Corrosion of Steel in Concrete

Use of Galvanic technologies to Mitigate Corrosion in Steel Reinforced Concrete Structures

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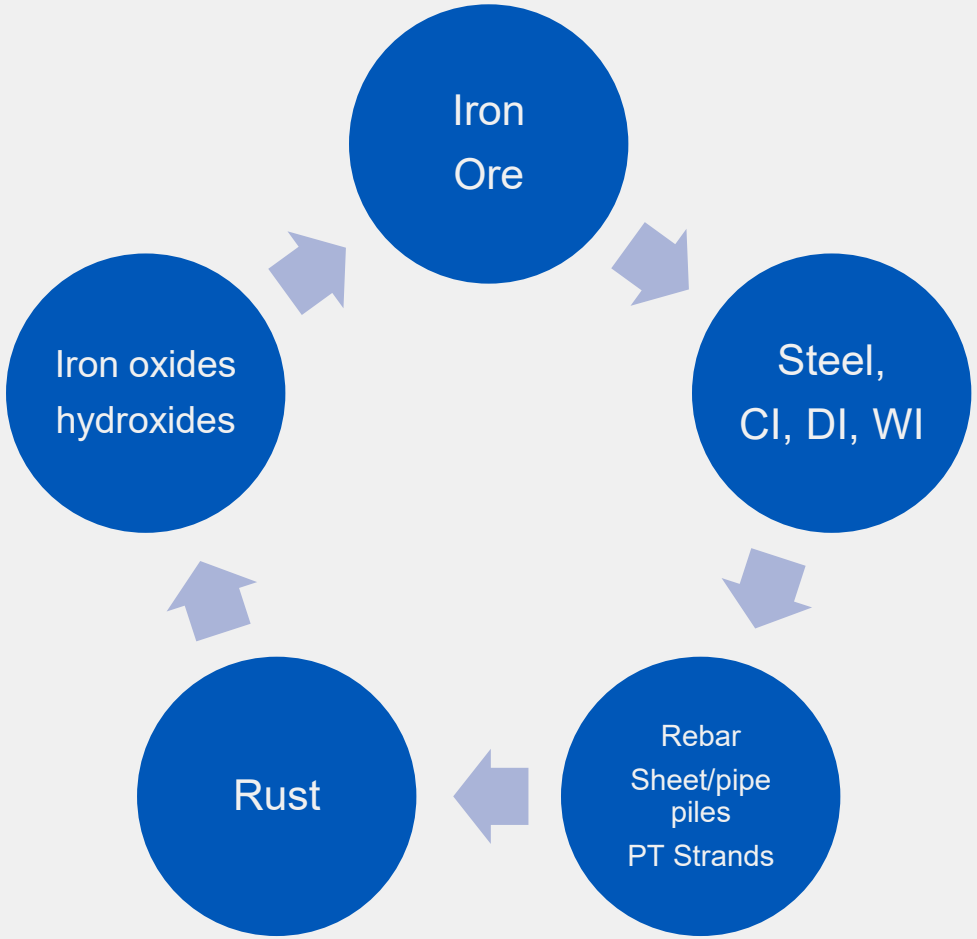
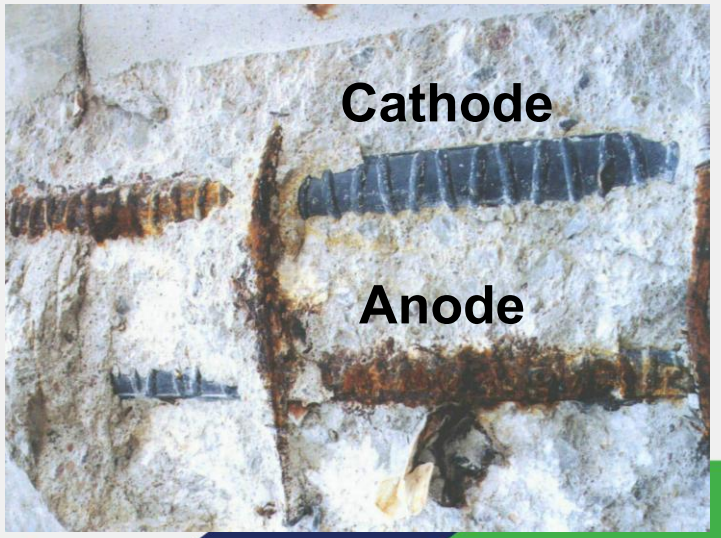
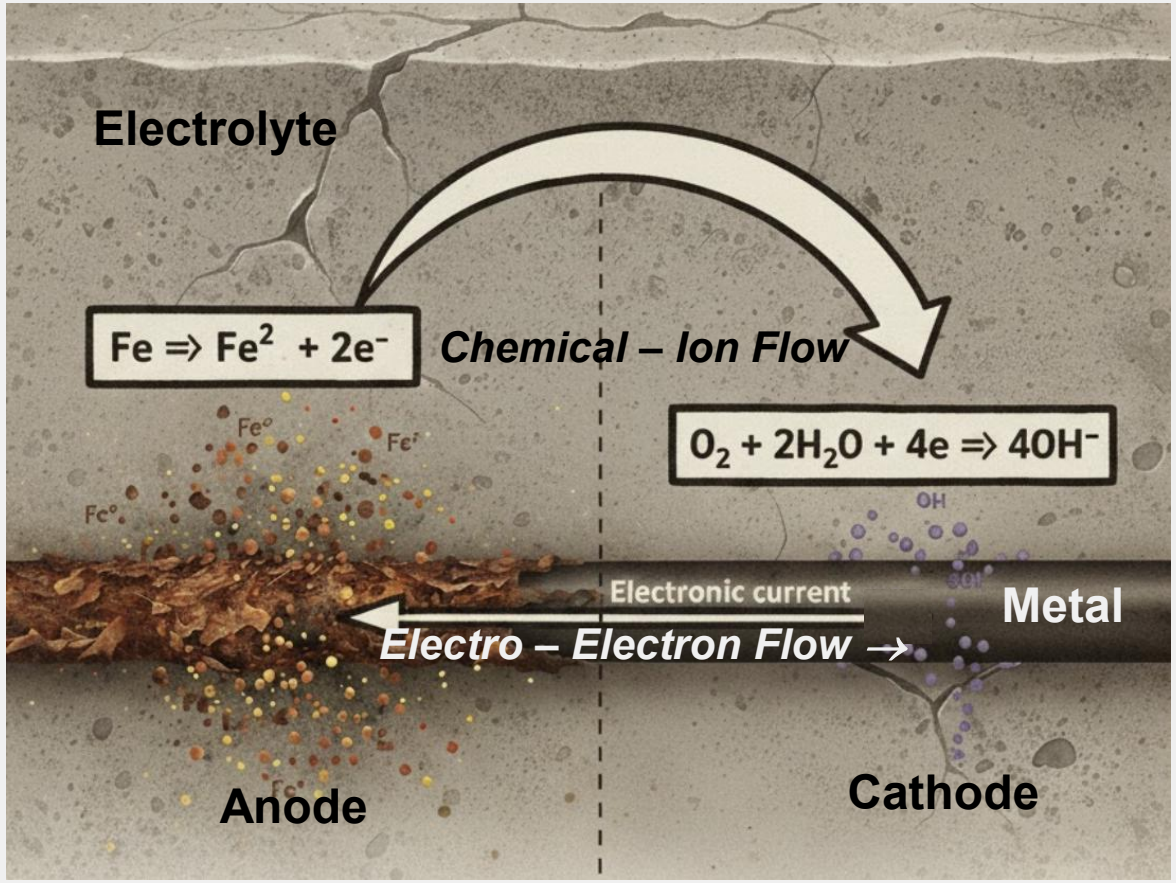
Corrosion Energy Cycle



Corrosion Mechanism

- Electrochemical Reaction
- Requires (**A C M E**)
  - **A**node – Section Loss or Rust
  - **C**athode - Protected
  - **M**etal – Rebar, PT
  - **E**lectrolyte – Concrete





Concrete!

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

Passivation and Corrosion

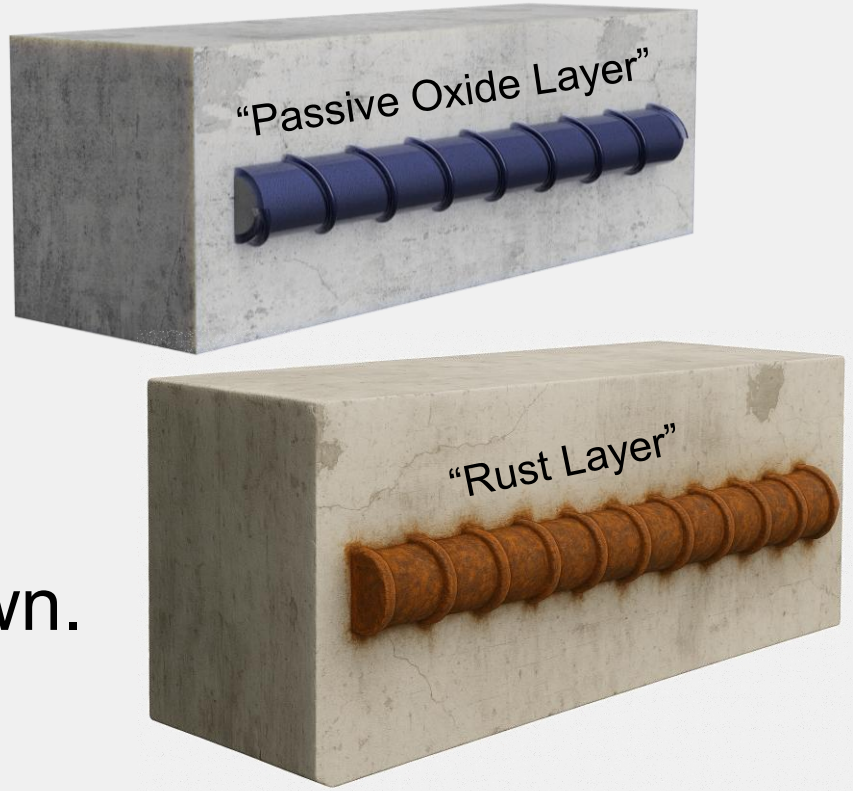
- Passivation = A protective layer that holds energy in, prevents steel from corroding
- Good quality concrete forms a protective passivation layer over the steel.

