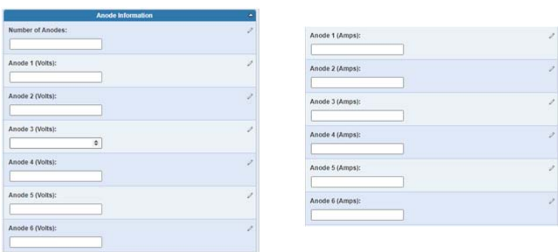
Test Station Location:

Needs Traffic Control:

Test Station Notes:

Asset Management: Cityworks

Test Station Inspection Form (Continued)



Anode Information

Number of Anodes:

Anode 1 (Volts):

Anode 2 (Volts):

Anode 3 (Volts):

Anode 4 (Volts):

Anode 5 (Volts):

Anode 6 (Volts):

Anode 1 (Amps):

Anode 2 (Amps):

Anode 3 (Amps):

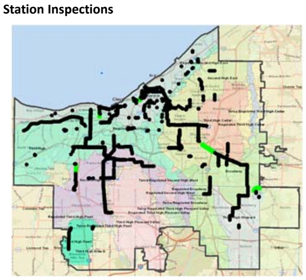
Anode 4 (Amps):

Anode 5 (Amps):

Anode 6 (Amps):

Asset Management: Cityworks

Test Station Inspections



ENG IN | Open Test Station Inspections

ENG IN | Open Test Station Inspections

ENG IN | Complete Test Station Inspections

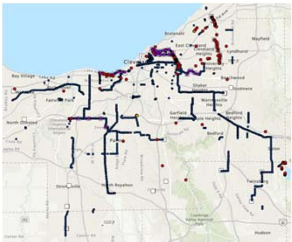
ENG IN | Complete Test Station Inspections

ENG IN | Closed Test Station Inspections

ENG IN | Closed Test Station Inspections

Asset Management: GIS

Cathodic Protection Assets and Information



- cwdGIS1.CWDDIST.SingleAnode
- cwdGIS1.CWDDIST.DeepWellAnode
- cwdGIS1.CWDDIST.CathodicProtectionTestStation
- cwdGIS1.CWDDIST.SoilTest
- cwdGIS1.CWDDIST.Rectifier

Asset Management: GIS

Cathodic Protection Test Stations

- GIS is used in conjunction with Cityworks to track Test Stations

	TestStationID	INSTALLDATE	INSTALLDATESRC	DATELASTREADING	PipeSoilOn	PipeSoilOff	NativePotential	CathodicPolarizationPerformance	StructureElectrolytePerformance	NeedsTrafficControl	TestStationLocation
1	1	1/1/1894	V08P003	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
2	2	1/1/1894	V08P003	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
3	3	1/1/1912	8M006668	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
4	4	1/1/1914	V27P035	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
5	5	1/1/1915	V22P015	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
6	6	1/1/1920	V15P031	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
7	7	1/1/1921	V18P021	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
8	8	1/1/1923	V27P028	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
9	9	1/1/1923	V27P028	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
10	10	1/1/1923	V27P002	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
11	11	1/1/1923	V25P055; 677C	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
12	12	1/1/1923	V27P005	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>

Soil Testing

- **Historical Soil Samples are recorded in GIS to track areas of high corrosivity**
  - Soil samples are collected for:
    - Water Main Renewal Projects according to the ECCDM
    - Lead Service Line Replacements
    - When directed by CWD

OBJECTID	COMMENTS	SOILRESISTIVITY	pH	RedoxPotential	ChlorideContent	SulfideContent	MoistureContent	PipeLocation	LikelihoodOfCorrosion	ConsequenceOfFailure	ECCDMResult
2	Depth: 1.5-5.5'	570	8.6	222	848	1.51	15	Above Water Table	39.5	9	Category 2
3	Depth: 5.5-9.5', Sulfide is < 1.0	1007	7.8	247	255	1	17	Above Water Table	36.5	9	Category 2
4	Depth: 1.5-5.5'	939	10	118	113	1.65	19	Above Water Table	42	9	Category 2
5	Depth: 5.5-9.5'	1141	7.8	238	62	1.17	1.17	Above Water Table	34	9	Category 1
6	Depth: 1.5-5.5'	436	8.3	224	1098	1.56	8.9	Above Water Table	44.5	9	Category 2 - 3
8	Depth: 1.5-5.5'	1141	9	154	126	1.38	12	Above Water Table	36.5	9	Category 2

Additional Initiatives

Projects
- Transmission Main Corrosion Control
  - Focuses on the rehabilitation of existing ICCP systems on steel trunk mains
- Cathodic Protection Improvements I
  - Focuses on repairs and/or replacements to the ICCP system in four steel storage tanks/towers

Inspections
- Annual Rectifier Inspections for Storage Tanks/Towers
- Test Station Locating and Testing
- Tank and Tower Inspections (5 sites annually)

Coatings
- Coatings are inspected during tank and tower inspections
- Cycle Projects – Focuses on secondary facilities improvements and repairs. Tanks/Towers are typically recoated during these projects
- Coating Catalog

Stray Current and Ductile Iron Pipelines

Paul Hanson, Ductile Iron Pipe Research Association

phanson@dipra.org

PRESENTATION TO….

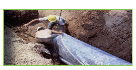
APPALACHIAN UNDERGROUND CORROSION SHORT COURSE

May 8, 2024

1

STRAY CURRENT & DUCTILE IRON PIPELINES

APPALACHIAN UNDERGROUND CORROSION SHORT COURSE

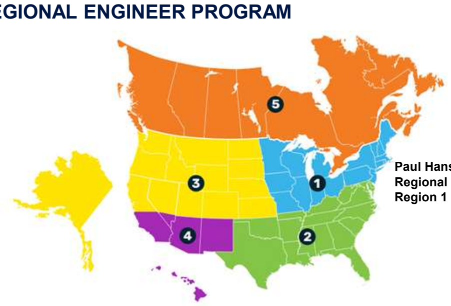


AUCSCO

2

2

REGIONAL ENGINEER PROGRAM



Paul Hanson, P.E.
Regional Director
Region 1

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

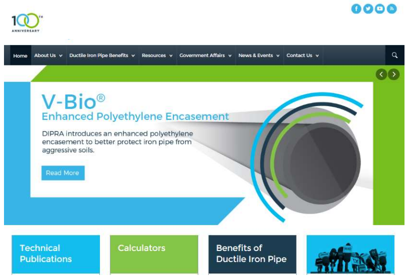
5

- 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

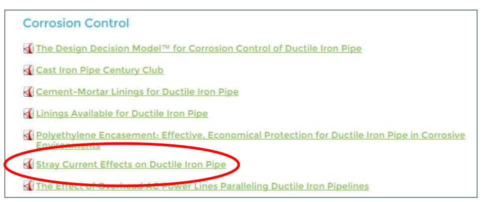
DIPRA WEBSITE | WWW.DIPRA.ORG



7

7

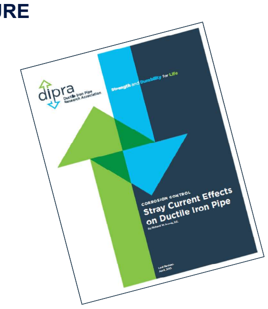
DIPRA TECHNICAL PUBLICATIONS



8

8

DIPRA BROCHURE



9

9

LEARNING OBJECTIVES

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

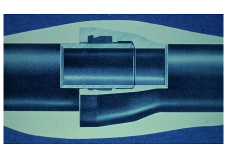
10

10

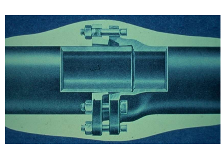
11

11

DUCTILE IRON PIPELINES ARE ELECTRICALLY DISCONTINUOUS



Push-on Joint

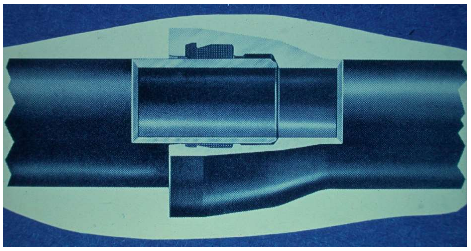


Mechanical Joint

12

12

PUSH-ON JOINT



13

13

PUSH-ON JOINT ASSEMBLY

STEP 1: Clean Joint Assembly

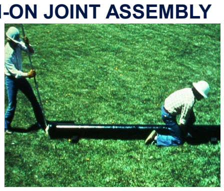
STEP 2: Insert Gasket

STEP 3: Apply Lubricant

14

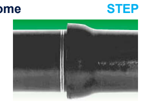
14

PUSH-ON JOINT ASSEMBLY



STEP 4: Push Home

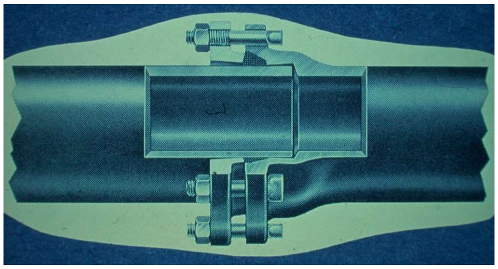
STEP 5: Completed Assembly



15

15

MECHANICAL JOINT



16

16

MECHANICAL JOINT ASSEMBLY

STEP 1: Clean Joint Assembly

STEP 2: Lubricate Joint with Soapy Water

17

17

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

18

18

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

45 joints tested

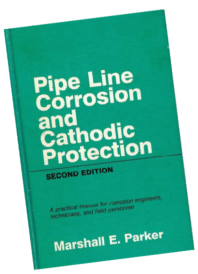
9 were shorted

Resistance: 2.3 to 23.0 ohms

19

19

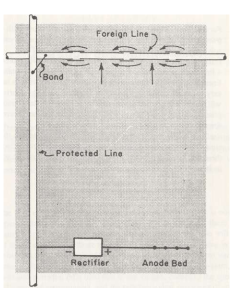
STRAY CURRENT INTERFERENCE



20

20

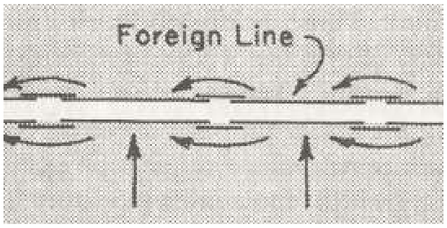
STRAY CURRENT INTERFERENCE



21

21

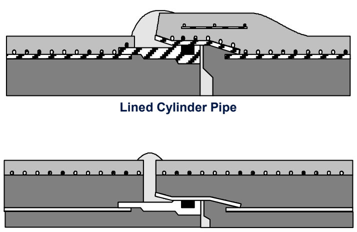
STRAY CURRENT INTERFERENCE



22

22

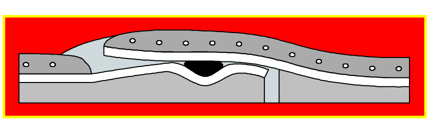
PRESTRESSED CONCRETE CYLINDER PIPE
(AWWA C-301)



23

23

CEMENT-COATED STEEL PIPE
(AWWA C-200)



24

24

Stray (Direct) Current Corrosion

25

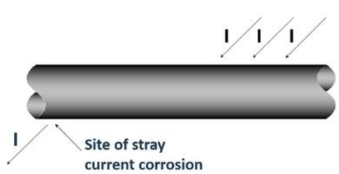
STRAY CURRENT CORROSION

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

26

26

STRAY CURRENT CORROSION



27

27

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

28

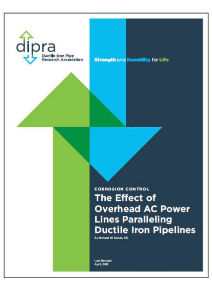
28

AC OVERHEAD POWER LINE RIGHT-OF-WAYS

29

29

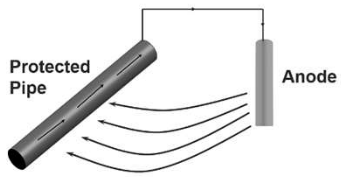
EFFECT OF OVERHEAD AC POWER LINES



30

30

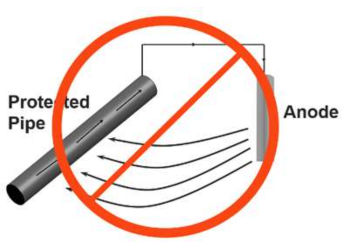
SACRIFICIAL ANODE CATHODIC PROTECTION



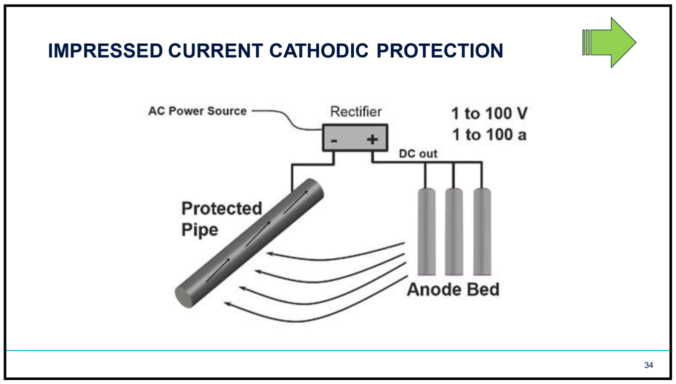
31

32

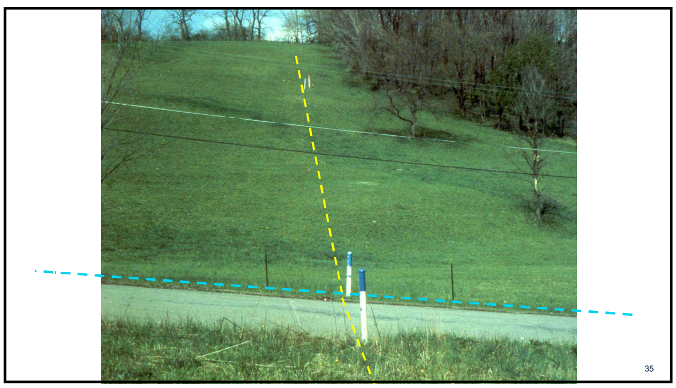
SACRIFICIAL ANODE CATHODIC PROTECTION



33


IMPRESSED CURRENT CATHODIC PROTECTION
AC Power Source
Rectifier
1 to 100 V
1 to 100 a
DC out
Protected Pipe
Anode Bed
34

34

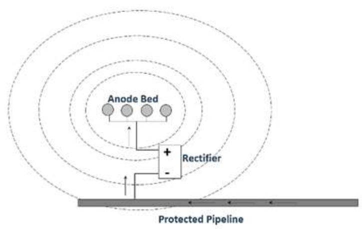

35

35


36

36

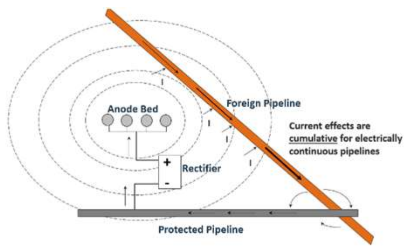
TYPICAL STRAY CURRENT ENVIRONMENT



37

37

TYPICAL STRAY CURRENT ENVIRONMENT



38

38

OHM'S LAW

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

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

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

39

39

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 · Direct Current · Time

40

40

FARADAY'S LAW

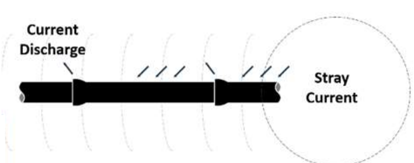
Weight Loss per Ampere-Year at 100% Corrosion Efficiency

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

41

41

DISCONTINUOUS JOINT

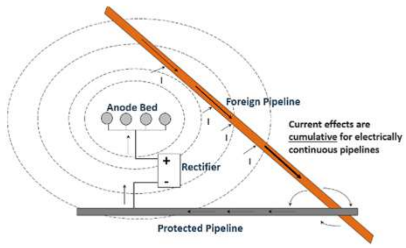


Current does not accumulate on **electrically discontinuous** piping systems.

