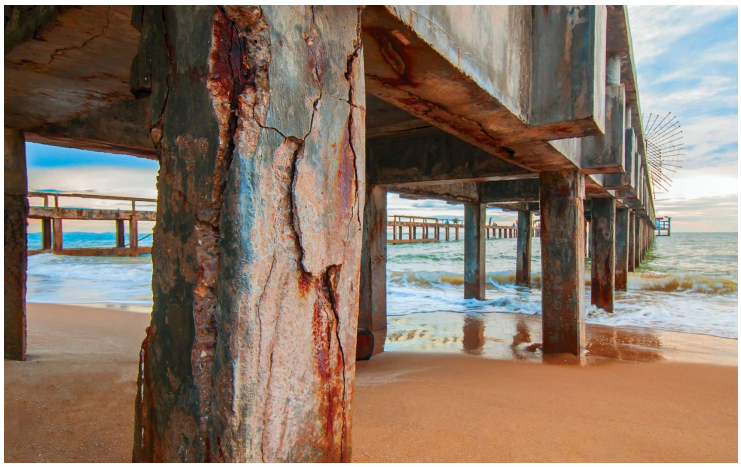
Corrosion Mitigation of Reinforced Concrete Structures



Corrosion Basics

Very few metals are found as pure metals

- Gold

- Occasionally Copper & Silver

Steel Manufacturing

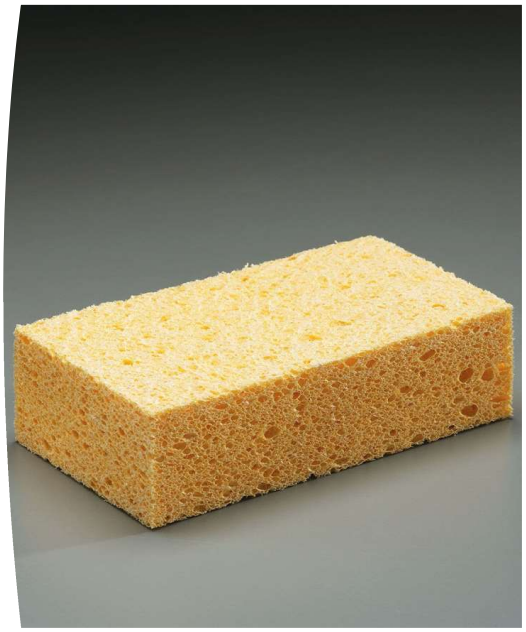
+ Energy =

The Corrosion Process

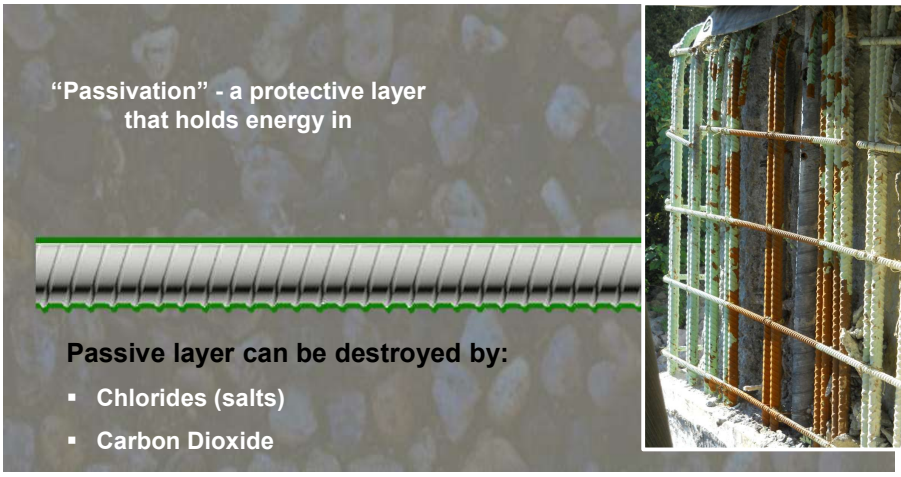
- Energy =

Concrete Is:

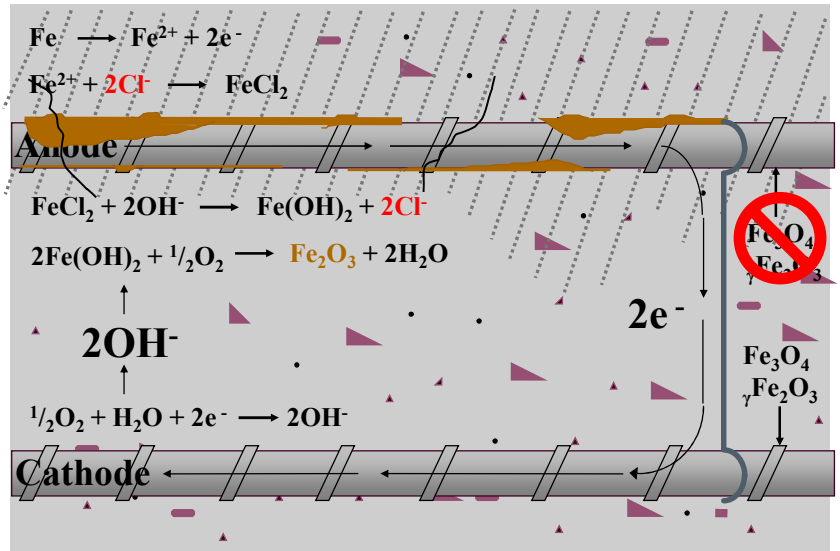
- A Hard Sponge (very porous)
- Great in Compression
- Poor in Tension
- Requires Reinforcement
- Highly Alkaline (pH 13+)



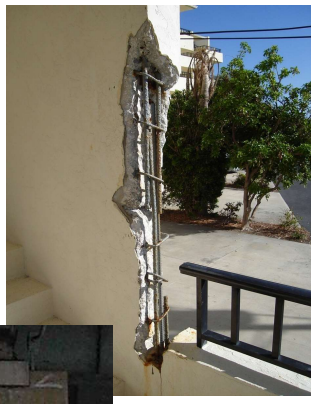
Why Concrete Protects Against Corrosion



Corrosion Cell in Concrete

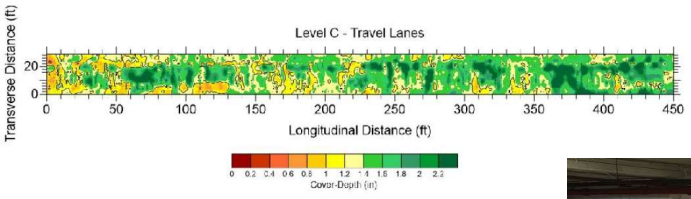


Types of Inspections



- Visual Inspection
  - Identify areas of visual damage
  - Cracking
  - Spalls
  - Exposed steel
- Delamination Survey
  - Hammer sounding
  - Chain drag

GPR Evaluation



Electromagnetic evaluation

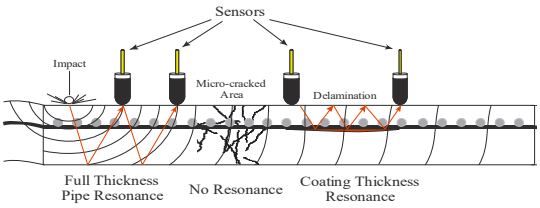
- Reinforcement layout
- Cover Depth
  - Compare to chloride profile or carbonation depth
- Qualitative condition of reinforced concrete
  - Chlorides, moisture, and concrete deterioration attenuate GPR

Impact Echo / Pulse Velocity Testing
(sonic/ultrasonic)

- Stress wave created by Impact
- Sensors measure time of travel for compressional and shear waves
- Velocity is correlated with strength

Non-destructive Method to Determine:

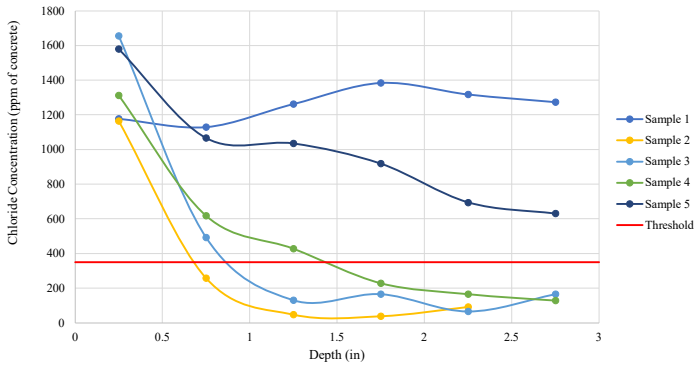
- Cracking / deterioration
- Delaminations
- Voids & honeycombing
- Compressive Strength
- Thickness



Chloride Concentration Threshold

Generally accepted chloride thresholds
- 350 ppm of ***concrete***
- 0.035% by mass of ***concrete***
- 1 .5 lbs per cubic yard of ***concrete***

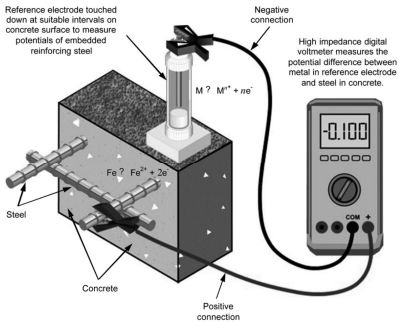
Chloride Concentration with Depth



Corrosion Potentials

- Determines the risk of active corrosion.
- Measures the potential difference between the steel reinforcement and a reference electrode to identify the probability of active corrosion.