2 Main Disruptions to Passivation- Corrosion:

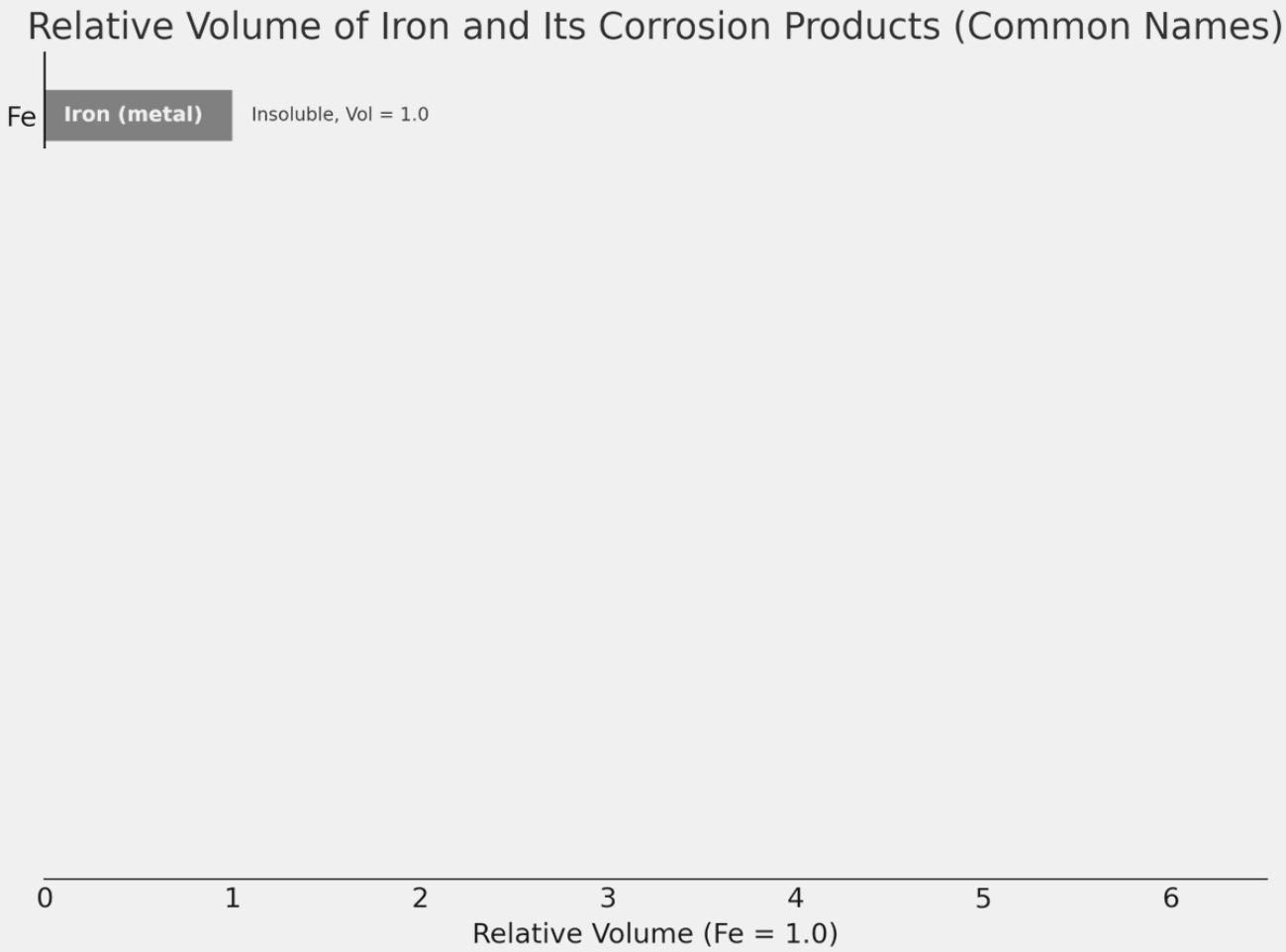
- **Carbon Dioxide** (CO_2)
- **Chlorides** (salts)

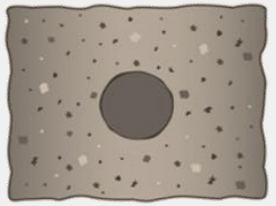
- **<u>Needs Moisture – Follow the Water!</u>**

- Results in the passivation layer breaking down.

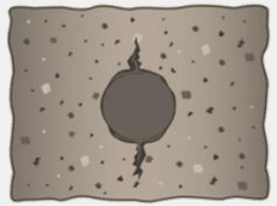


Relative Volumes



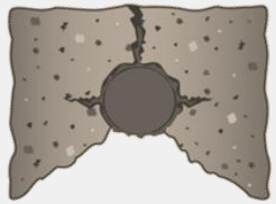


BEFORE CORROSION.



BUILD-UP OF
CORROSION PRODUCTS.

FURTHER CORROSION.
SURFACE CRACKS.
STAINS.



EVENTUAL SPALLING.
CORRODED BAR.
EXPOSED.

Visual Inspection

- Identify areas of visual damage
  - Rust staining
  - Cracking
  - Spalls
  - Exposed steel
  - Water infiltration
  - Efflorescence
- Note exposure conditions and other observations
- Identifies issues too late in the deterioration process

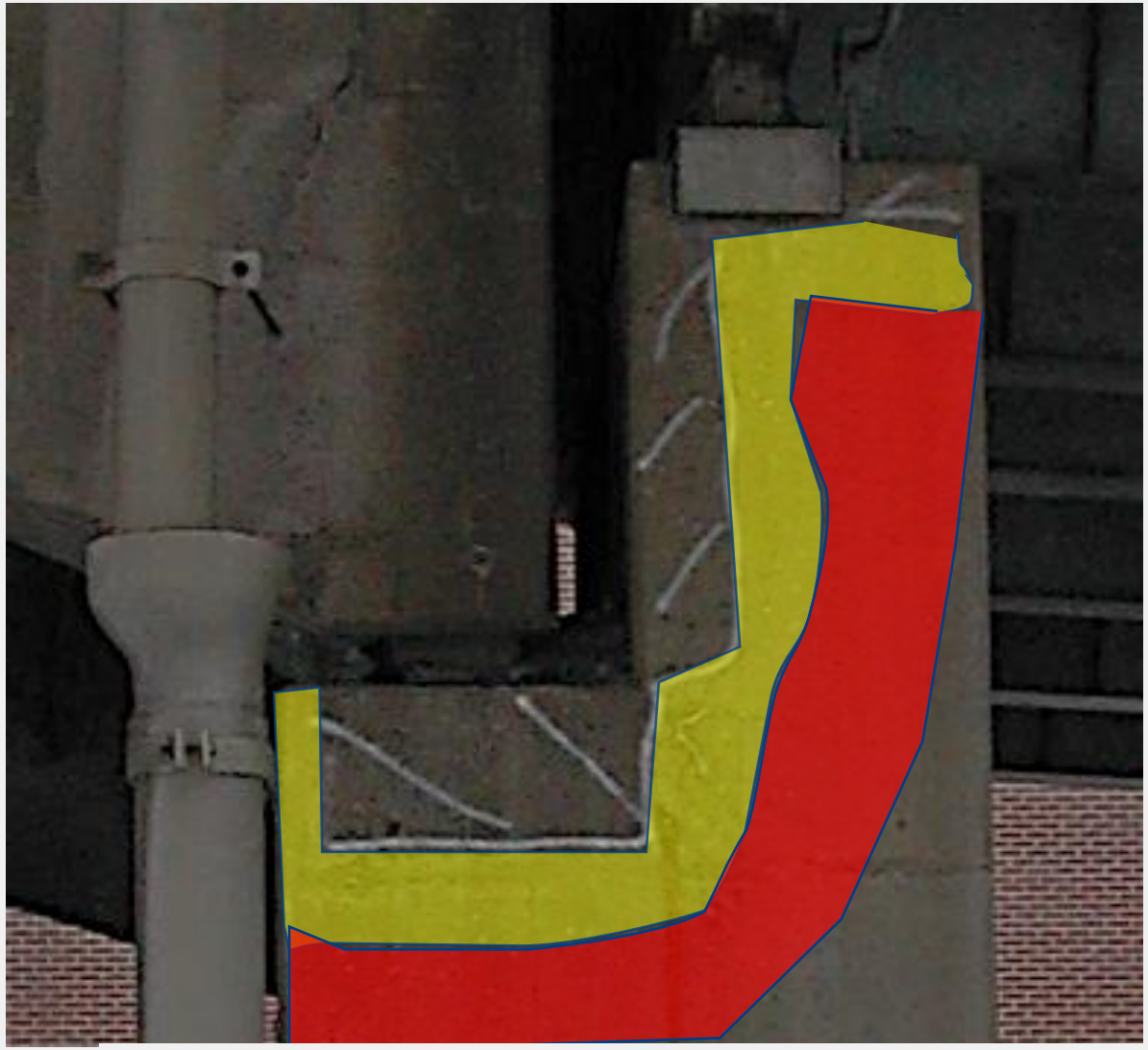
Delamination Survey

- ASTM D4580
  - Hammer sounding
  - Chain drag
- Locating areas where concrete sections have debonded
  - Falling hazard. Has the potential to become a spall

Large Near surface Delamination

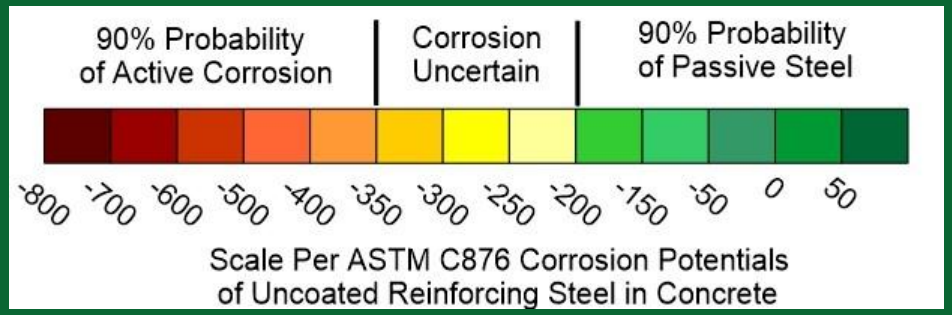
Extent of delamination beyond what sounding can pick up

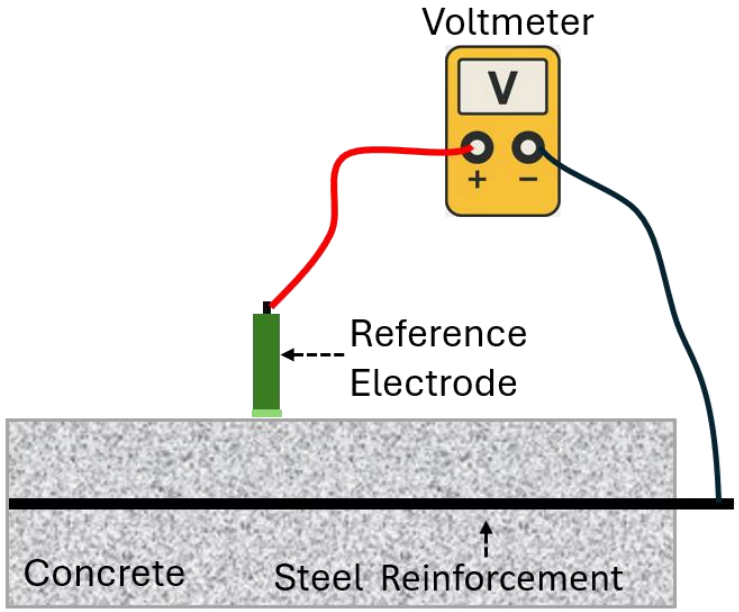
Corrosion is active but has not formed enough iron oxide to create significant cracking

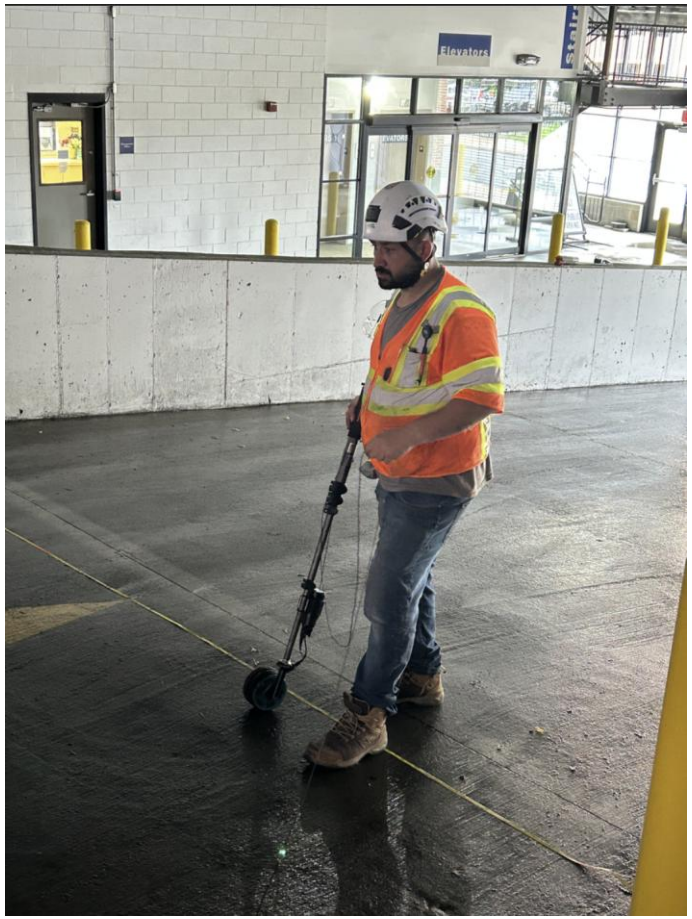


Corrosion Potential Survey

- Also known as Half-cell potential – ASTM C876
- Probability of active corrosion
- Measures the potential difference between the steel reinforcement and a reference electrode to identify the probably of active corrosion.