42

42

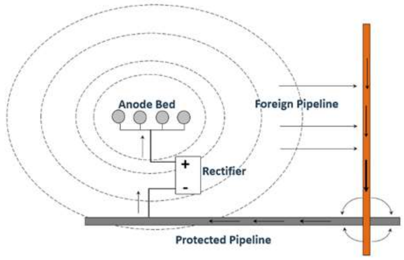
TYPICAL STRAY CURRENT ENVIRONMENT



43

43

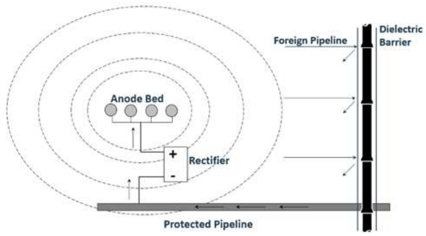
TYPICAL STRAY CURRENT ENVIRONMENT



44

44

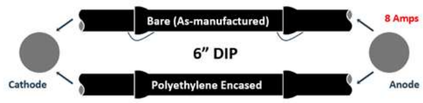
DISCONTINUOUS JOINT EFFECTS



45

45

DIPRA STRAY CURRENT STUDY



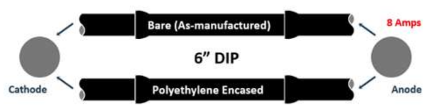
Current Pick-Up

	Bonded
Bare	1,650.0 ma

46

46

DIPRA STRAY CURRENT STUDY



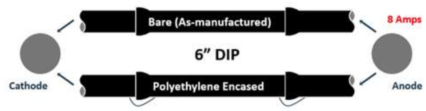
Current Pick-Up

	Bonded	Unbonded
Bare	1,650.0 ma	538.0 ma

47

47

DIPRA STRAY CURRENT STUDY



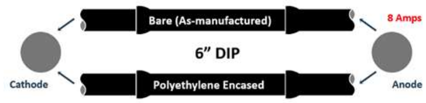
Current Pick-Up

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

48

48

DIPRA STRAY CURRENT STUDY



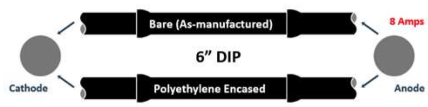
Current Pick-Up

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

49

49

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

50

50

51

51

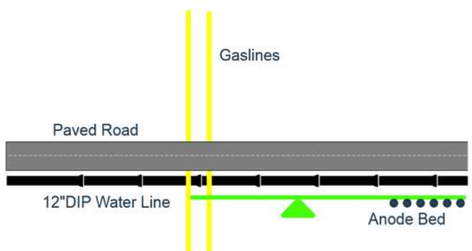
STRAY CURRENT INTERFERENCE IS DEPENDENT ON:

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

52

52

NEW BRAUNFELS, TEXAS



53

53

SURFACE POTENTIAL GRADIENT SURVEY

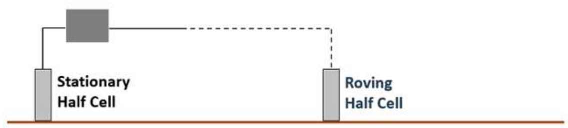
High Resistance Voltmeter

54

54

SURFACE POTENTIAL GRADIENT SURVEY

High Resistance Voltmeter



55

55

SURFACE POTENTIAL GRADIENT SURVEY

High Resistance Voltmeter

56

56

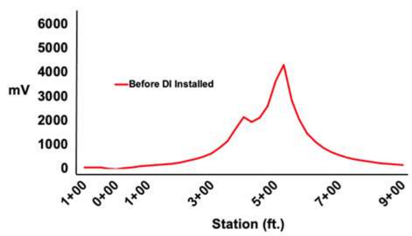
57

57

58

58

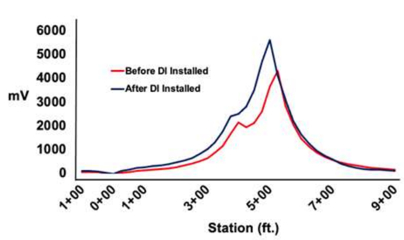
POTENTIAL PROFILE COMPARISON NEW BRAUNFELS, TEXAS



59

59

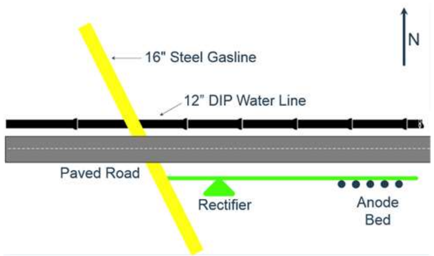
POTENTIAL PROFILE COMPARISON NEW BRAUNFELS, TEXAS



60

60

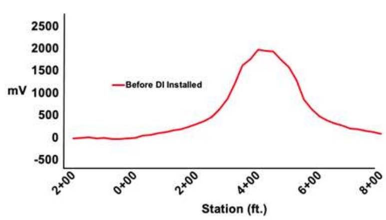
SAN ANTONIO, TEXAS



61

61

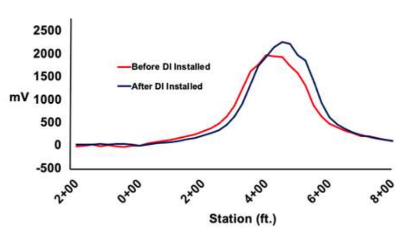
POTENTIAL PROFILE COMPARISON SAN ANTONIO, TEXAS



62

62

POTENTIAL PROFILE COMPARISON SAN ANTONIO, TEXAS



63

63

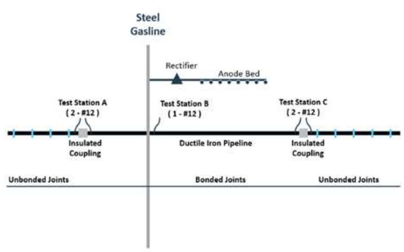
STRAT CURRENT RCOMMENDATION CRITERIA

- **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”

64

64

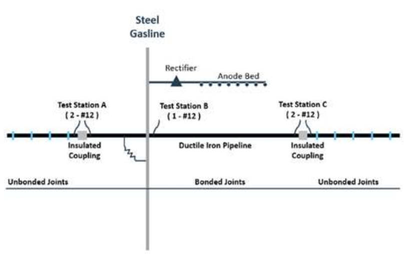
TYPICAL DUCTILE IRON PIPE BONDED SECTION FOR THE MITIGATION OF STRAY CURRENT INTERFERENCE



65

65

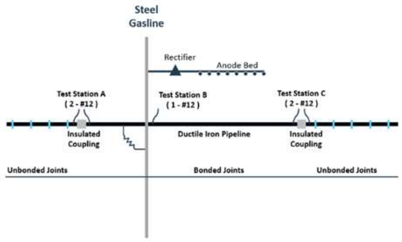
TYPICAL DUCTILE IRON PIPE BONDED SECTION FOR THE MITIGATION OF STRAY CURRENT INTERFERENCE



66

66

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



67

67

BONDING DUCTILE IRON PIPE JOINTS

68

68

BONDING DUCTILE IRON PIPE JOINTS

69

69

BONDING DUCTILE IRON PIPE JOINTS

70

70

BONDING DUCTILE IRON PIPE JOINTS

71

71

BONDING DUCTILE IRON PIPE JOINTS

72

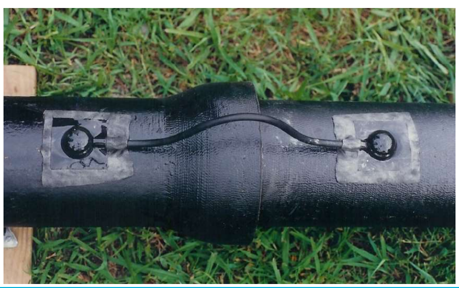
72

BONDING DUCTILE IRON PIPE JOINTS

73

73

BONDING DUCTILE IRON PIPE JOINTS



74

74

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

75

75

STRAY CURRENT RECOMMENDATION CRITERIA

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

76

76

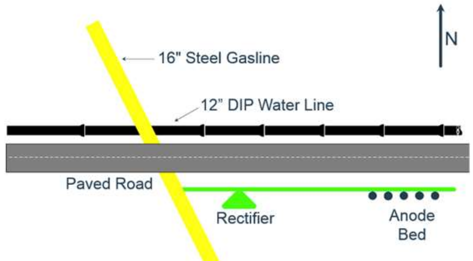
STRAY CURRENT RECOMMENDATION CRITERIA

- **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

77

77

SAN ANTONIO, TEXAS



78

78

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

79

79

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

80

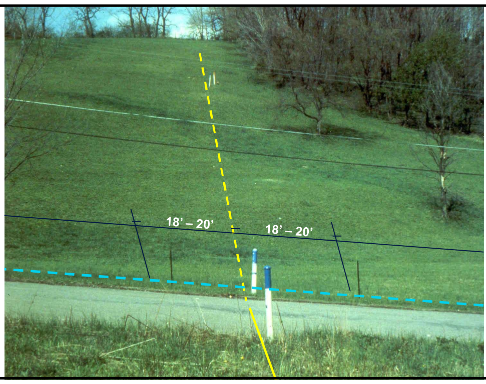
80

CP CURRENT REQUIREMENTS
POLYETHYLENE ENCASED

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

81

81



82

82

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

83

83

84

84

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

85

85

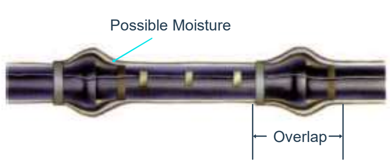
SUMMARY . . .

- 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

86

86

POLYETHYLENE ENCASEMENT



87

87

LAFOURCHE PARISH, LOUISIANA
4-INCH CAST IRON PIPE

88

88

POLYWRAPPED DIP WITH CP – ASTM G218

89

89

90

90

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

91

91

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.
www.freemanindustriesinc.com
(440) 858-2600
adam.freeman@freemanindustriesinc.com

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

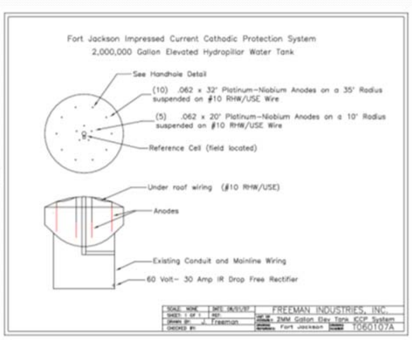
DC Wiring

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

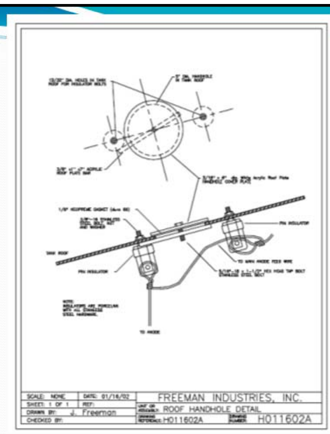
Choosing the Anode Configuration

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

Vertical CP System



Hand Hole

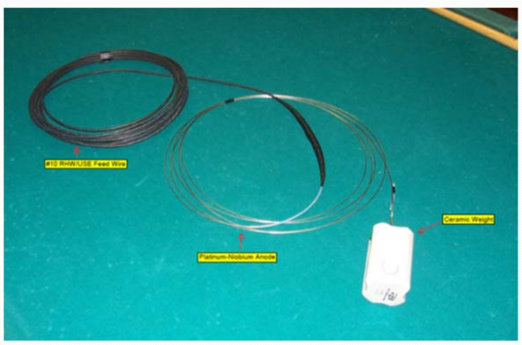


Rectifier

Rectifier

Anode

Anode



Reference Cell

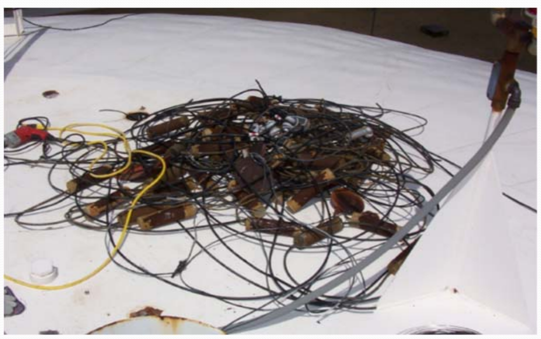
4. Optional antifreeze protection to -70F