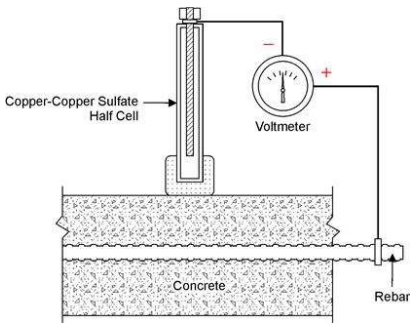
Copper / Copper Sulphate Electrode	Corrosion Condition
> -200 mV	Low – 10% risk of corrosion
-200 to –350 mV	Intermediate corrosion risk
< -350 mV	High - <90% risk of corrosion



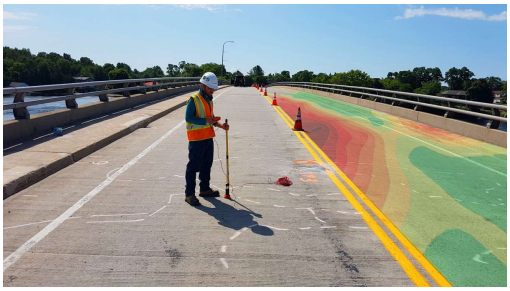
Corrosion Potential Measurements

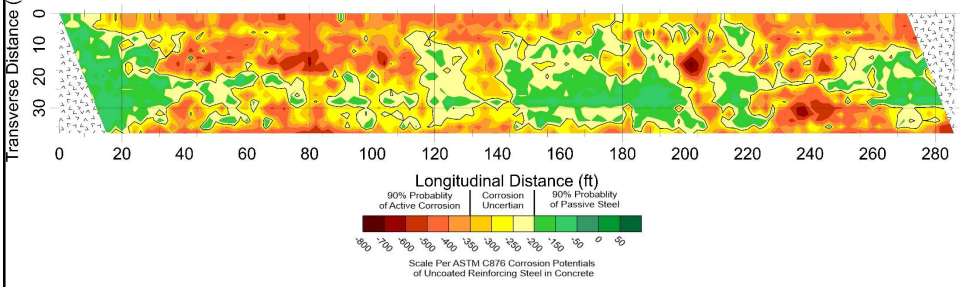
Corrosion potential: Half-Cell potential (ASTM C876)

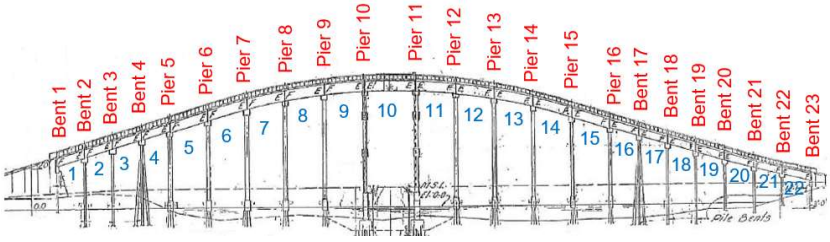
- Measures the potential difference between the reinforcement and a reference electrode to identify the probability of active corrosion.



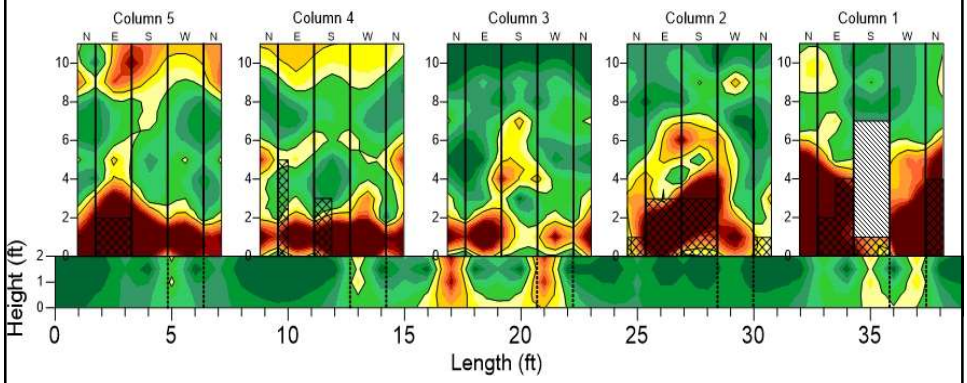
Corrosion Potential – Bridge Deck







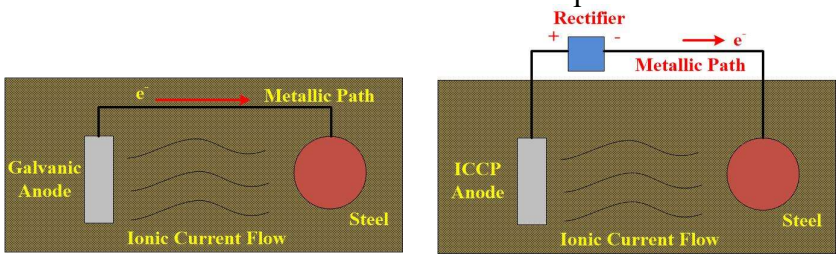
Rail Road Bridge – Springfield, MO



Cathodic Protection Systems

Cathodic Protection (CP) is a means to control corrosion through applying direct current to a metal, forcing it to become a cathode. We want our structures to act as a cathode.

Galvanic VS Impressed Current



Where are the Corrosion Problems?

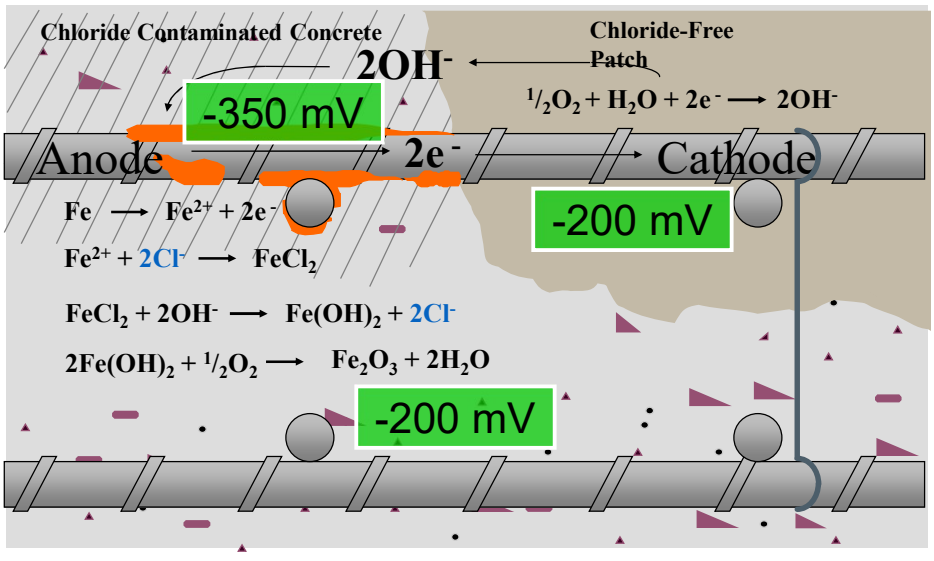
1. Repairs/Patches
2. Targeted Areas
3. Joints & Interfaces
4. Larger Areas

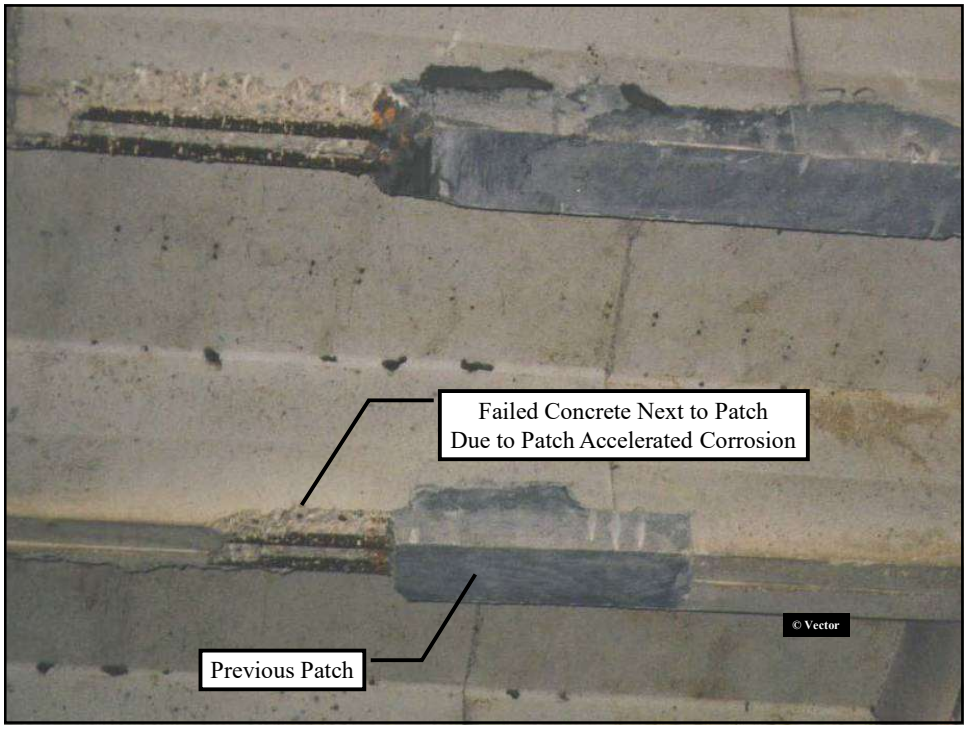
Different Areas Require Different Solutions