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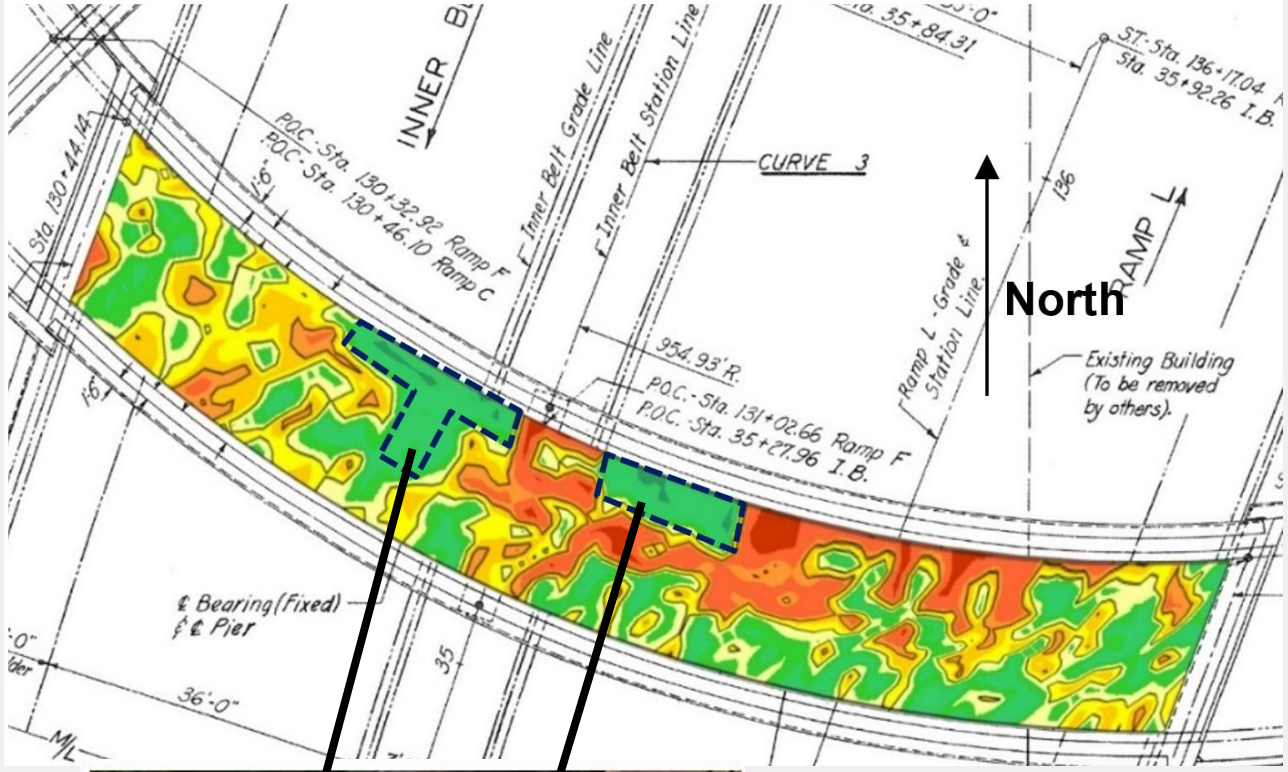
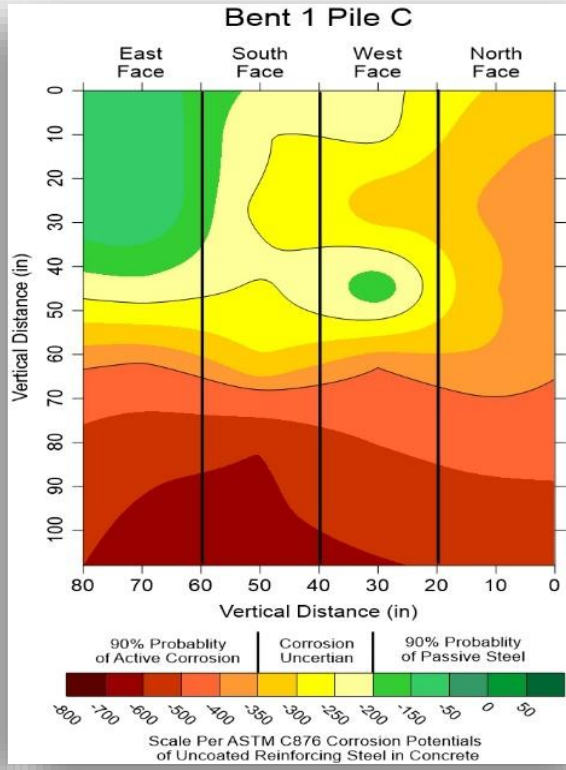


90% Probability of Active Corrosion | Corrosion Uncertain | 90% Probability of Passive Steel

-800 -700 -600 -500 -400 -350 -300 -250 -200 -150 -50 0 50

Scale Per ASTM C876 Corrosion Potentials of Uncoated Reinforcing Steel in Concrete



Chloride Concentration

- Caused by chlorides breaking up passive oxide layer
- Sources of chlorides:
  - Marine Environments
  - De-icing Salts (NaCl, $CaCl_2$)
  - Chemical Plant Environment
  - Cast-in Chlorides
- **Chlorides are never consumed**

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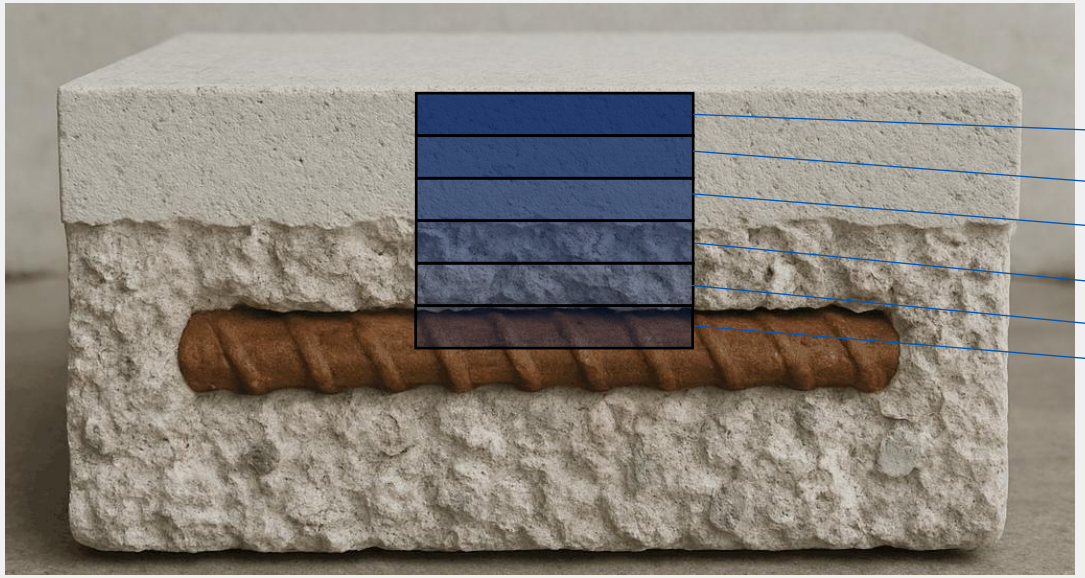
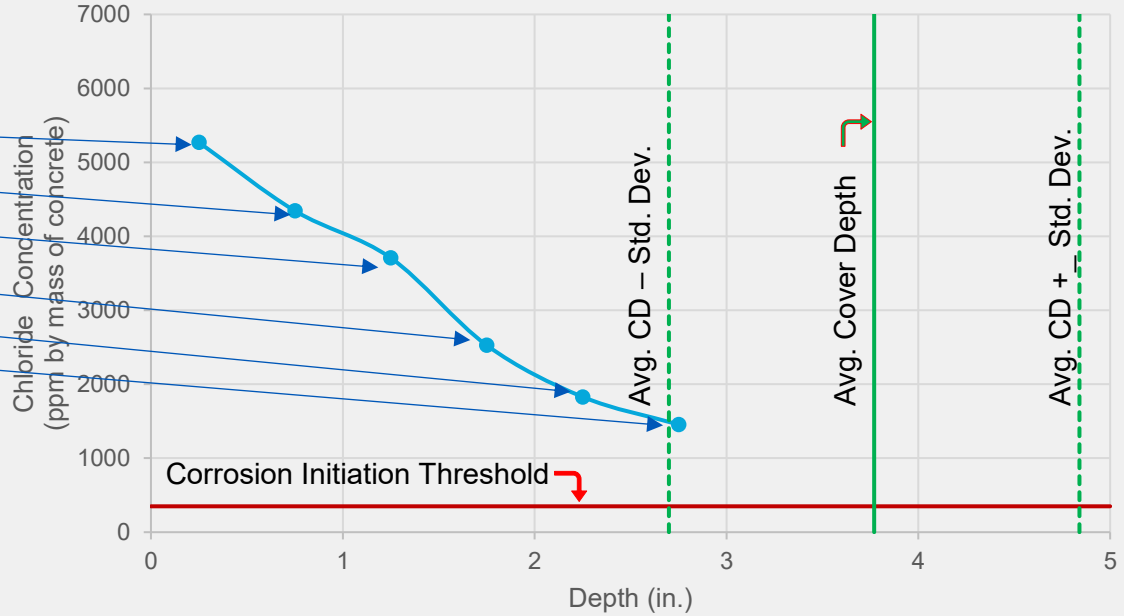
Chloride Concentration Threshold