Housing Specifications
1 5/8 inch (4 cm) dia. x 10 ¾ inch (28 cm) long
Heavy duty strain relief at wire end
Shipping weight – 1 lb (½ kg)

Termination
LWnnn nnn ft. #12 AWG RHW/USE
CWnnn nnn ft. of custom wire

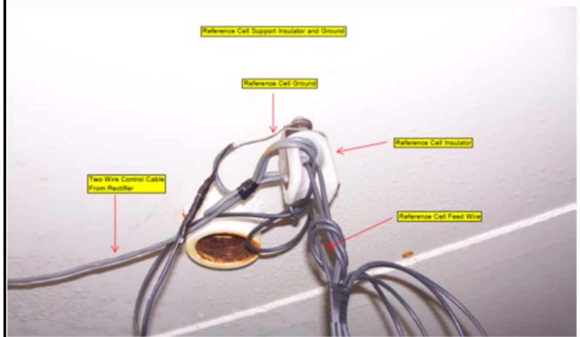
Anodes on Tank

Old Anodes



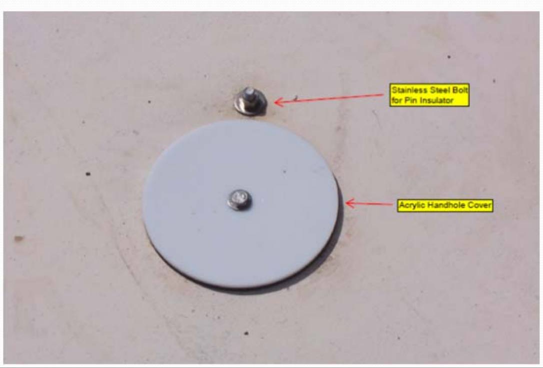
Tank Roof

Reference Cell Insulator

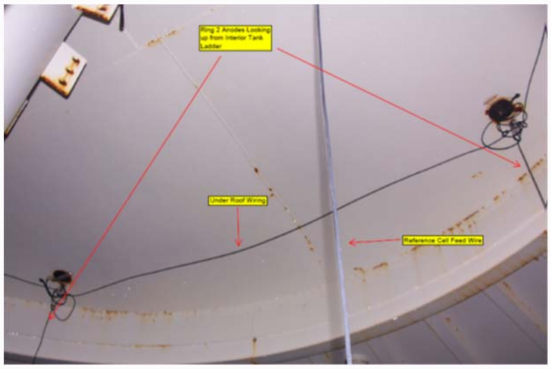


Rectifier Ground

Hand Hole



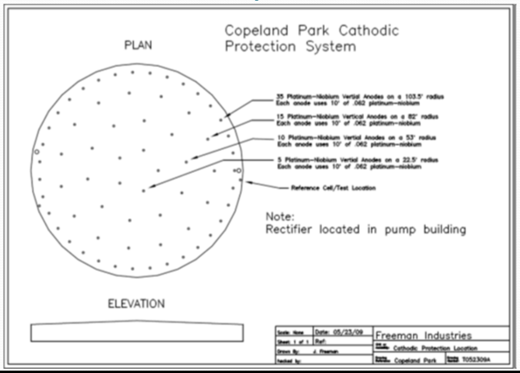
Anode Feed Wires



Anode Insulator

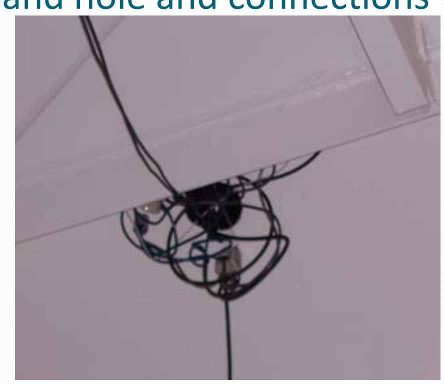
Vertical Anodes

Vertical Anode System

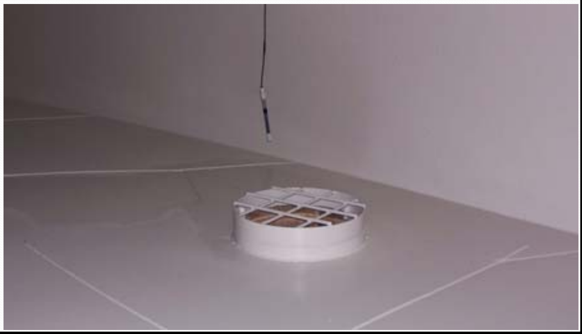


Inside tank

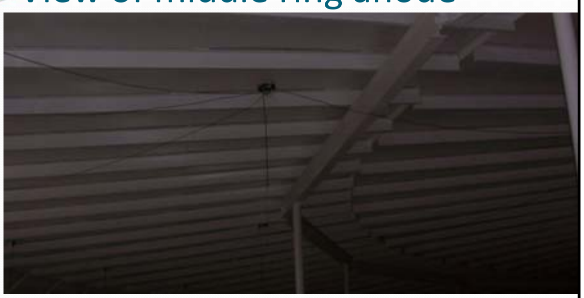
Hand hole and connections



Cell and fill pipe



View of middle ring anode

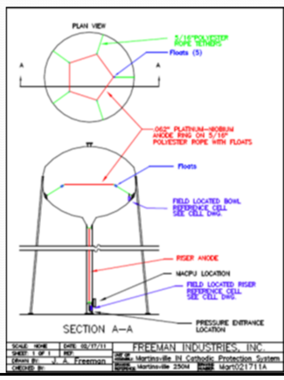


- Note the radial wiring

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

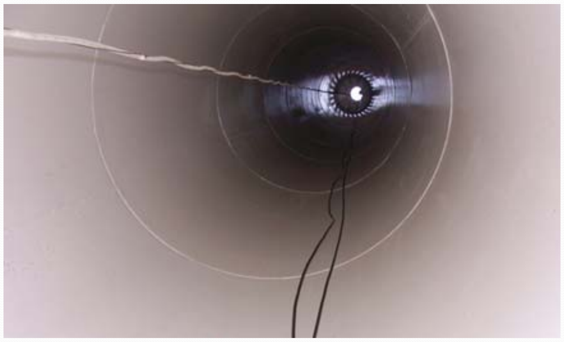
Rectifier

Stainless steel pressure entrance

AC and DC wiring

Pressure entrance fitting

View looking up the riser

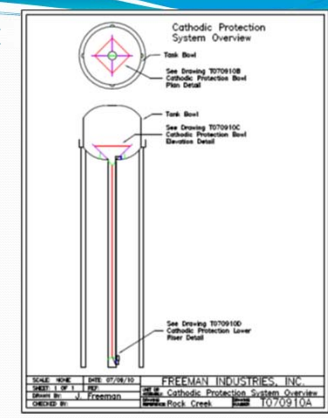


Strain relief for feed wires

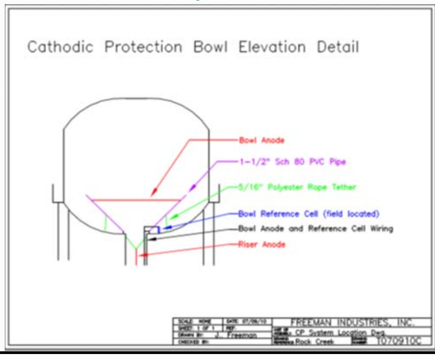
Inside view of pressure entrance fitting and reference cell

