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Bridge Preservation in Corrosive Environments Using Cathodic Protection

Transportation Research Board Webinar

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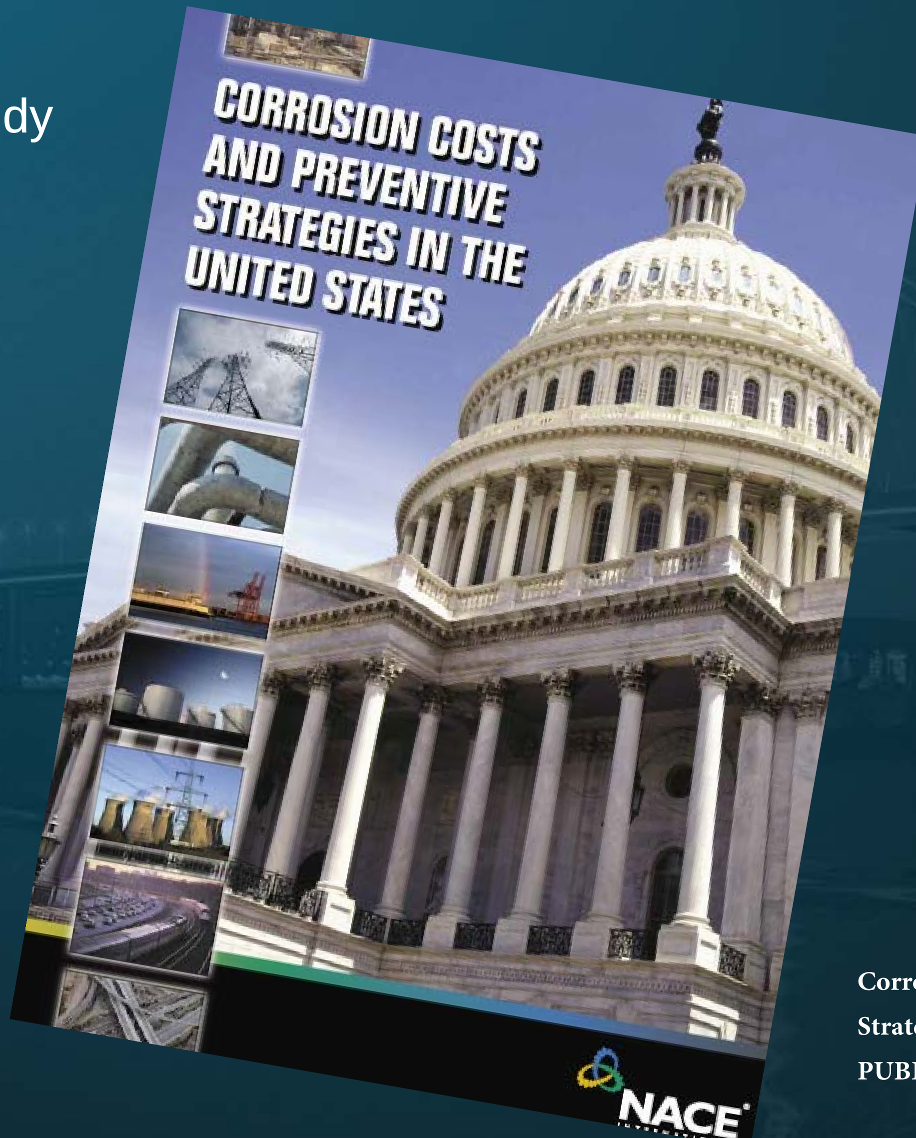
Concorr, Inc.

Statistics

Cost of Corrosion

Corrosion

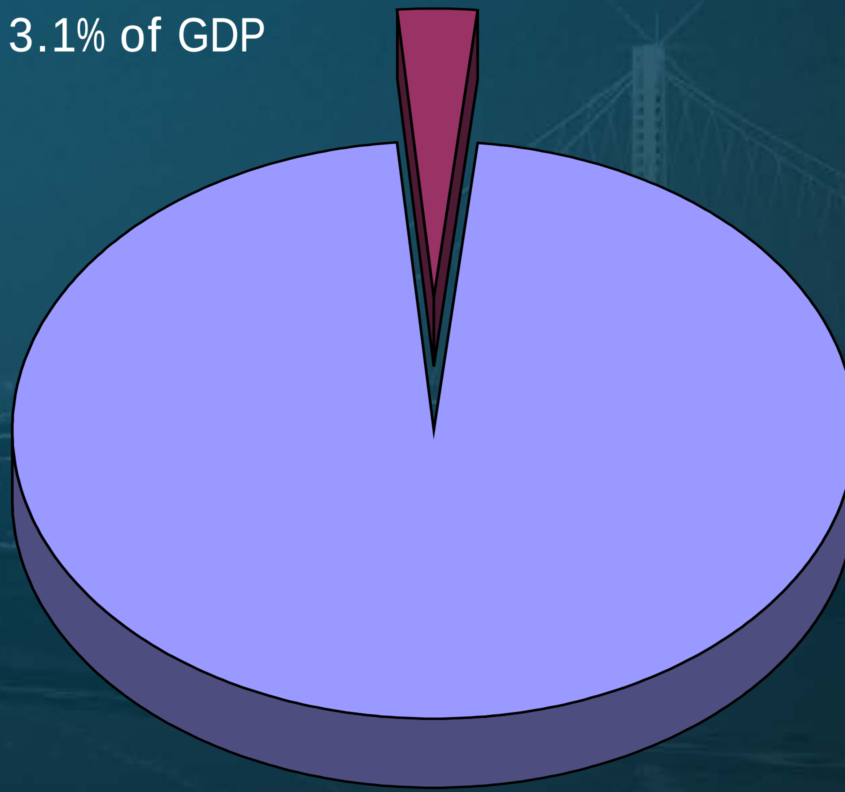
Comprehensive Study
2002



Corrosion Costs and Preventive Strategies in the United States”
PUBLICATION NO. FHWA-RD-01-156