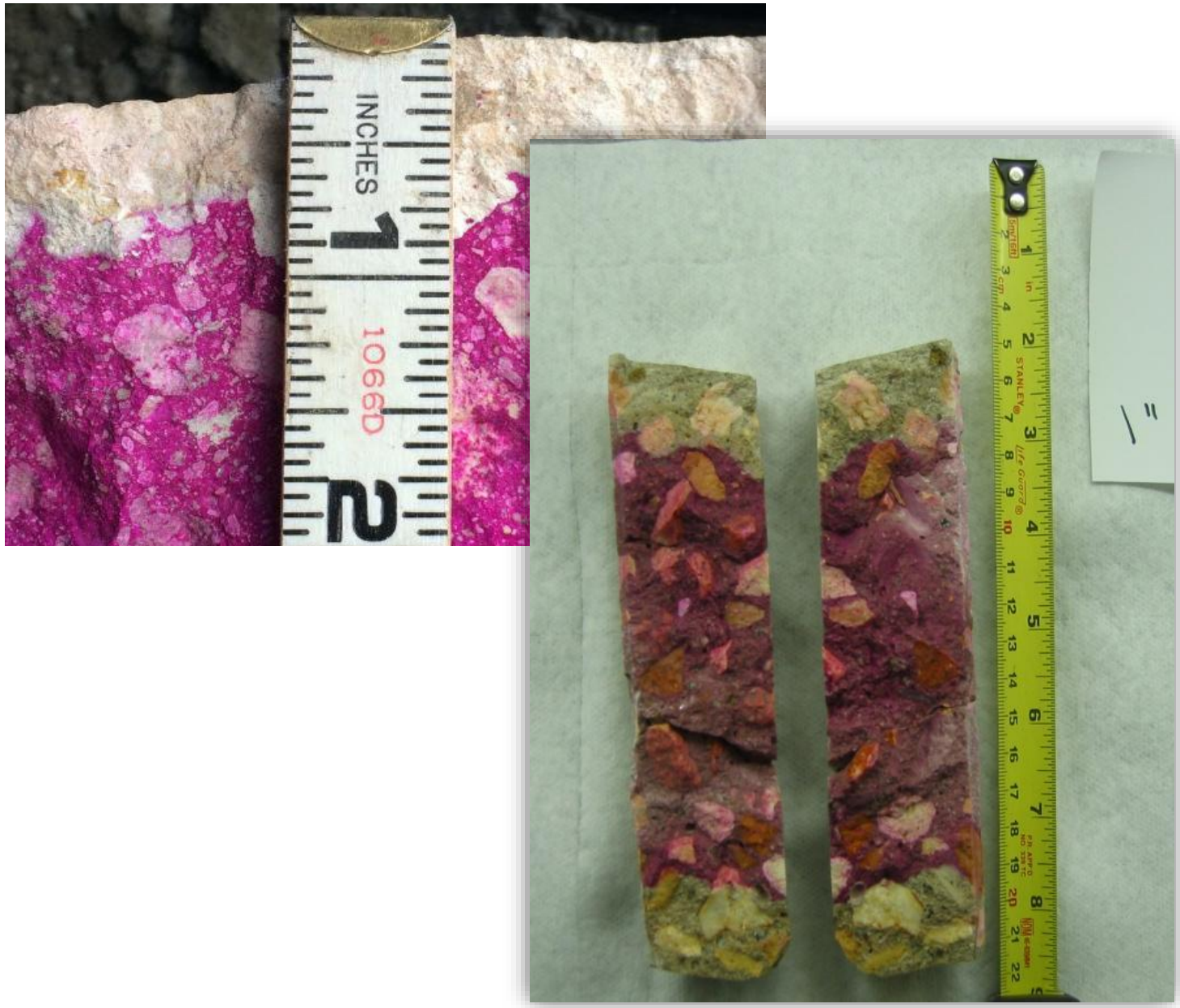
- Chloride concentration at reinforcement depth can identify if chloride is cause of corrosion – ASTM C1152
- Typically, chloride concentration is measured with relation to depth.
  - Identify rate at which chloride is diffusing into concrete
- Cores | Powders
- Threshold
  - 350 ppm | 0.035% by mass of concrete | 1.5 lbs. per cubic yard of concrete





Carbonation Depth

- CO_2 diffusion into concrete- Reduces pH
  - CO_2 reacts with free lime, $Ca(OH)_2$, resulting in $CaCO_3$ and H_2O
- Reduced pH de-passivates steel
- Often seen when
  - Concrete permeability is high
  - Industrial sites
  - Very old structures – carbonation is a result of time and exposure
- In a chloride environment, carbonation can initiate corrosion at lower levels of chlorides
- Important to identify the cause of corrosion for cathodic protection system design



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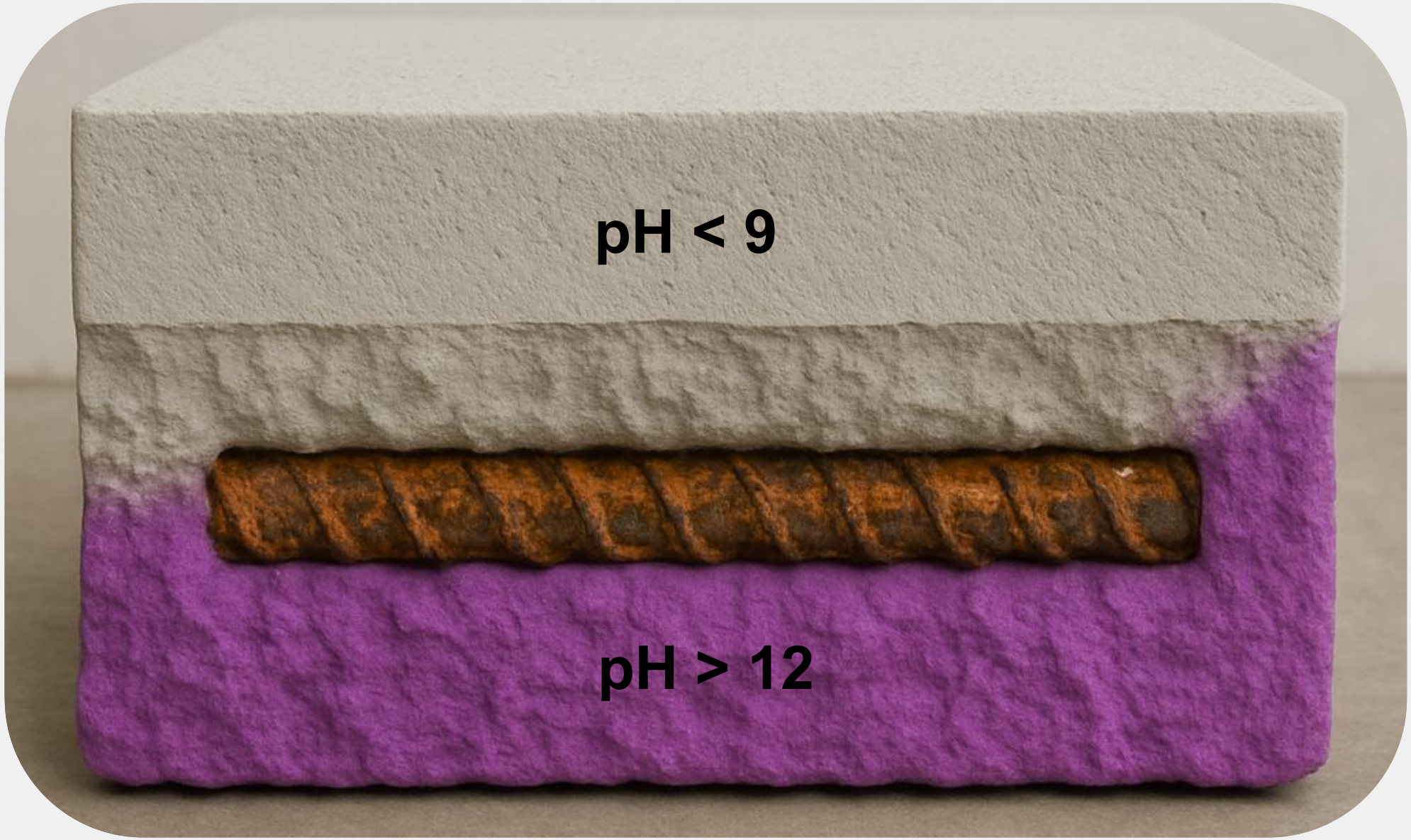
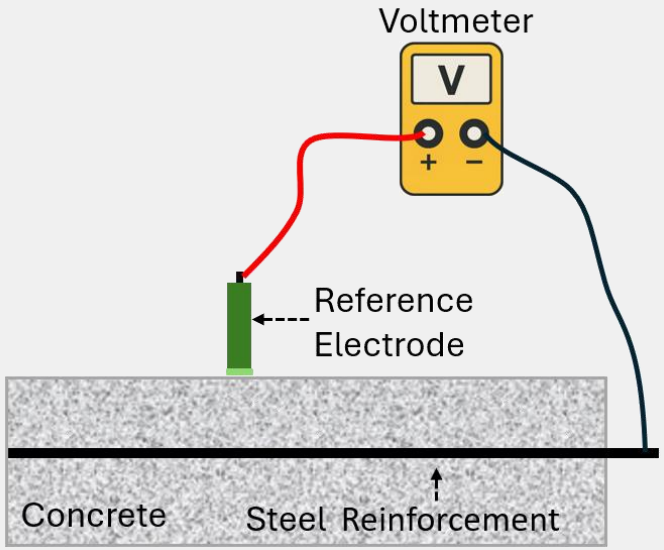
Carbonation-Induced Corrosion