Repairs/Patches

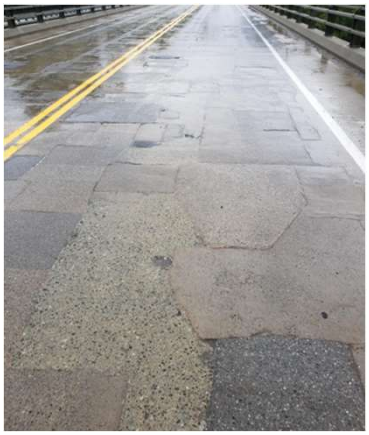
Galvanic Anodes

Patch Accelerated Corrosion



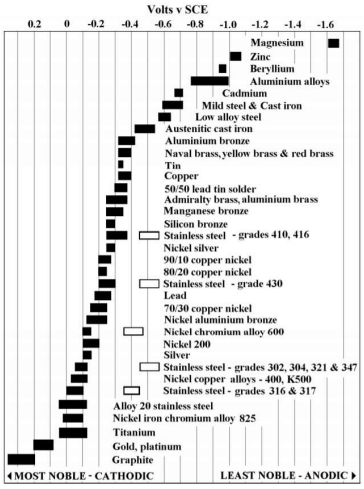

Failed Concrete Next to Patch
Due to Patch Accelerated Corrosion
Previous Patch
© Vector

Halo Effect OR Ring Anode Effect



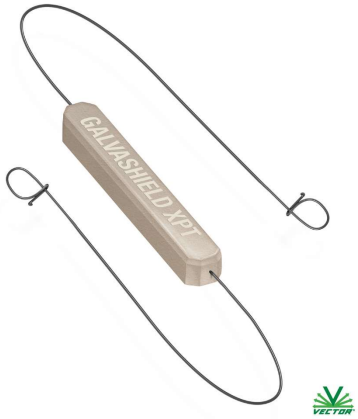
Galvanic Corrosion Protection Systems

Galvanic Series of Metals



Protect one metal while sacrificing another metal.

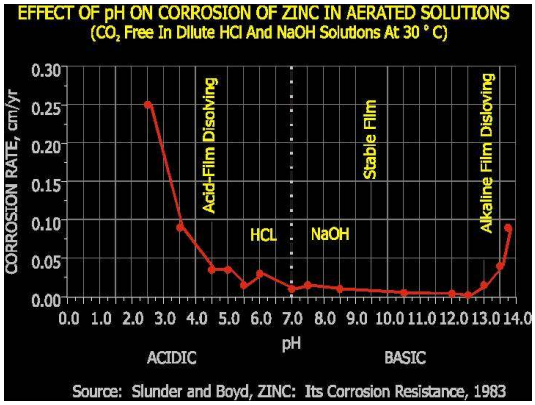
How to Prevent Patch Accelerated Corrosion?



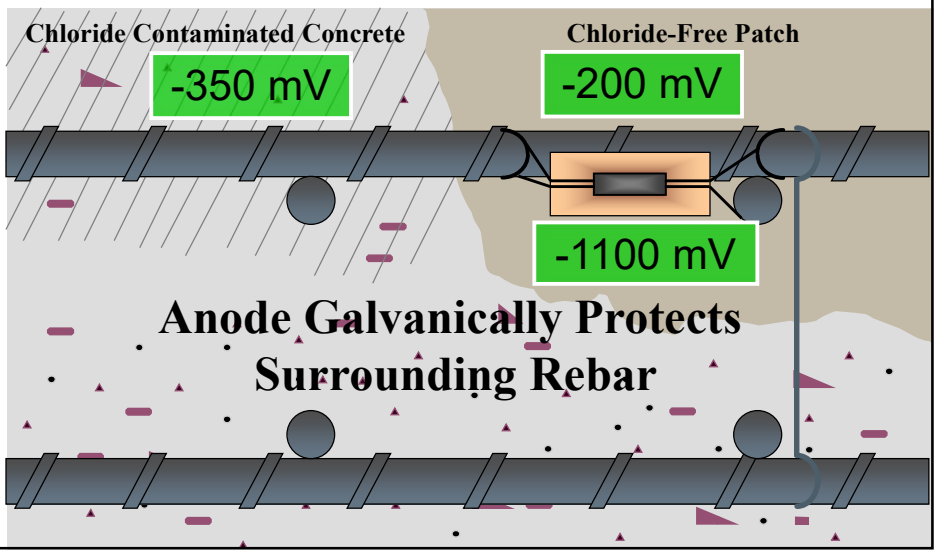
Activation Technology

Alkali Activated

- High pH is corrosive to zinc but not to steel
- Allows zinc anodes to provide protection to reinforced concrete over time



Installed Galvanic Anode

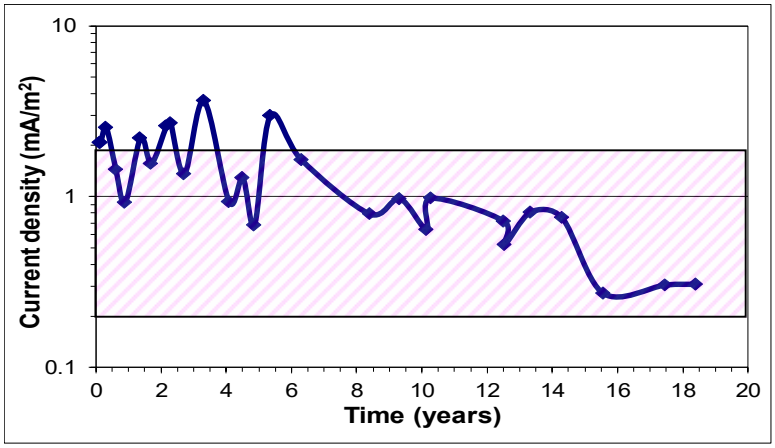


GALVANIC SYSTEMS

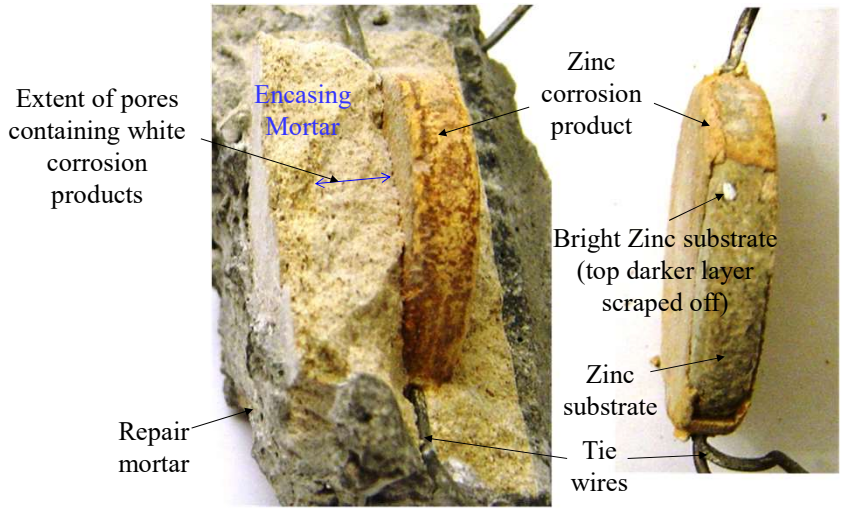
Leister Bridge Cross Beam

- Completed in 1999
- Monitored for 20 years

18.5 Year Evaluation of Current



Galvanic Anodes removed after 10 years



Targeted Areas

Areas with High Risk of Corrosion

Galvashield CC Anode
Galvashield N
Fusion Anode
Post Tension Impregnation

Embedded Galvanic Anodes - Nomenclature

Type 1

–Installed in Standard Repairs

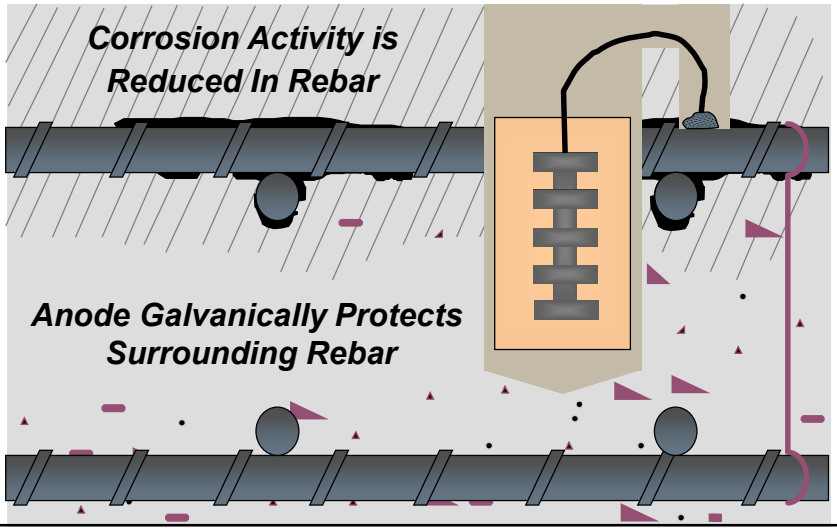
Type 2

–Installed in Sound Concrete

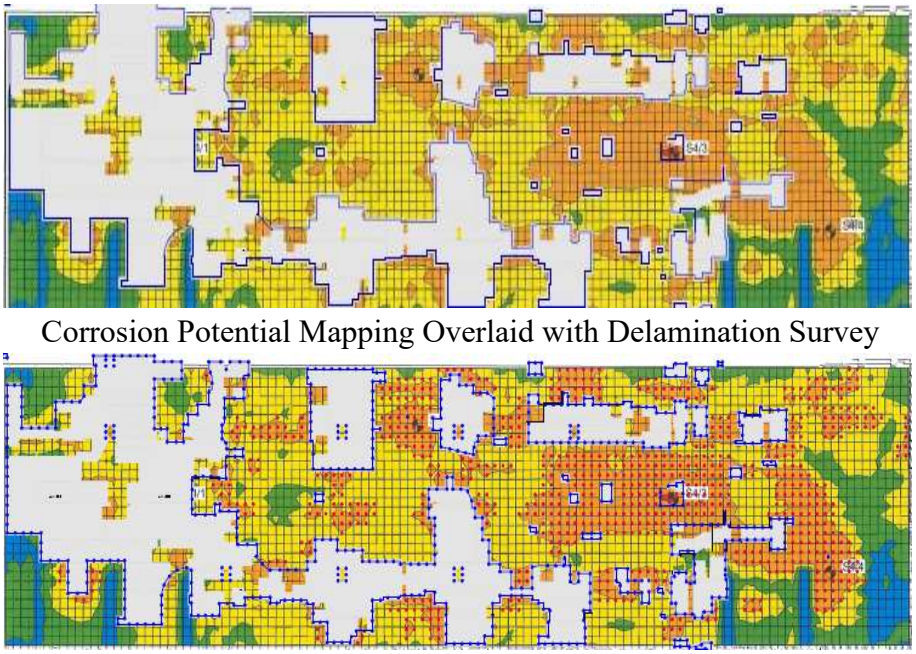
Source: Installation of Embedded Galvanic Anodes (ACI RAP Bulletin 8, 2010)

