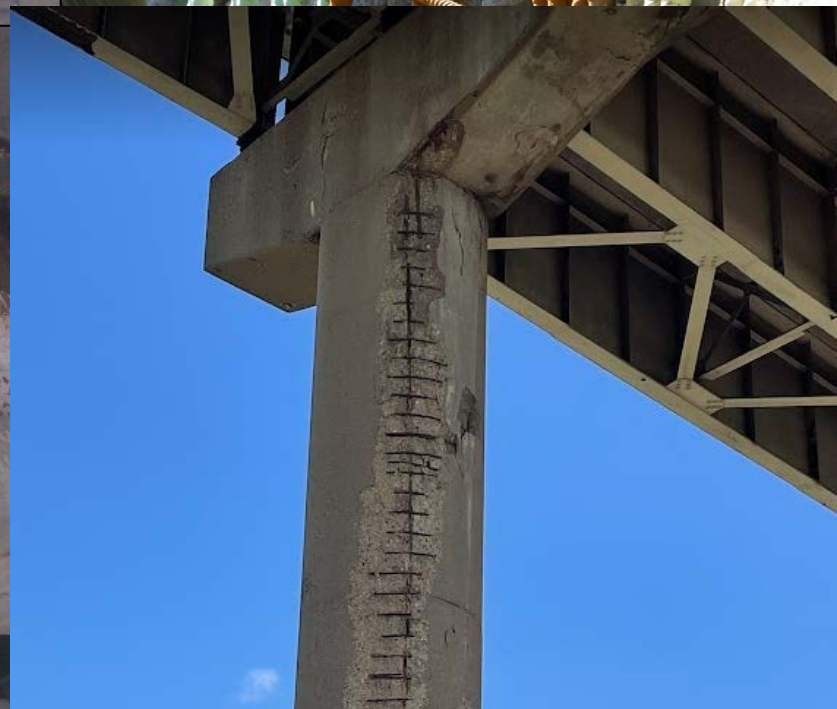
Cathodic Protection Case Studies for Bridges in the USA

Chris Ball

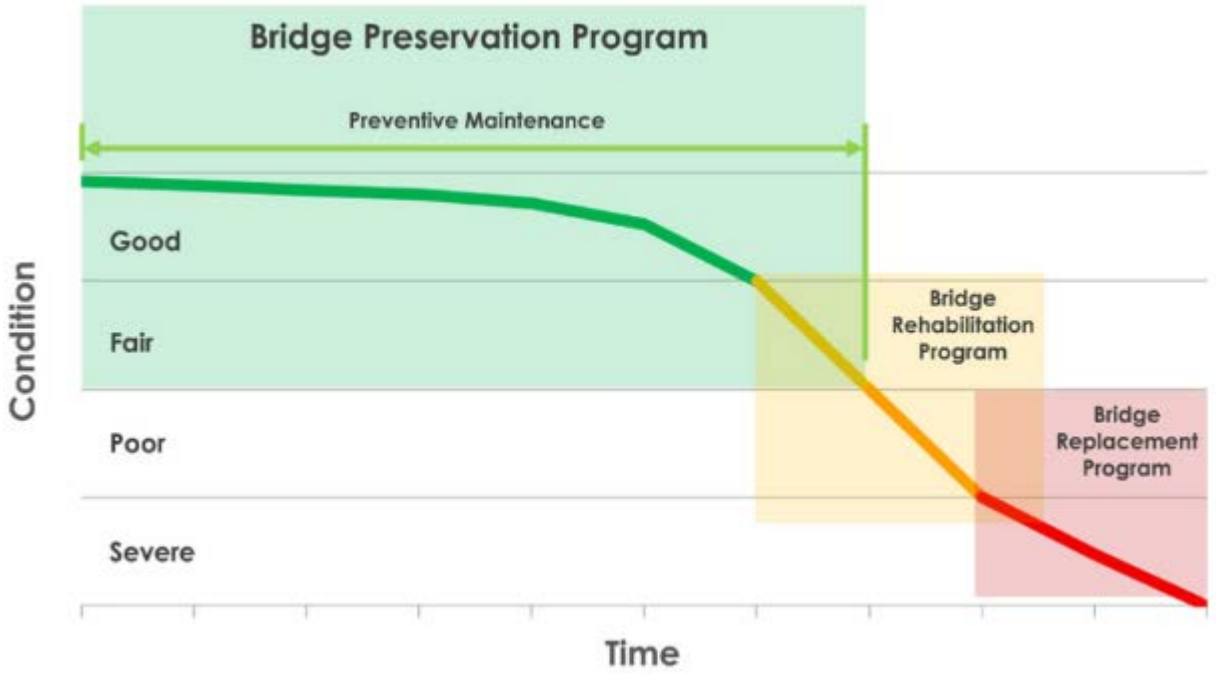
Vector Corrosion Technologies

Concrete Reinforcing Steel Corrosion on Bridges in the United States



Appendix A. Common Actions Based on National Bridge Inventory General Condition Ratings

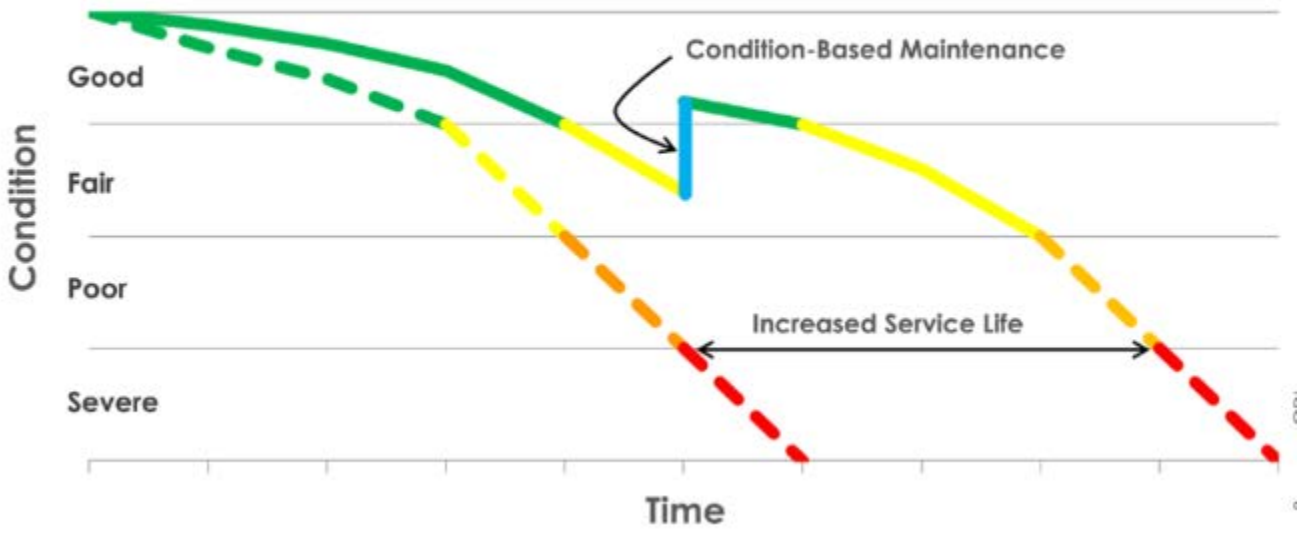
Code	Description	Common Actions
9	EXCELLENT CONDITION	Preservation/Cyclic Maintenance
8	VERY GOOD CONDITION—No problems noted.	
7	GOOD CONDITION—Some minor problems.	
6	SATISFACTORY CONDITION—Structural elements show some minor deterioration.	Preservation/ Condition-Based Maintenance
5	FAIR CONDITION—All primary structural elements are sound but may have some minor section loss, cracking, spalling, or scour.	
4	POOR CONDITION—Advanced section loss, deterioration, spalling, or scour.	Rehabilitation or Replacement
3	SERIOUS CONDITION—Loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.	
2	CRITICAL CONDITION—Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present, or scour may have removed substructure support. Unless closely monitored, the bridge may have to be closed until corrective action is taken.	
1	IMMINENT FAILURE CONDITION—Major deterioration or section loss present in critical structural components, or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic, but corrective action may put it back in light service.	
0	FAILED CONDITION—Out of service. Bridge is beyond corrective action.	



Source: FHWA Bridge Preservation Guide, 2018

Impact of Bridge Preservation and Maintenance Activities

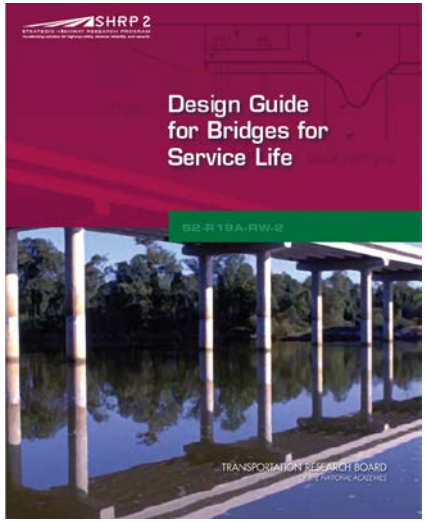
Solid-colored lines = With Preservation (cyclical and condition-based maintenance)
Dashed-colored lines = Without Preservation



Examples of Condition-Based Maintenance Activity	Bridge Component
Drains, Repair/Replace	Deck
Joint Seal Replacement	Deck
Joint Repair/Replace/Elimination	Deck
Electrochemical Extraction (ECE)/Cathodic Protection (CP)	Deck
Concrete Deck Repair (see halo effect below) in Conjunction with Overlays, CP Systems or ECE Treatment	Deck
Deck Overlays (thin polymer epoxy, asphalt with waterproof membrane, rigid overlays)	Deck
Repair/Replace Approach Slabs	Approach
Seal/Patch/Repair Superstructure Concrete	Superstructure
Protective Coat Concrete/Steel Elements	Superstructure
Spot/Zone/Full Painting Steel Elements	Superstructure
Steel Member Repair	Superstructure
Fatigue Crack Mitigation (pin-and-hanger replacement, retrofit fracture critical members)	Superstructure
Bearing Restoration (cleaning, lubrication, resetting, replacement)	Superstructure
Movable Bridge Machinery Cleaning/Lubrication/Repair	Superstructure
Patch/Repair Substructure Concrete	Substructure/Culvert
Protective Coat/Concrete/Steel Substructure	Substructure/Culvert
ECE/CP	Substructure/Culvert
Spot/Zone/Full Painting Steel Substructure	Substructure
Pile Preservation (jackets/wraps/CP)	Substructure
Channel Cleaning / Debris Removal	Channel
Scour Countermeasure (installation/repair)	Channel

Source: FHWA Bridge Preservation Guide, 2018

Strategic Highway Research Program 2: Project R19A



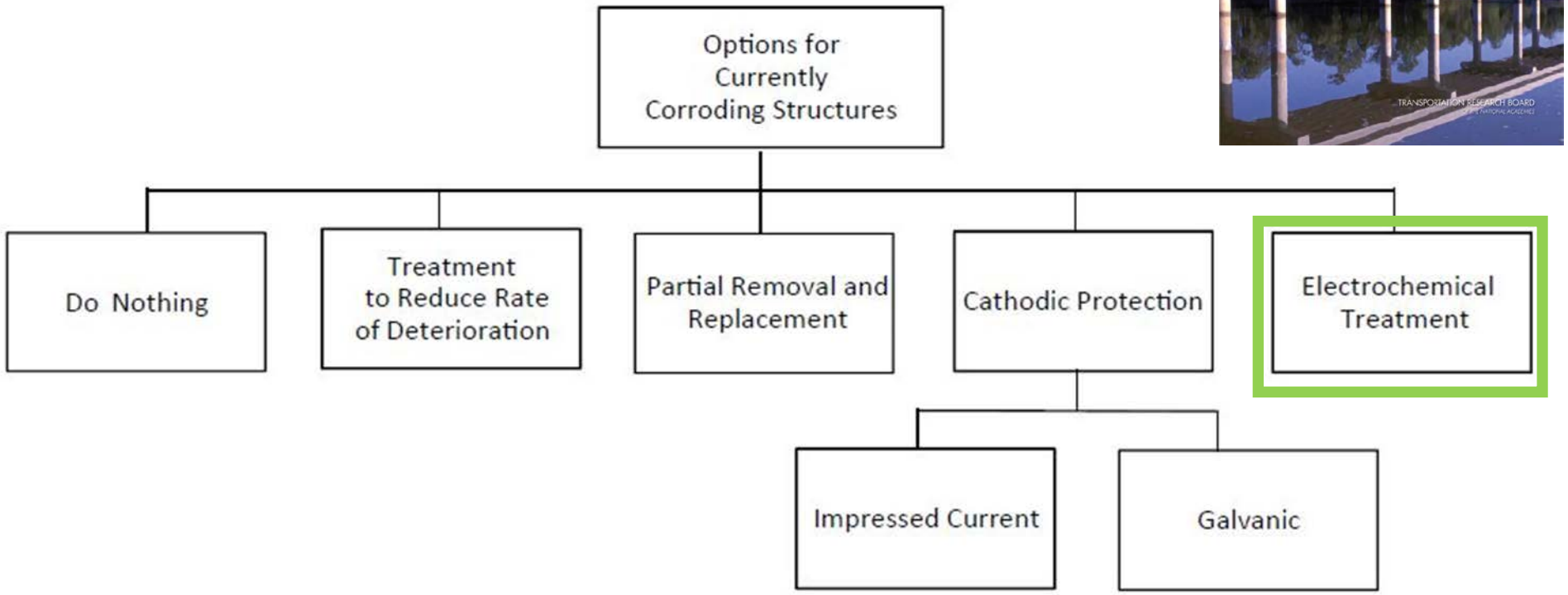


Figure 5.13. *Options for corroding structures.*

Electrochemical Chloride Extraction (ECE)

Rainbow Bridge, Idaho
2007 ICRI Project of the Year

What is Cathodic Protection?