Fill pipe, pressure entrance fitting, and reference cell

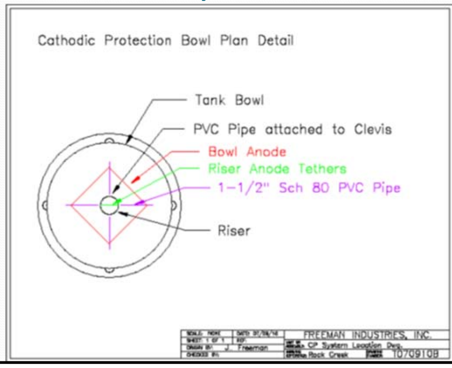
Ice Resistant System



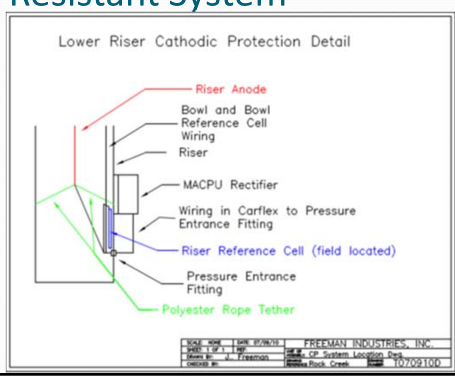
Ice Resistant System



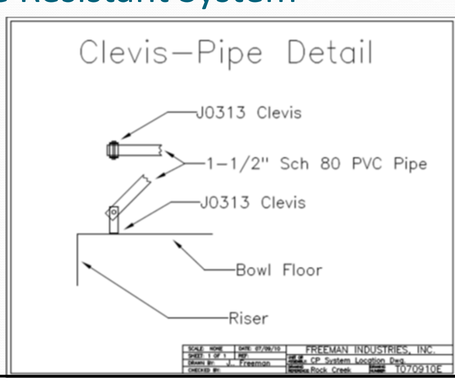
Ice Resistant System



Ice Resistant System



Ice Resistant System



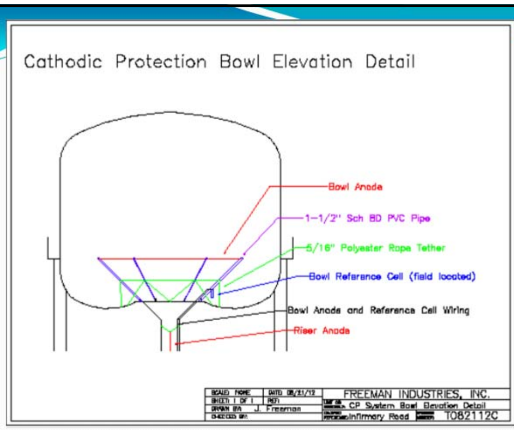
Riser Anode

Clevis

Bowl anode

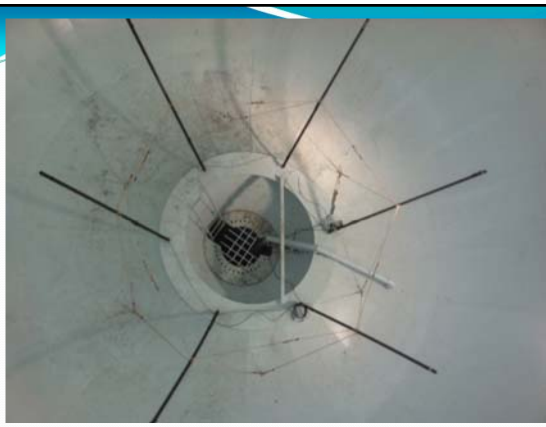
Riser Cell

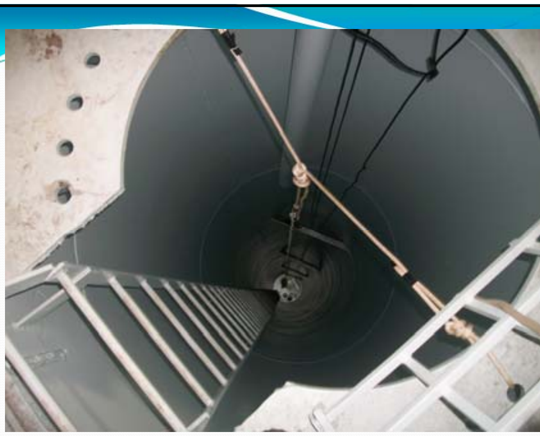
Riser Anode and Feed Wires



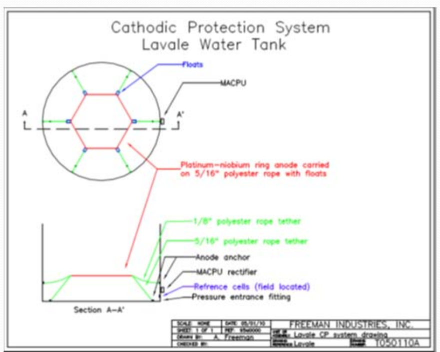
Tie down

Clevis





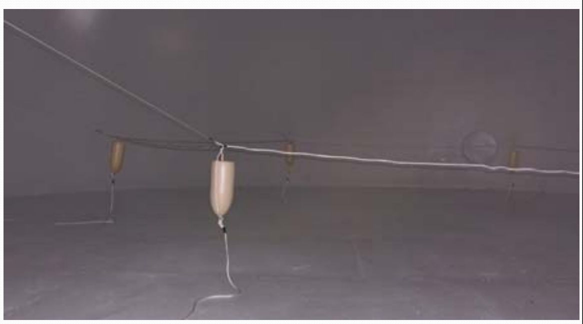
Submerged CP System



Rectifier and Pressure Entrance Fitting

Solid State Rectifier module and feed wires

Anode

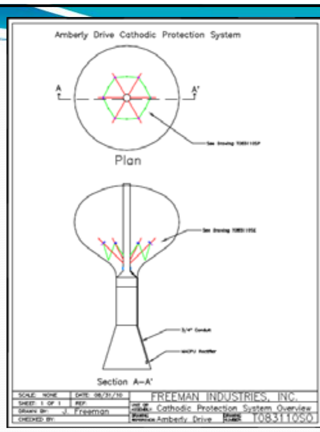


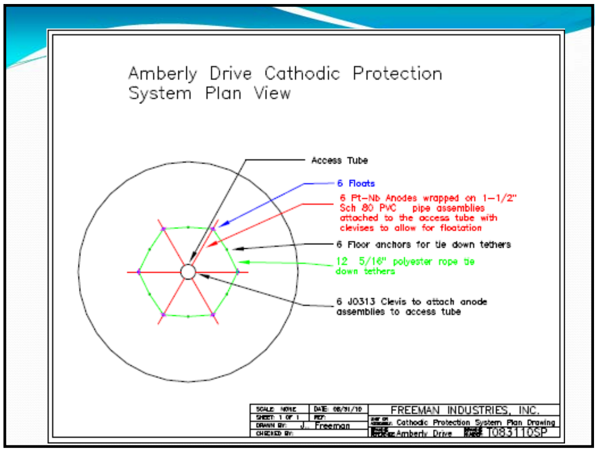
Anode

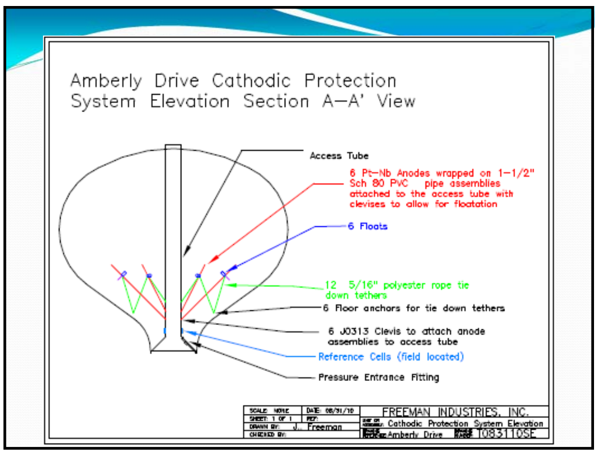
Control Cells

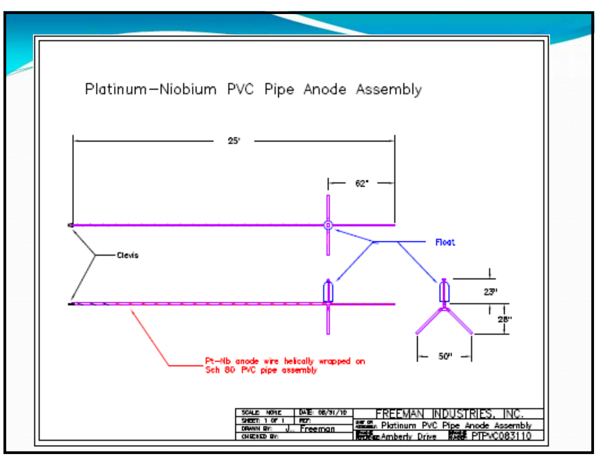
Control Cells

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
FREEMAN INDUSTRIES, INC.
Cathodic Protection System Plan Drawing
Amberly Drive
J. Freeman
1083110SP


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
FREEMAN INDUSTRIES, INC.
Cathodic Protection System Elevation
Amberly Drive
J. Freeman
1083110SE


Platinum-Niobium PVC Pipe Anode Assembly
25'
62"
Clevis
Float
23"
28"
50"
Pt-Nb anode wire helically wrapped on Sch 80 PVC pipe assembly
FREEMAN INDUSTRIES, INC.
Platinum PVC Pipe Anode Assembly
Amberly Drive
J. Freeman
PTPVC083110

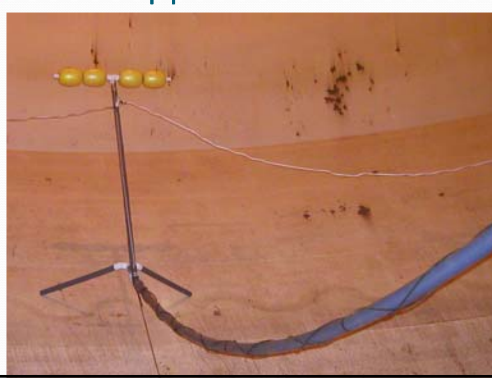
Anode support arm

View from top

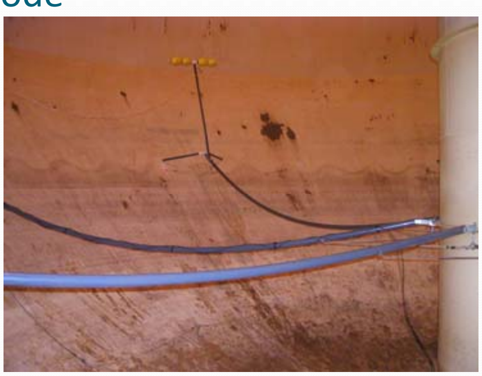
Reference Cell

DC Junction Box and PE

Anode support arm



Anode



Anode

Reference Cell

Support Arm

Reference Cell

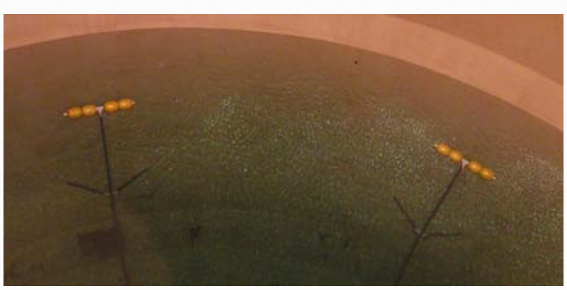
Tie Down

Top View

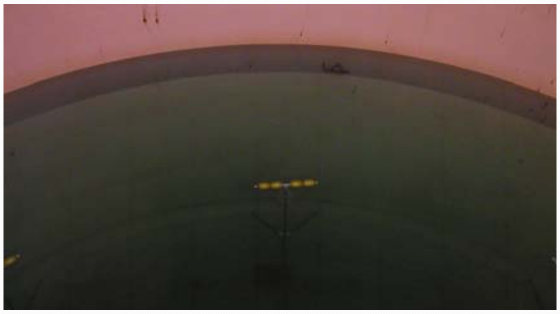
View from Top

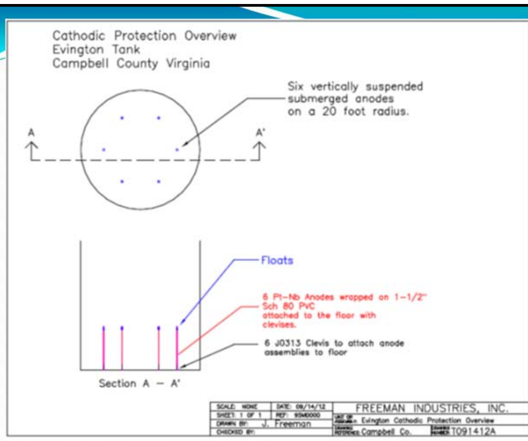
Filling Tank

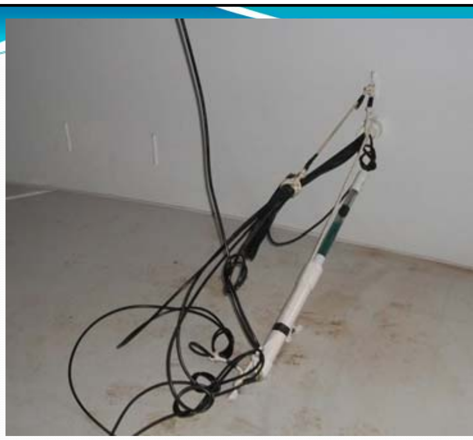
Filling Tank



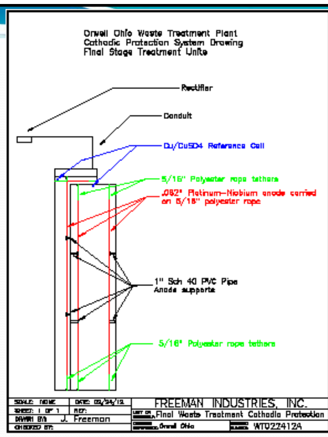
Filling Tank







CP System

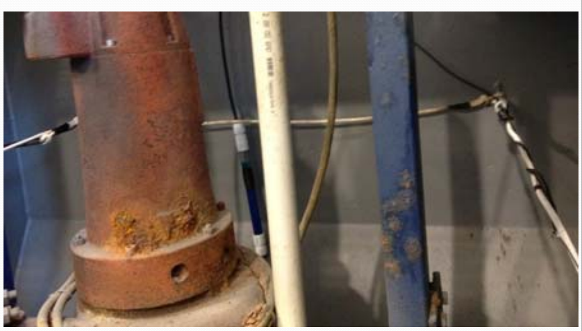


Anode

Anode

Anode

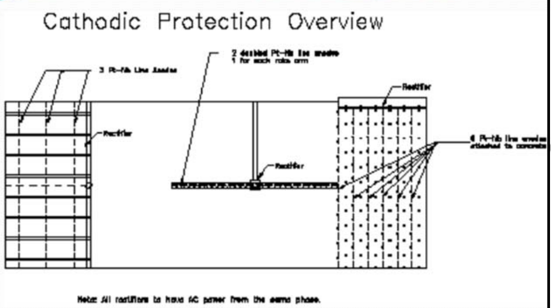
Anode and Cell



Anode

Anode and Cell

Anode

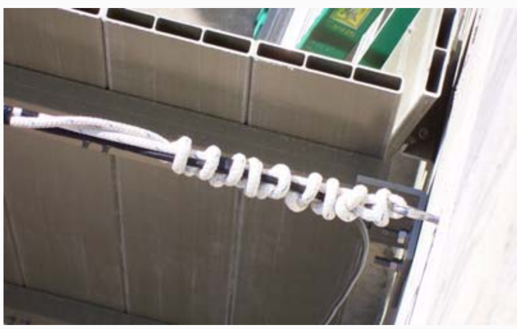


Flocculator Anodes

Flocculator Anode

Flocculator Anode

Anode Tie-off

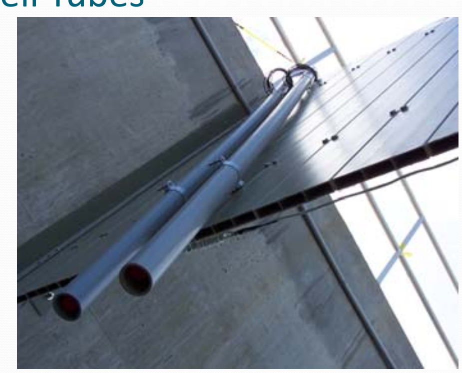


Grounding Wires

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

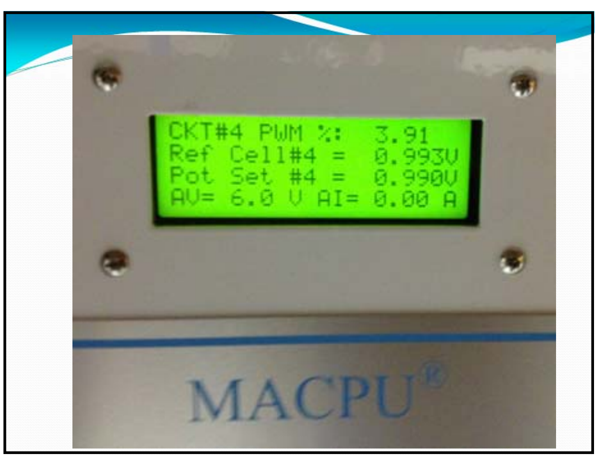
Launder Anodes

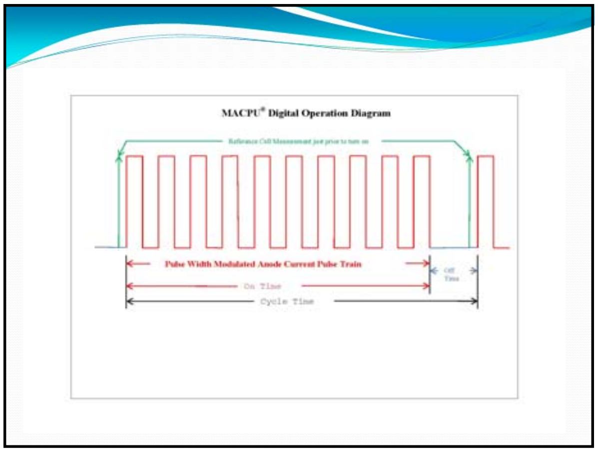
Launder Anodes

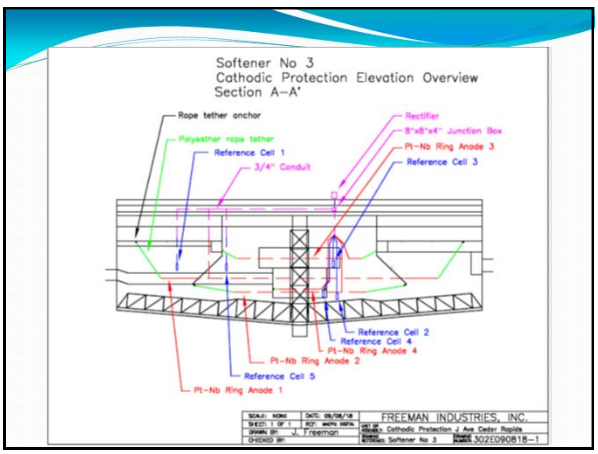
Uncoated Stainless Steel Inside a Water Tank

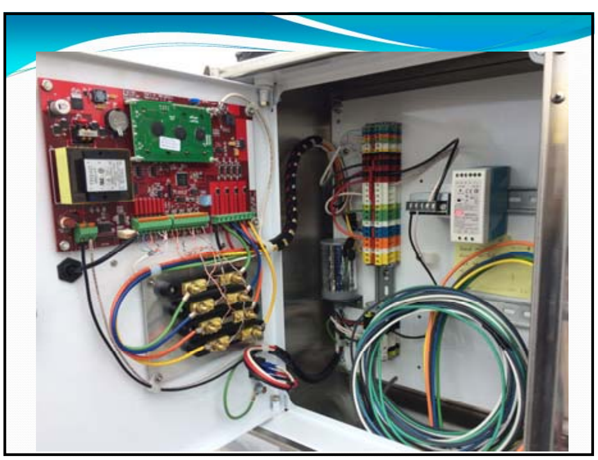
Digitally Controlled Rectifier


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
Pulse Width Modulated Anode Current Pulse Train
On Time
Cycle Time

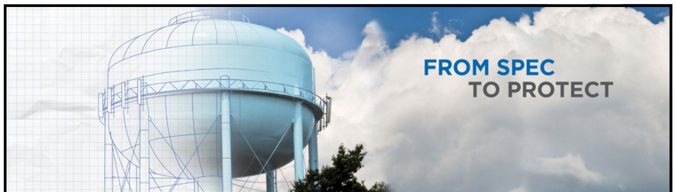

Softener No 3
Cathodic Protection Elevation Overview
Section A–A'
Rope tether anchor
Polyesther rope tether
Reference Cell 1
3/4" Conduit
Rectifier
8"x8"x4" Junction Box
Pt–Nb Ring Anode 3
Reference Cell 3
Reference Cell 2
Reference Cell 4
Pt–Nb Ring Anode 4
Pt–Nb Ring Anode 2
Reference Cell 5
Pt–Nb Ring Anode 1
DRAWN BY: J. Freeman
FREEMAN INDUSTRIES, INC.
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

2

2

Question

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.)