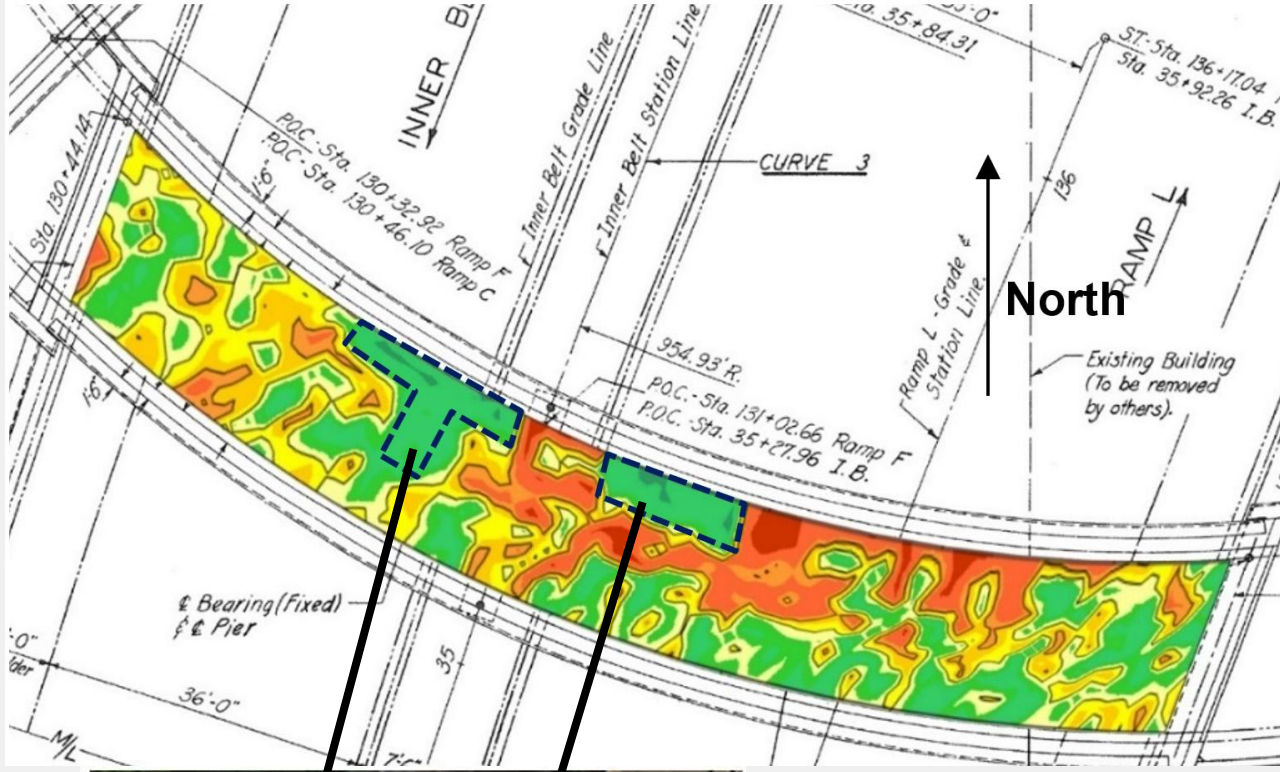


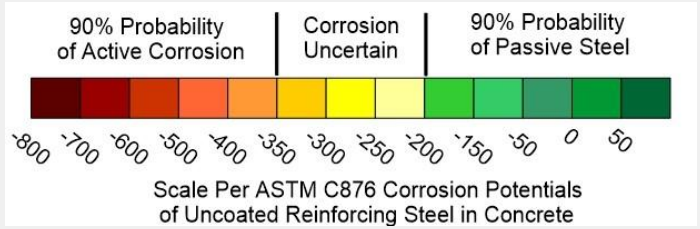
Local Protection

Partial/Full Depth Concrete Repair- Corrosion Mitigation

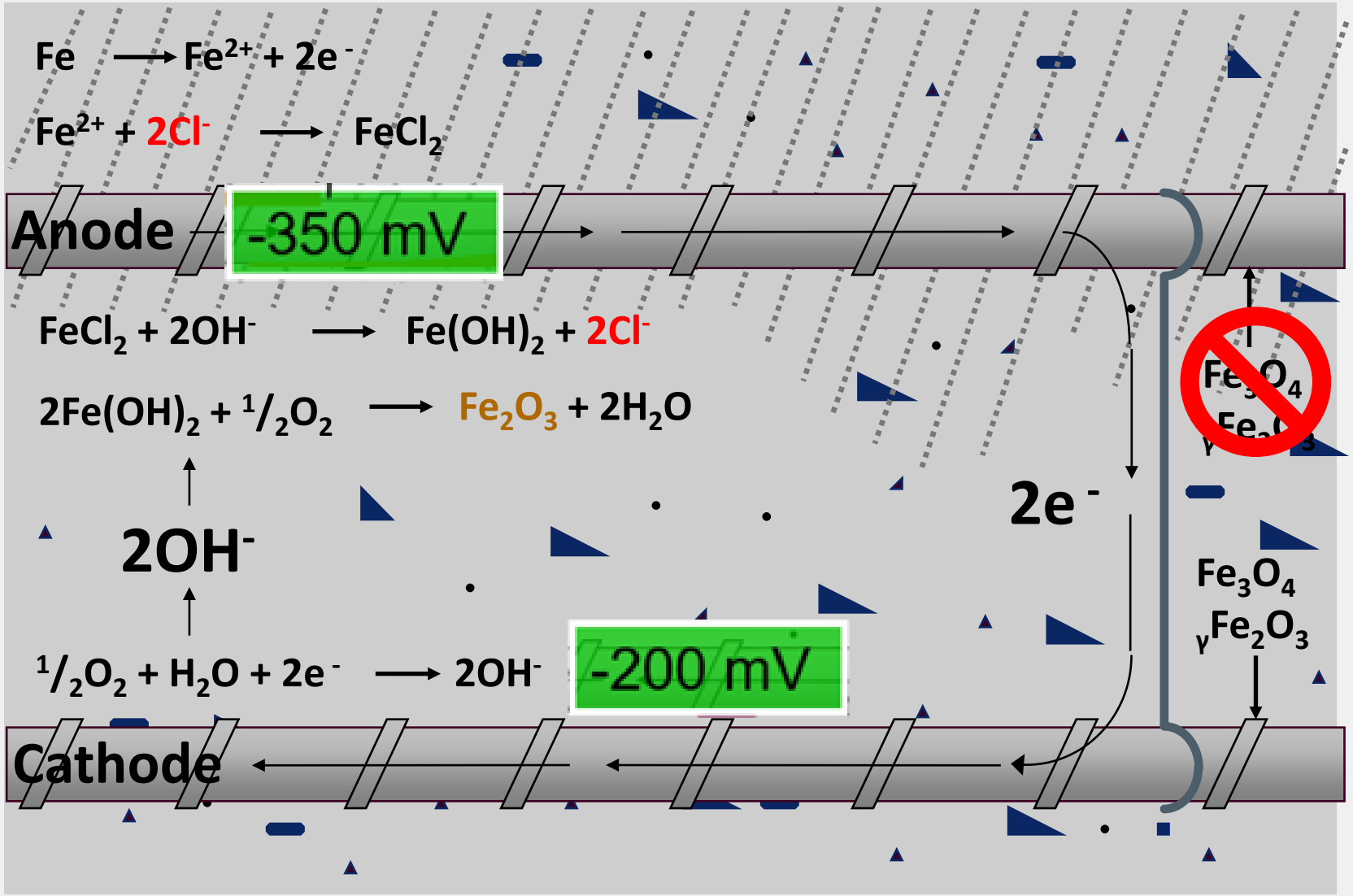
Concrete Repairs



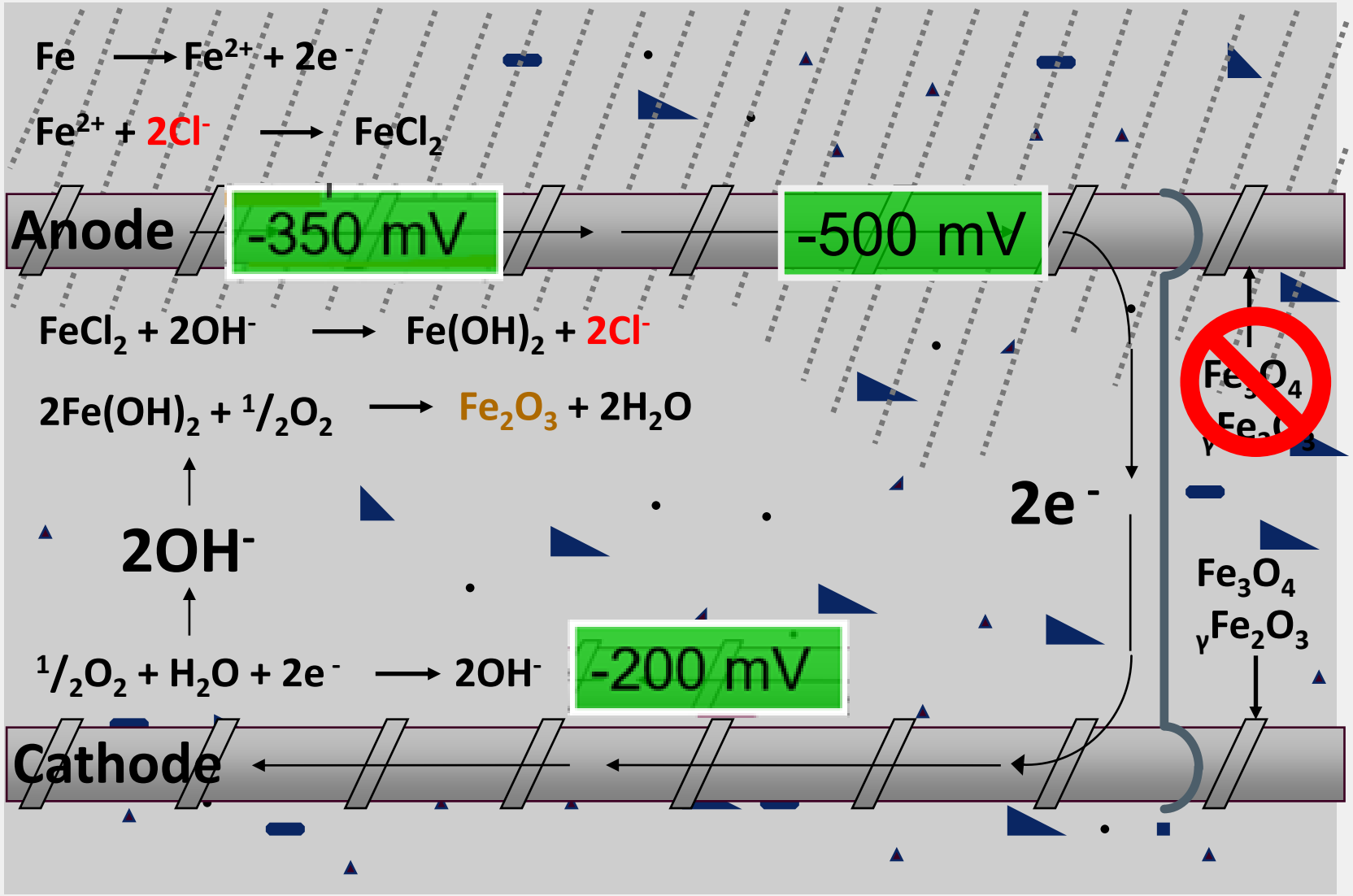




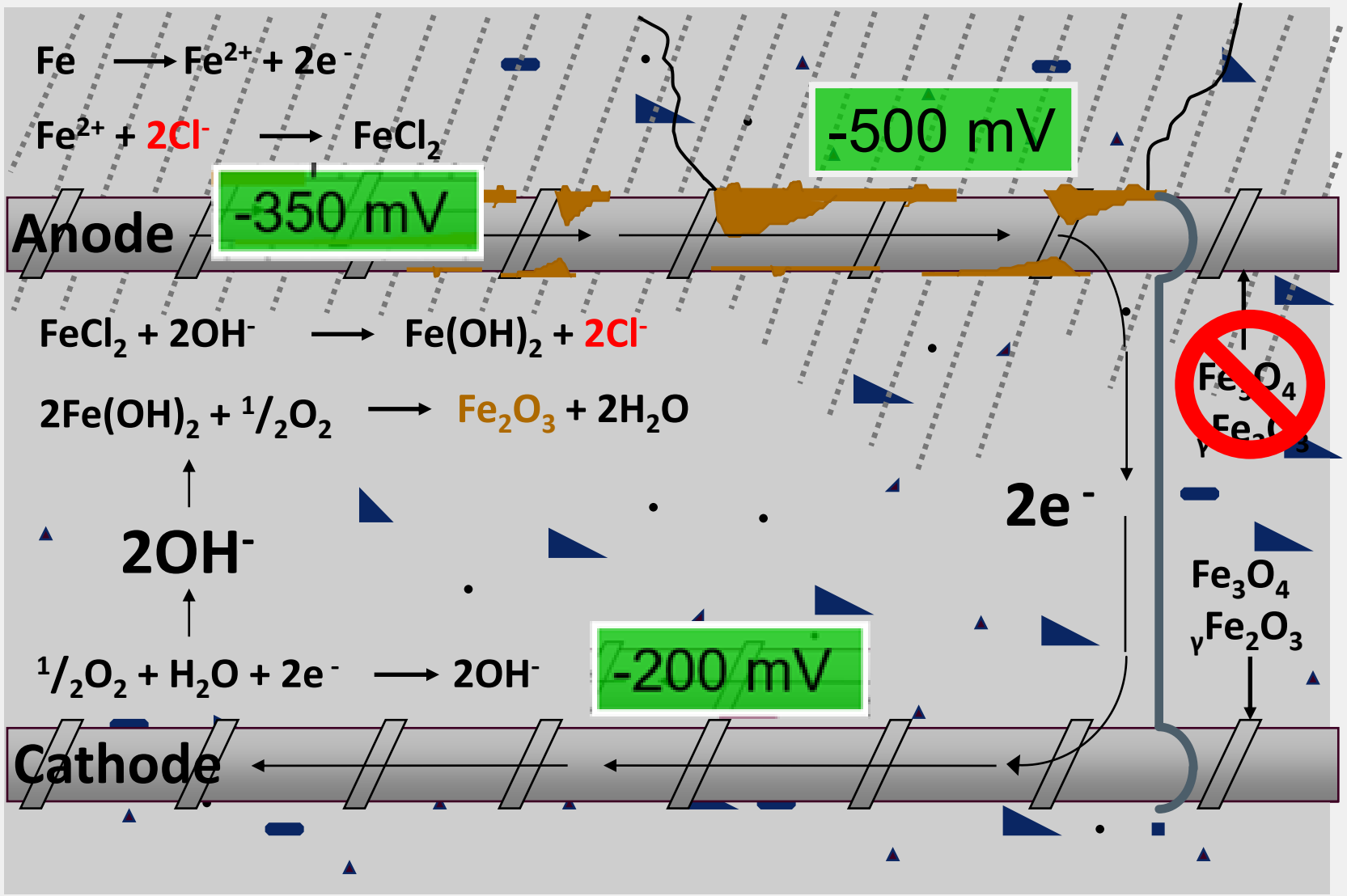
Concrete Patch Repairs