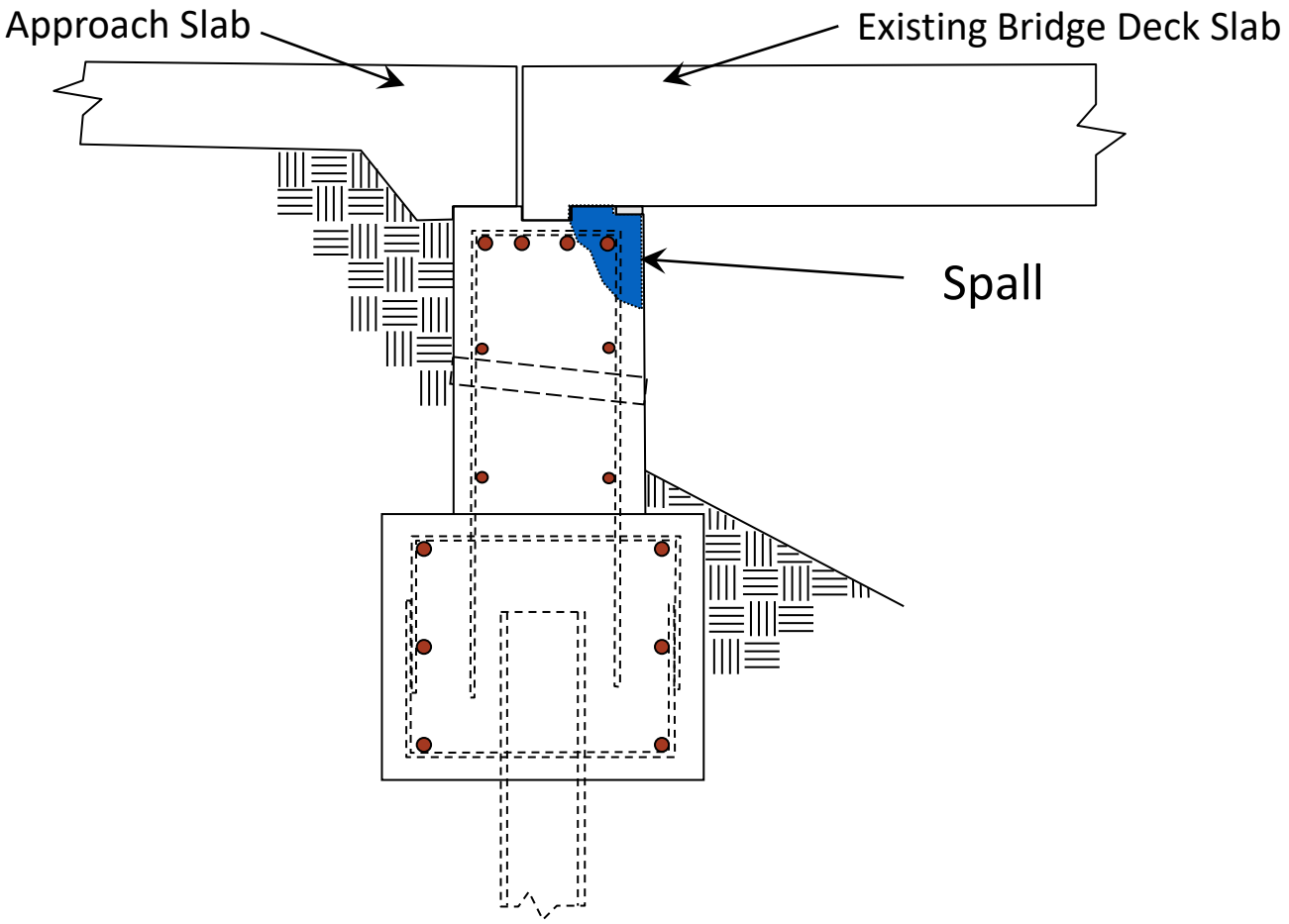
- Corrosion is an electrochemical process.
  - The anode is where oxidation occurs (rust)
  - The cathode is protected by the anode and does not rust.
  - Concrete alkalinity creates a buffer but eventually loses out to chlorides and/or carbonation.

- Cathodic protection (CP) is an electrochemical process.
  - Direct current is applied to the steel by galvanic anodes or impressed current.
  - CP slows down or stops corrosion by making the reinforcing steel cathodic and does not act like an anode.

Galvanic Encasement of I-75 Slab Bridge Abutments

Ohio DOT

- Overlay / enlargement for one step repair and protection
- Supplemental reinforcing
- Embedded galvanic anodes provided within encasement area



Slab Bridge Abutment Corrosion

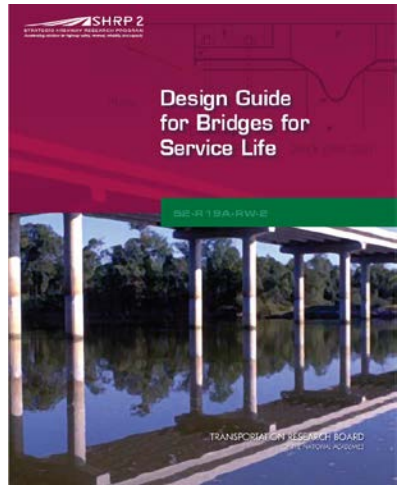
Abutment Conditions, circa 2005

Early Repair Techniques included Discrete Anodes on Exposed Bars for Halo Effect Protection

BUT

The Widespread Corrosion Problem Needed a Widespread Solution

Strategic Highway Research Program 2: Project R19A



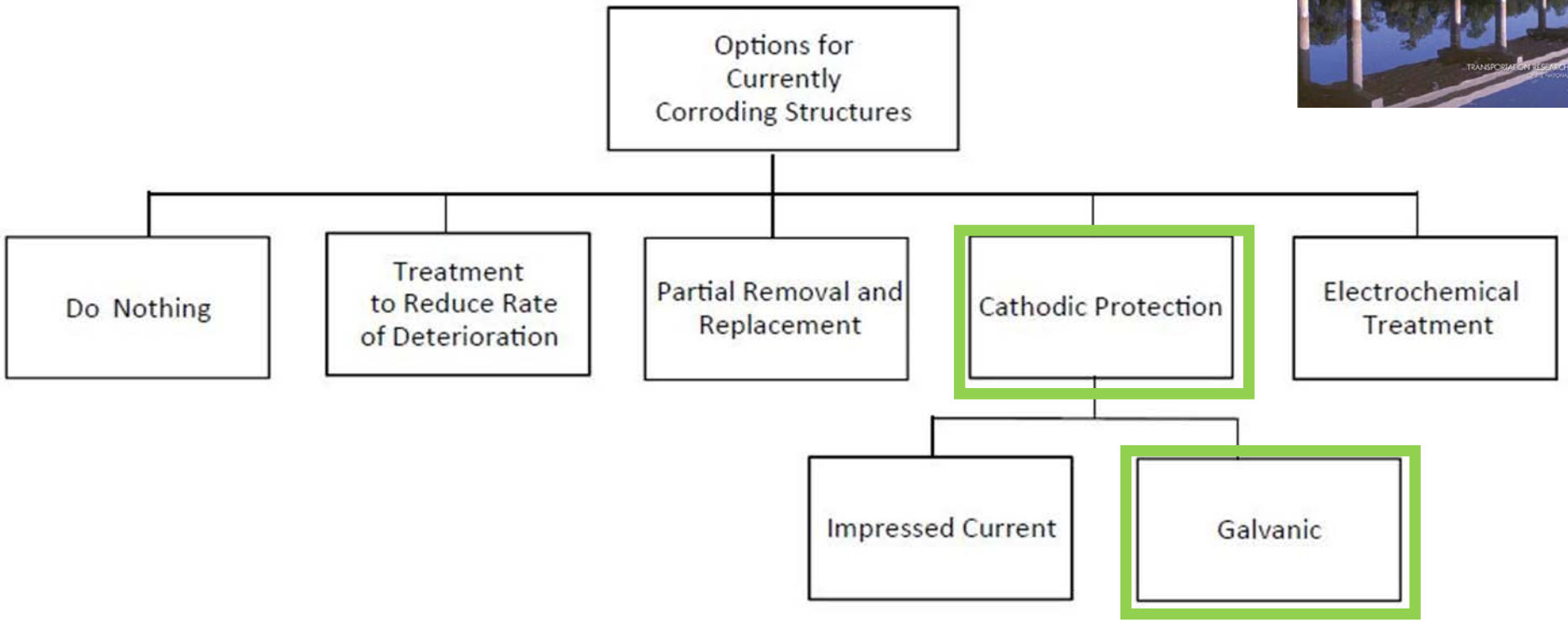
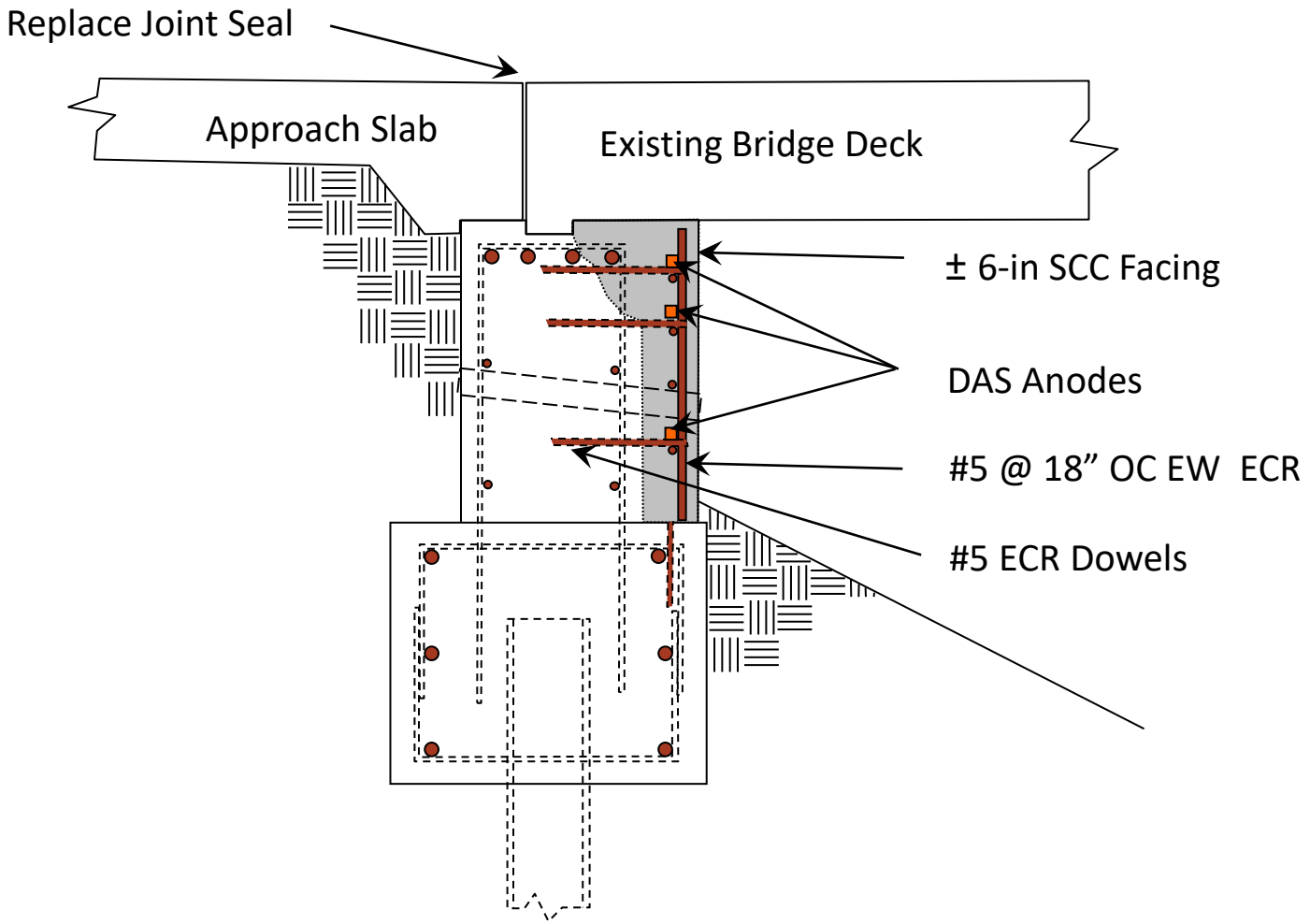