Corrosion

Total Direct Cost of Corrosion in the U.S.
$276 billion per year = 3.1% of GDP



Corrosion Costs and Preventive Strategies in the United States"
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Corrosion

- 587,964 Bridges
- Average Age = 40 years
- 40% are ate least 40 years or older
- 14% Structurally Deficient w/ Corrosion as Primary Cause
- Cost to maintain $5.8 billion per year
- Cost to improve $10.6 billion
- Cost of corrosion to bridges $8.29 billion (not including cost to traveling public)

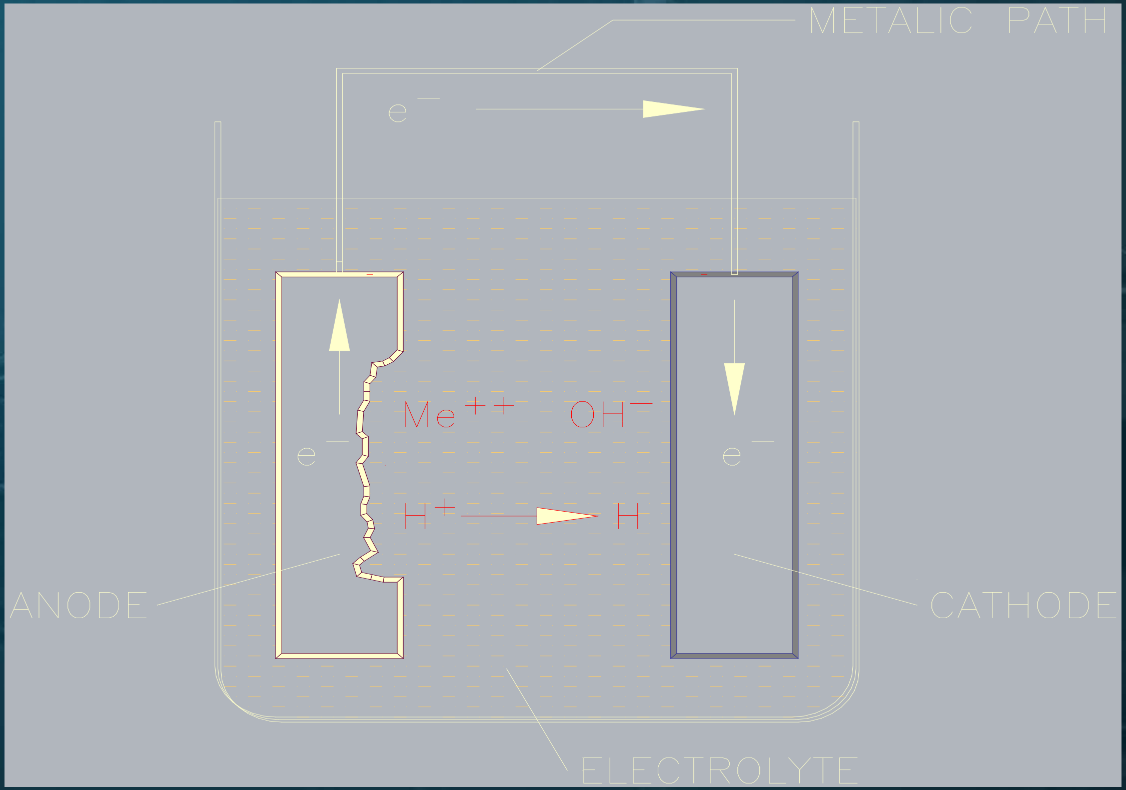
Corrosion Costs and Preventive
Strategies in the United States"
PUBLICATION NO. FHWA-RD-01-156

Overview of the Corrosion Process

Corrosion Process

Four Components Needed for Corrosion Process

- Electrolyte
- Anodic Reaction
- Cathodic Reaction
- Electrical Path



Corrosion Process

Metals Return to Nature

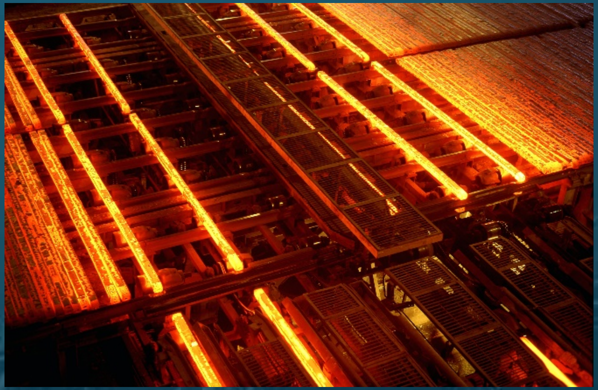
- Natural Ores Combined with Oxygen, Sulfur, etc.
- Smelting Process
- Extracted Metallic Materials
- Eventually Return to Natural Condition - Corrosion