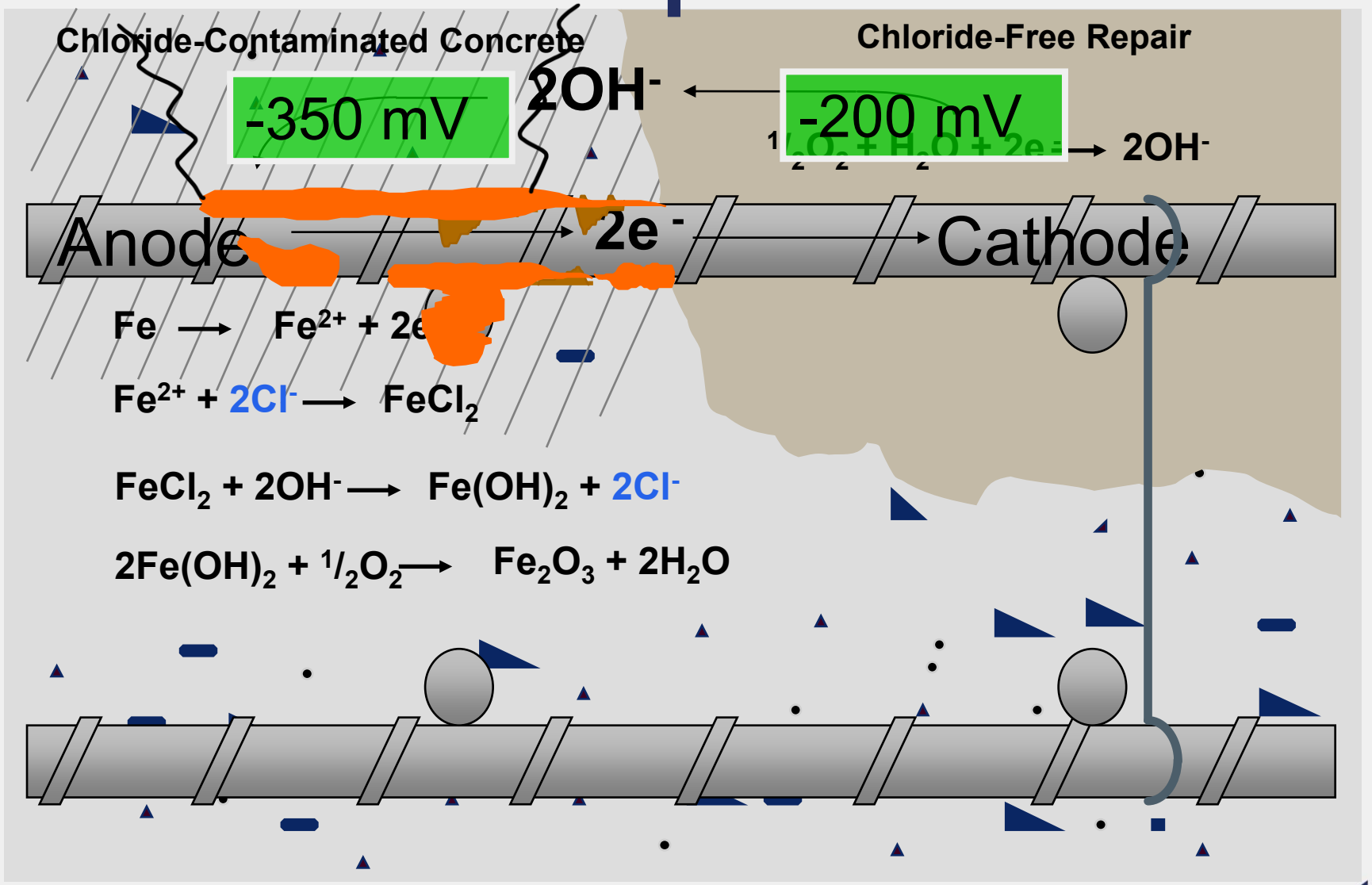
Concrete Patch Repairs



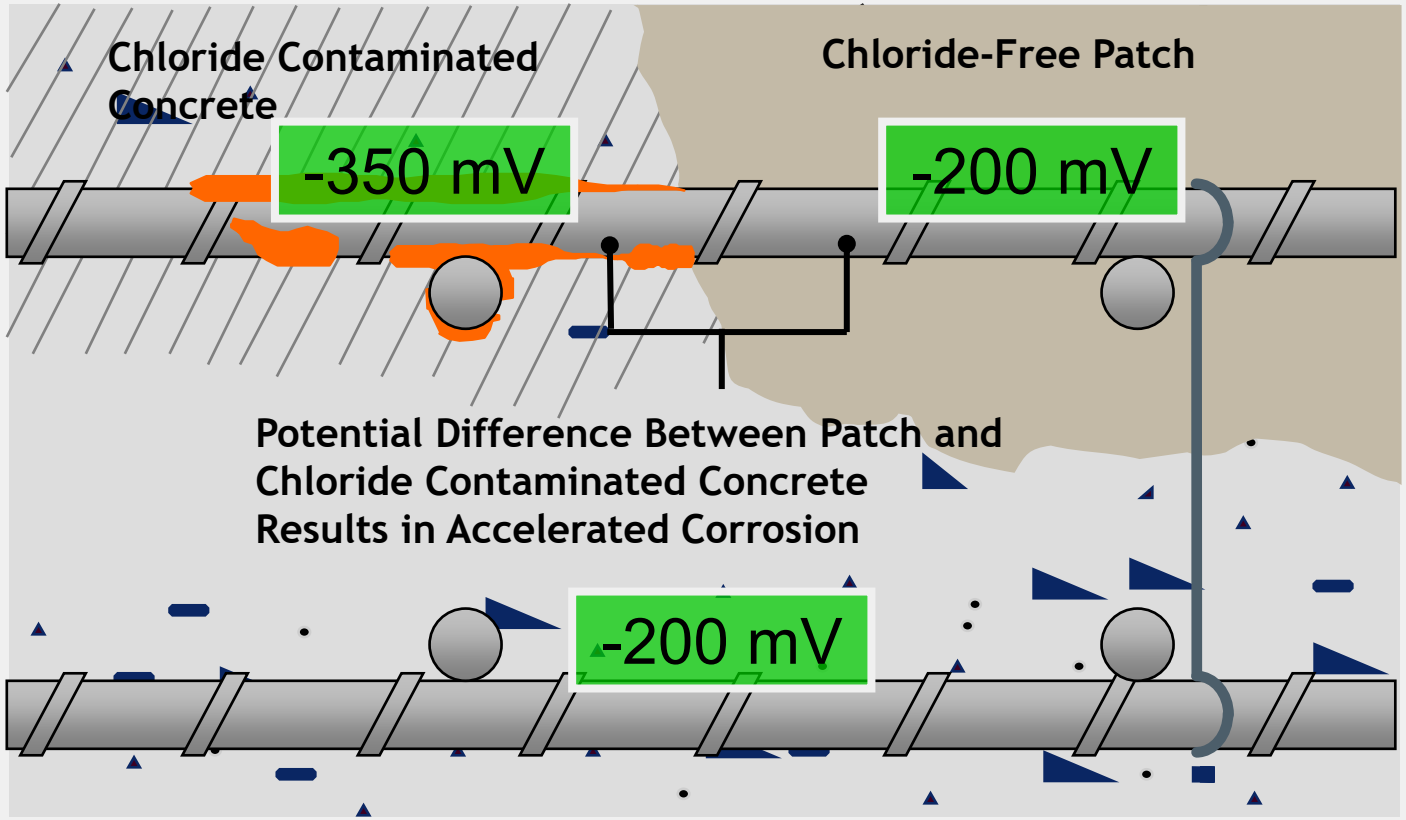
Concrete Patch Repairs



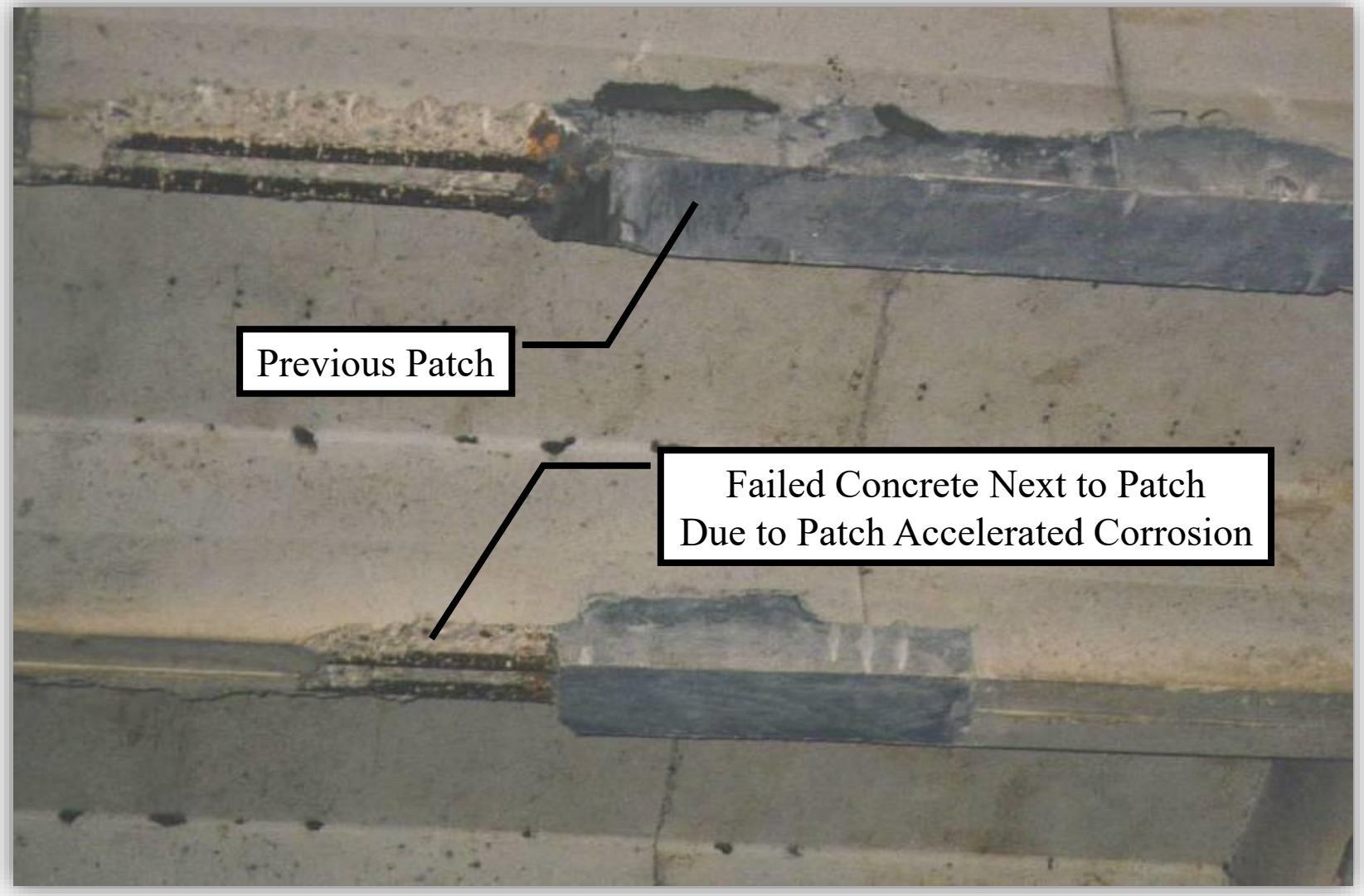
Concrete Patch Repairs



Patch Accelerated Corrosion

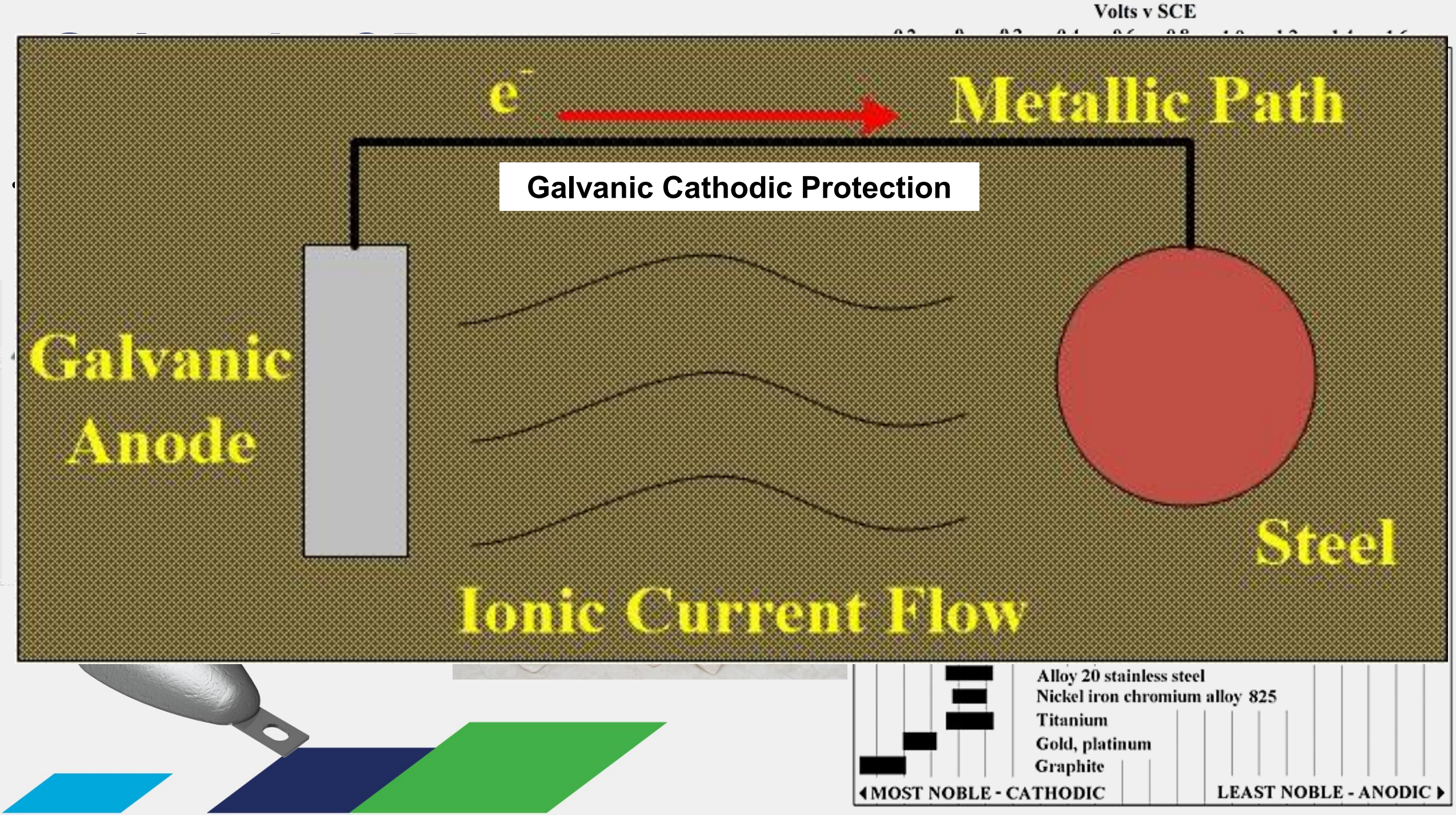


Patch Corrosion “Halo Effect”

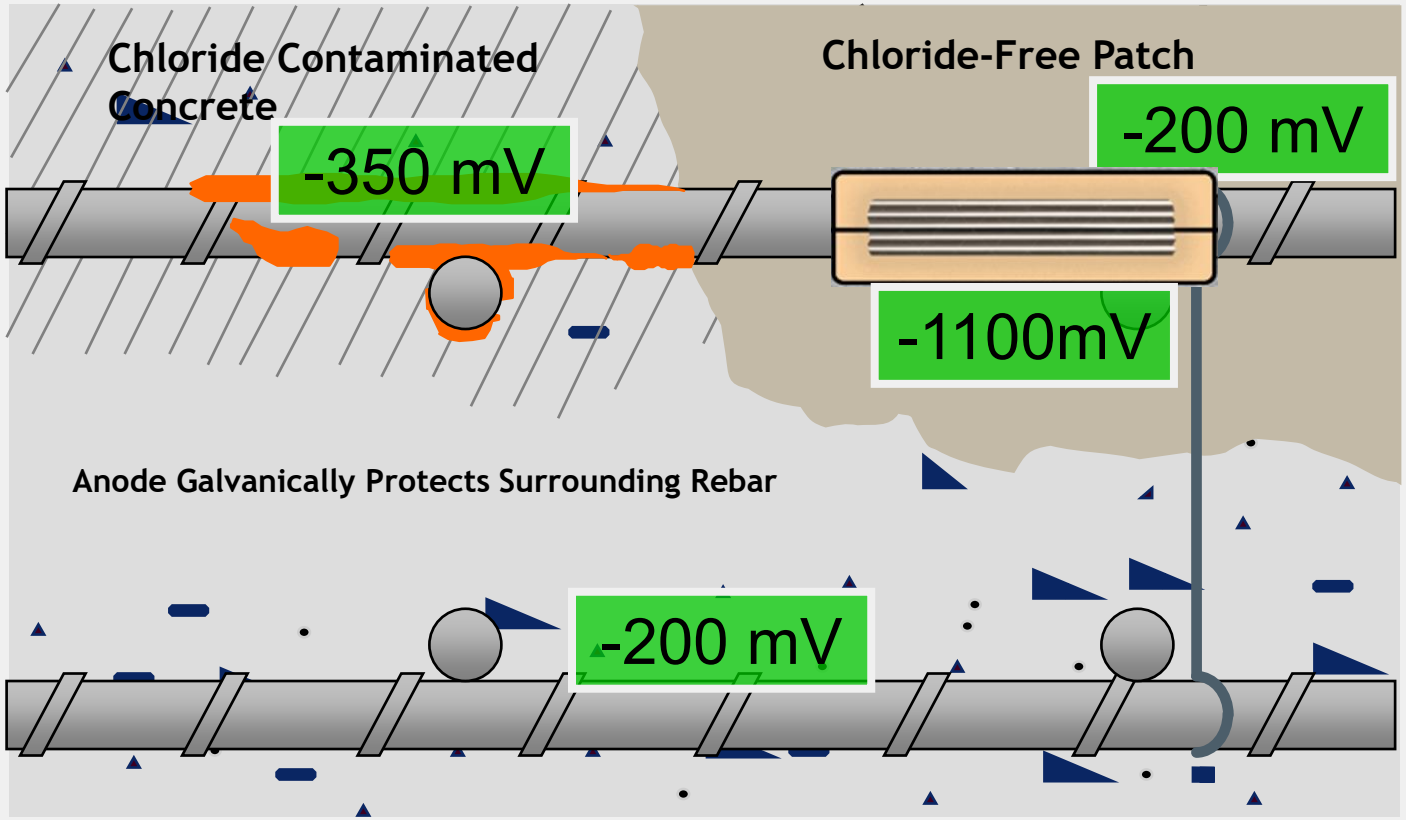


Cathodic Protection