Vector® Galvashield® CC Embedded Galvanic Anodes for Corrosion Control

Corrosion Control Anode Installation



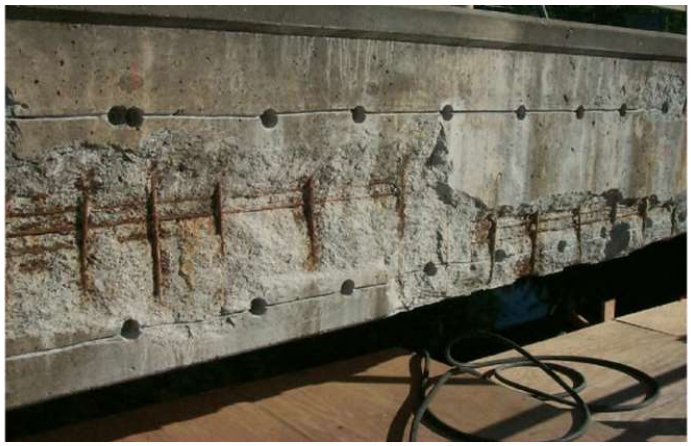
Predrilled Holes for CC Installation
Parking Garage Deck



Corrosion Potential Mapping Overlaid with Delamination Survey

Galvanic Anodes in Prestressed Box Girder

Galvanic Anodes in Prestressed Box Girder

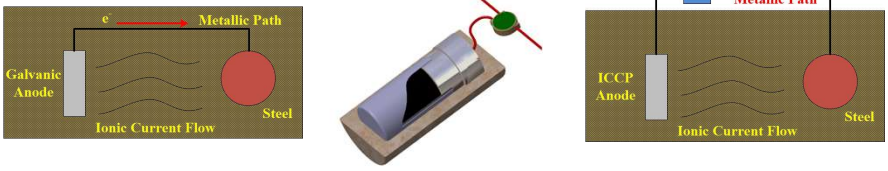


Galvanic Anodes in Prestressed Box Girder

Galvanic Anodes in Pre-stressed Box Girder

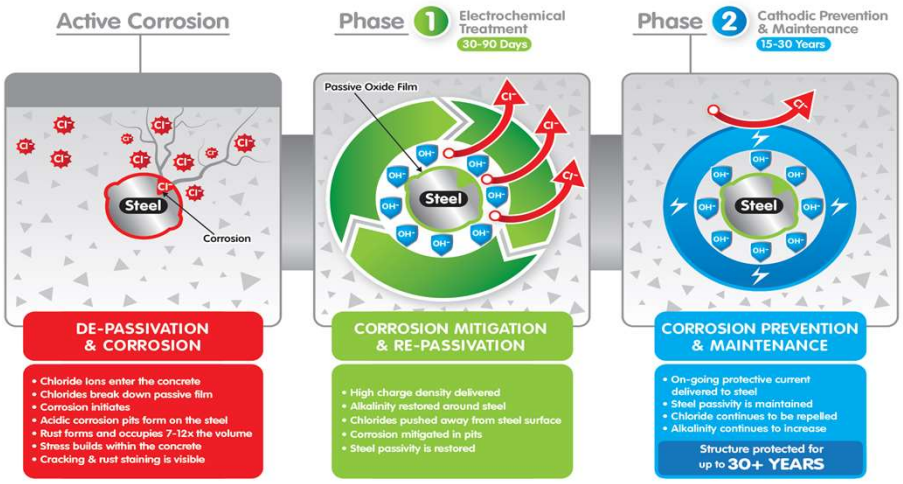
Hybrid Fusion Technology

Galvanic → FUSION ← Impressed Current

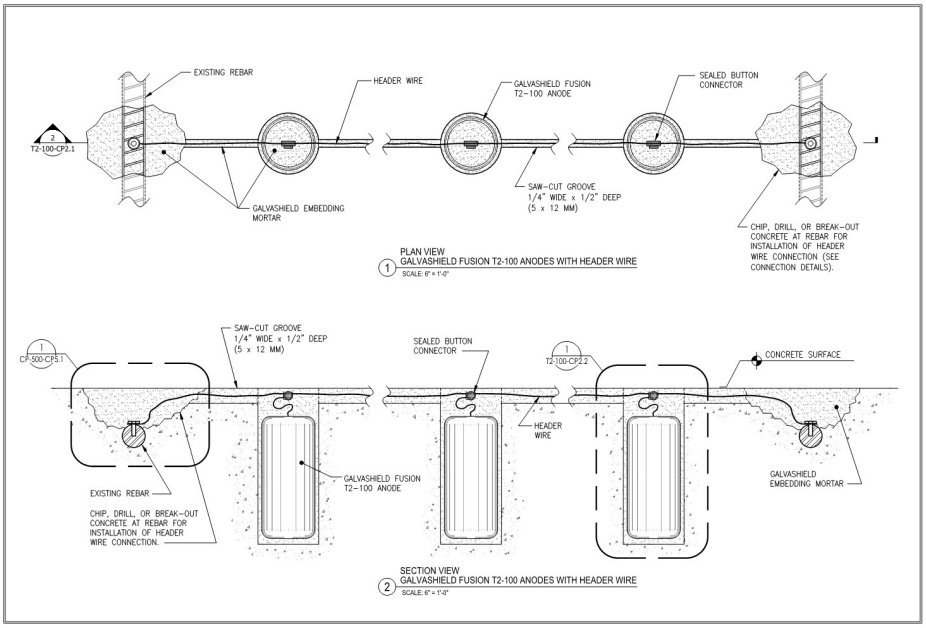


- Combining the steel passivation performance of an Impressed Current system.
- With the simplicity, maintenance free performance of a Galvanic system.

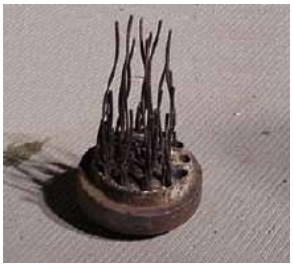
Galvashield Fusion



Arlington Memorial Bridge



Grouted Post Tension Cables

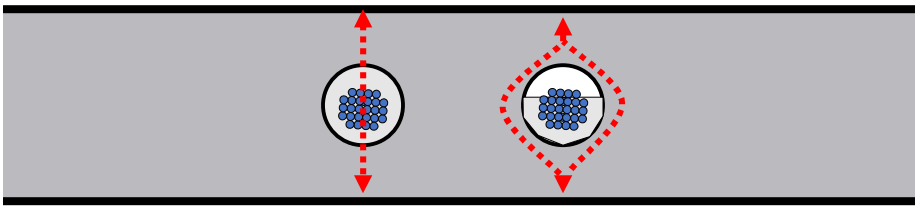


Grout Issues that lead to Tendon Corrosion:

1. Bleed water voids
2. Voids due to grouting problems
3. Segregated grout
4. Chloride contaminated grout
5. Soft grout

Bleed water in duct

Post Tensioning Theory



Grouted Duct wave passes through grout

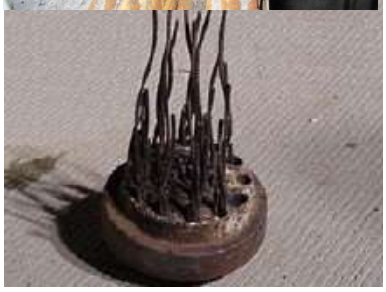
Voided Duct wave passes around void/tendon duct