Corrosion Process

Ores in Natural State

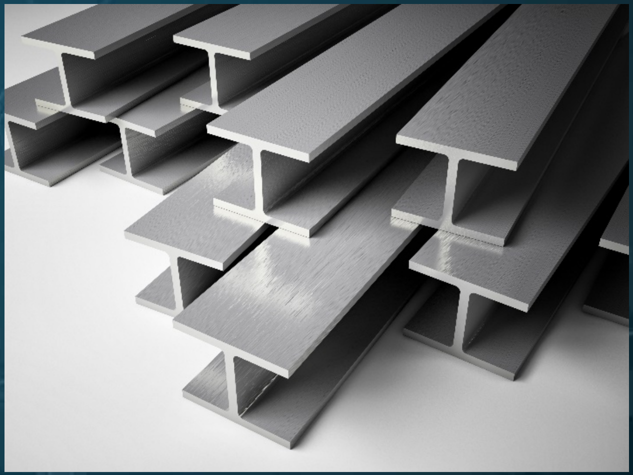
Corrosion Process

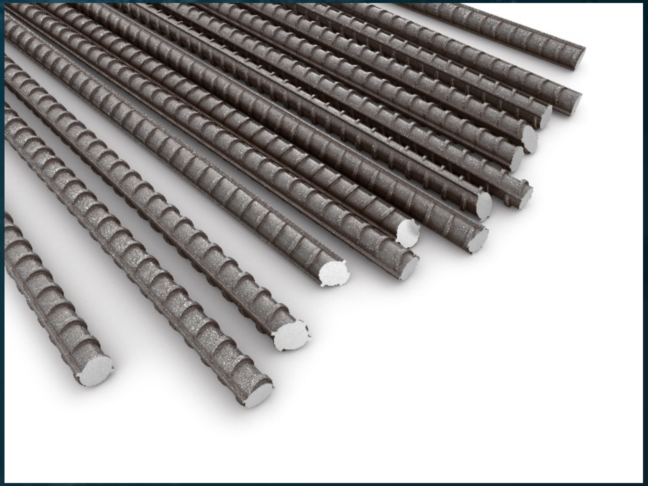
Smelting Process



Corrosion Process

Extracted Metallic Materials





Corrosion Process

Eventual Return to Natural Condition

Corrosion

Deterioration in Marine Environment

Corrosion

Deterioration in Marine Environment

Corrosion

Deterioration of Bridge Decks

Conventional Repairs

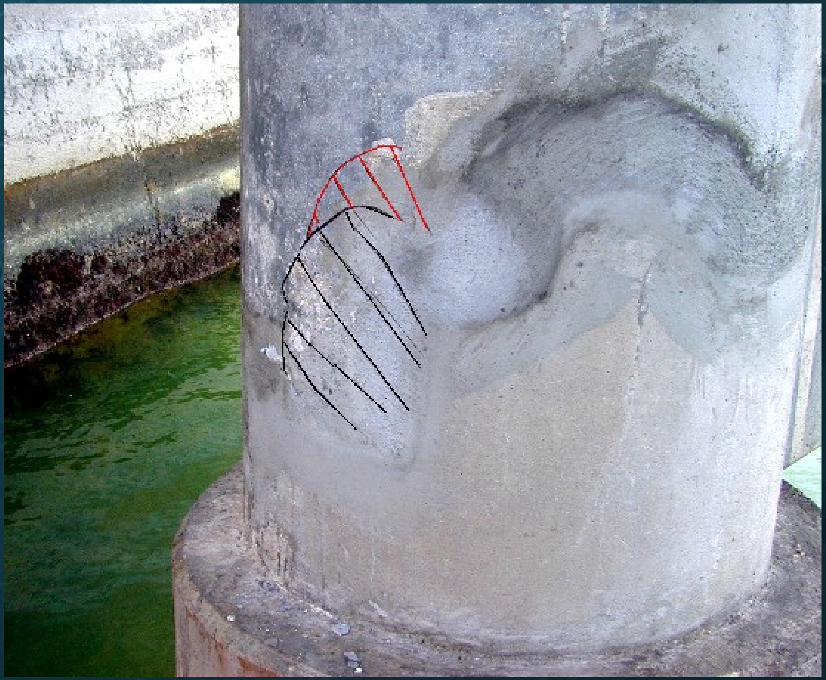
Deterioration on Superstructure Elements

Conventional Repairs

Deterioration on Superstructure Elements

Conventional Repairs

Deterioration on Substructure Elements



Conventional Repairs

Deterioration of Bridge Piles

Conventional Repairs

- Wisdom of Conventional Repairs in Corrosive Environments?
- Alternative is Cathodic Protection

Cathodic Protection

Cathodic Protection

Application of an electric field onto the surface of the corroding reinforcement such that it favors the cathodic and deters the anodic reaction.

- Corrosion is a result of an anodic reaction on the metal surface
- First used in 1824 by Sir Humphry Davy
- Only technology capable of completely stopping corrosion

Cathodic Protection

- It is widely accepted that conventional repairs are not adequate for the rehabilitation of chloride contaminated structures.
- An alternative approach to preserve these corrosion affected bridges is based on the concepts of corrosion control using *cathodic protection* and concrete rehabilitation.
- This approach will extend the service life of the structure.
- Extensions up to 50 years are possible