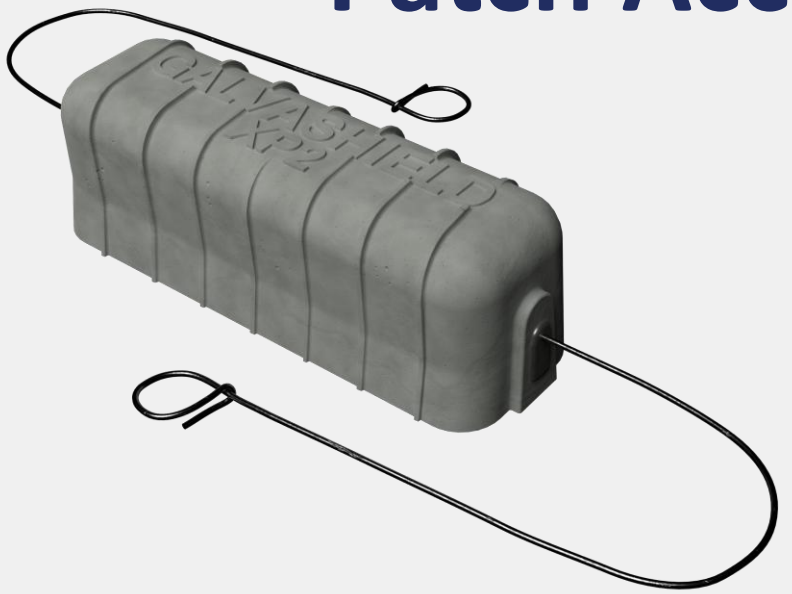
- Cathodic protection (CP) is a method of corrosion control through the application of direct current to a metal under protection, forcing it to become a cathode
  - Anode is where rust occurs and the cathode is protected from section loss
- Two main types of CP
  - Galvanic
  - Impressed current