3

3

Answer

Linings and secondary containment require increased attention regarding:

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

4

4

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

5

5

Surface Preparation

- Surface preparation is the most important factor 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.

6

6

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)

7

7

Surface Preparation Standards

- 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"

8

8

Cleanliness Standards

Tools Used to Measure Surface Cleanliness

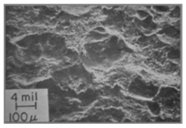
- Establish a project-specific surface cleanliness standard. Best and typical of NACE and/or SSPC Written Standards.
- Ensure removal of abrasive and dust from surface prior to primer application
- Visual references are available.

9

9

Why do we Blast Metal and Concrete

To Achieve a Surface Profile



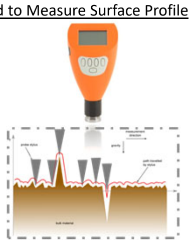
- Measurement of the roughness of a surface which results from abrasive blast cleaning
- Measured from the bottom of the lowest valley to the top of the highest peak
- Achieving proper surface profile improves the mechanical bonding of a coating to the substrate.

10

Surface Profile

Tools Used to Measure Surface Profile

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



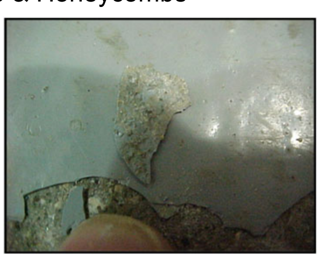
Depth Micrometer (Steel)

Replica Tape and
Anville Micrometer (Steel)

11

Concrete Surface Preparation

Bugholes, Voids & Honeycombs



12

Secondary Containment

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

13

13

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?

14

14

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.

15

15

Secondary Containment

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

16

16

Tank Linings

Linings are also referred to as
PRIMARY CONTAINMENT

17

17

Tank Linings

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

18

18

Tank Linings

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)

19

19

Tank Linings

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

20

20

Tank Linings

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

21

21

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

22

22

Tank Linings

BIOGENIC SULFIDE CORROSION/VAPOR PHASE

23

23

Tank Linings

BIOGENIC SULFIDE CORROSION/VAPOR PHASE

24

24

Tank Linings

BIOGENIC SULFIDE CORROSION/VAPOR PHASE

25

25

Tank Linings

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

26

26

Tank Linings

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.

27

27

Tank Linings

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)

28

28

Tank Linings

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

29

29

Tank Linings

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

30

30

Tank Linings

Dura-Plate 6000
High Performance Epoxy Uses

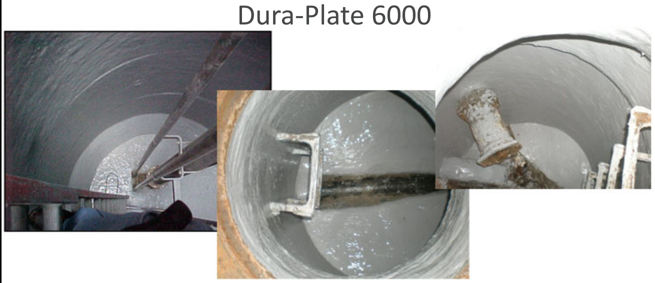
- Structures requiring NSF approval
- Lift stations
- Concrete pipe
- Wet wells
- Steel pipe
- Manholes
- Sumps
- Digesters
- Trenches
- Clarifiers
- Sluice ways
- Basins
- Influent chambers

31

31

Tank Linings

Dura-Plate 6000



32

32

Tank Linings

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

33

33

Tank Linings

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

34

34

Tank Linings

35

35

Tank Linings

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

36

36

Tank Linings

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

37

37

Tank Linings

Poly-Cote 115

38

38

Water Tank Linings

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

39

39

Tank Linings

Sherplate 600 Uses

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

40

40

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

41

41

Tank Linings

Macropoxy 5500 Uses

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

42

42

Water Tank Linings

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

43

43

Water Tank Linings

Optically Activated Pigment (OAP)

44

44

Water Tank Linings

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

45

45

Water Tank Linings

Sherplate PW

46

46

Water Tank Linings

Sherplate PW

47

47

Water Tank Linings

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

48

48

Water Tank Linings

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

49

49

Water Tank Linings

Dura-Plate UHS

50

50

Tech Service

PART OF WORKING WITH SHERWIN WILLIAMS INCLUDES INVOLEMENT FROM OUR

TECHNICAL SERVICE DEPARTMENT.

51

51

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

52

52

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

53

53

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.

54

54

Tech Service

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

55

Tech Service

Visual Standards

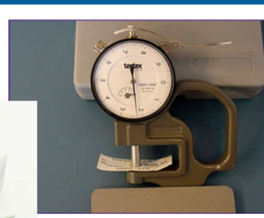
ICRI Visual Standards

AMPP Visual Standards

56

Tech Service

Steel Surface Profile



57

Tech Service

Concrete Surface pH

58

58

Tech Service

Coating thickness

59

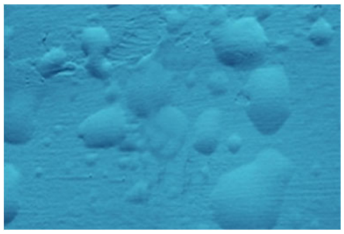
59

What if We Do Not Get it Right?

60

60

Consequences of Inadequate Selection/Application



61

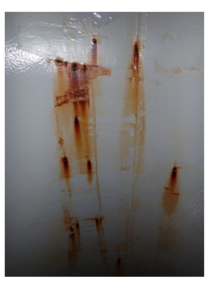
61

Consequences of Inadequate Selection/Application

62

62

Consequences of Inadequate Selection/Application



63

63

Thank You!

Questions?

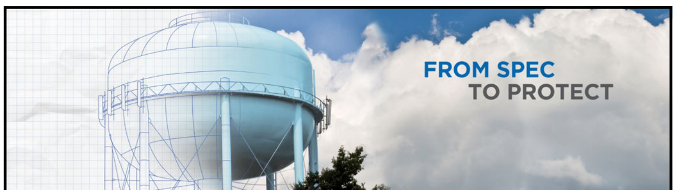
Visit our website
to view archived webinars.

Contact swwater@sherwin.com
regarding webinar questions.

Steven Roetter, PE
Business Development Manager, Water & Wastewater
steven.p.roetter@sherwin.com
317-840-5499

64

64



THANK YOU

65

Corrosion Control Training – GACP and ICCP Systems

Sasan Hosein, Pond & Company

hoseins@pondco.com

Corrosion Control Training

Vdvdq#Krvhlq#P V/#
VVSF#SFV/#DP SS#FS7
DP SS#Frurvlrq#Vshfldolvw
Ylfh#Suhvlghqw/#Frurvlrq#Frqwuro

1

Agenda

- What is Corrosion?
- Basic Corrosion
- Soil Corrosivity
- Corrosion Control Methodologies
- Cathodic Protection Corrosion Control Design
- Commissioning
- Data Analysis and Criteria
- Static and Dynamic Interference

2

What is Corrosion?

3

As understood in the Corrosion industry:

"Corrosion is the deterioration of a material, typically metal, due to a reaction with its environment."

AUCSC

4

Why Study the Effects of Corrosion?

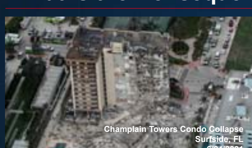
- Safety → Protect Human Life, Health, and the Environment
- Mission Readiness
- By Compliance with Regulation → UFC,CPC, DOT/PHMSA, and EPA
- Corrosion Costs the USA → $2.5 trillion/year (3.4% of global GDP) study completed in 2013
- Engineering Best Practice
- Industry Proven Technologies
- Asset Management → Life Extension
- Reduce Long Term Operation & Maintenance (O&M) and Asset Replacement Costs

PG&E Gas Main Failure
San Bruno, CA
09/09/2010

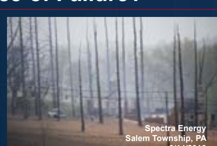
AUCSC

5

What is the Consequence of Failure?



Champlain Towers Condo Collapse
Surfside, FL
6/24/2021



Spectra Energy
Salem Township, PA
9/14/2016

Great Lakes Water Authority
Oakland County, MI
10/23/2017

SALEM TOWNSHIP (KDKA) – A gas pipeline explosion sparked a massive fire Friday morning, sending balls of flames high into the sky over Westmoreland County and radiating heat so intense homes thousands of feet away felt it.

According to officials at the scene, a 30-inch Spectra Energy natural gas line exploded around 8:30 a.m. The line is located near the intersection of Routes 22 and 819 in Salem Township.

The fire chief on scene said it looked like a bomb had gone off and the blast could be felt for miles.

"When I came around the bend, it looked like you were looking down into hell, is what I would compare it to," Forbes Road Fire Department Chief Bob Rosatti said. "As far across my windshield as I can see, it was just a massive fireball, and I parked a quarter mile away and I couldn't get out of my truck because it was that hot."

One nearby home was destroyed and two others were damaged.

AUCSC

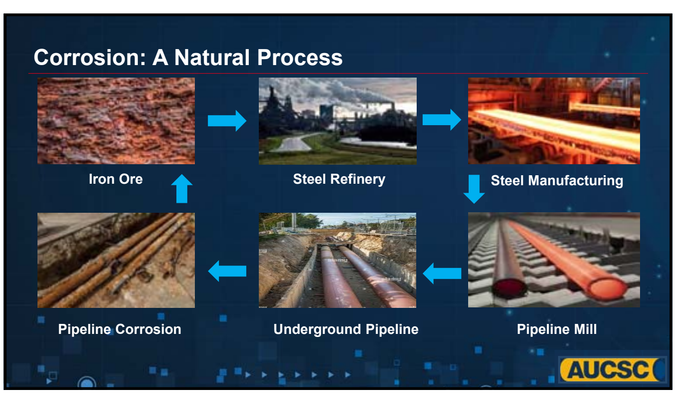
6


Examples of Corrosion
High Pressure, Steel Natural Gas Transmission Main
AUCSC

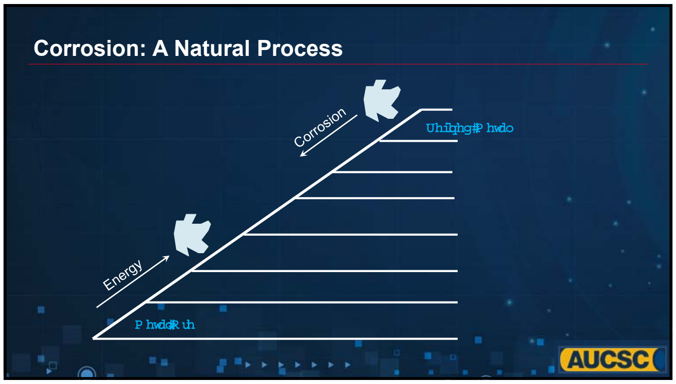
7


Corrosion Control Requirements
Corrosion Control for Pipelines Transport Hazardous Materials:
It is NOT just a luxury item on the list.
It is LAW.
▪ CFR 192
▪ CFR 195
▪ CFR 193
AUCSC

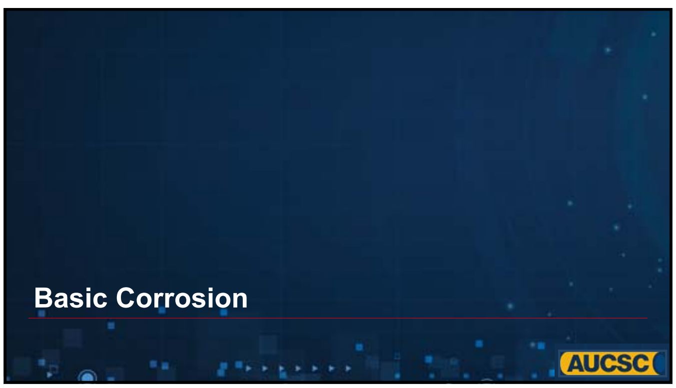
8


Corrosion: A Natural Process
Iron Ore
Steel Refinery
Steel Manufacturing
Pipeline Corrosion
Underground Pipeline
Pipeline Mill
AUCSC