Cathodic Protection Practices

Typically Implemented on a Case By Case Basis

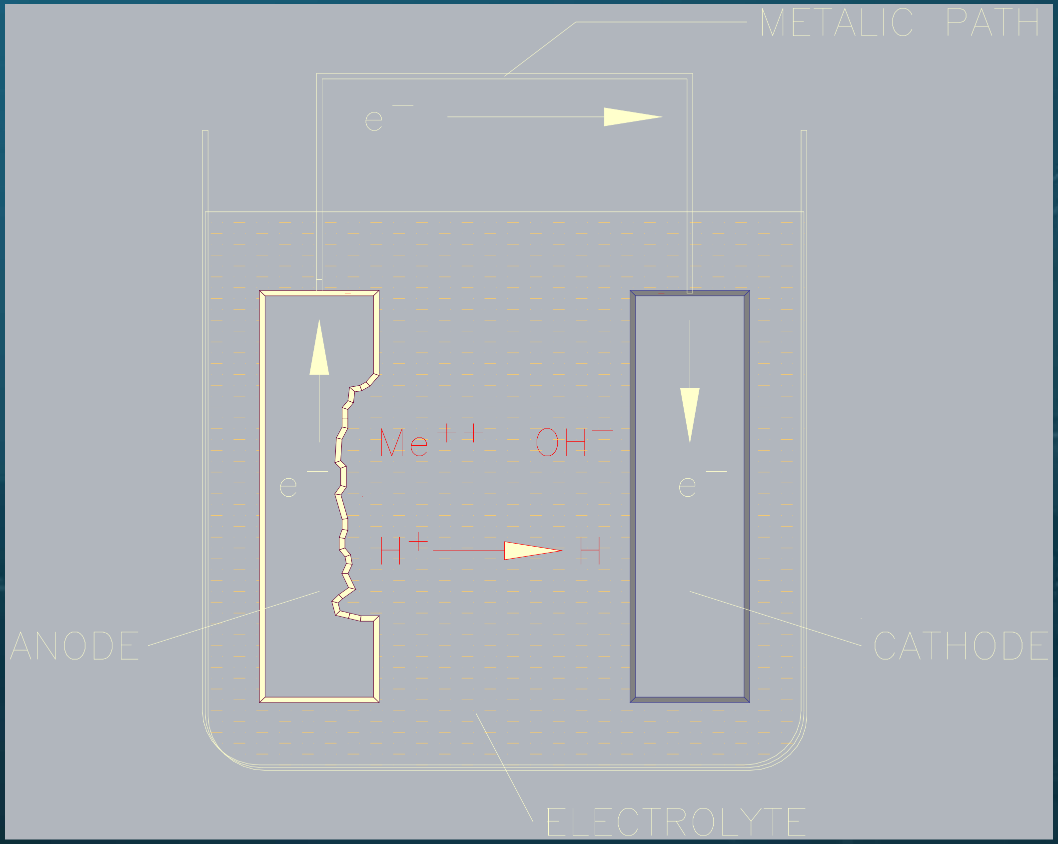
1. A corrosion analysis must be performed prior to the design of the rehabilitation strategy.
2. Cause and magnitude of corrosion should be determined to identify the appropriate technology that will achieve the desired extension in service life.
3. Type of cathodic protection selected based on element to be protected, costs, and resources available to monitor and maintain it.
4. A NACE-Certified CP specialist should provides technical support for design and construction.
5. It will be necessary to monitor and maintain the cathodic protection systems during its service life.

Cathodic Protection Types

Two Main Categories of Cathodic Protection

1. Galvanic or Sacrificial Cathodic Protection (SCP)
2. Impressed Current Cathodic Protection (ICCP)

Corrosion Cell



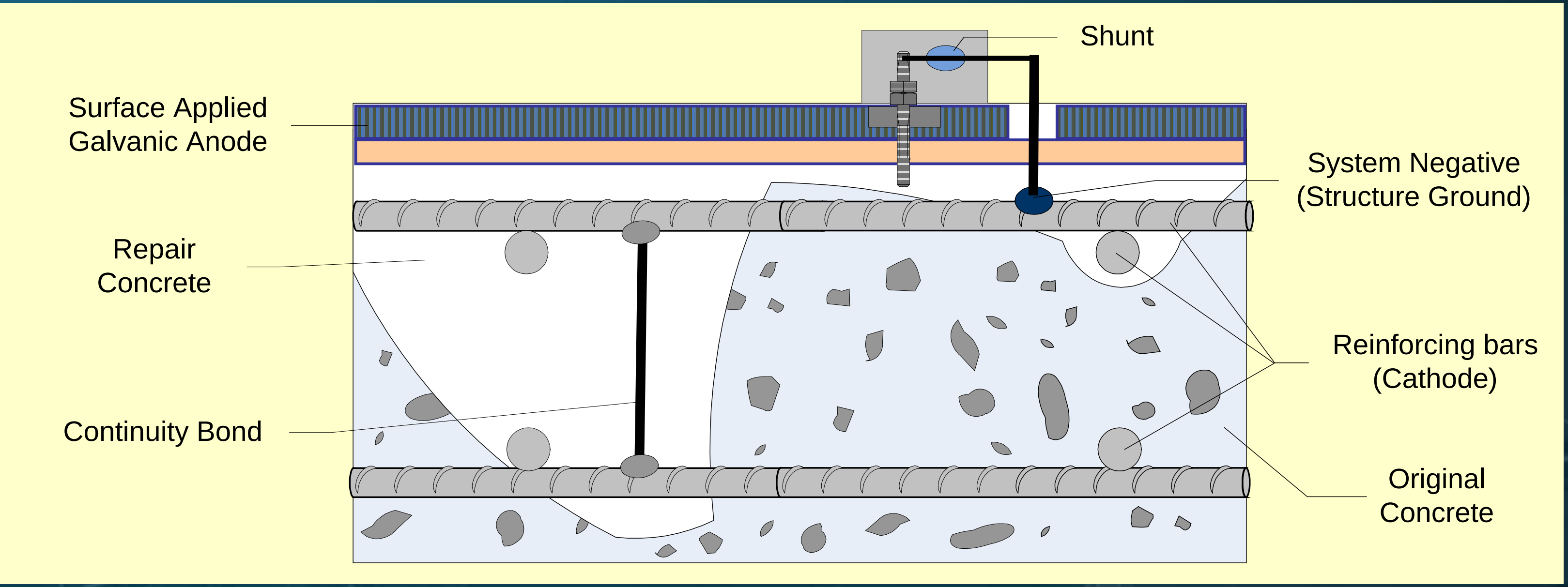
1. In a corrosion cell the anode corrodes.