Figure 5.13. *Options for corroding structures.*

Galvanic Encasement of Slab Bridge Abutment Utilizing Distributed Galvanic Anodes



Kirkwood Road Bridge Before Repair

Spall Removal

Galvanic Encasement of Abutment

Sidney, OH

APRIL 21-24, 2024

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Forms Installed

Forms Removed

Completed Repair

I-75 over Kirkwood Road, 2022

Note efflorescence from leaking joint and weep holes

Galvanic Cathodic Protection System Performance Summary

NOTE: AMPP Polarization Criteria for Full Cathodic Protection >100 mV Shift

Date	Temperature, degree C	On Potential E_{ON}, mV	Instant Off E_{IOFF}, mV	Current Density Icp, mA/m^2	Polarization, Epol, mV
5/6/2005	(*Native*)		*-654*	37.7	
7/20/2005		-1061	-990	14.0	346
8/16/2005	30.6	-1136	-998	12.7	344
10/26/2005	12.2	-1082	-1023	5.4	369
12/7/2005	10.6	-982	-964	2.9	310
5/1/2006	13.9	-1051	-967	7.3	313
12/20/2006	4.6	-1176	-1113	3.7	459
5/30/2007	26.3	-1212	-1104	7.5	450
9/20/2007	23.9	-1238	-1136	9.1	482
12/19/2008	4.4	-1174	-1105	3.5	451
7/9/2009	23.3	-1146	-1125	2.8	471
5/11/2010	12.2	-1160	-1139	3.4	485
10/16/2011	22.2	-1193	-1142	5.9	488
4/22/2013	21.1	-1113	-1079	3.1	425
3/24/2015	1.7	-1060	-1035	2.0	381
9/17/2018	25.6	-1044	-1007	5.3	353
9/9/2020	26.7	-1036	-1005	3.6	351
8/23/2022	26.7	-1008	-986	2.0	332

Project Summary

- The rehabilitation project had minimal impact on interstate traffic.
- The selected system provided a one-step repair with galvanic protection
- Cost Comparison
  - Rehabilitation with anodes -$319,000
  - Abutment Replacement / Temporary Shoring - $427,000
  - Replacement of structures -$4,500,000
- 17+ Years of success, continues to be monitored

Longevity and Sustainability Award, 2023

Repair and Protection of Historic 3rd Avenue Bridge

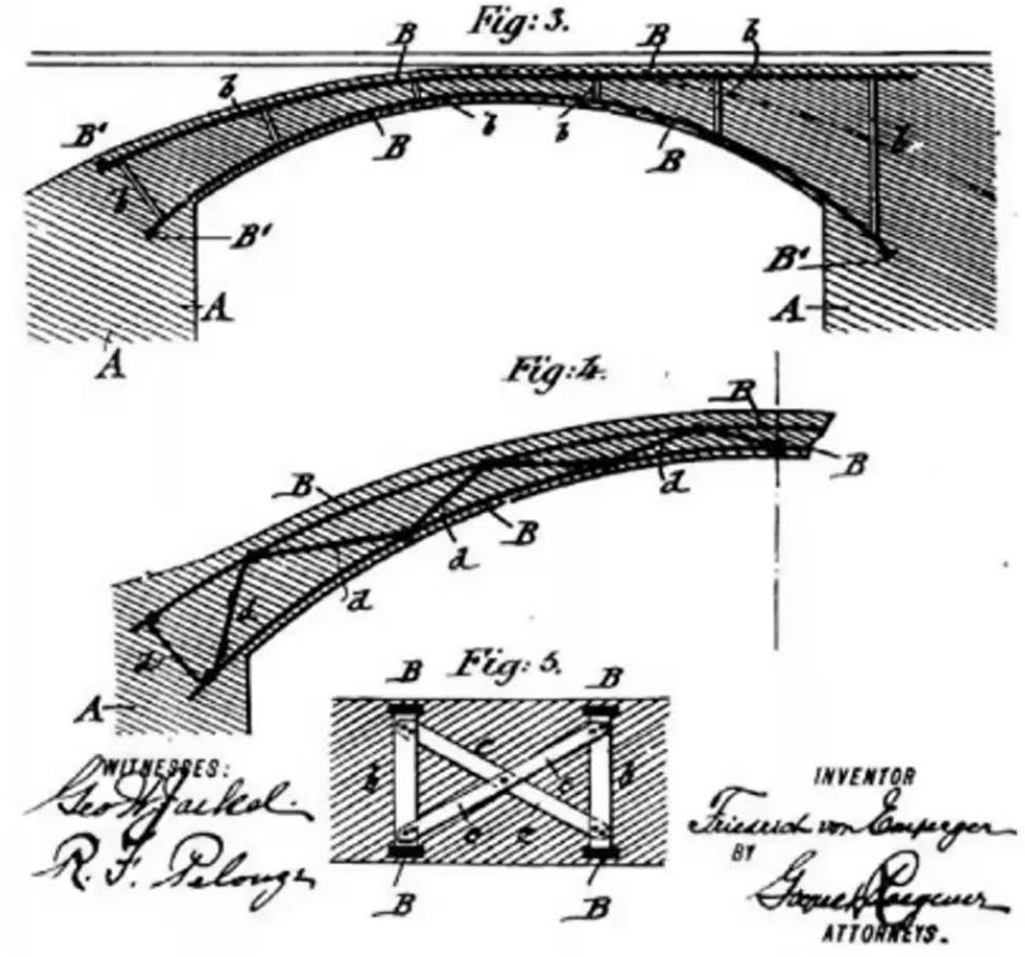
Minneapolis, MN

- Construction started in August 1914 spanning the Mississippi
  - Cost was around $650,000
- Opened in 1918

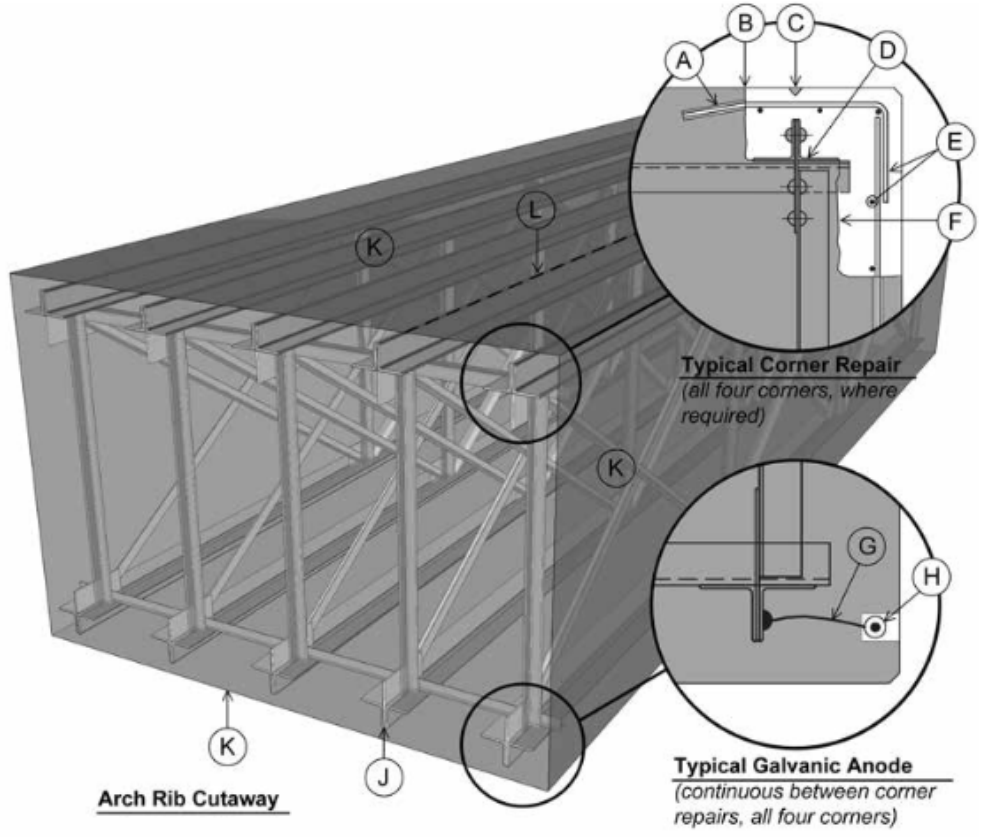
- Minor Repairs in 1930s, 1950s
- Major Repairs in 1979-80
- Early 2000s inspections indicated major repairs imminent