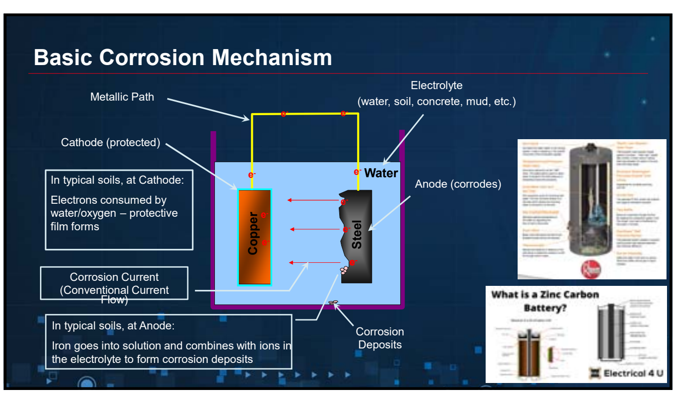
9


Corrosion: A Natural Process
Corrosion
Uhilqhg#P hwdo
Energy
P hwdoR uh
AUCSC

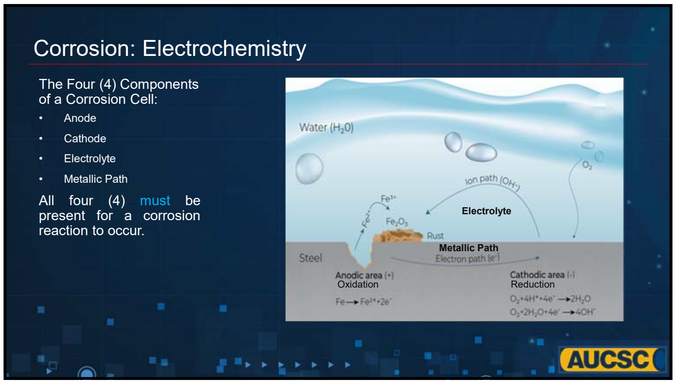
10


Basic Corrosion
AUCSC

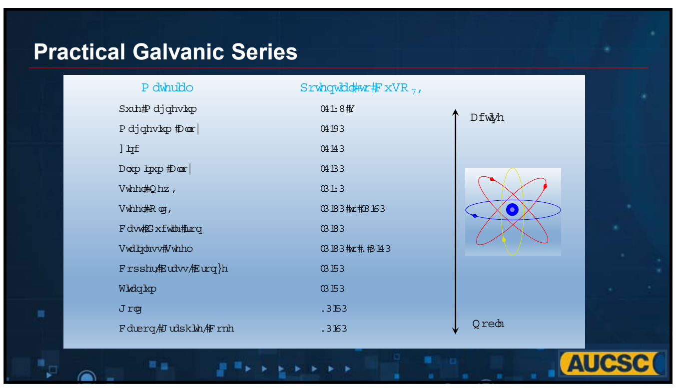
11


Basic Corrosion Mechanism
Metallic Path
Electrolyte
(water, soil, concrete, mud, etc.)
Cathode (protected)
Water
Anode (corrodes)
In typical soils, at Cathode:
Electrons consumed by water/oxygen – protective film forms
Copper
Steel
Corrosion Current (Conventional Current Flow)
In typical soils, at Anode:
Iron goes into solution and combines with ions in the electrolyte to form corrosion deposits
Corrosion Deposits
What is a Zinc Carbon Battery?
Electrical 4 U

12


Corrosion: Electrochemistry
The Four (4) Components of a Corrosion Cell:
• Anode
• Cathode
• Electrolyte
• Metallic Path
All four (4) must be present for a corrosion reaction to occur.
Water (H_2O)
Ion path (OH^-)
O_2
Fe^{2+}
Fe_2O_3
Electrolyte
Rust
Metallic Path
Electron path (e^-)
Steel
Anodic area (+) Oxidation
$Fe \rightarrow Fe^{2+} + 2e^-$
Cathodic area (-) Reduction
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$
AUCSC

13

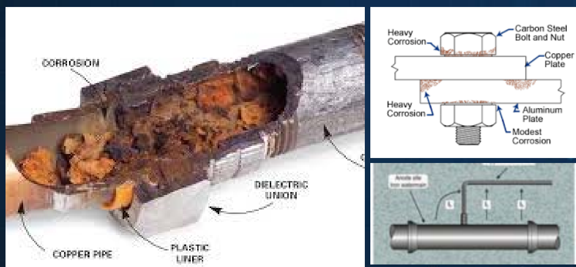

Practical Galvanic Series
P dwhuldo
Srwhqwldo#wr#FxVR 7,
Sxuh#P djqhvlxp 041:8#Y
P djqhvlxp #Door| 04193
] lqf 04143
Doxp lqxp #Door| 04133
Vwhho#Qhz , 031:3
Vwhho#R og, 03183#wr#03163
Fdvw#Gxfwlh#Lurq 03183
Vwdlqohvv#Vwhho 03183#wr#.#3143
Frsshu/#Eudvv/#Eurq}h 03153
Wlwdqlxp 03153
Jrog .3153
Fduerq/#Judsklwh/#Frnh .3163
Dfwlyh
Qreoh
AUCSC

14


Corrosion Causes
Bi-metallic Couples
Non-homogeneous Environment
▪ Mixed Fill Material
▪ Differential Oxygen Concentration
DC Interference
AC Induced Corrosion
Microbiological Induced
AUCSC

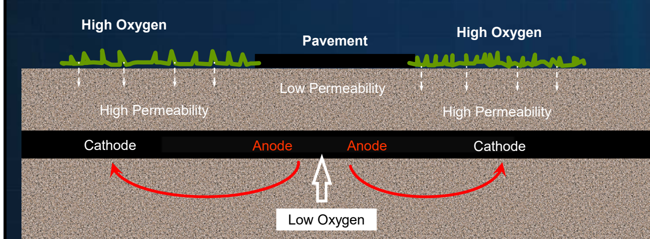
15

Bi-Metallic Corrosion



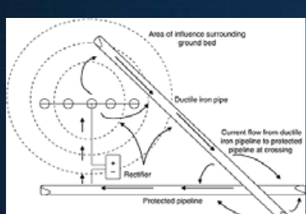
16

Corrosion Caused by Differential O_2 Concentrations

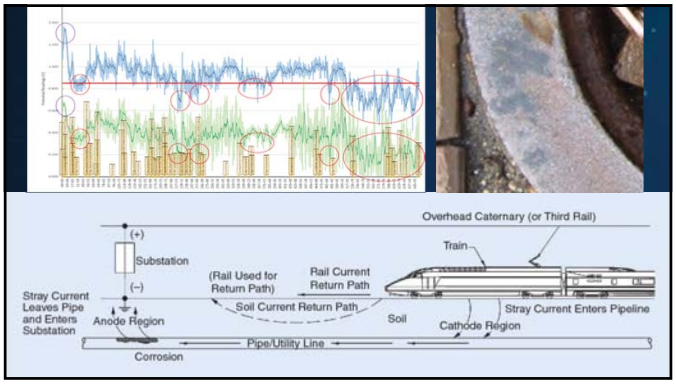


17

Stray Current Corrosion



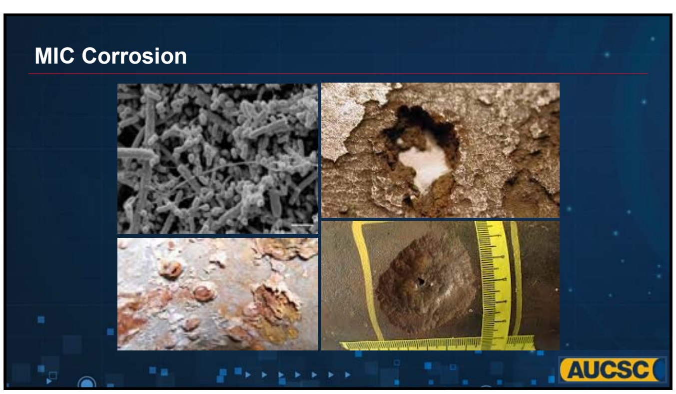
18


Overhead Caternary (or Third Rail)
(+)
Substation
Train
(–)
(Rail Used for
Return Path)
Rail Current
Return Path
Stray Current
Leaves Pipe
and Enters
Substation
Soil Current Return Path
Soil
Stray Current Enters Pipeline
Anode Region
Cathode Region
Pipe/Utility Line
Corrosion

19


AC Corrosion
10 20 30 40
AUCSC

20


MIC Corrosion
AUCSC

21

Soil Corrosivity

AUCSC

22

Laboratory Analytical Data

- Soil Moisture Content | ASTM D2216
- Conductivity | ASTM D1125
- Soil Resistivity | ASTM G57 (As Received & Saturated)
- Soil pH | ASTM D4972 or G51
- Chloride Ion Concentration | AASHTO T291 or ASTM D512
- Sulfide Ion Concentration | EPA 376.1
- Sulfate Ion Concentration | AASHTO T290 or ASTM C1580
- Redox Potential | ASTM G200
- Linear Polarization Resistance (LPR) | ASTM G102

AUCSC

23

Soil Moisture Content (ASTM D2216)

- Prevailing moisture content of the soil is very important to all soil corrosion
- Moisture content can vary throughout the year and heavily dependent on soil type
- High moisture content of soils helps increase conductivity, which helps sustain the corrosion process
- There is no established threshold as it relates to corrosivity
- Typically, more than 20-25% for clay soils is very conducive to sustaining corrosion

AUCSC

24

Soil pH (ASTM G51)

- pH is the measure of the acidity in the soil
  - pH of 7.0 → Neutral
  - pH lower than 7.0 → Acidic
  - pH higher than 7.0 → Basic or Alkaline to
- Acidic environments are corrosive to ferrous piping such as cast iron, ductile iron, or steel
- pH range of 6.5 – 7.5, soil conditions are optimum for MIC (microbiologically induced corrosion) by sulfate reducing bacteria, provided that other conditions exist such as high sulfates and anaerobic conditions

pH	
< 5.5	Severely Corrosive
5.5 - 6.5	Moderately Corrosive
6.5 - 7.5	Neutral
>7.5	None (alkaline) to ferrous metals

AUCSC

25

Soil Resistivity (ASTM G57)

Soil resistivity is a common parameter for evaluating the corrosiveness of soil. Resistivity is the inverse of conductivity and is measured in the units of ohm-centimeters.

Corrosivity Classifications:

Soil Resistivity (ohm-cm)	
0 - 500	Very Corrosive
500 - 1,000	Corrosive
1,000 - 2,000	Moderately Corrosive
2,000 - 10,000	Mildly Corrosive
>10,000	Negligibly Corrosive

Single Probe

Wenner 4-Pin

AUCSC

26

Chloride Ion Concentration (ASTM D512)

Chloride ions affect the corrosion rate of metals by severely increasing the conductivity of the environment and by disrupting passive protective films on the metal surface.

Environments high in chloride ion concentrations are very aggressive to metallic structures (an example of an environment rich in chloride ions is seawater).

Note: There is no set threshold above which corrosion is imminent. The ACI – 318 Building Code, as represented in NACE Corrosion Engineer's Handbook, 3rd Edition, **lists the chloride threshold at < 500 ppm**. However, it is believed that chloride concentrations in excess of 50 ppm are high enough to be a cause for concern.

AUCSC

27

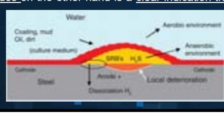
Sulfate Ion (ASTM C1580) and Sulfide Ion Concentration

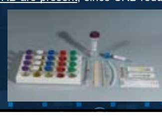
The presence of high concentrations of sulfates can have a tremendous impact on the corrosivity of the environment. It is well documented in the literature that sulfate reducing bacteria can accelerate the corrosion reaction by several folds leading to accelerated pitting and rapid failure of metallic structures.

The presence of sulfates alone does not necessarily mean that **sulfate reducing bacteria (SRB)** are present, but is a conducive environment to SRB provided other factors are present, such as **anaerobic conditions** (found generally in clay, muck, organic soils).

The ACI – 318 Building Code, as represented in NACE Corrosion Engineer's Handbook, 3rd Edition, states that **sulfate concentrations of 150 – 1500 ppm have a corrosive effect with higher values have increasing corrosion effects**. There is no known threshold per se above which sulfates contribute greatly to the corrosivity of the soil, but it is believed that concentrations in excess of 150 ppm should not be discounted.

The presence of sulfides on the other hand is a clear indication that SRB are present, since SRB reduces the sulfate into sulfides.





AUCSC

28

Redox Potential (ORP) (ASTM G200)

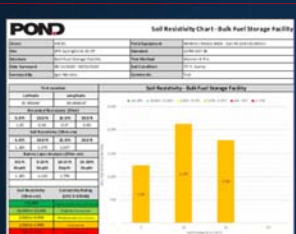
The redox potential (oxidation reduction potential) of soil is of significance because the most common sulfate reducing bacteria can live only in anaerobic conditions. Typically, a redox potential greater than + 100 mV indicates that the soil is sufficiently aerated, preventing attack by sulfate reducers. A Redox potential between 0 mV to +100 mV may or may not indicate anaerobic conditions, and a negative redox potential definitely indicates anaerobic conditions.

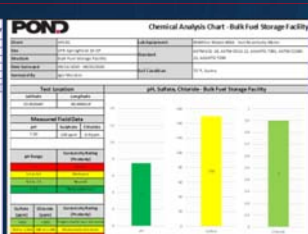
Soil Redox is a time sensitive measurement. For an accurate representation, the measurement should be made as soon as practicable after the removal of the soils sample from the ground.