2. The cathode is protected.

3. Ionic current(positively charged ions) flow from the anode to the cathode in the electrolyte.

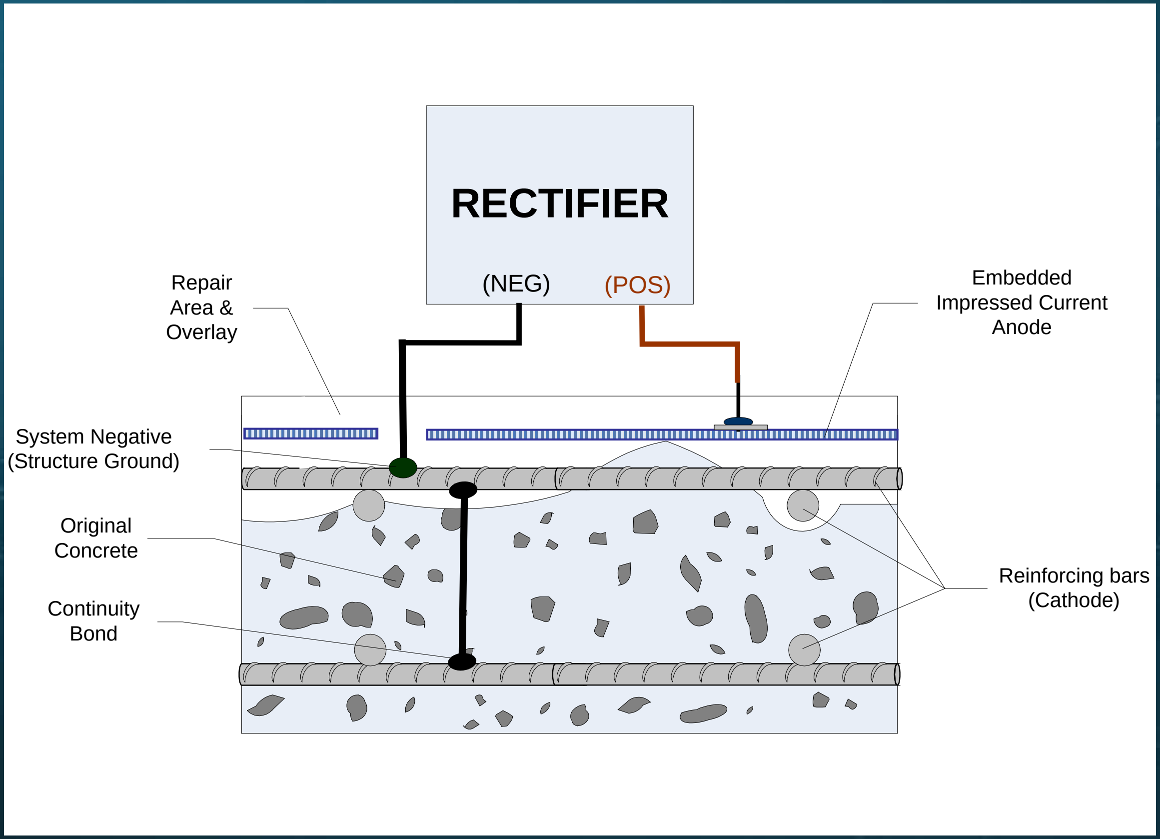
4. Electrons flow from the anode to the cathode in the external circuit.

Galvanic CP System Layout



1. Utilizes active metals such as zinc, aluminum, magnesium, zinc-aluminum alloy, etc.
2. Requires no power source.
3. Can be used on high-strength pre- and post-tensioned strands with minimal monitoring.
4. Requires minimal monitoring and maintenance.

Impressed Current CP System Layout



1. Requires a power source.
2. Utilizes many different types of anode materials from paints to coated titanium.
3. Can be used on high-strength pre- and post-tensioned stands with caution.
4. The electrical components require regular monitoring and maintenance.

Usage of CP for Bridge Preservation in US

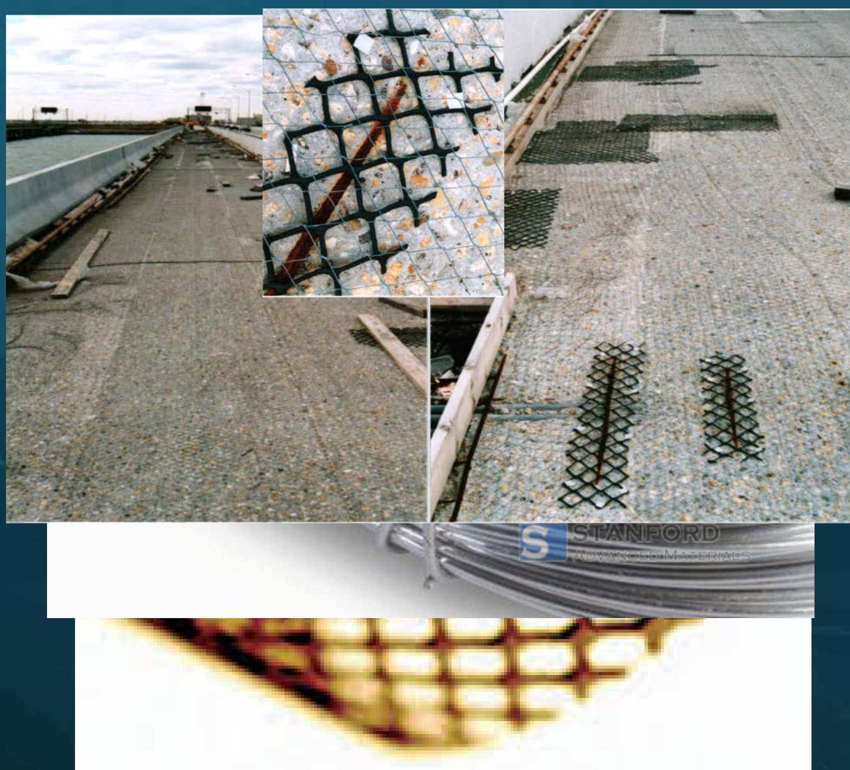
TABLE 2
Use of Cathodic Protection on Various Bridge Components