100+ Year Bridge Seeking 50 Year Service Life Extension

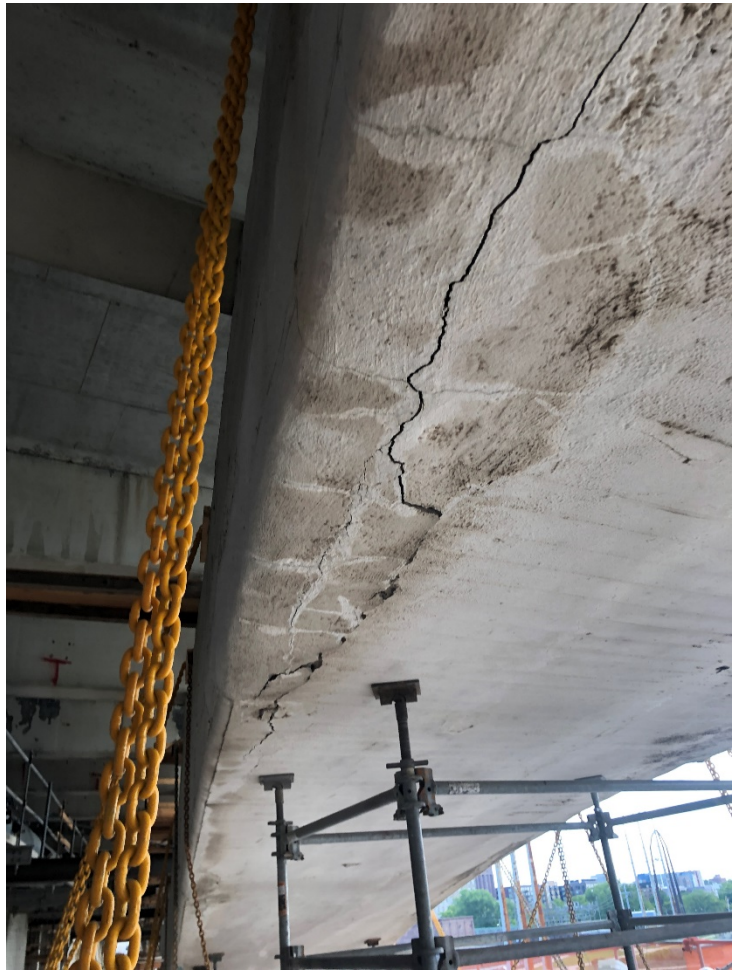
Utilizes the Melan Truss System

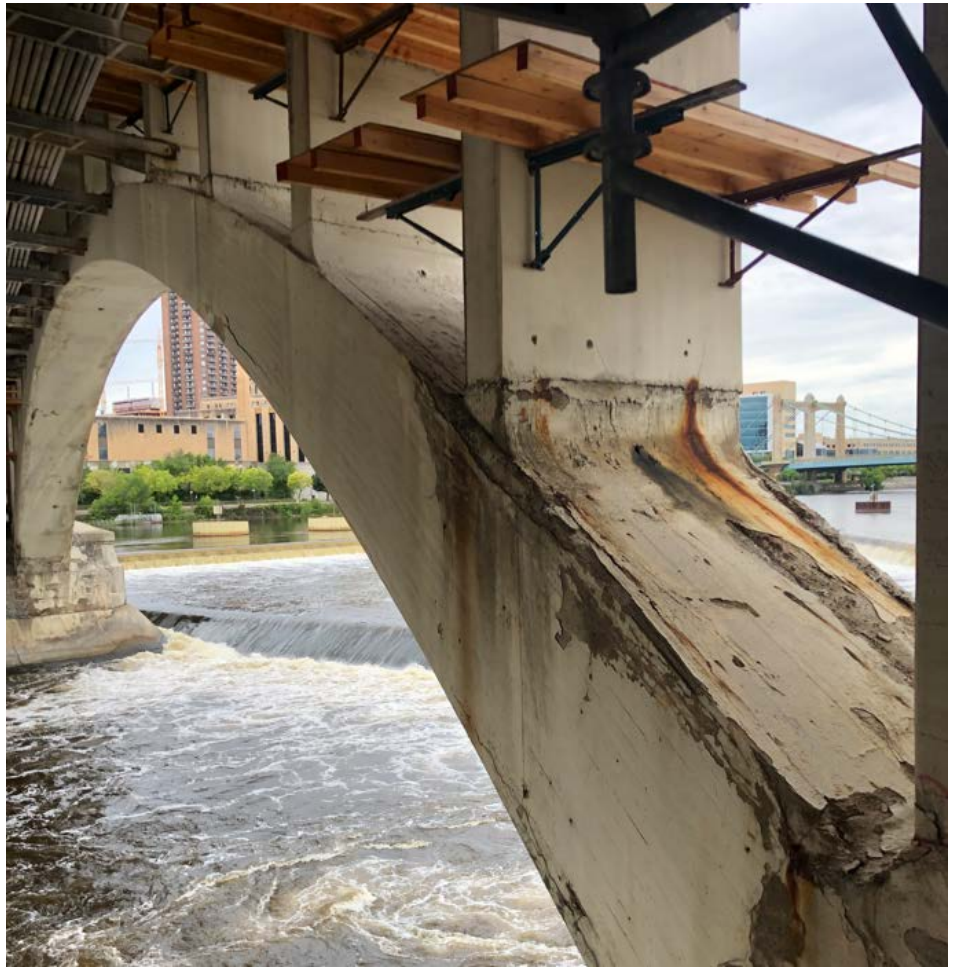


Emperger 1897 Patent. Source: Savor and Bleiziffer



Condition of Arch





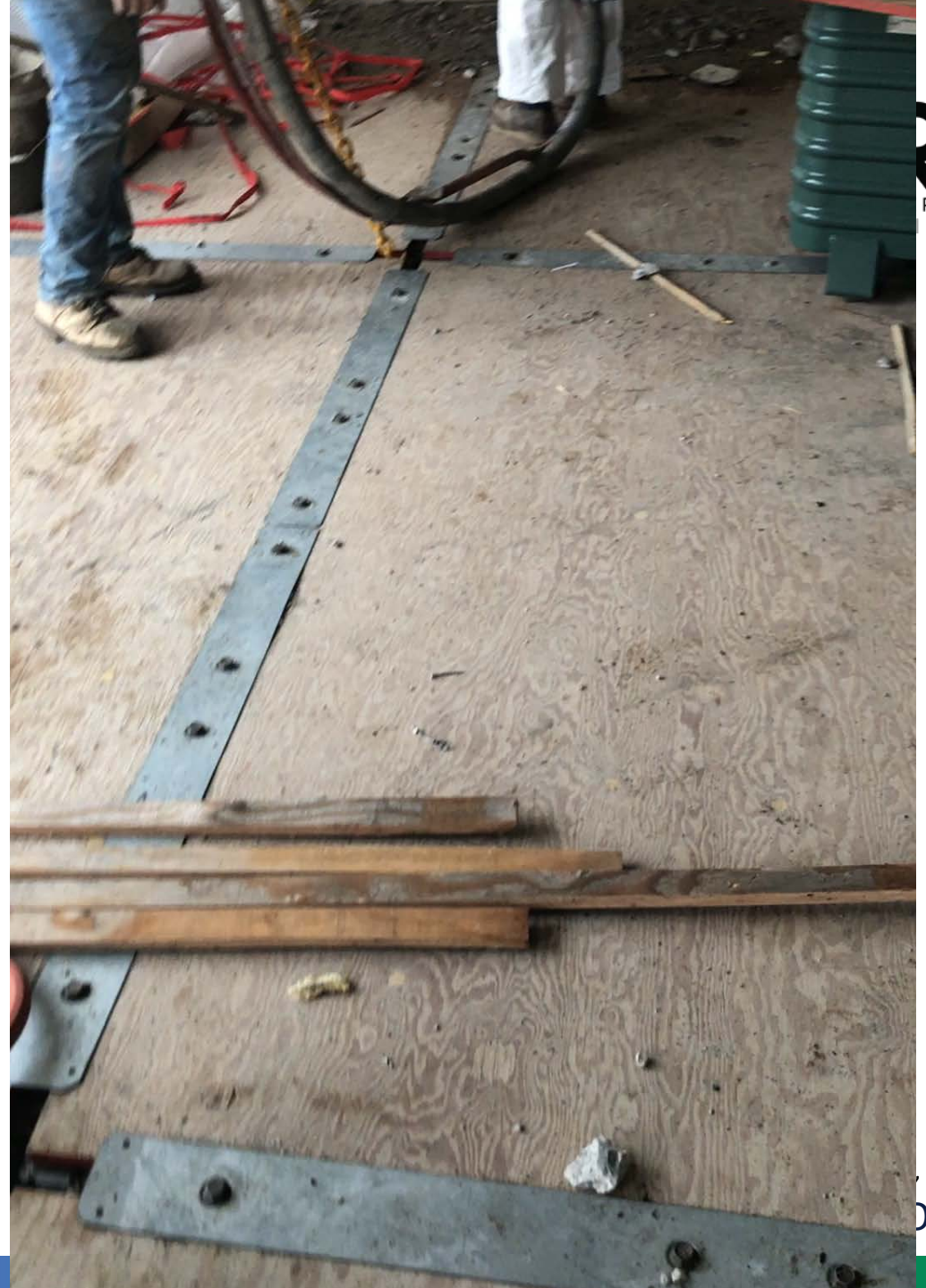
Identify Unsound Concrete

Remove Unsound Concrete

Concrete Removal Complete

Wet Shotcrete

*Repairs on the top and bottom of the arches had no Corrosion Mitigation specified



Shotcrete Finishing

Discrete and Distributed Galvanic Anodes

Cathodic Protection Technologies Used on Project

Two-stage Type 2 Anodes and Metalizing

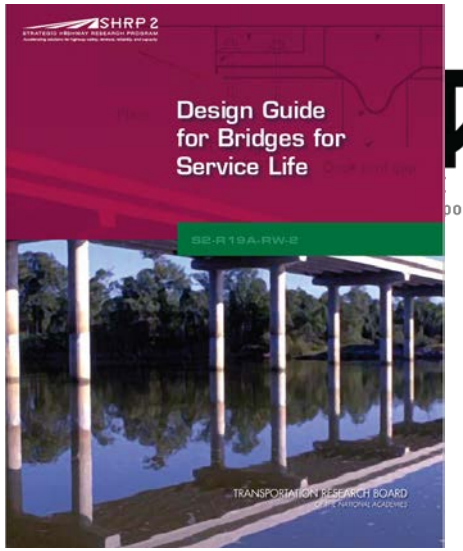
Distributed Galvanic Anode System - DAS

- Higher capacity than discrete anodes
  - More zinc and more current
- Flexibility in design
- Less connections to make during installation
- Provides protection to long stretches of the Melan steel arches

Typical Arch Repair Preparation Complete

Protection of Sound Concrete Areas in Arch Corners with Corrosive Conditions
(Identified by Corrosion Potential Testing)

Strategic Highway Research Program 2: Project R19A



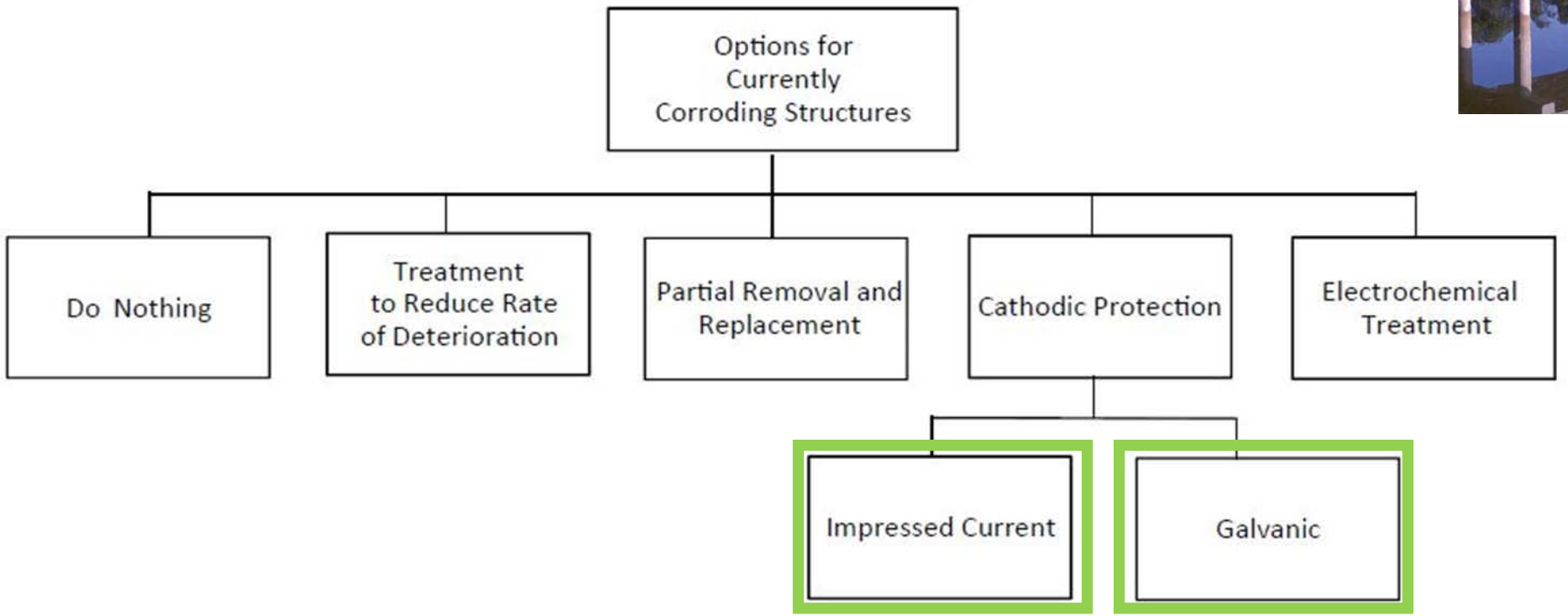
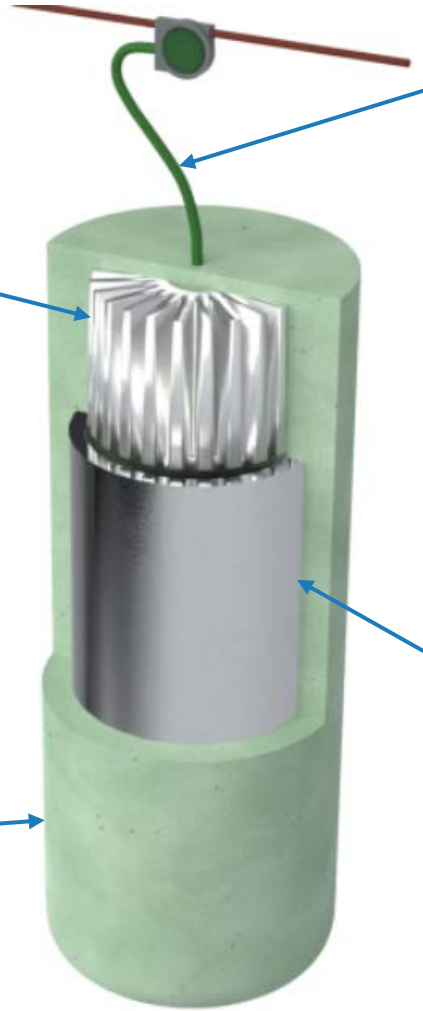