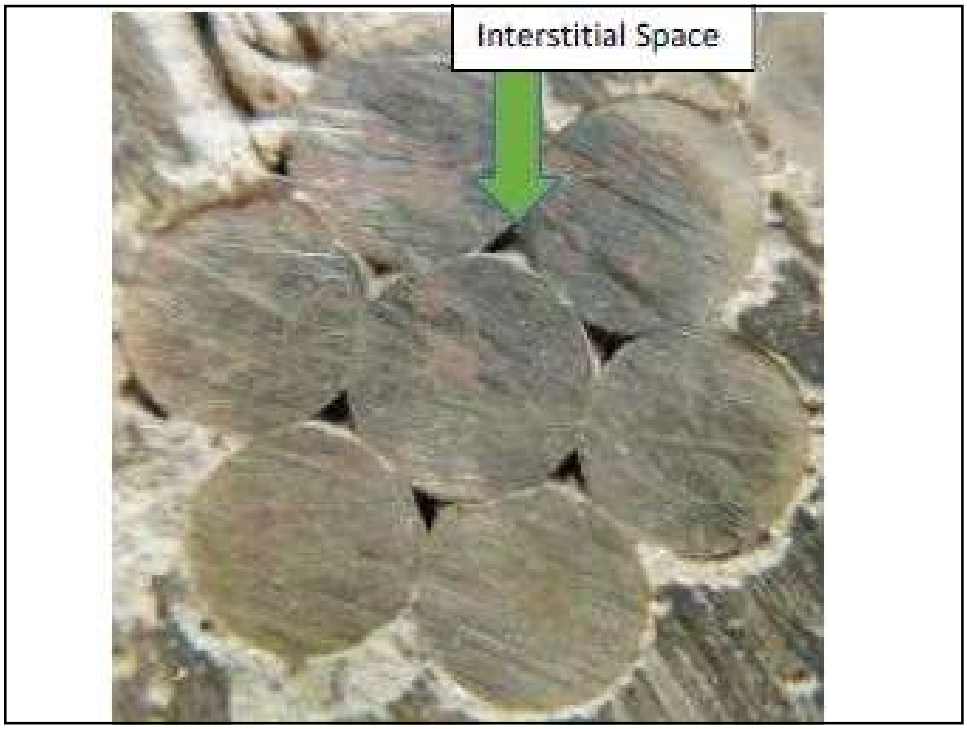
PT Duct Location/Testing

PT Testing on Beam

PT Duct Inspection

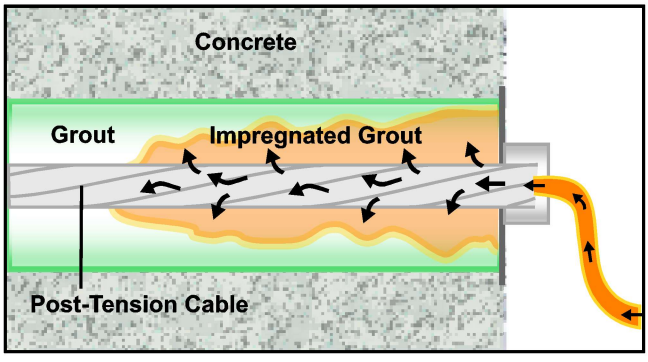
Voided/Corroded Tendons





Impregnation material mitigates corrosion by:

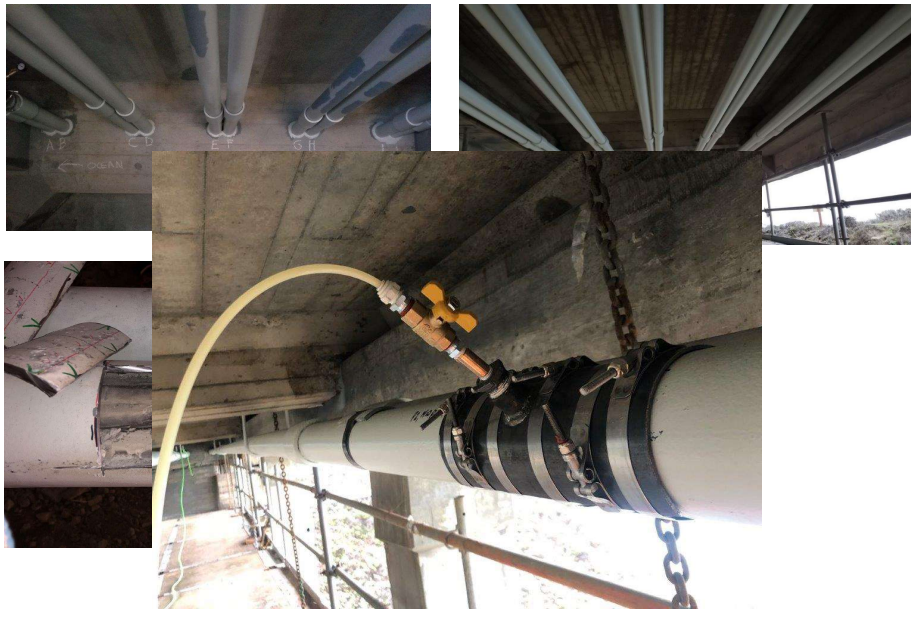
- Reducing permeability of grout/concrete
- Forming a coating on exposed steel in voids



Chipping grout to expose strands and observe the level of saturation

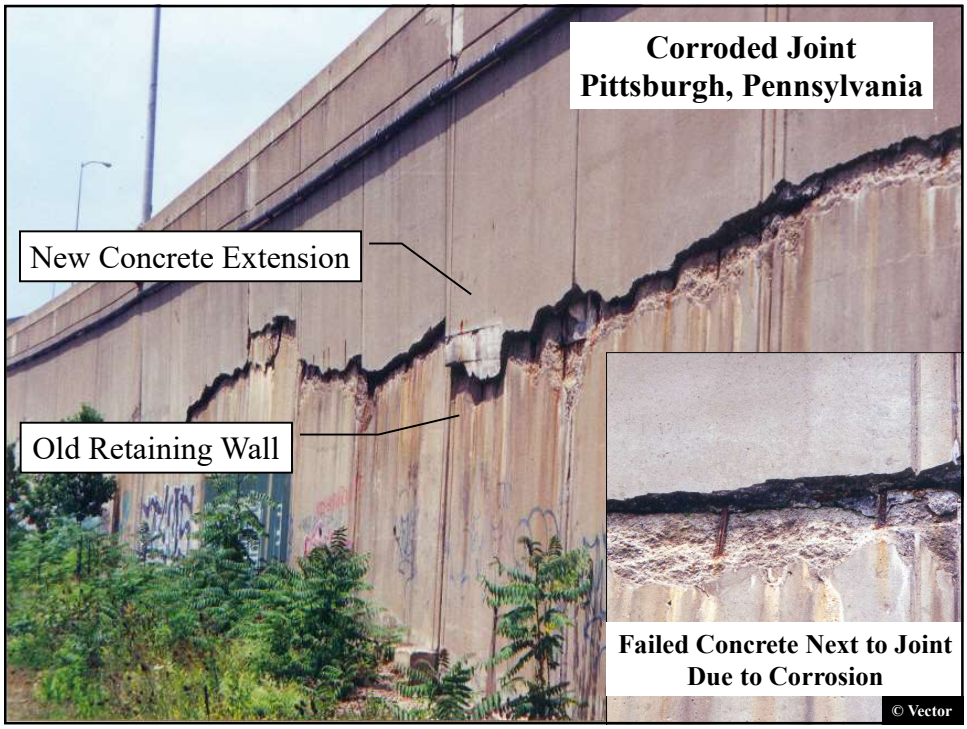
Impregnation of Strands in Prestressed Concrete

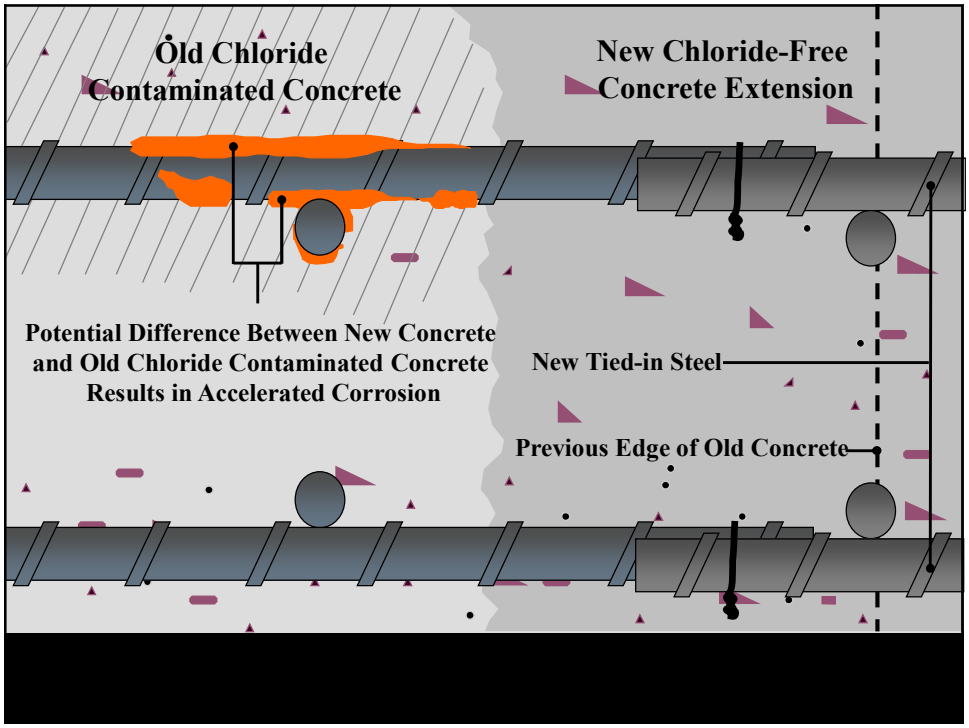
Rocky Creek Bridge, Caltrans District 5



Joints and Interfaces

Distributed Anode System (DAS)

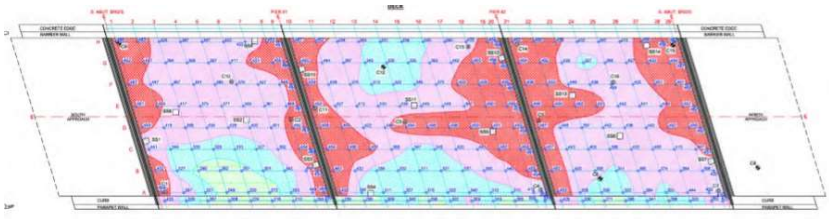

Corroded Joint
Pittsburgh, Pennsylvania
New Concrete Extension
Old Retaining Wall
Failed Concrete Next to Joint
Due to Corrosion
© Vector