Cathodic Protection Installed on Bridge Components	No. of Respondents
Deck	22
Superstructure	9
Caps	12
Columns	19
Piles	8
Footers	4

Note: Table based on results of Question 21 of the survey.

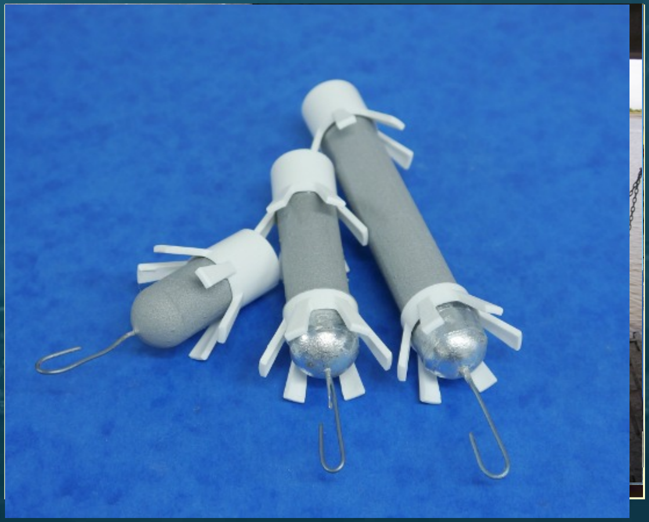
NCHRP Synthesis Report 398 - *Cathodic Protection for Life Extension of Existing Reinforced Concrete Bridge Elements*

Types of Cathodic Protection Systems for Bridge Decks



1. Slotted, overlay and non-overlay, ICCP
2. Titanium Mesh ICCP
3. Titanium Ribbon Anode ICCP
4. Ladder Anode ICCP
5. Galvanic anodes in patch

Types of Cathodic Protection Systems for Beams and Caps



1. Zinc with Adhesive, Galvanic
2. Arc Sprayed Zinc, ICCP & Galvanic
3. Tubular Zinc Anodes, Galvanic
4. Hybrid Anodes
5. Slotted ICCP

Cathodic Protection Systems for Pre-tensioned and Post-tensioned Elements

1. Pos
2. Pol
3. Gal … n
   evo
4. Imp … ed
   and
   hyd

Cathodic Protection Systems for Bridge Substructures

Impressed Current C.P. Anodes

1. Titanium Mesh
2. Titanium Ribbon
3. Titanium Tubular Anodes
4. Thermal-Sprayed Anodes in ICCP Mode

Cathodic Protection Systems for Bridge Substructures

Galvanic (Sacrificial) C.P. Anodes

1. Thermal-Sprayed Zinc Anode in Sacrificial Mode
2. Zinc Mesh Anode in Conventional Pile Jackets
3. Activated Zinc Bar Anodes
4. Submerged Bulk Anode Systems (Zn, Al or Mg)

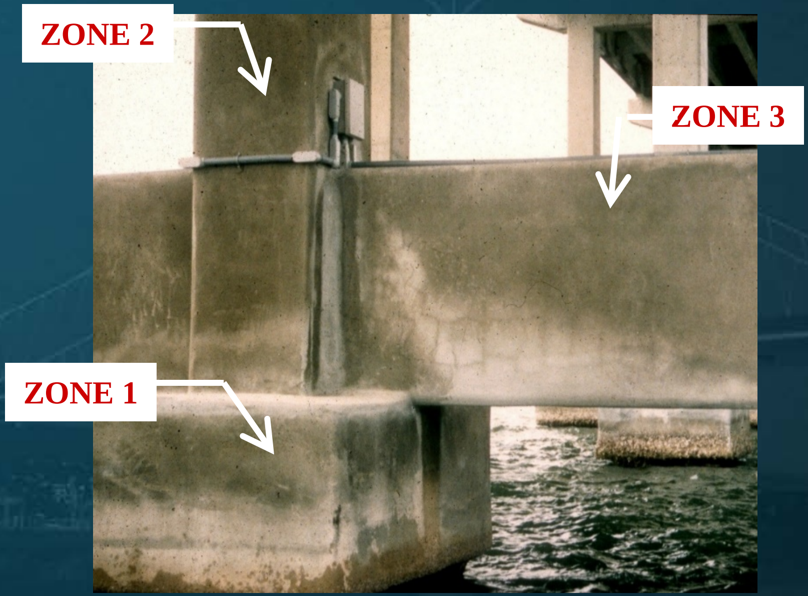
Impressed Current Cathodic Protection

Titanium Mesh Anode

- The anode is typically attached to the concrete surface with plastic fasteners and then is encapsulated in a cementitious materials.
- Easily conforms to the structure geometry.
- Available in three output capacities (20, 30, and 40 mA/m2).
- The most used impressed current anode for concrete.