Figure 5.13. *Options for corroding structures.*

Two-Stage ICCP / Galvanic Anodes
Galvashield® Fusion

Galvashield CC
alkali-activated anode

Single wire
installation



Fully Alkali-Activated and
Acid Buffering

Self-powered ICCP
System

Arc Spray Zinc Metalizing

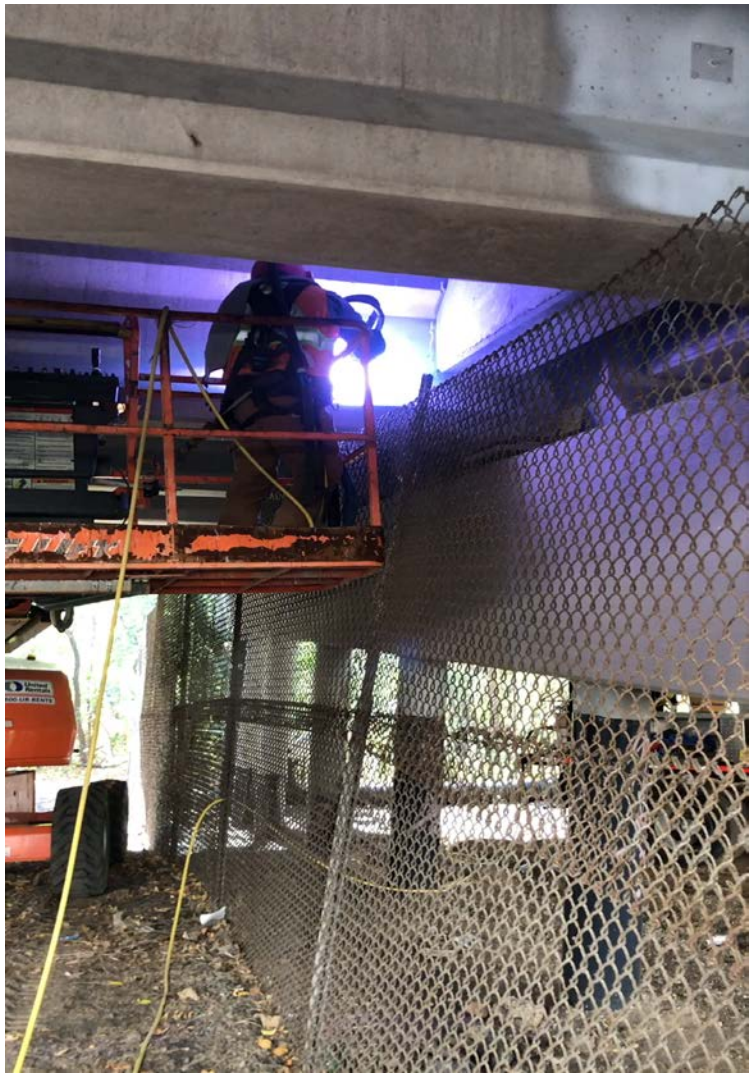
Metalized Zinc Anode
- 20 mil thickness

Humectant Activator
- Attracts moisture to zinc/concrete interface

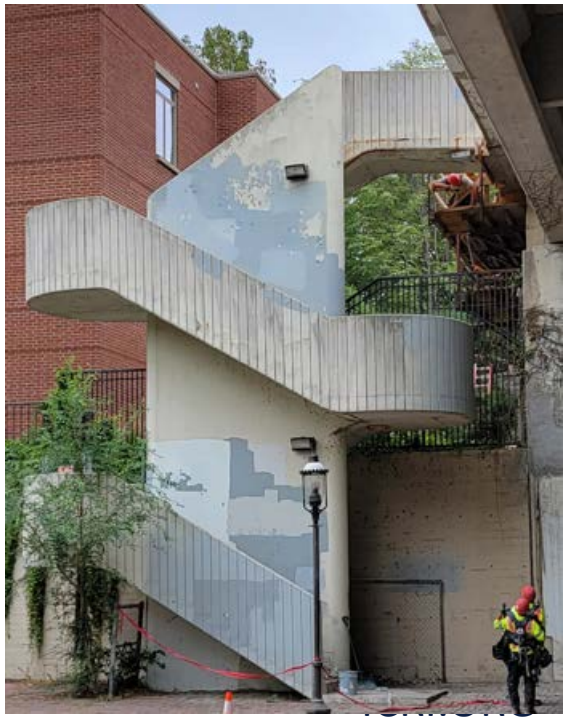
Inorganic Zinc Coating
- Protects zinc from self corrosion

Application to Select Beam Ends, Under Joints, Other Exposed Areas

Galvanic Systems



Areas To Be Metalized

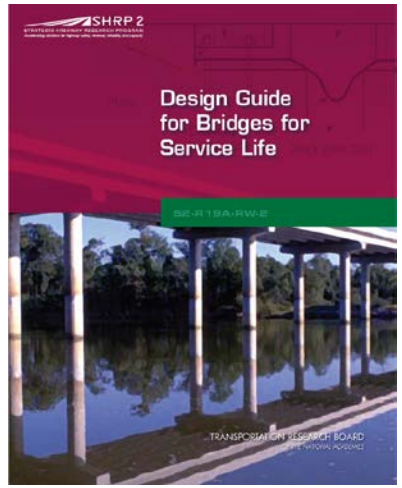


Scope of Work

- 35,000 SF Concrete Repair
- 7,500 LF Concrete Arch Corner Repair
- 7,300 SF Historic Board Form Finish
- 59,000 EA Epoxy Coated Dowels
- 15,000 LBS Epoxy Coated Rebar
- 3,000 EA Discrete Anodes
- 2,400 EA Two-Stage Anodes
- 9,500 LF Distributed Anodes
- 1,700 SF Zinc Metalizing
- 23,500 LF Various Types of Crack Repair

Reopening Celebration
October 28, 2023

Strategic Highway Research Program 2: Project R19A



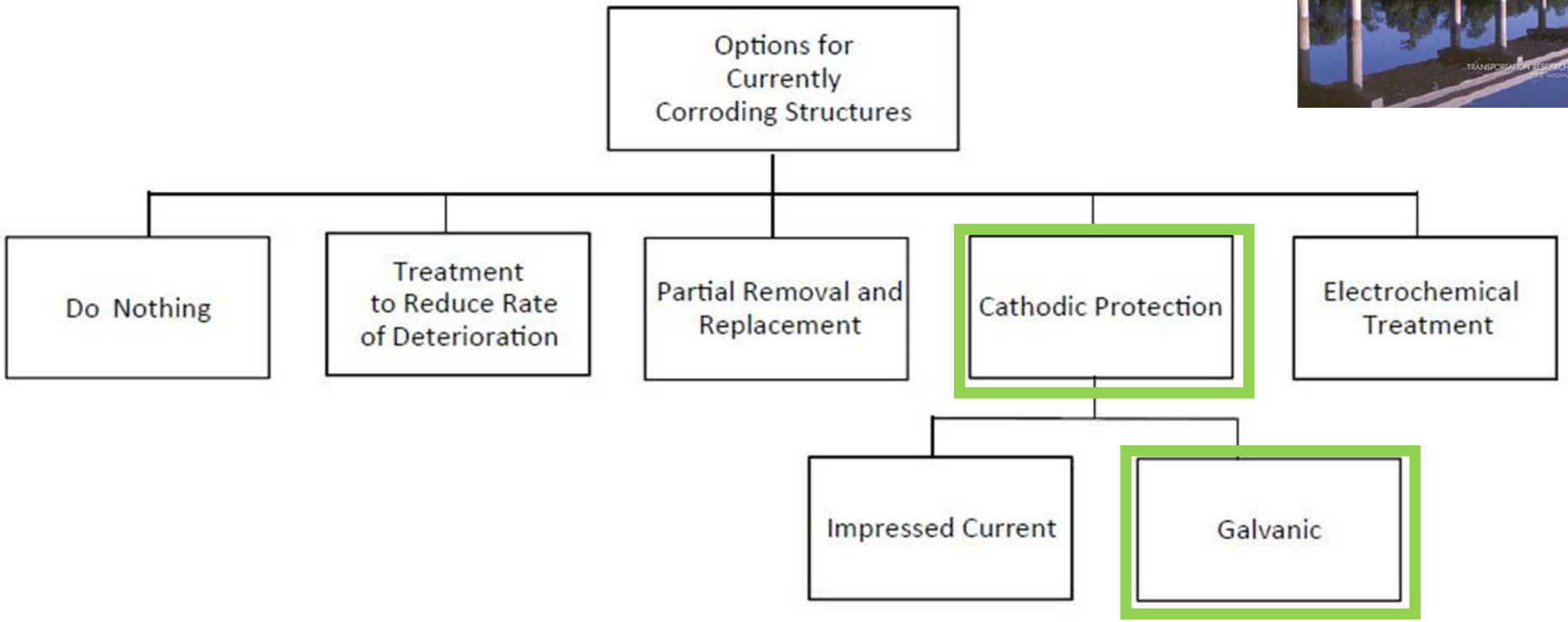
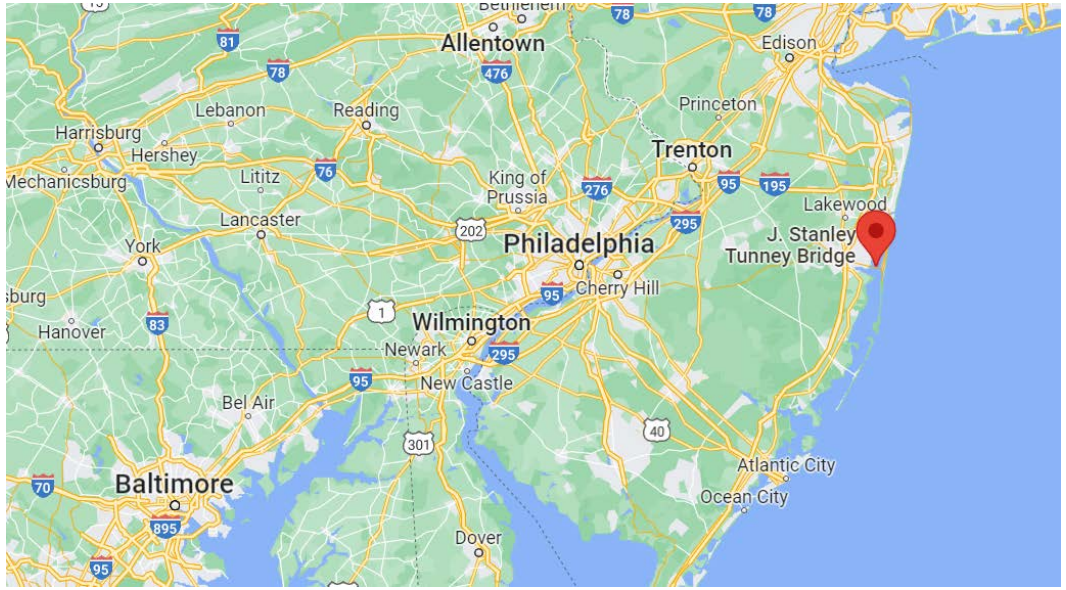


Figure 5.13. *Options for corroding structures.*

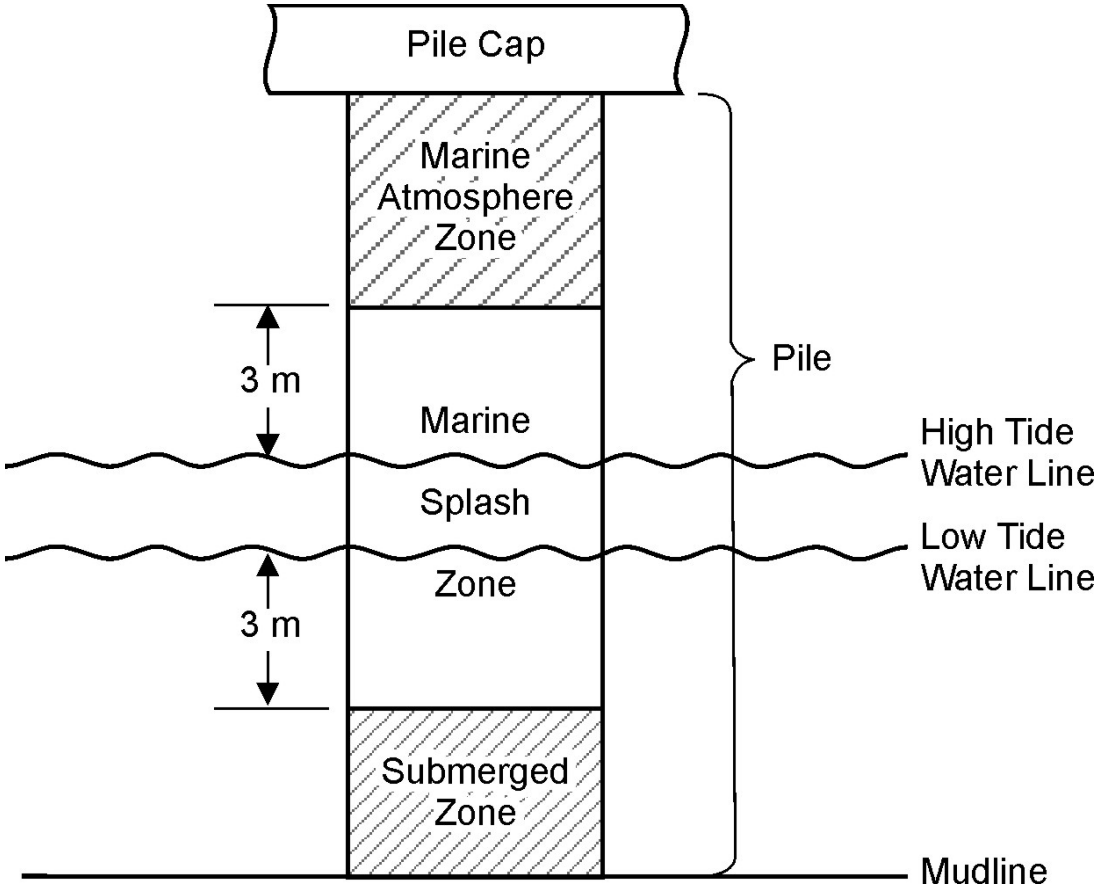
Tunney Bridge

- Connects Toms River to Seaside, NJ
- Constructed in 1969
- 50 spans
- Length 4,877 ft
- Precast prestressed girders
- Bents with 54” precast prestressed cylinder piles