AUCSC

29

Soil Corrosivity Analysis





AUCSC

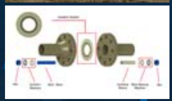
30

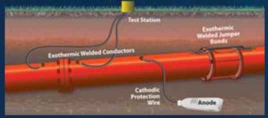
Corrosion Control Methodologies

31

Corrosion Control Methodologies

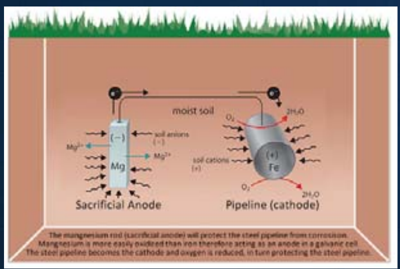
- Material Selection
- Add Corrosion Allowance | Extra Metal to Structure
- Alter Service Environment
- Electrical Isolation
- Protective Coatings
- Construction QA/QC
- Cathodic Protection





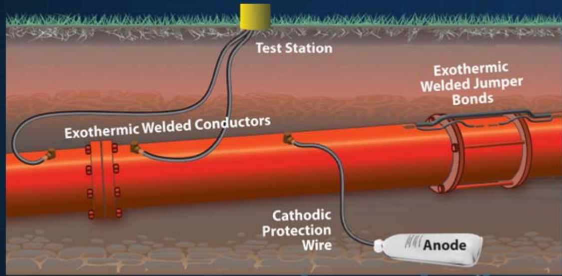
32

Sacrificial Anodes or Galvanic Cathodic Protection



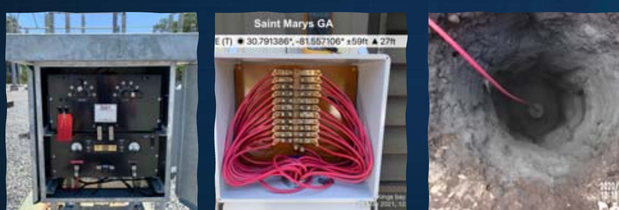
33

Sacrificial Anodes or Galvanic Cathodic Protection



34

DC Transformer through Anodes (ICCP)



35

System Characteristics and Comparison

Galvanic	ICCP
No external power	External power required
Fixed driving voltage and hence CP current	Voltage and Current Output can be adjusted
Limited current from sacrificial anodes (Mag, AL, Zn)	Higher current output from ICCP anodes (MMO, Graphite, HSCI)
Ideal for smaller and effectively isolated assets with low corrosion control current requirements	Ideal for larger systems with multiple assets, and larger bare surface areas (e.g. tank bottoms) and potential (or presence) of electrical grounding which require higher CP current
Best used in lower resistivity soils	Could be used in almost any resistivity environment
Causes negligible interference issues	Must consider interference with other structures when designing, installing and testing

36

Cathodic Protection Corrosion Control Design

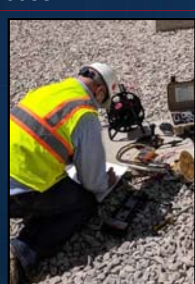
37

Cathodic Protection Design

38

Cathodic Protection Design Process

- Pre-assessment Study
- Detailed Corrosion Study
- Design Process
- Application of Correct NACE Criteria
- Proper Installation
- CP Commissioning
- Maintenance Program
- Future Upgrades



39

Pre-Assessment Study

- Pipeline Construction History
- Soil Types and Environmental
- Pipe Material
- High Risk and Critical Pipeline
- Coating Materials
- Physical Location of Pipeline
- Paved Areas
- Restricted Areas
- Construction Related
- Grounding System

AUCSC

40

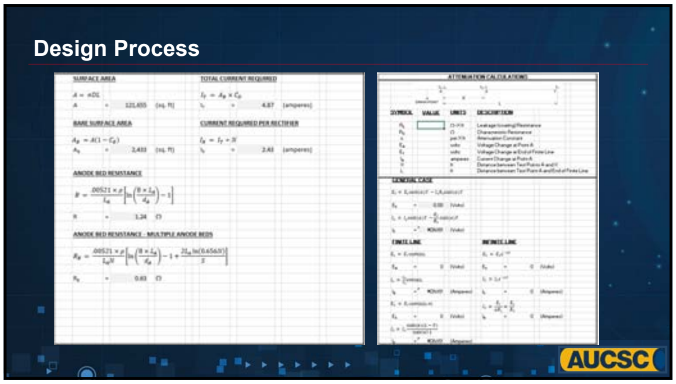
Design Process

- Electrical Continuity Verification
- Current Requirement Testing
- Design Calculation
- Determination of Cathodic Protection Type
- A/C Power Supply
- Identification of Groundbed Locations
- Identification of Rectifier Locations
- Electrical Continuity Verification

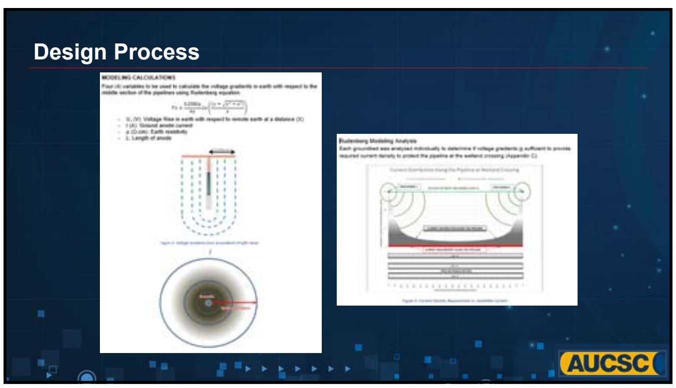
AUCSC

41

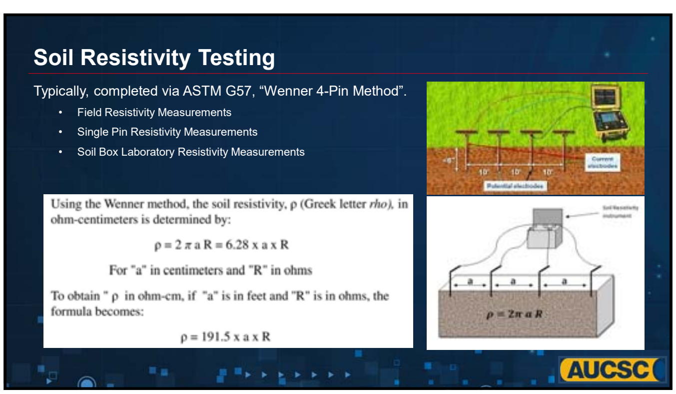
42


Design Process
SURFACE AREA
TOTAL CURRENT REQUIRED
BARE SURFACE AREA
CURRENT REQUIRED PER RECTIFIER
ANODE BED RESISTANCE
ANODE BED RESISTANCE - MULTIPLE ANODE BEDS
ATTENUATION CALCULATIONS
SYMBOL
VALUE
UNITS
DESCRIPTION
GENERAL CASE
FINITE LINE
INFINITE LINE
AUCSC

43


Design Process
MODELING CALCULATIONS
Rudenberg Modeling Analysis
AUCSC

44


Soil Resistivity Testing
Typically, completed via ASTM G57, "Wenner 4-Pin Method".
• Field Resistivity Measurements
• Single Pin Resistivity Measurements
• Soil Box Laboratory Resistivity Measurements
Using the Wenner method, the soil resistivity, ρ (Greek letter rho), in ohm-centimeters is determined by:
ρ = 2 π a R = 6.28 x a x R
For "a" in centimeters and "R" in ohms
To obtain " ρ in ohm-cm, if "a" is in feet and "R" is in ohms, the formula becomes:
ρ = 191.5 x a x R
10'
10'
10'
a
a
a
ρ = 2π a R
AUCSC

45

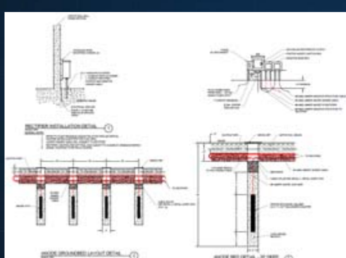
Cathodic Protection System Options

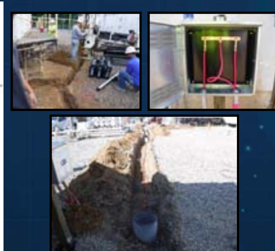
Protection (CP) system design falls into three (3) configurations:

- Shallow distributed groundbeds
- Deep anode groundbeds
- Linear anodes
- Combination of Groundbeds

46

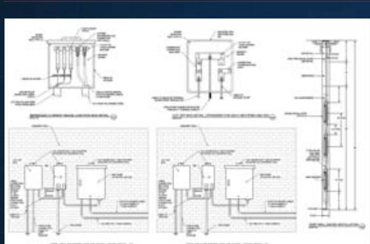
Cathodic Protection System Options: Shallow Distributed Anodes Beds

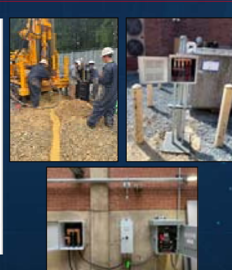




47

Cathodic Protection System Options: Deep Well





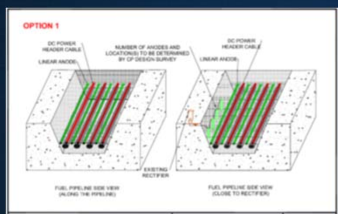
48

Slide 46

MJ0 I recommend adding a slide with photo for linear anodes. I do not have any photos. I added slides for deep well and distributed

Morales, Jose, 2023-01-13T23:06:51.742

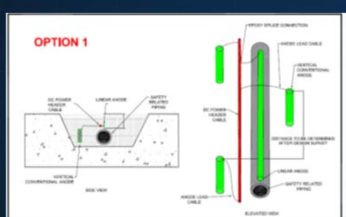
Cathodic Protection System Options: Linear Anode



AUCSC

49

Cathodic Protection System Options – Combination



AUCSC

50

Commissioning

AUCSC

51

Commissioning

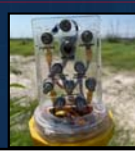
All buried pipelines with cathodic protection systems shall be commissioned:

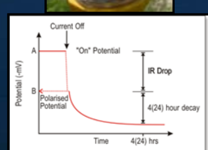
- Collect Native Potential
- Verify Electrical Continuity
- Energizing Groundbeds
- Checking the Initial Polarization
- Polarizing the Pipeline Systems
- Conducting Instant Off Potential Survey
- Adjusting the Rectifier Outputs

52

Corrosion Control Monitoring

- As an Operator, knowing an accurate pipeline location
- Performance monitoring of a cathodic protection system is an integral part of the system.
- 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.
- 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.
- Upon activation of a new or refurbished cathodic protection system, the system shall be tested for proper function and performance





53

Annual CP Surveys

- Surveys should be performed under direction of a Corrosion or Cathodic Protection Specialist.
- Surveys should include:
  - Rectifier operation
  - Continuity testing
  - Potential survey at Test Stations
  - Checking the Isolation Effectiveness
  - Critical Locations, such as:
    - Bonding Stations
    - Crossing with Foreign Pipeline
- Interference testing
- Always should include a detailed report of findings and recommendations for continued operation.

54

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.

AUCSC

55

What is the Most Important Part of Survey?

Gdwd#Dffxudf|

AUCSC

56

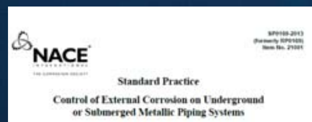
Data Analysis and Criteria

AUCSC

57

Cathodic Protection Criteria

- Measurement of a polarized (instant off) pipe to soil potential relative to a copper/copper sulfate electrode which is not more positive than -850 mV (-850 mV and more negative potentials are acceptable).
- Measurement of a current applied (system on) pipe to soil potential relative to a copper/copper sulfate electrode when corrected for potential drop due to electrolyte resistance (IR drop) which is not more positive than -850 mV (-850 mV and more negative potentials are acceptable).


NACE

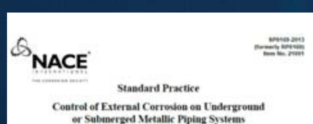
Standard Practice

Control of External Corrosion on Underground or Submerged Metallic Piping Systems

58

Cathodic Protection Criteria

- For piping systems composed solely of steel and gray or ductile cast-iron, i.e., those systems which are not connected to a grounding grid or any other dissimilar metal, the measurement of at least a 100 mV cathodic polarization between the polarized and non polarized conditions.
- When active MIC has been identified or is probable, (e.g., caused by acid-producing or sulfate-reducing bacteria) at temperatures greater than 60 °C (140 °F), the criteria listed might not be sufficient. Under some conditions, a polarized potential of –950 mV CSE or more negative of cathodic polarization may be required.


NACE

Standard Practice

Control of External Corrosion on Underground or Submerged Metallic Piping Systems

59

IR Drop Consideration

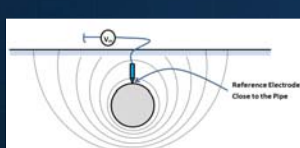
Current Interruption Method

$E_p = V_m - IR$

I = 0 **(Interrupting Current Momentarily)**

Then; **IR = 0**

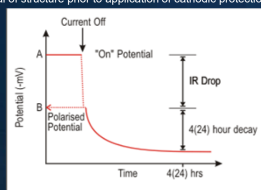
Reference Electrode Placement Close to the Structure



60

Cathodic Protection Criteria

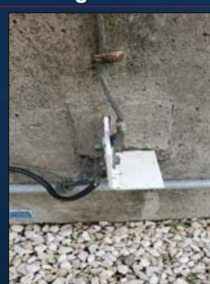
- -850 mV Structure to Soil Potential
  - Potential measured with a copper/copper sulfate reference cell and voltmeter. Measurement must allow for IR Drop.
- 100 mV Polarization
  - Requires record of potential of structure prior to application of cathodic protection



61

Shorted Systems Integrity Management Program

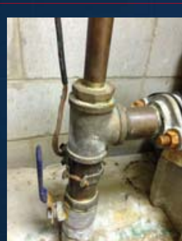
- The basic purpose of corrosion control is to maintain the soundness and integrity of a structure
- The reasons for corrosion control…
  - Asset Management/Life Extension
  - Regulatory Compliance
- Corrosion control offers proven, cost-effective ways to reduce the premature deterioration of materials and protect both the public and the environment in the process
- Another equally important aspect of controlling corrosion is recognizing that corrosion is indeed a threat
- Prioritizes maintenance and monitoring procedures based upon:
  - Risk of Failure
  - Consequence of Failure



62

Shorted Systems Complexity

- Due to the inter-connection of the metallic piping to the copper grounding system or other underground structures, corrosion rates can increase on some of the buried piping.
- When cathodic protection (CP) is applied at shorted Systems to control corrosion of the buried piping, much of the current will tend to flow to other metallic structures that are not intended for CP.



63

Shorted Systems Cathodic Protection

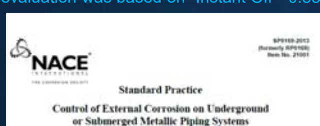
- Cathodic protection criteria must be met on the entire surface of the buried pipeline, not just at the test stations.
- Cathodic protection, misapplied can accelerate corrosion.
- The evaluation techniques and survey methods described are useful tools in determining the effectiveness of your total corrosion control program.
- Implementing a proactive pipeline integrity management program will reduce the overall costs and risks associated with operating a pipeline network.