Impressed Current Cathodic Protection

Titanium Mesh Anode



- Encapsulation with machine applied mortar/concrete (shotcrete)
- Current flows through the new shotcrete and the old concrete onto the reinforcing steel

Impressed Current Cathodic Protection

Titanium Anode Mesh

- Encapsulation in structural concrete
- Includes placement of additional reinforcement
- C.P. Provided for new and existing reinforcement

Impressed Current Cathodic Protection

Titanium Anode Mesh

(Completed Structural Concrete Encapsulation)

Wires are routed to the rectifier or power supply in conduit

Impressed Current Cathodic Protection

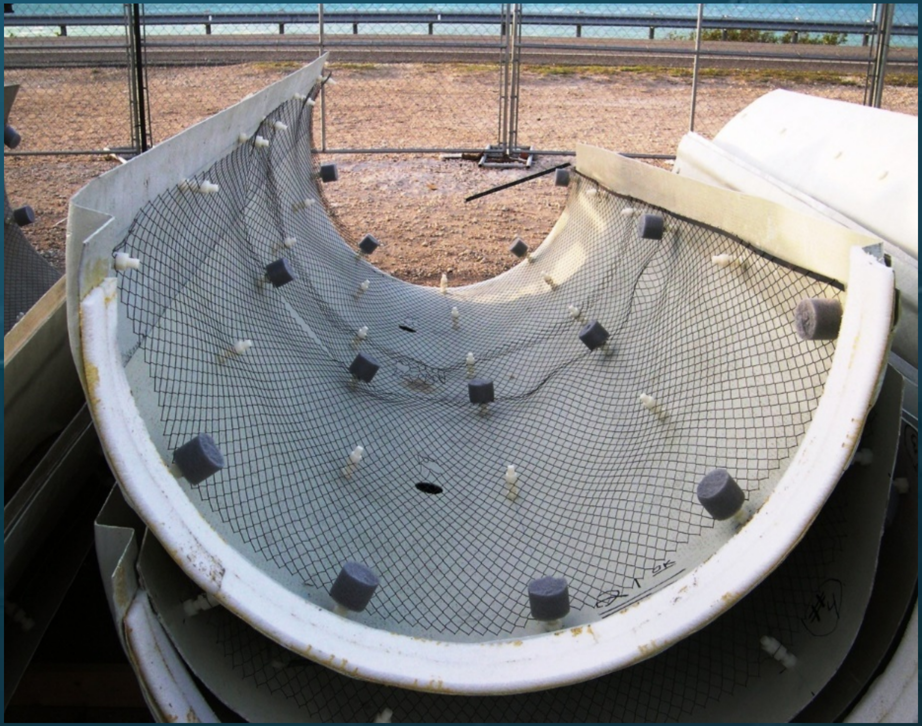
Titanium Anode Mesh

- Encapsulation of Ti mesh within a pile jacket.
- A fiberglass stay-in-place form is placed around the pile leaving an annular space between pile and form.
- Form is filled with mortar or concrete.
- Additional reinforcement can be added to restore capacity if the existing corrosion condition is severe.
- Several piles are combined into one C.P. Circuit.

(ICCP Pile Jacket)

Impressed Current Cathodic Protection

Titanium Anode Mesh



The titanium mesh anode is pre-installed inside the stay-in-place fiberglass form for square and circular piles/columns.

Impressed Current Cathodic Protection

Titanium Ribbon Anode

- Installed in grooves cut in the concrete after the spalls are repaired.
- Once installed the grooves are filled with mortar to match the existing profile.
- All ribbons connected to form one electrical circuit within the concrete component.
- The spacing of the ribbon strips are pre-engineered based on the cover and the electrical resistivity of the concrete.

Impressed Current Cathodic Protection

Discrete Ti Tubular Anode

- Cylindrical anode made of titanium and ceramic composite (other configurations also available).
- Are embedded in the concrete and the excavation sealed with a conductive grout.
- All wires within one cathodic protection zone are spliced together and routed in cut groves to the rectifier.

Sacrificial Cathodic Protection

ARC-Sprayed Zinc

- Zinc anode is applied over the concrete surface.
- Needs a direct connection to the reinforcement.

- Application similar to spray painting.
- Can be used without concrete restoration by application directly to the reinforcement to serve as the connection.

Cathodic Protection

ARC-Sprayed Zinc – ICCP Mode

(Oregon DOT)

- Arc sprayed anodes can also be used as impressed current C.P. anodes.
- In addition to zinc, other metals can be used when in ICCP mode.

Sacrificial Cathodic Protection

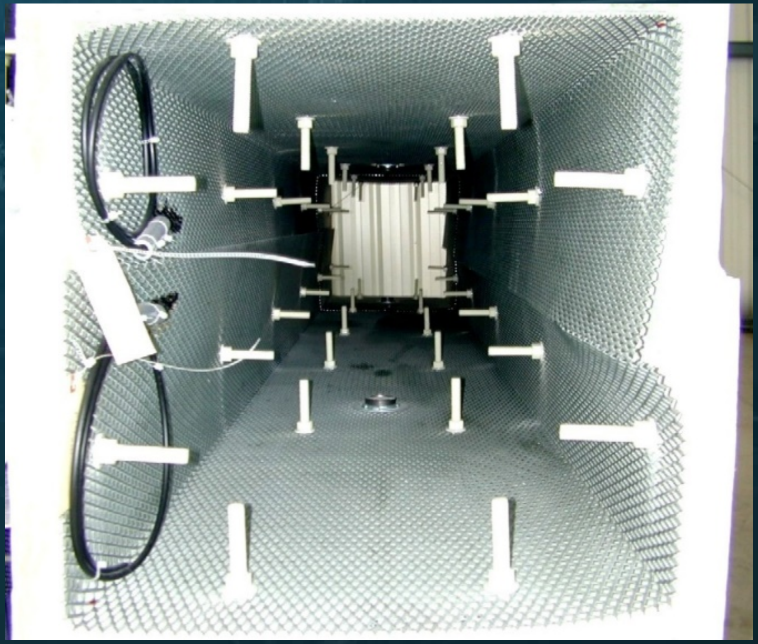
ARC-Sprayed Zinc

Thermally sprayed anodes are also used on structural steel as a protective coating with a paint system overcoat.