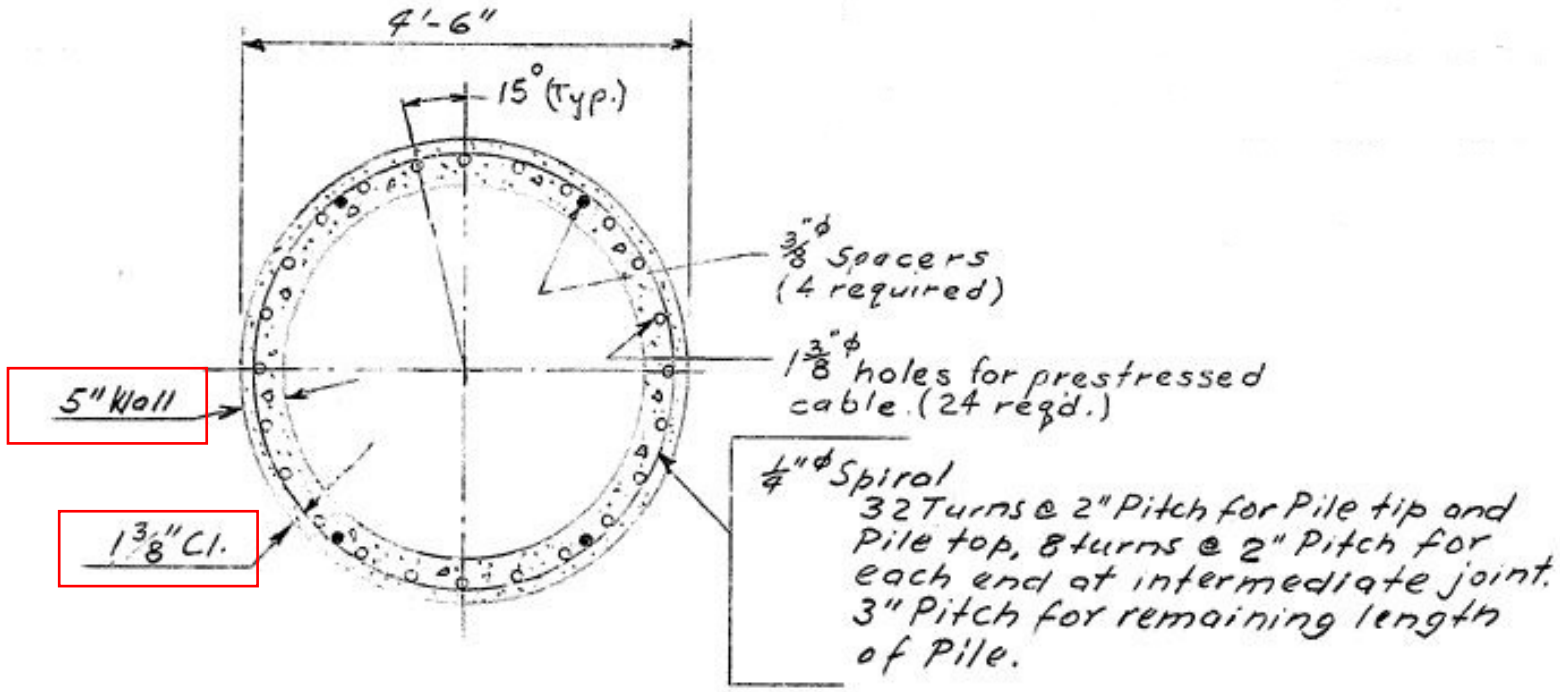


Marine Corrosion Zones

- Most severe marine environment?
  - Tidal splash zone – for both reinforced concrete and bare steel
    - Repeated wet/drying cycles
    - High oxygen availability
    - Exposure to chlorides in saltwater and brackish waterways
- Corrosion can still occur in the atmospheric and submerged zoned



Substructure Details



DETAIL OF PRESTRESSED CONCRETE CYLINDER PILES

Scale 1"/2 = 1'-0"

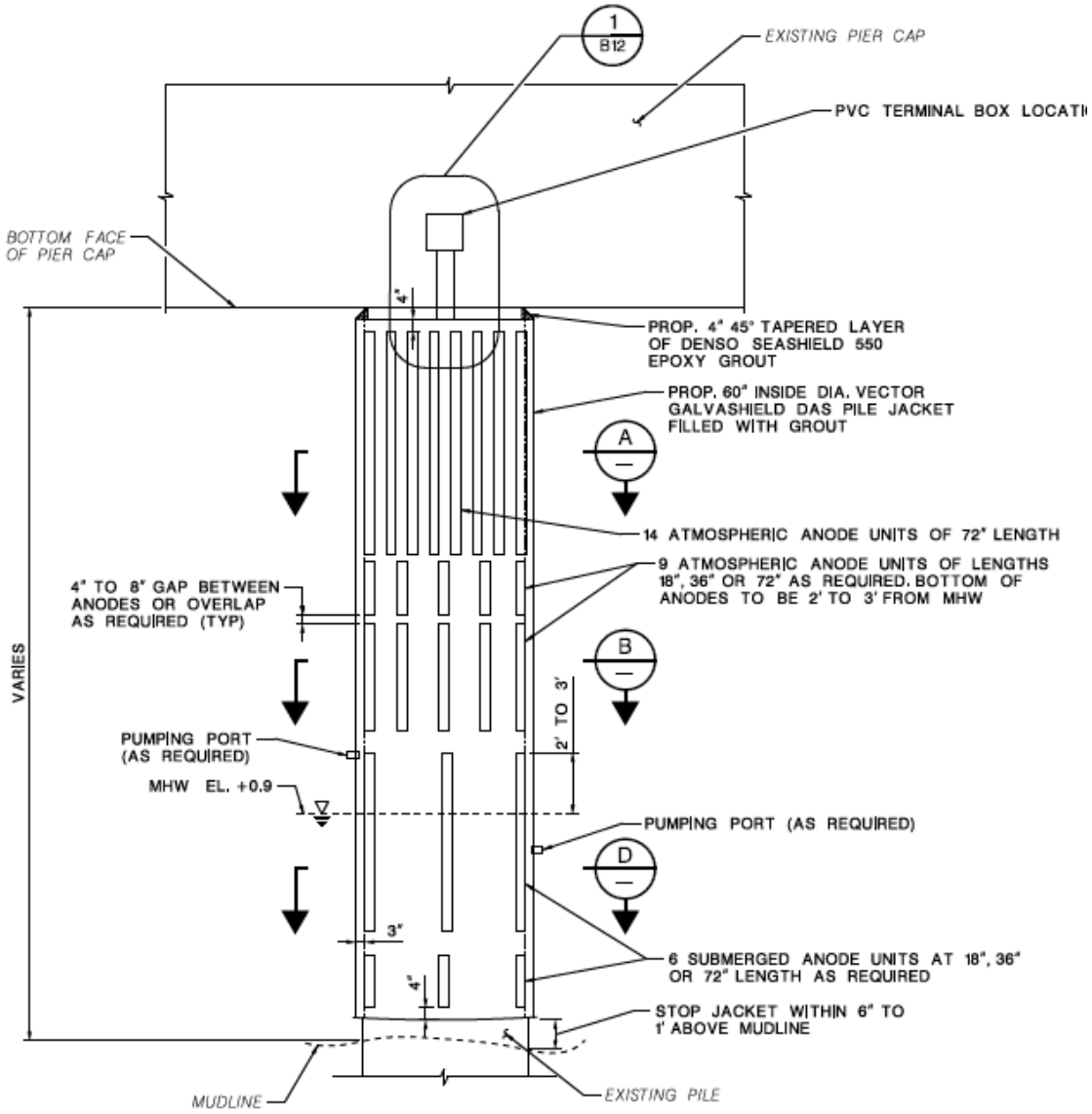
Existing Pile Condition

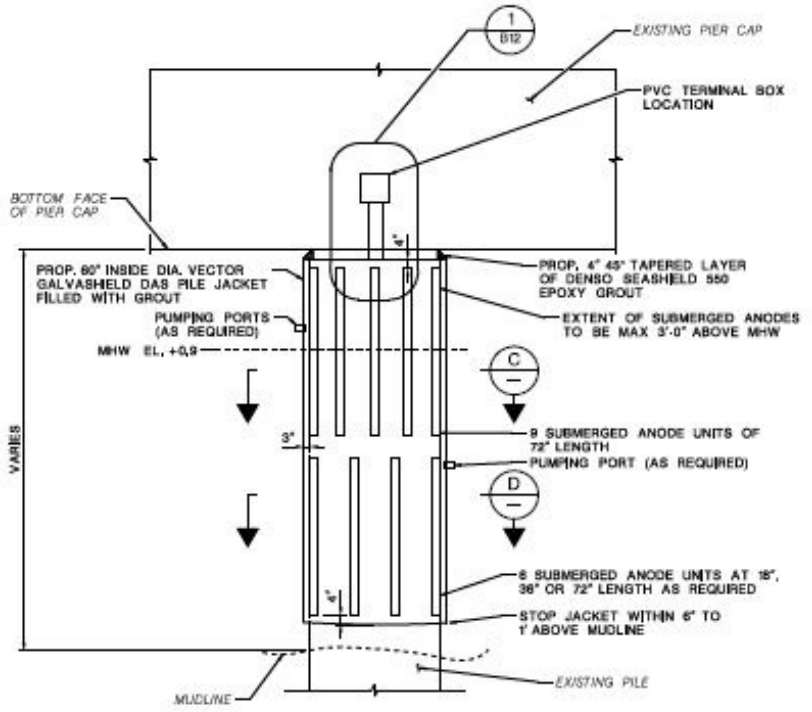
Low Cover (1.25”) – Chloride up to 5x Threshold – High Corrosion Potentials

Openings

Opening Identified Completely Corroded Ties

Cathodic Protection Design





Anode Selection Dependent on Exposure Conditions - Atmospheric or Submerged

ICRI
CONCRETE REPAIR
Restore | Repurpose | Renew

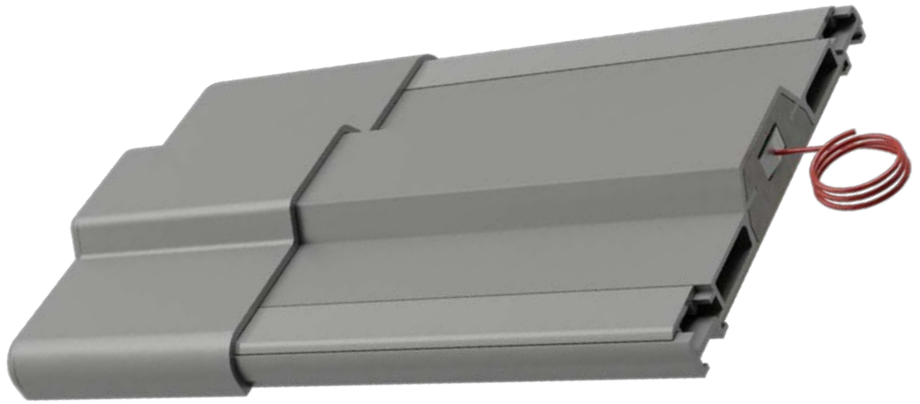
ICRI
CONCRETE REPAIR
Restore | Repurpose | Renew

Jacket Performance

- Project commenced December 2021
- CP criteria
  - NACE SP0408 Cathodic Protection of Reinforcing Steel in Buried or Submerged Concrete Structures
    - Instant off potential of at least -850 mV or more negative
    - 100 mV polarization
- All installed jackets have met the 100 mV polarization criteria
- Initial current at activation
  - Total average measured at the shunt – 246 mA
  - 18.5 mA/ft^2 steel
- Current after 24 hours – average 8.8 mA/ft^2 steel