Old Chloride
Contaminated Concrete
New Chloride-Free
Concrete Extension
Potential Difference Between New Concrete
and Old Chloride Contaminated Concrete
Results in Accelerated Corrosion
New Tied-in Steel
Previous Edge of Old Concrete

Bridge Widenings

Distributed Anode System (DAS)

Corrosion Potential Map

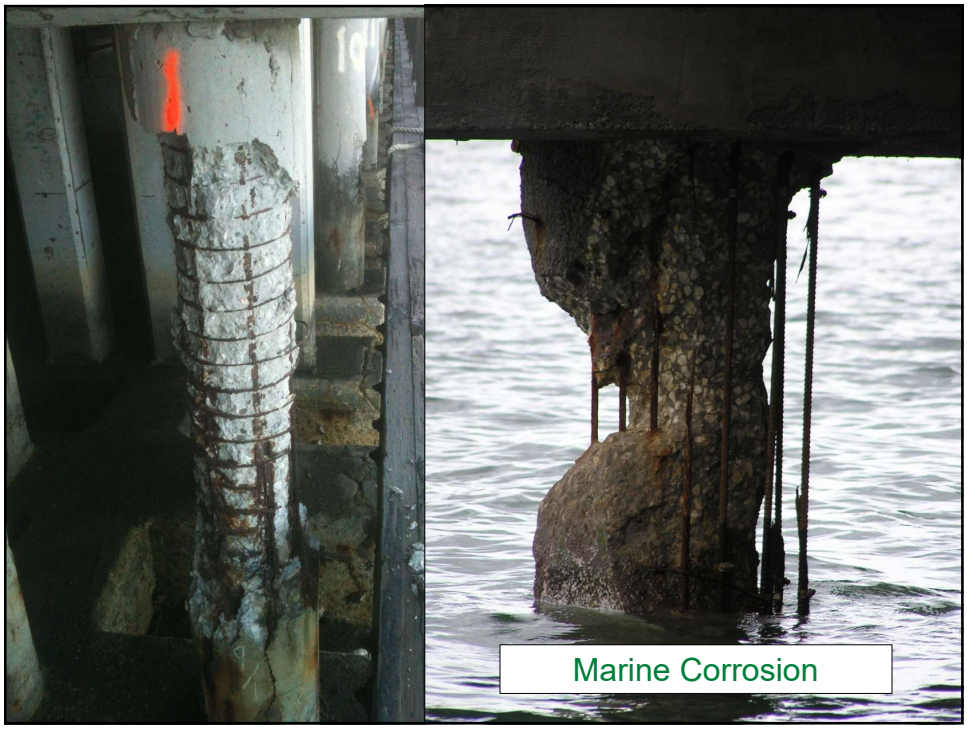


Bridge Decks

Larger Areas

Repair or Replacement?

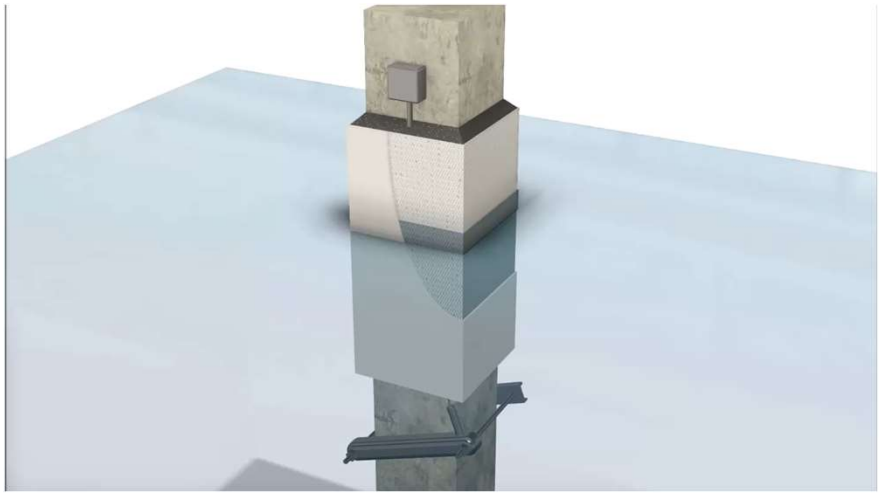
Tidal Jackets & Galvanic Encasements
Arc Sprayed Zinc
Impressed Current Cathodic Protection
Electrochemical Chloride Extraction & Re-Alkalization


Marine Corrosion

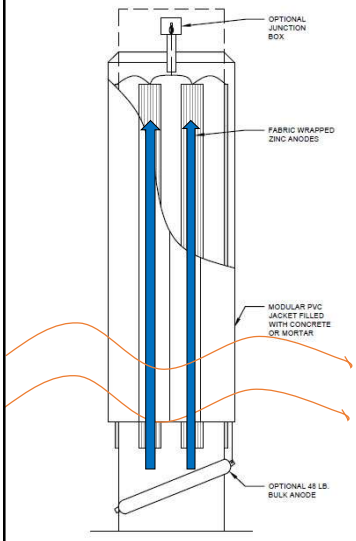
Tidal Jacket

- Tidal zone protected
  - Zinc mesh anode
  - Open bottomed FRP Jacket
  - Allows saltwater inside
- Bulk anode for underwater protection

Tidal Jacket (zinc mesh)



Tidal Plus Jacket



Tidal Plus Jacket

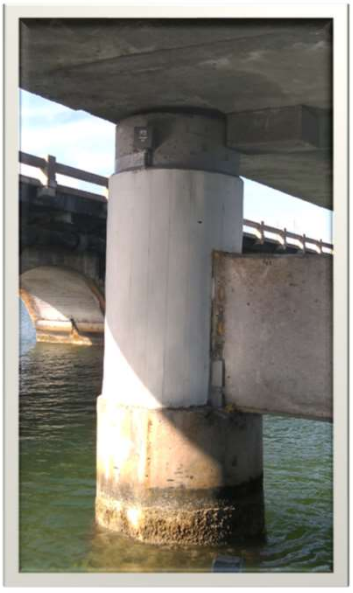
Marine DAS Jacket

Saltwater **NOT** required!

- Alkali Activated Anodes (self-activating) used to protect piles and columns in:
  - Saltwater
  - Brackish water
  - Fresh water and
  - Dry land applications.

Marine DAS Alkali Activated Anode Jacket

Florida Keys Column Encasement



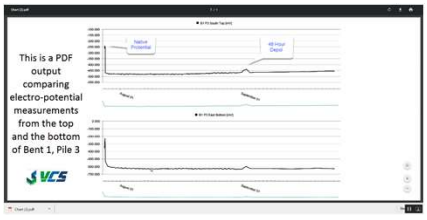
Stay-in-Place Forms
Options

Modular Jacket Panel
"Jacket in a Box"

FRP

STRUCTUREVIEW®

Remote monitoring
Web access
Cathodic Protection
Structural Health Monitoring

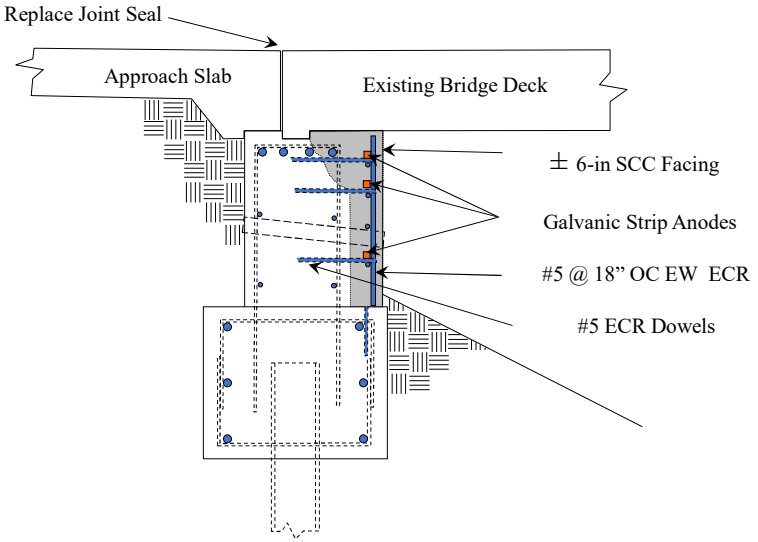


Distributed Galvanic Anodes

On Many Slab Bridges…

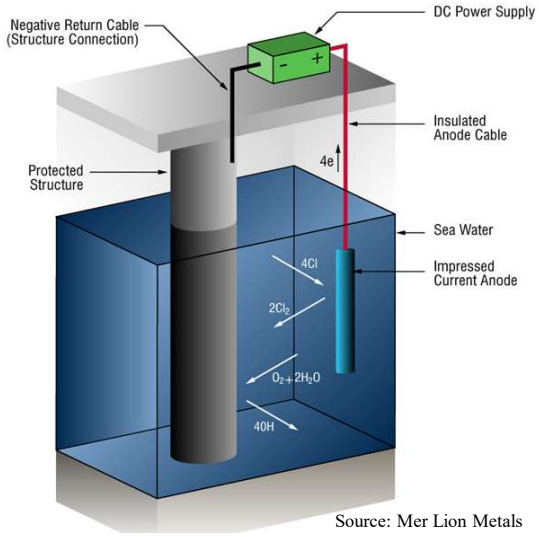
- Slabs are in good condition
- Deterioration at abutment