Sacrificial Cathodic Protection

Expanded Zinc Mesh Anode Pile Jacket

Sacrificial C.P. Jacket is placed around the pile and connected directly to the reinforcement without an external power supply.



The zinc mesh anode is inside the form to provide an annular space of 50 mm, which is then filled with mortar or concrete.

Sacrificial Cathodic Protection

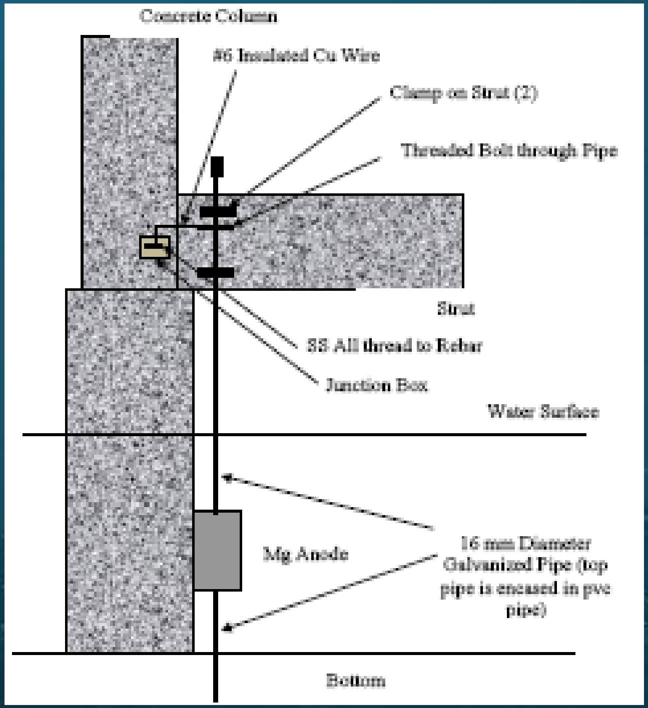
Activated Zinc Anode Jacket

Anode bars are covered by an activated grout and placed externally to the structure.

All anodes are then encapsulated in concrete using a stay-in-place form.

Sacrificial Cathodic Protection

Submerged Bulk Anodes



- These anodes are mostly used to provide cathodic protection to structures with underwater corrosion.
- Similar anodes are also used to complement galvanic pile jackets.

Remote Monitoring for Cathodic Protection Systems

Florida Department of Transportation > ***State Materials Office / Corrosion Research Laboratory***

Bridge #780074 / A1A Bridge of Lions / CP Monitoring System

CP Report & Picture | *CP Graphics* | *CP Data Table* | *Site Pictures* | *Links* | *Home*

Bridge_of_Lions Data Report
Date: 01/30/2014
Time: 15:00

CH 1	Pier 16 Zone 1 Voltage	1.763
CH 2	Pier 16 Zone 1 Current	1.000
CH 3	Pier 16 Zone 1 ON Potential	-0.512
CH 4	Pier 16 Zone 1 OFF Potential (-.502)	-0.480
CH 5	Pier 16 Zone 2 Voltage	1.704
CH 6	Pier 16 Zone 2 Current	0.600
CH 7	Pier 16 Zone 2 ON Potential	-0.665
CH 8	Pier 16 Zone 2 OFF Potential (-.213)	-0.620
CH 9	Pier 15 Zone 1 Voltage	2.037
CH 10	Pier 15 Zone 1 Current	2.200
CH 11	Pier 15 Zone 1 ON Potential	-0.556
CH 12	Pier 15 Zone 1 OFF Potential (-.611)	-0.554
CH 13	Pier 15 Zone 2 Voltage	3.103
CH 14	Pier 15 Zone 2 Current	0.500
CH 15	Pier 15 Zone 2 ON Potential	-0.705
CH 16	Pier 15 Zone 2 OFF Potential (-.443)	-0.675

End of Report

CP Data Report

Click here for downloadable text file

Latest Picture

Last 24 Hours

http://fdotcpl.com/

Performance Parameters for Cathodic Protection

NACE International provides standard criteria to validate the performance of cathodic protection systems.

- NACE SP0290: “Impressed Current Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures”

- NACE SP0216: “Sacrificial Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures”

- NACE SP0408: “Cathodic Protection of Reinforcing Steel in Buried or Submerged Concrete Structures”

Conclusions

- Bridge preservation using cathodic protection principles has proven to be a cost effective means to extend the service life of corrosion affected structures.
- The performance of cathodic protection systems needs to be periodically monitored to ensure satisfactory performance.
- Data collection for cathodic protection systems could be automated and telemetry can be provided for ease of monitoring, adjustments, and maintenance.
- Personnel dedicated to corrosion and cathodic protection, continuity in design, monitoring, and maintenance are essential for a successful cathodic protection program.

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Questions

Thank you!