Surface Mounted Galvanic Anode to Protect Pier Cap

Louisville, KY



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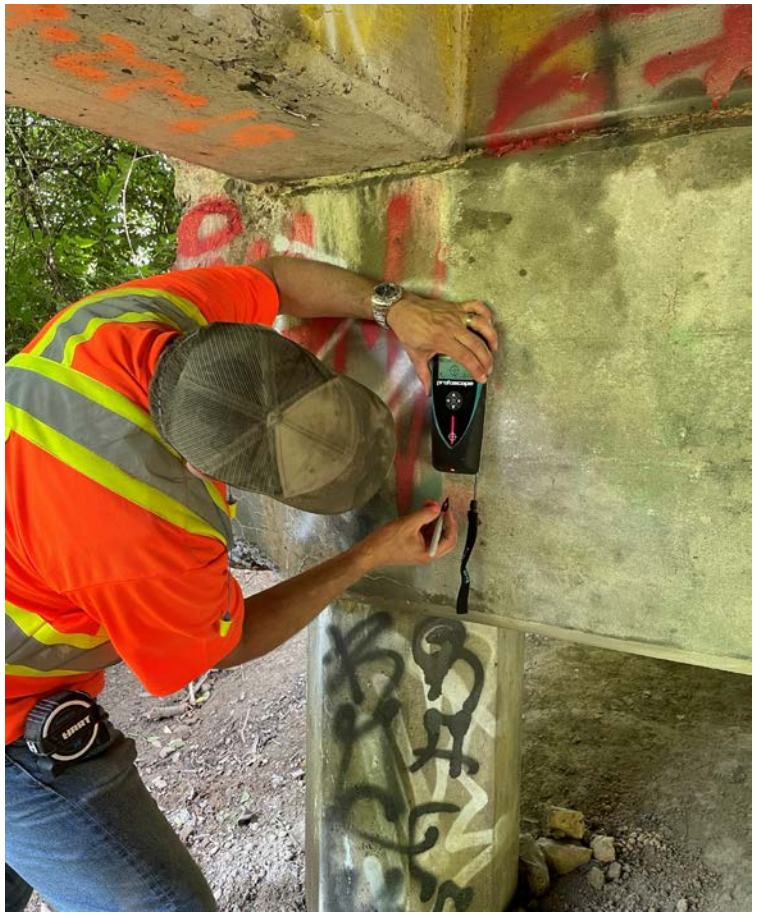
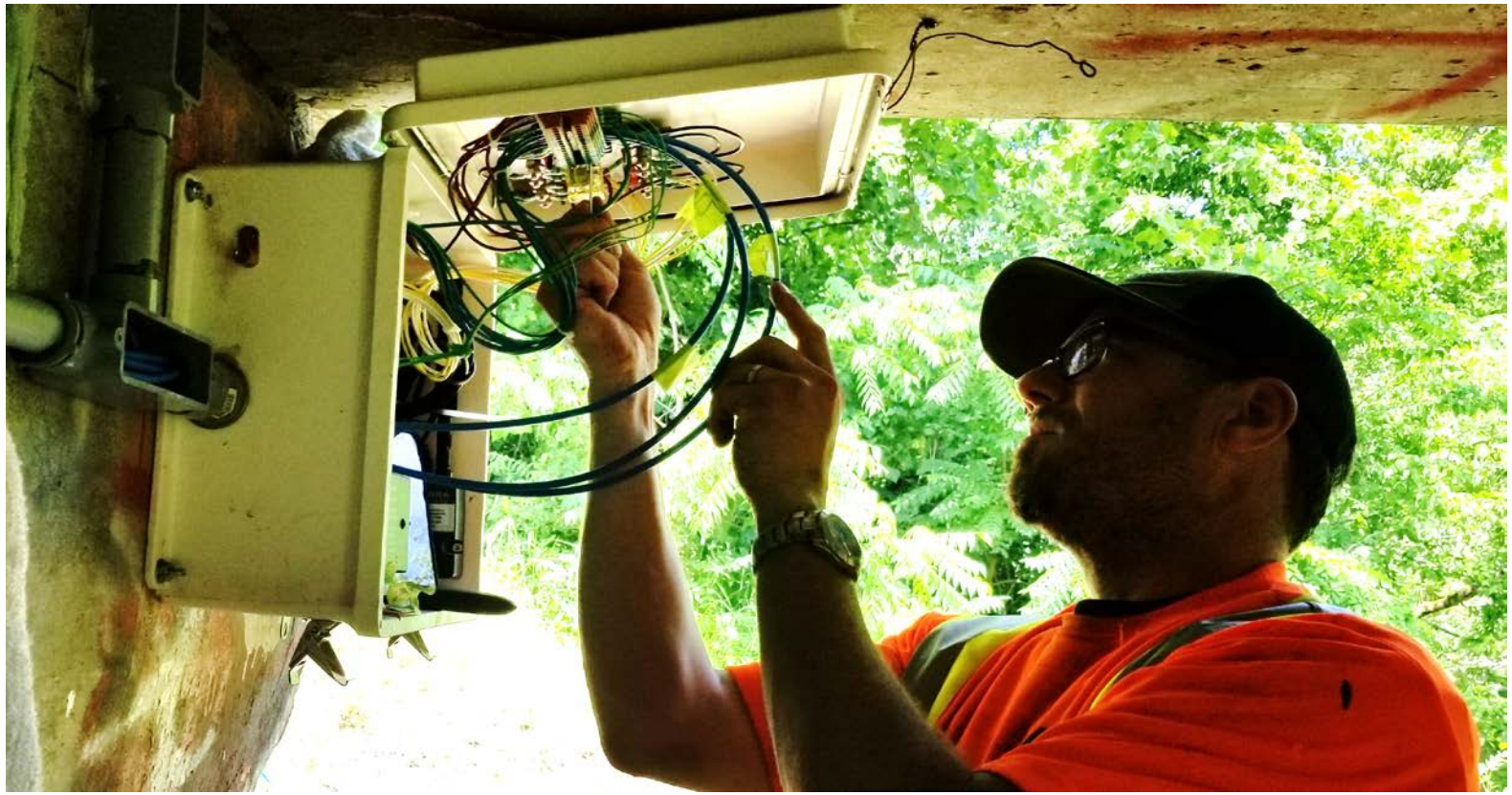
Surface Preparation