Abutment Repair Detail With Galvanic Protection



Activated Arc Spray Zinc

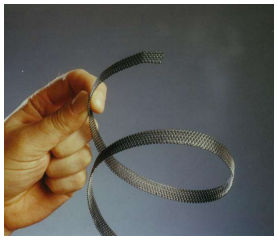
Impressed Current Cathodic Protection (ICCP)



Source: Mer Lion Metals

Impressed Current CP (ICCP)

Discrete Anodes & MMO Titanium Mesh



Electrochemical Treatments

"Reset the Clock on your Structure"

- **Chloride Extraction (ECE)**
- **Re-alkalization**

Norcure® ECE Treatment Process

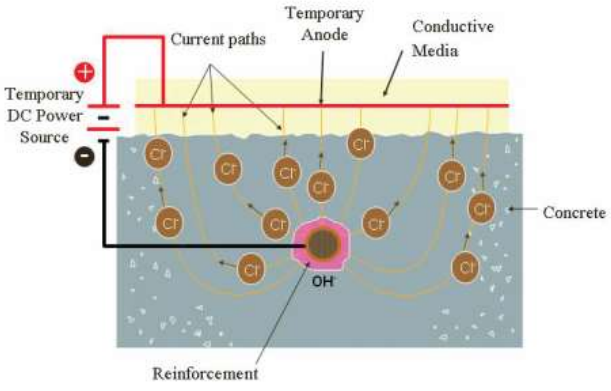


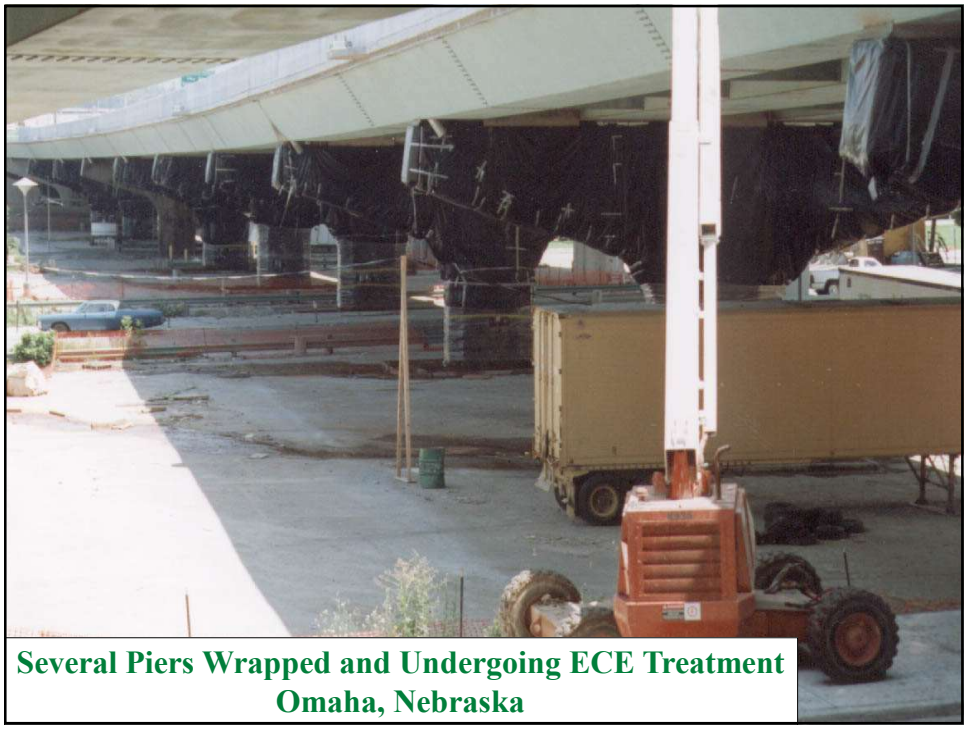
Figure 5: Illustration of the Electrochemical Chloride Extraction Process. Note the Movement of Chloride (Cl-) Toward the Temporary Anode and the Generation of Hydroxyl (OH-) around the Reinforcement.

Norcure® ECE Treatment Process

Norcure® ECE Treatment Process

Cellulose Fiber Serves as Electrolyte

Installation Complete
Ready to Start Treatment



Several Piers Wrapped and Undergoing ECE Treatment
Omaha, Nebraska

Piers after ECE Treatment
Cleaned and Sealed

Rainbow Bridge

Carbonation

- Carbon dioxide permeates into concrete and reacts with hydroxides to form carbonates.

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$$

- Reduces pH of concrete (<10)
- The passivity on the protective layer of reinforcement is destroyed which creates a corrosive environment around the reinforcement.

Phenolphthalein Testing

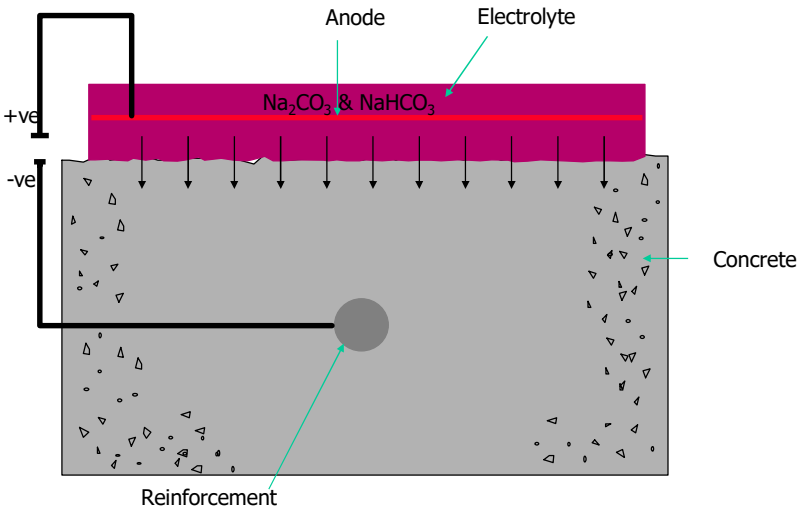
Electrochemical Re-alkalization

Electrically drive a high pH solution into the concrete around the reinforcing steel.