AUCSC

64

Application of Correct NACE Criteria

This evaluation was based on "Instant Off" -0.850 Volt


NACE

Standard Practice

Control of External Corrosion on Underground or Submerged Metallic Piping Systems

AUCSC

65

Q & A

AUCSC

66

Design of CP for Water Systems

Andrew Fuller, Engineering Design Technologies

Andrew.fuller@edtinc.net

CP FOR WATER SYSTEMS

BY: ANDREW FULLER, PE, CP4, PMP, CIP1

1

AGENDA

Corrosion Control
Cathodic Protection
CP in Water Systems
Pipe Material Considerations
Examples of CP on Water Pipes

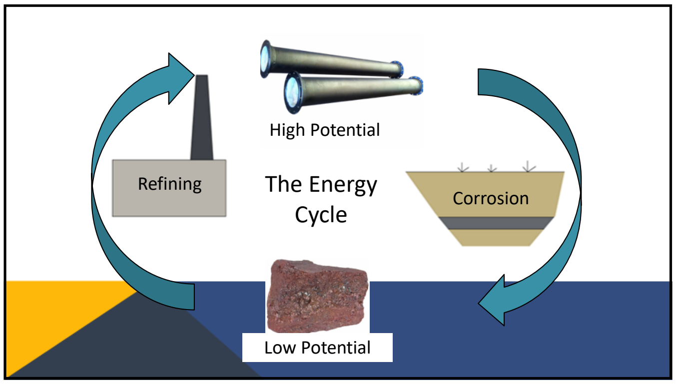
OBJECTIVE

Review how CP is applied in the water industry with a focus on buried pipelines.

2

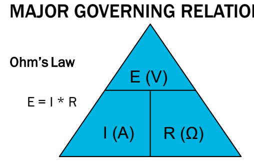
CORROSION CONTROL

3



4

MAJOR GOVERNING RELATIONSHIPS



Faraday's Constant

Material	K (lb/A-yr)
Graphite	2.5
Magnesium	8.8
Steel	20
Copper	45
Lead	74

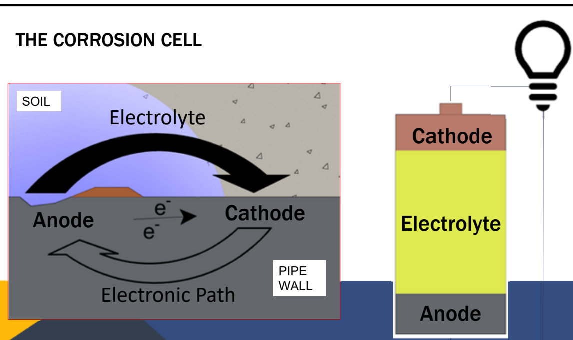
Galvanic Series

Material	Potential* (V)
Graphite	+0.3
Copper, Brass, Bronze	-0.2
Mild Steel in Concrete	-0.2
Mild Steel (Rusted)	-0.2 to -0.5
Lead	-0.5
Mild Steel (Clean)	-0.5 to -0.8
Zinc	-1.1

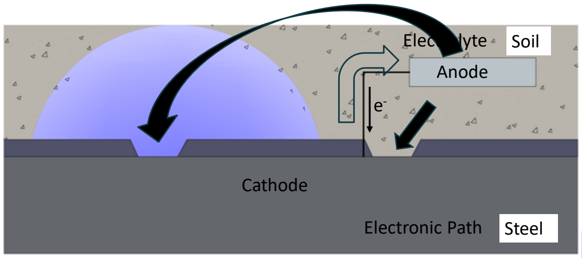
*Approximate, for neutral soil and fresh water vs. $Cu/CuSO_4$ Electrode

5

THE CORROSION CELL



6



7

CATHODIC PROTECTION

8

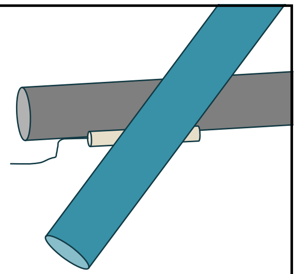
CATHODIC PROTECTION DESIGN APPROACH

1. Structure Documentation Review (existing or proposed?)
2. Environment (risk of corrosion, limitations to CP)
3. Material and Coating Type (condition if existing)
4. Determine whether to apply CP (triple bottom line)
5. What type of CP (galvanic or impressed current)
6. Construction Restrictions (land use and power supply for ICCP)
7. Long Term Operations and Maintenance

9

STRUCTURAL FACTORS

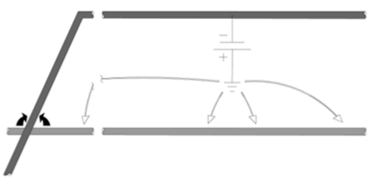
Existing or proposed
Material type(s)
Bonding
Isolation
Coating quality
Current requirement
Geometry



10

ENVIRONMENTAL FACTORS

Type of electrolyte
Site access and land use restrictions
Site corrosivity
History of corrosion-related failures
Consequence of failure (Financial, Social, and Environmental)

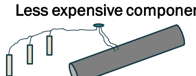


11

GALVANIC VS. ICCP

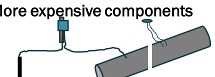
GALVANIC

Self-regulates current output
Environmental conductivity is critical to output
More material required
Less expensive components



IMPRESSED CURRENT

Output controlled at rectifier(s)
Power supply, material, and risk of interference limit output
Less material required
More expensive components



12

DESIGNING GALVANIC CP

Considering:

1. Current Requirement,
2. Electrolyte Resistivity, and
3. Required Service Life

Anode Material Selection (e.g. HiPot Magnesium, Zinc, Magnesium, or Aluminum)
Anode Placement (Land Use, Operations & Maintenance, Construction Requirements)
Groundbed Sizing (Anode Size, Number, Orientation, Spacing, Depth)
Site Layout (Constructability/O&M Review)

13

DESIGNING IMPRESSED CURRENT CP

Considering:

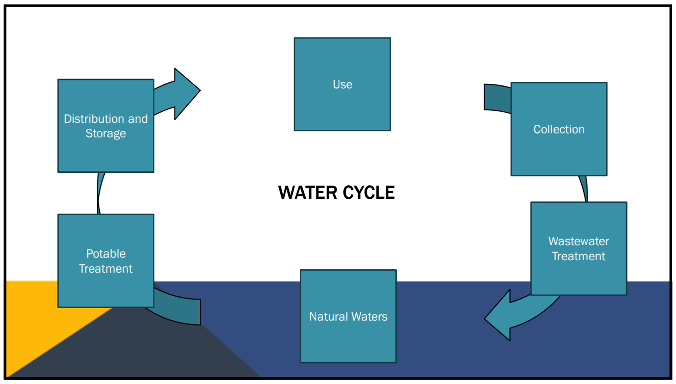
1. Interference,
2. Electrolyte Resistivity, and
3. Power Supply

Anode Placement (Land Use, Operations & Maintenance, Construction Requirements)
Groundbed Sizing (Anode Size, Number, Orientation, Spacing, Depth)
Site Layout (Constructability/O&M Review)
Anode Material Selection (e.g. HiPot Magnesium, Zinc, Magnesium, or Aluminum)

14

CP IN WATER SYSTEMS

15



16

WATER AND WASTEWATER SYSTEMS

Reservoirs
Intake Structures
Treatment Tanks/Basins
Pumps
Valves, Fittings, and Hydrants
Potable Storage Tanks
Service Connections

Pipelines
- Transmission vs. Distribution
- Pressurized vs. Gravity

Pipe Materials:
- (Gray) Cast Iron, (Carbon) Steel, Concrete Pipe (RCP, PCCP, BWP), and Ductile (Cast) Iron
- Non-metallic:
  - Asbestos Cement, PVC, HDPE
  - CIPP, CFRP (rehab)
- Special applications:
  - Copper, stainless steels

17

COMPONENTS OF CP IN WATER

Anodes
- Prepackaged zinc or magnesium in bags
- Impressed current groundbeds
- Probe type impressed current anodes
- Hull type galvanic anodes
- Ribbon galvanic anodes

Test Points
- Test stations, air release valves, blow offs, control valves, rectifiers, and risers (especially in the South)

Bonding
- Joint bond wires, welding, internal straps, and keyhole bonding

Isolation
- Insulating flange kit, monolithic joint, plastic spool pieces, and no OVP required!

18

UNIQUE CONSIDERATIONS FOR ANODES IN WATER SYSTEMS

Metallic pipelines (cast iron, ductile iron, reinforced concrete, and even steel) installed without bonding for continuity.

Operations and maintenance staff familiarity

Stray current impacts and placement

Reinforcing steel and the halo effect

Corrosive, variable, or turbulent product

Moving components in storage and treatment tanks

Icing in aboveground storage tanks

Contamination of drinking water (or perception thereof)

19

CONSIDERATIONS FOR BONDING AND ISOLATION

In some cases, it is not worth it…
- An existing pipe in a roadway can be too expensive to bond
- A spill gate hinge is too integrated with the reinforcing steel of the foundation to isolate it

Large diameter and mortar-coated pipe have greater exposed surface area, so bond liberally and allow for some movement. Water is heavy.

IFKs are not meant for buried use… but alternatives get more expensive at large diameters.

Inspect IFKs thoroughly before burying. The larger the IFK the more difficult to isolate.

Moving parts make isolation more difficult and dissimilar metals may be necessary.

Isolation of copper services is critical, especially with PVC.

20

CONSIDERATIONS FOR TEST POINTS

Testing
- Pipeline continuity and intermittent contact
- Valve and stem to pipe resistance

Design
- Maintenance requirements
- Accessibility and vulnerability
- Foreign structures
- AC Interference

21

PRESSURIZED PIPE MATERIALS

22

HISTORIC PRODUCTION AND USE OF WATER PIPE BY MATERIAL

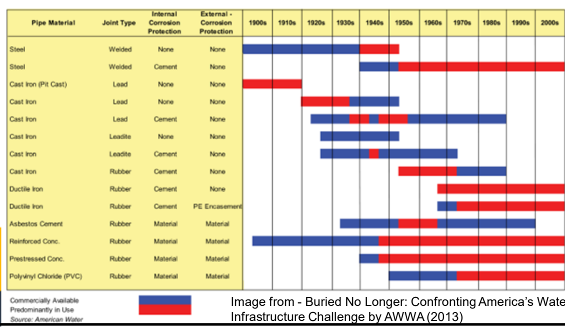


Image from - Buried No Longer: Confronting America's Water Infrastructure Challenge by AWWA (2013)

23

CAST IRON PIPE

Long history of use, many pit cast lines are still in use today

Graphite flakes cause galvanic cells, but once graphitized, surface corrosion is limited

Excessively thick walls of pit cast lines result extend life considerably

Centrifugal casting started in the early 1920s and then wall thickness was typically reduced

Most was installed unlined, so cleaning and lining may be prioritized over retrofitting CP

CP doesn't regrow wall, condition assessment guides efficient investment

24

STEEL PIPE

Multiple methods of forming and joining the pipe. Welded with relative ease. Welded pipe joints are the most reliably continuous for CP design.

Almost always installed with a bonded coating due to pitting risk. Shop-coating practices are very established. Various options exist for different applications.

Typically reserved for large diameter transmission mains in water systems.

Used as reinforcing steel for concrete and typical for non-pipe structures.

Cathodic protection best practices are well-documented.

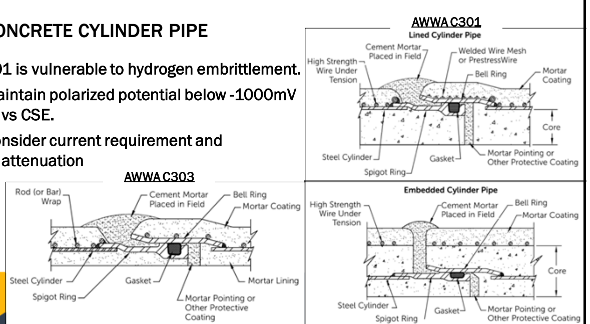
25

CONCRETE CYLINDER PIPE

301 is vulnerable to hydrogen embrittlement.

Maintain polarized potential below -1000mV vs CSE.

Consider current requirement and attenuation



From: American Concrete Pressure Pipe Association, Concrete Pipe Repair Guide (2015)

26

DUCTILE IRON PIPE

Joint bonding required

If field-applying bonded coating order the pipe bare and follow NAPF 500-03

Polyethylene encasement greatly reduces apparent current requirement and resistance to stray current but is not a bonded coating

27

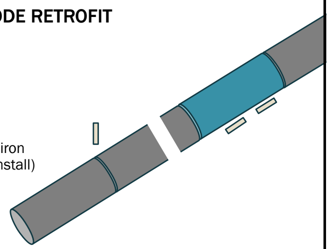
APPLICATION OF CP ON WATER PIPES

28

OPPORTUNISTIC (GALVANIC) ANODE RETROFIT

Example
- Existing gray cast iron pipe
- Electrically discontinuous
- Distribution pipe to remain in place

Considerations
- Timing and method of install (e.g. Ductile iron replacement, repair clamp, and keyhole install)
- Direct connect or test station
- Anode type (useful life vs. range)
- Use of ring terminals to avoid welding



29

NEW CONCRETE TRANSMISSION MAIN

PCCP, BWP, and RCP all use a steel barrel

CP Design
- Joint and reinforcing bonds must be considered. Refer to AWWA M9 for typical joint bonding and shorting strap applications.
- Consider current requirement and protective coatings
- If PCCP, Galvanic CP is especially preferred where practical
- Constant voltage rectifiers require inspection regularly after install
- Anodes should be as remote as practical

30

NEW DUCTILE IRON DISTRIBUTION PIPING

Distribution piping gets disturbed not just for repairs but for taps, tees, assessments, nearby work, and even accidental strikes. Consider the impacts on coating quality.

Polyethylene encasement is by far the most common method of coating DIP. It reduces current requirement, but, since it is not bonded, typical cathodic protection and monitoring assumptions are questionable.

Bonding at installation allows for future protection. Localized protection provides economical life extension,

31

CONCLUSION

Water utility owners have much to consider regarding corrosion control

Cathodic protection of water systems brings unique challenges

Different pipe materials (especially CIP, CCP, and DIP) have their own considerations and opportunities

32

THANK YOU!

Andrew Fuller, PE*, CP4, PMP, CIP1
*AL, AZ, DC, IL, MD, NC, ND, and TX
Vice President/Office Director
Engineering Design Technologies, Inc.
500 McCormick Drive | Suite E
Glen Burnie, MD 21061
Office: 410-344-7200
Direct: 443-410-0621
Mobile: 610-717-8925
andrew.fuller@edtinc.net

33