Rebar Connections



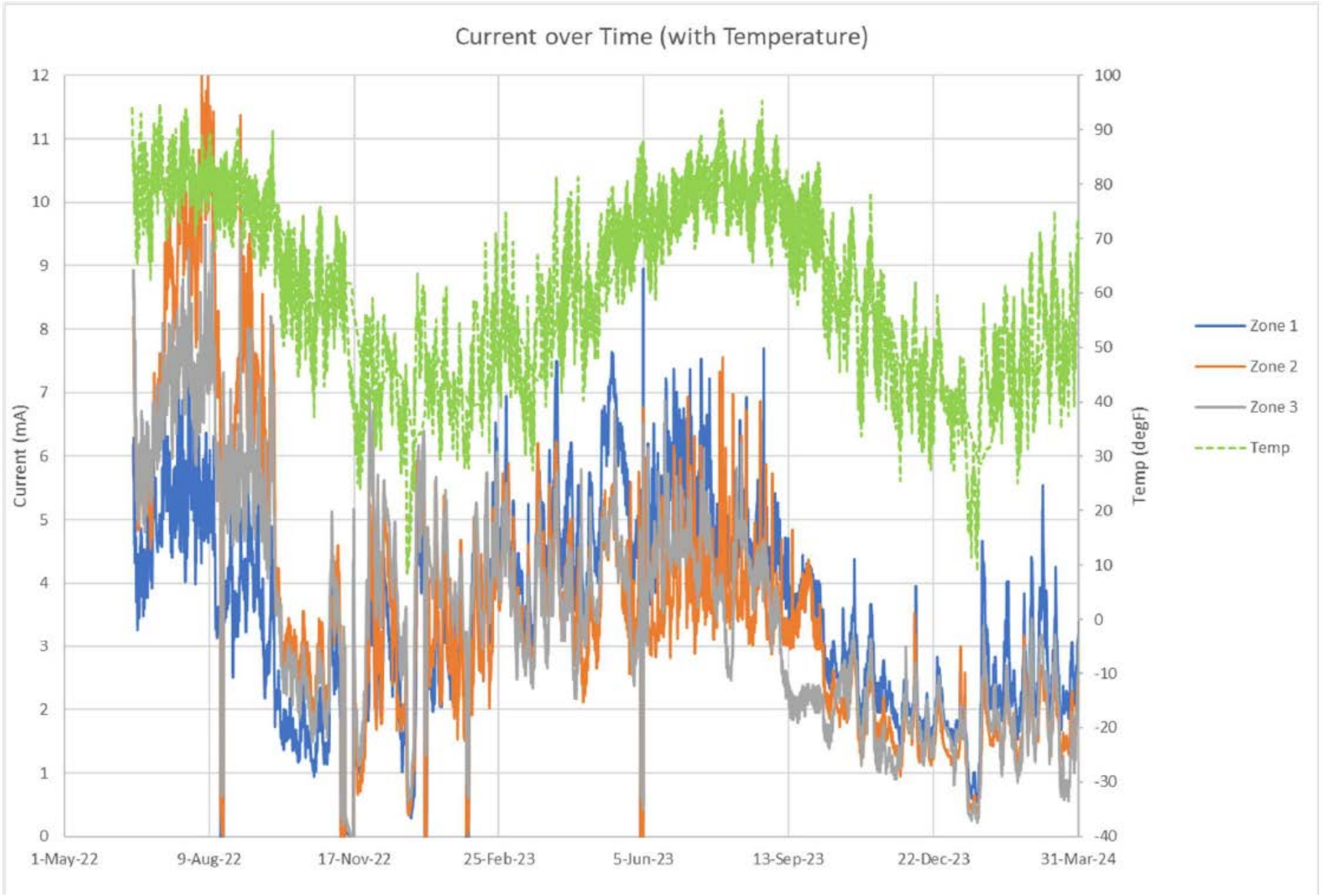
Bond and Anchor Anodes

RMU Installation

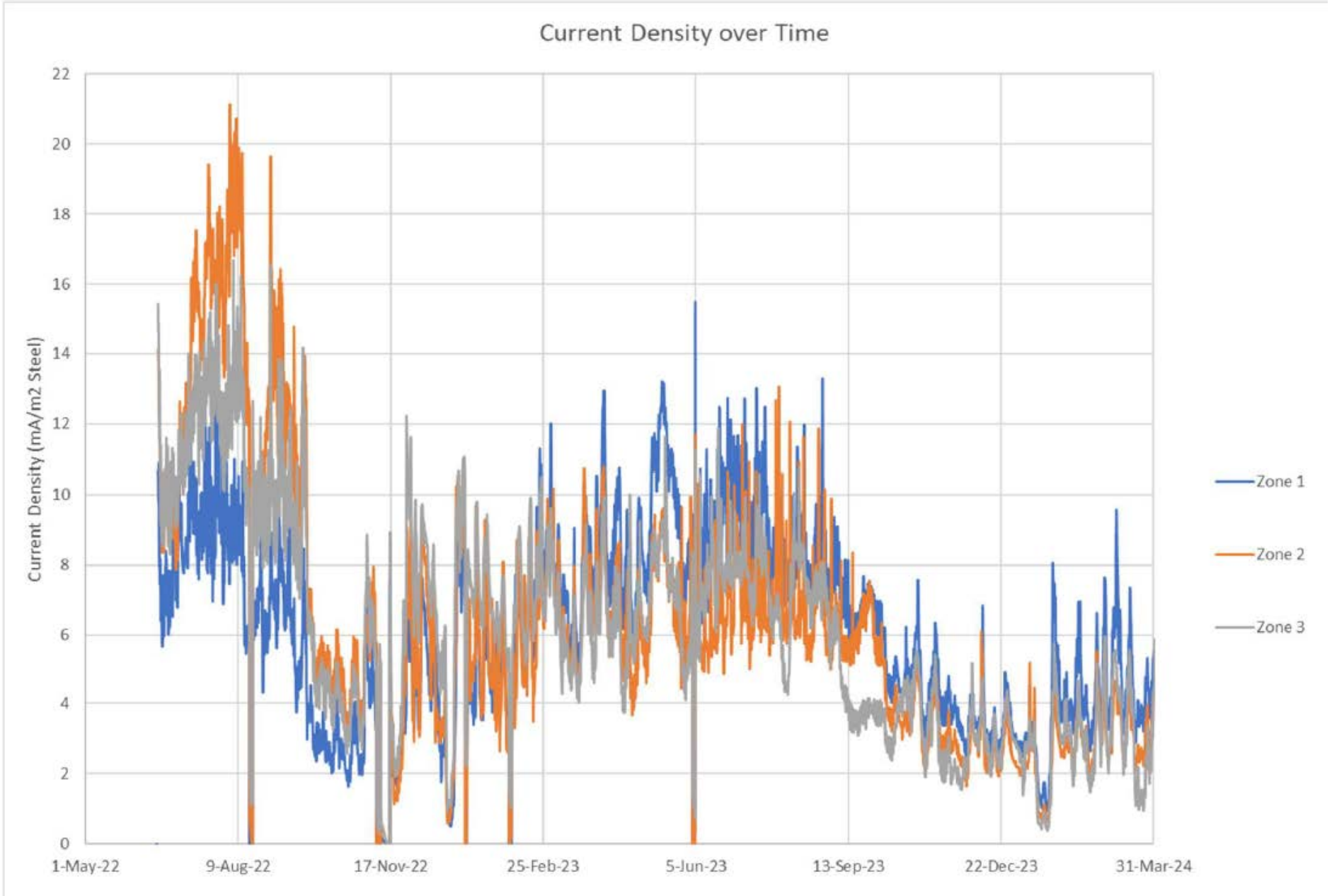


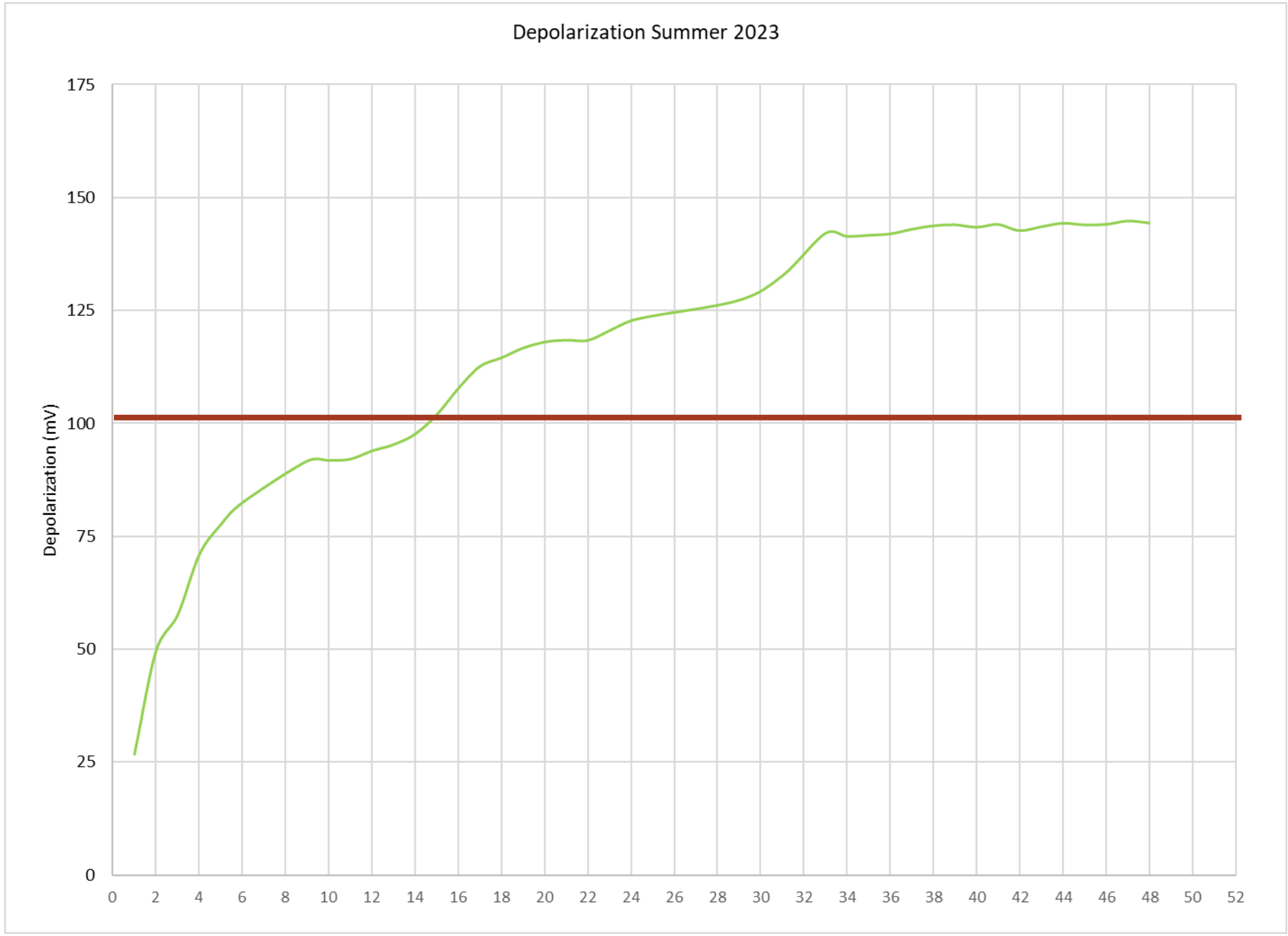
Monitored Installation

NOTE: Conduit Installation for Monitoring Purposes Only



ICRI CONCRETE REPAIR
Restore | Repurpose | Renew


Current Density over Time
Current Density (mA/m2 Steel)
22
20
18
16
14
12
10
8
6
4
2
0
1-May-22
9-Aug-22
17-Nov-22
25-Feb-23
5-Jun-23
13-Sep-23
22-Dec-23
31-Mar-24
Zone 1
Zone 2
Zone 3

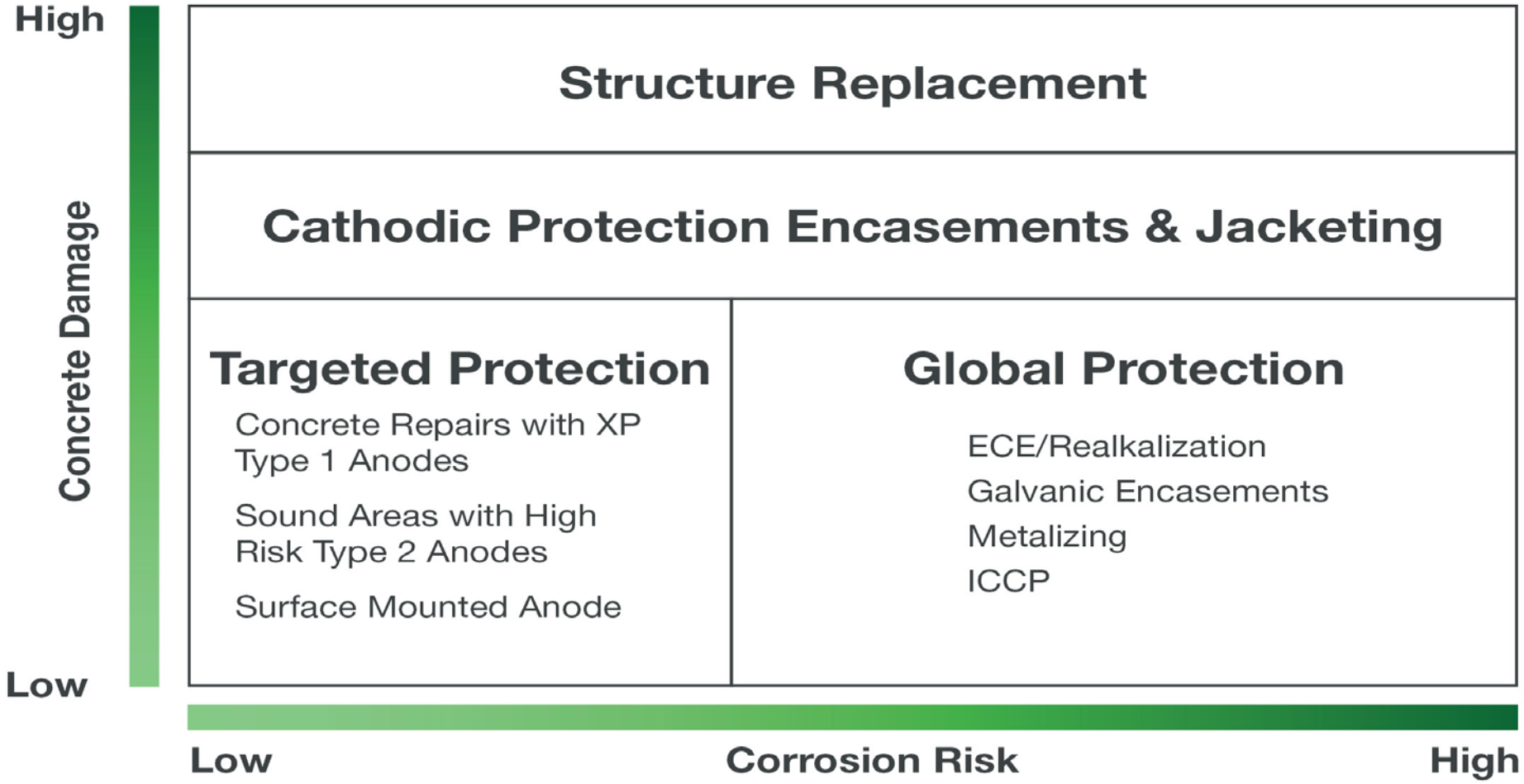


ICRI CONCRETE REPAIR
Restore | Repurpose | Renew

AMPP Criteria for Full Cathodic Protection

Corrosion Management Strategies

To Preserve & Extend the Service Life of Existing Structures



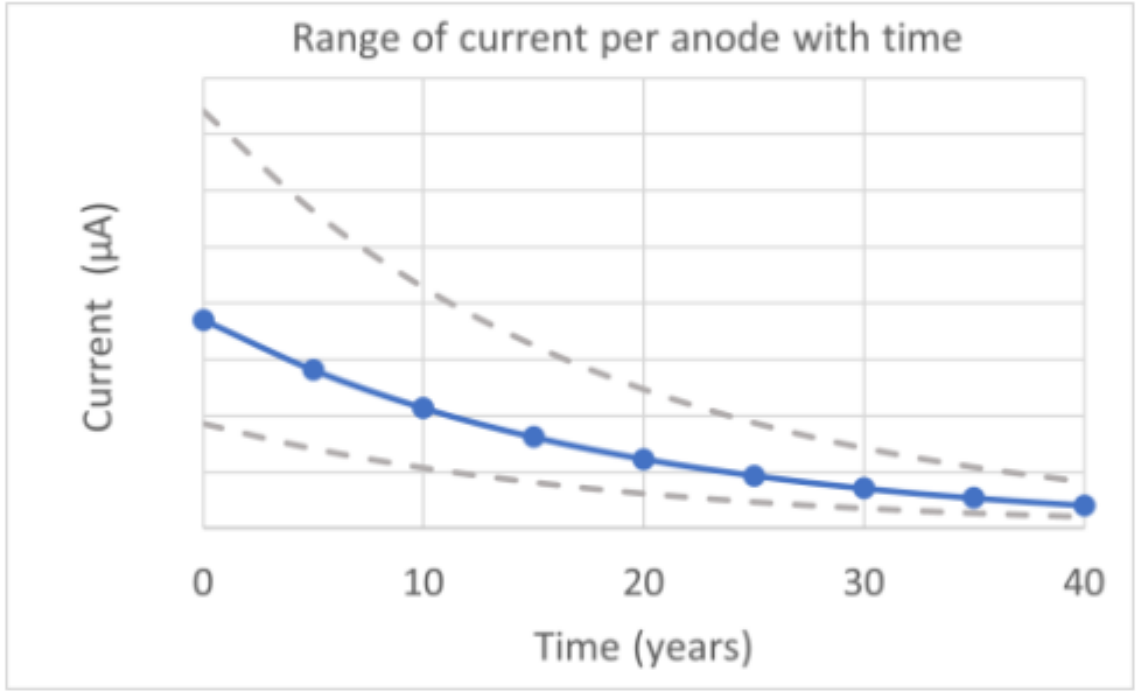
Industry Guidelines – AMPP

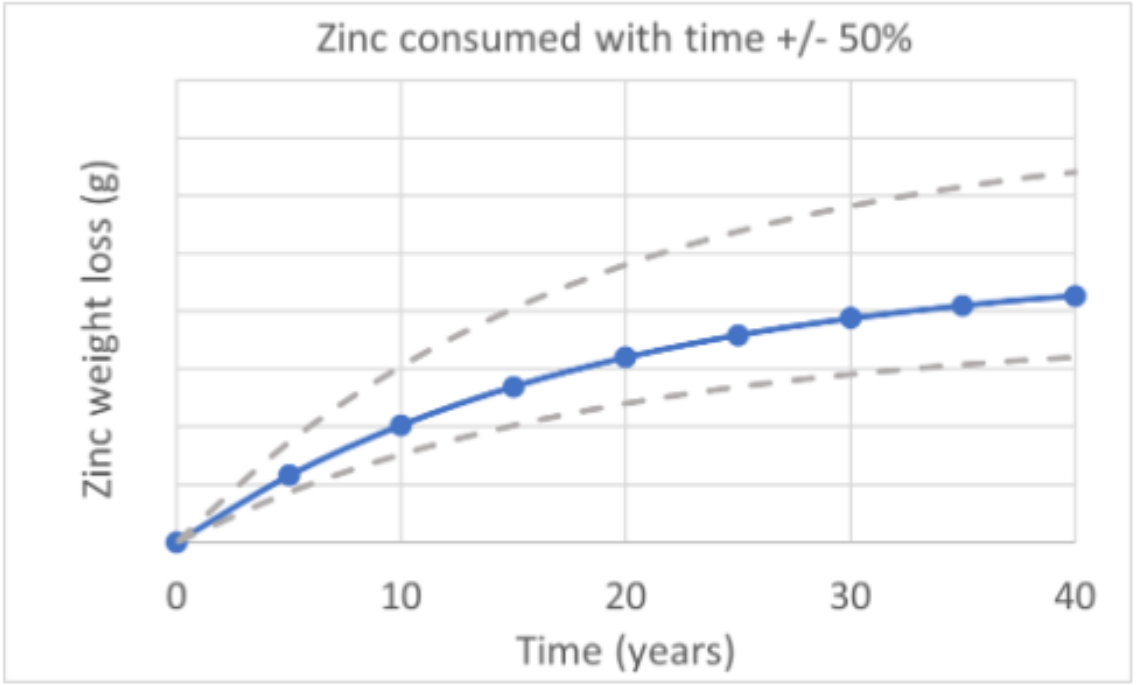
NACE SP0216-2023 - Galvanic Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures

Industry Guidelines – AMPP

This new (updated) standard requires designers of GCP systems to consider the performance of the anodes over their designed service life.

Zinc Mass ≠ Long Term Anode Performance





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