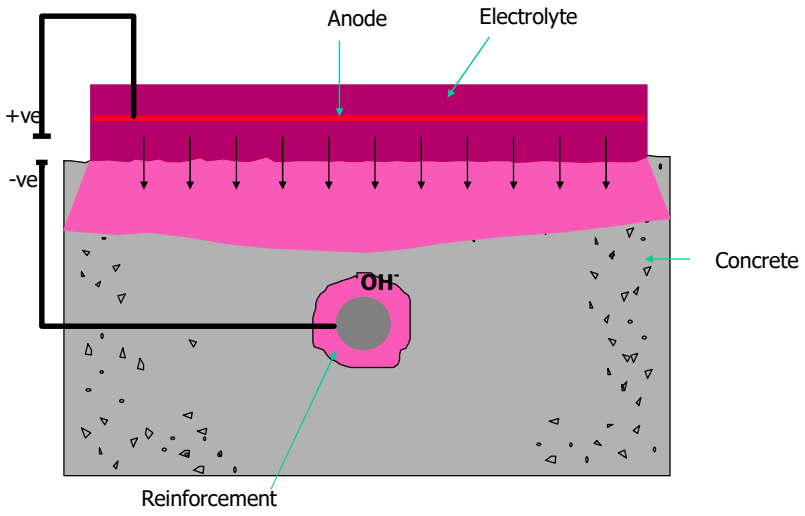
Regan National Airport, Washington DC

Dry Canyon Creek Bridge, Oregon DOT

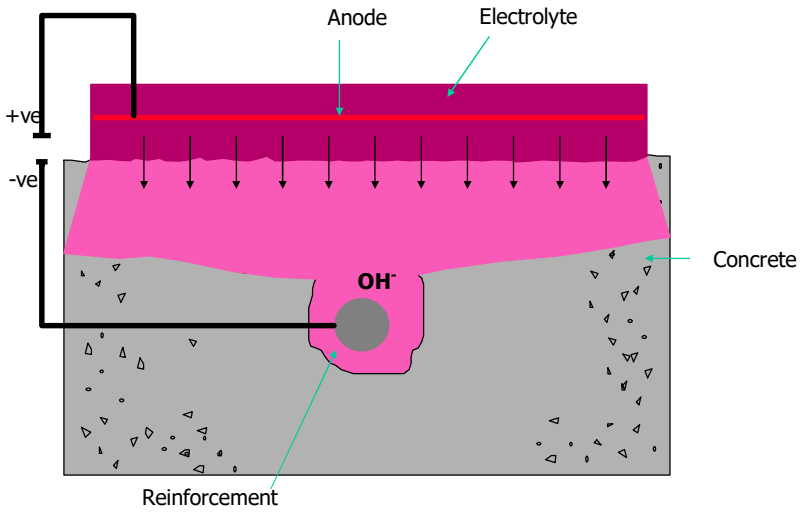
Norcure® Re-alkalization



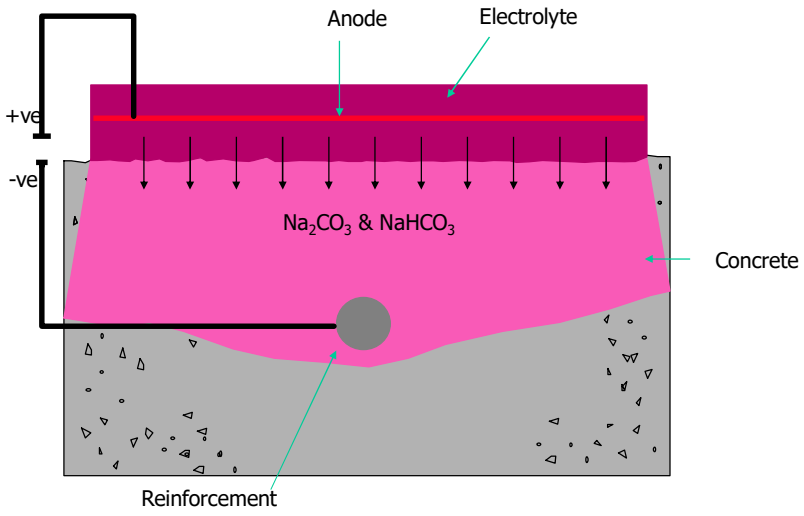
Norcure® Re-alkalization



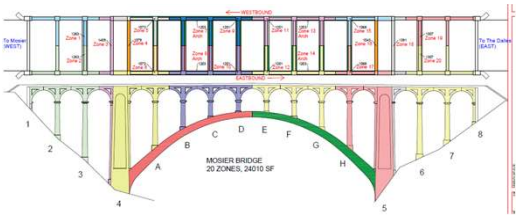
Norcure® Re-alkalization



Norcure® Re-alkalization



Pre-treatment Testing



Average Depth of Rebar
= 2.3 Inches

Average Depth of Carbonation
=2.3 Inches

Core	Sampled	Zone	Element	Element ID	Face	Depth of Rebar (in.)	Depth of Carbonation (in.)	Location
1	8/1/2017	1	Dec. Arch (Curtain)	btwn 2-3 WB	South	2 - 5.5	Full-Depth	1'-5" down from underside of deck and 2'-4" east of column 2
2	8/2/2017	2	Column Strut	Bent 3 EB	Top	1.5 - 3	2.25	1'-11" north of north face of column 3 and 4" west of east edge of strut
3	8/1/2017	3	Bent Pier	4 - WB	West	3 - 4.5	1.75	3'-11" down from underside of deck and 3'-2" north of column 4
4	8/7/2017	3	Bent Pier	4 - WB	South	2 - 4.5	1.25	12'-9" down from underside of deck and 7" east of west edge of pier
5	8/2/2017	4	Bent Pier	4 - EB	East	2 - 4	3.5	10'-8" down from bottom of capital and 3'-6" north of north edge of column
6	8/2/2017	5	Arch Col. (Spandrel)	A - WB	South	2 - 4	2	5'-3" down from bottom of column strut and 6" east of west edge of column
7	8/1/2017	6	Deck Beam	A - WB	East	2 - 3.5	2.75	1'-11" down from underside of deck and 4'-1" south of north curtain wall
8	8/2/2017	7	Arch	btwn A-B	Top	6 - 8	1	3'-5" east of centerline of column A and 1'-1" south of north edge of arch
9	8/2/2017	8	Arch	btwn B-C EB	North	1.5 - 3.5	1.75	7" down from top edge of arch & 5'-11" east of centerline of arch column B
10	8/7/2017	8	Arch	btwn 4-A EB	South	2 - 4.5	3	1'-2" down from top of arch and 3'-8" east of face of pier 4
11	8/7/2017	8	Arch	btwn A-B EB	South	2 - 5	1.5	9" down from top of arch and 8'-1" east of centerline and arch column A
12	8/2/2017	9	Arch Col. (Spandrel)	C - WB	East	2.5 - 4	Col. Replaced	2'-2" below bottom of capital & 5" south of north edge of column
13	8/2/2017	10	Arch Col. (Spandrel)	D - EB	South	2 - 3.25	2	1'-3" up from top of arch and 10" east of west edge of column
14	8/1/2017	11	Arch Col. (Spandrel)	E - WB	South	2 - 3.5	3	4'-7" down from underside of deck & 6" east of west edge of arch col.
15	8/2/2017	11	Corbel	F - WB	East	2 - 4	1.5	9' down from underside of deck and 6" north of north face of curtain wall
16	8/2/2017	12	Arch Col. (Spandrel)	F - EB	North	1.5 - 3.5	Col. Replaced	3'-1" down from bottom of capital and 5" east of west edge of arch col.
17	8/2/2017	13	Arch	btwn G-H WB	North	2 - 3.5	2	4'-5" up from earth grade & 2'-7" west of centerline of arch column H
18	8/2/2017	14	Arch	btwn E-F EB	South	1.5 - 3	1.5	7" down from top edge of arch & 3'-11" east of centerline of arch column E
19	8/2/20107	15	Arch Col. (Spandrel)	H - WB	West	2 - 4	3.5	2-3" down from bottom of col. Strut and 5" north of south edge of arch col.
20	8/7/2017	16	Deck Beam	5 - WB	West	1 - 2.25	2.25	2'-11" down from underside of deck & 6'-2" south of curtain wall
21	8/7/2017	17	Dec. Arch (Curtain)	btwn G-H EB	North	4 - 6	3.25	1'-0" down from underside of deck and 2'-7" west of column H
22	8/7/2017	18	Column	S-WB Pilaster	East	4 - 5.5	3	11' down from bottom of capital & 1'-2" north of column edge
23	8/7/2017	19	Column	7 - WB	North	4 - 6	2.75	7'-4" down from bottom of capital & 1'-3" west of east edge
24	8/7/2017	20	Column Strut	6	East	1.5 - 4	3.5	1'-4" down from top of strut and 1'-10" north of column east face
			Avg. shallower depth of rebar	**2.33**				
			Avg. deeper depth of rebar	**4.27**				
			Avg. depth of carbonation	**2.33**				

Pre-treatment Cores

Deep Purple Indicator Test

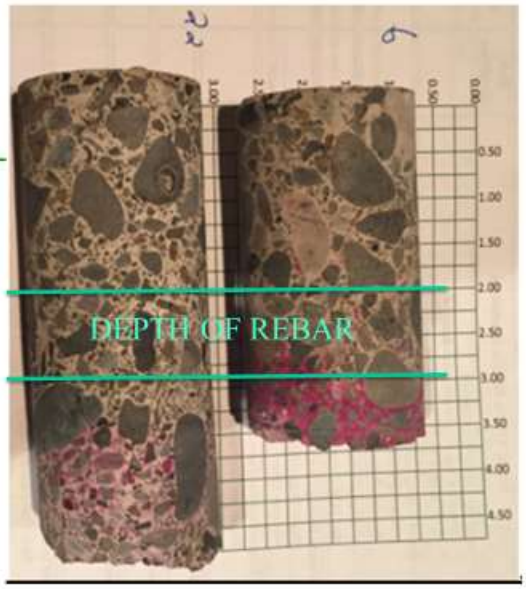
- Carbonated Concrete is in the 'clear' portion of the core – above the red line.
- The concrete that is pink/purple is good and is not carbonated at this time

Color:
pH: 8.5 to 9.5

In Summary:

Clear = Bad

Purple = Good

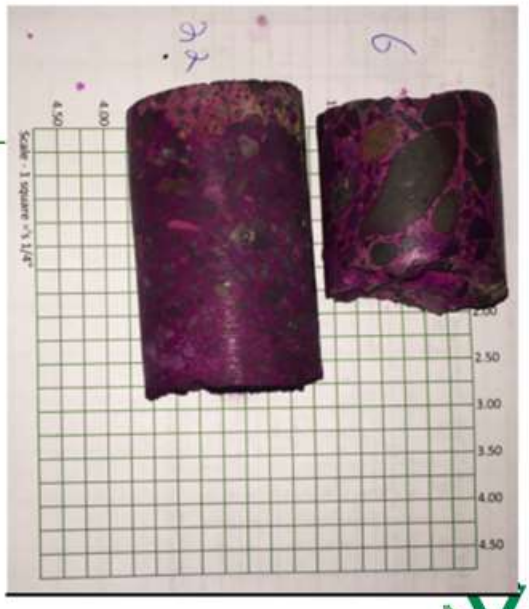


Post Treatment Cores

Deep Purple Indicator Test

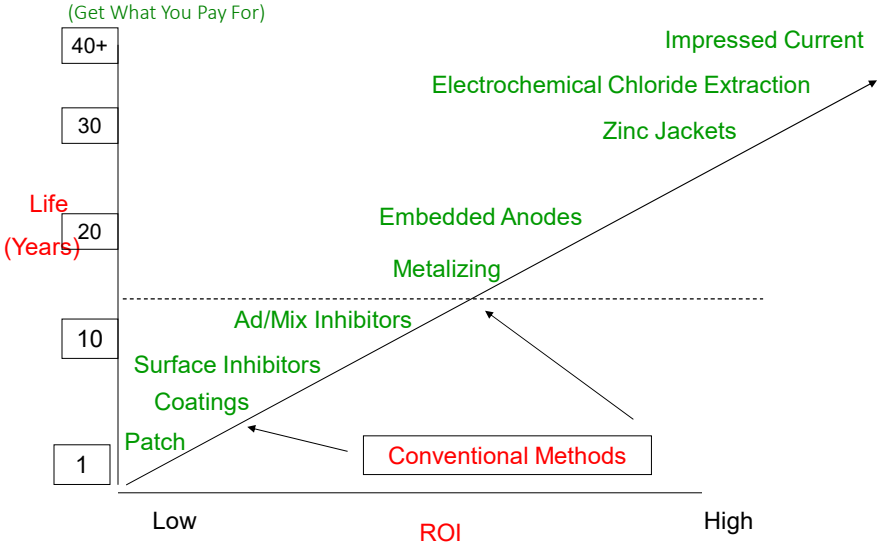
- Concrete is realkalized from the surface of the concrete to the depth of reinforcing.
- These cores were taken directly above the bar.

Color:
pH: 8.5 to 9.5



Corrosion Control Economics

(Get What You Pay For)



Questions?

Contact:
Travis Marman
701-261-5579
TravisM@Vector-Construction.com