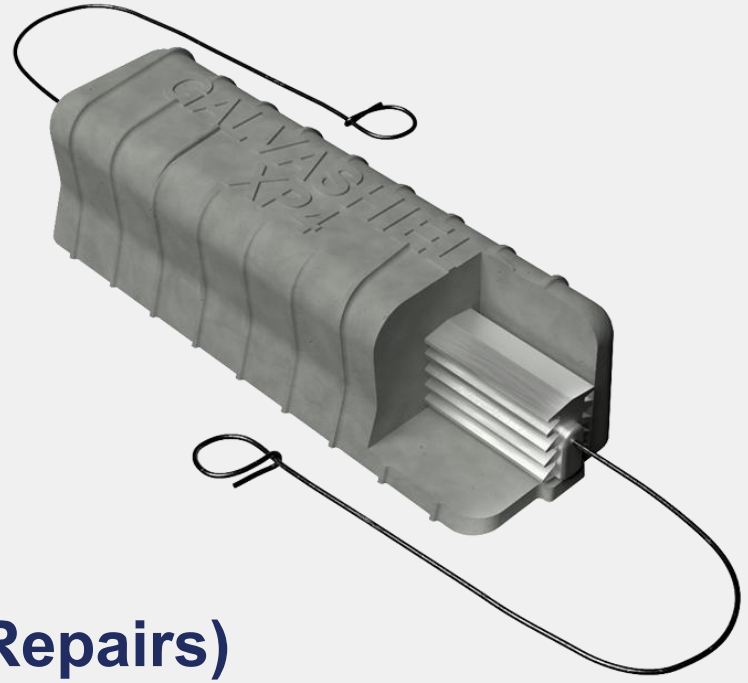

Volts v SCE
e⁻
Metallic Path
Galvanic Cathodic Protection
Galvanic Anode
Steel
Ionic Current Flow
Alloy 20 stainless steel
Nickel iron chromium alloy 825
Titanium
Gold, platinum
Graphite
MOST NOBLE - CATHODIC
LEAST NOBLE - ANODIC

Make the Steel Cathode - Install Sacrificial Anode
Concept of Dissimilar Metals



How to Prevent Patch Accelerated Corrosion?





Type 1 Anodes (Concrete Repairs)

- Type A: Alkali Activated (High pH)
- Type H: Halide Activated (Chlorides/Bromides)

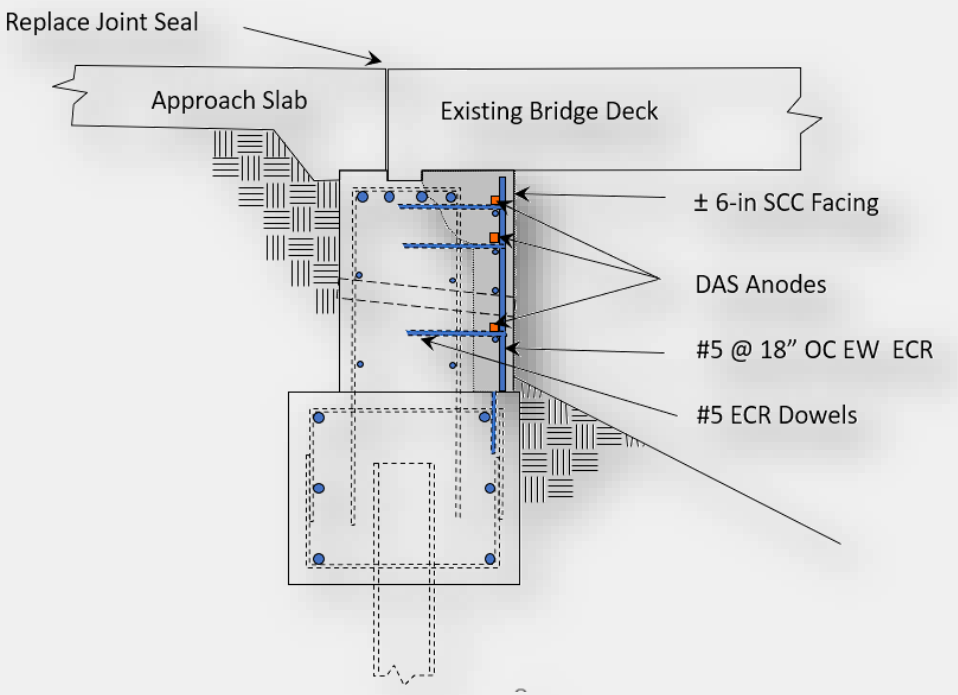
Distributed Galvanic Anodes

- Distributed anode units are pre-manufactured
  - Zinc around a steel core
  - Integral connections
- Anode size and spacing: based on steel-to-concrete surface area ratio and service life

I-75 Slab Bridge Abutments Ohio DOT
Abutment Conditions, 2005

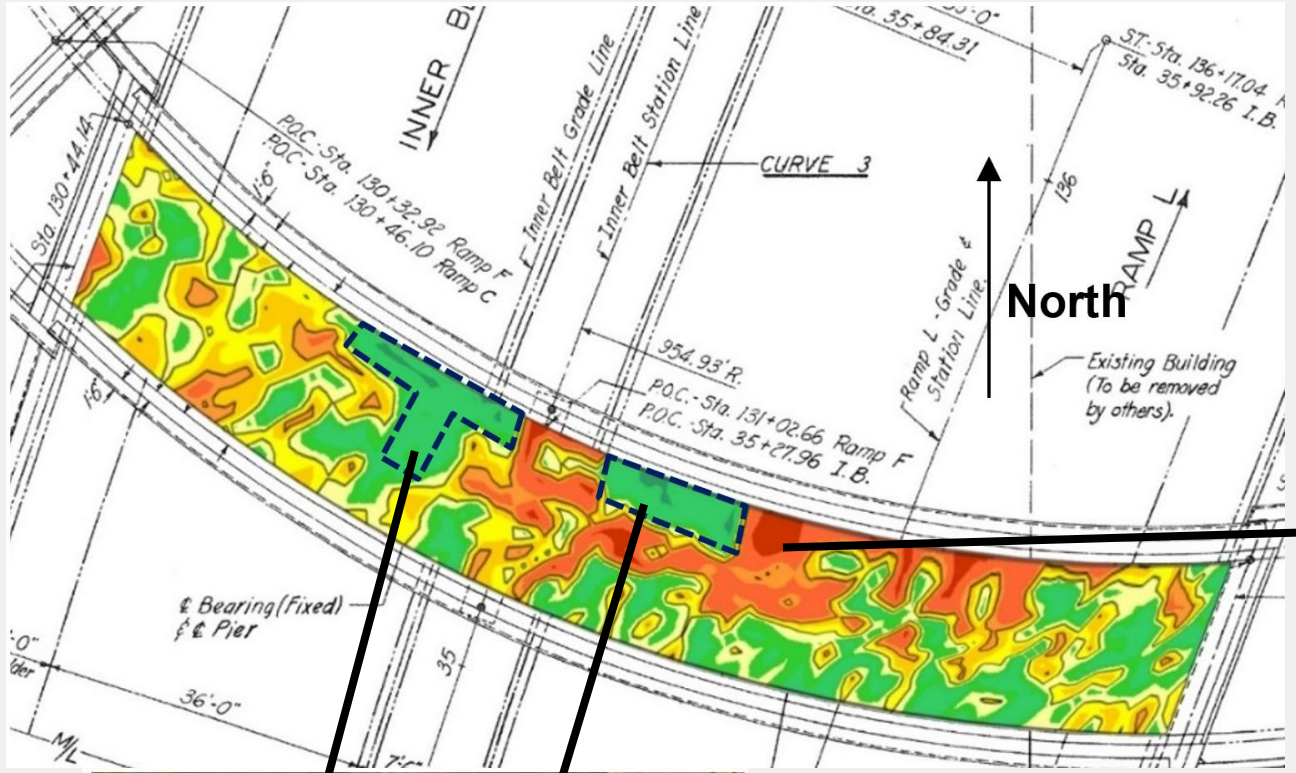
Galvanic Encasement of Slab

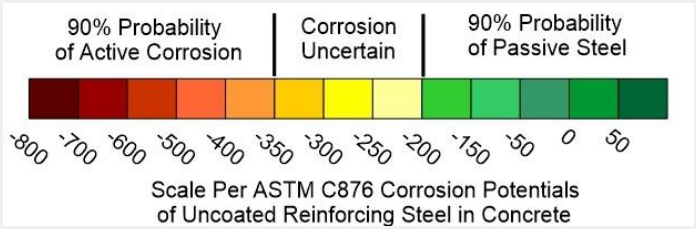
Bridge Abutment Utilizing Distributed Galvanic Anodes



Galvanic Encasement of Slab

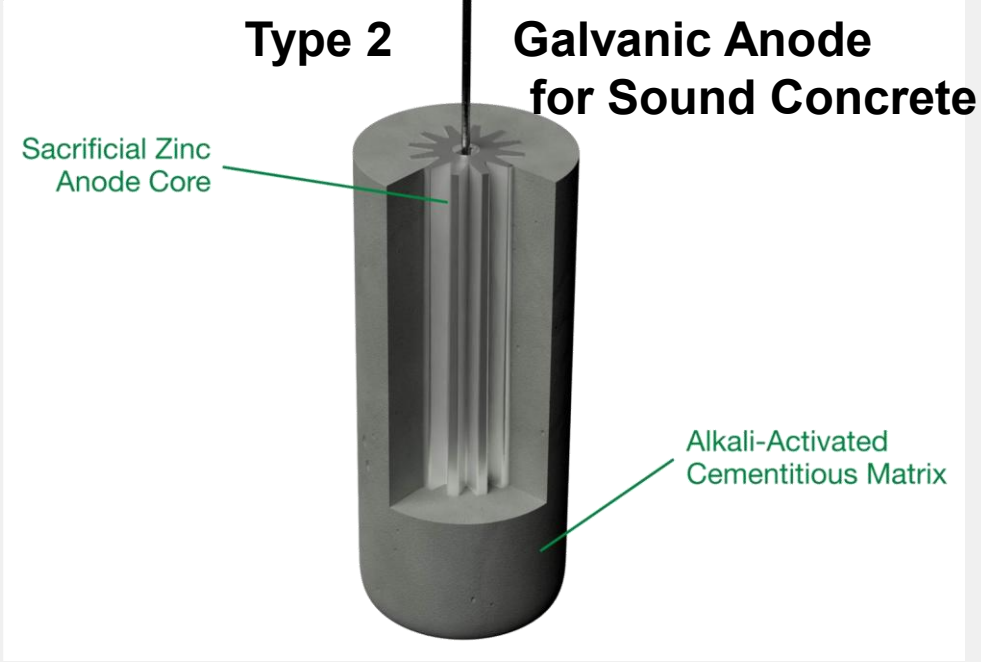
Bridge Abutment Utilizing Distributed Galvanic Anodes

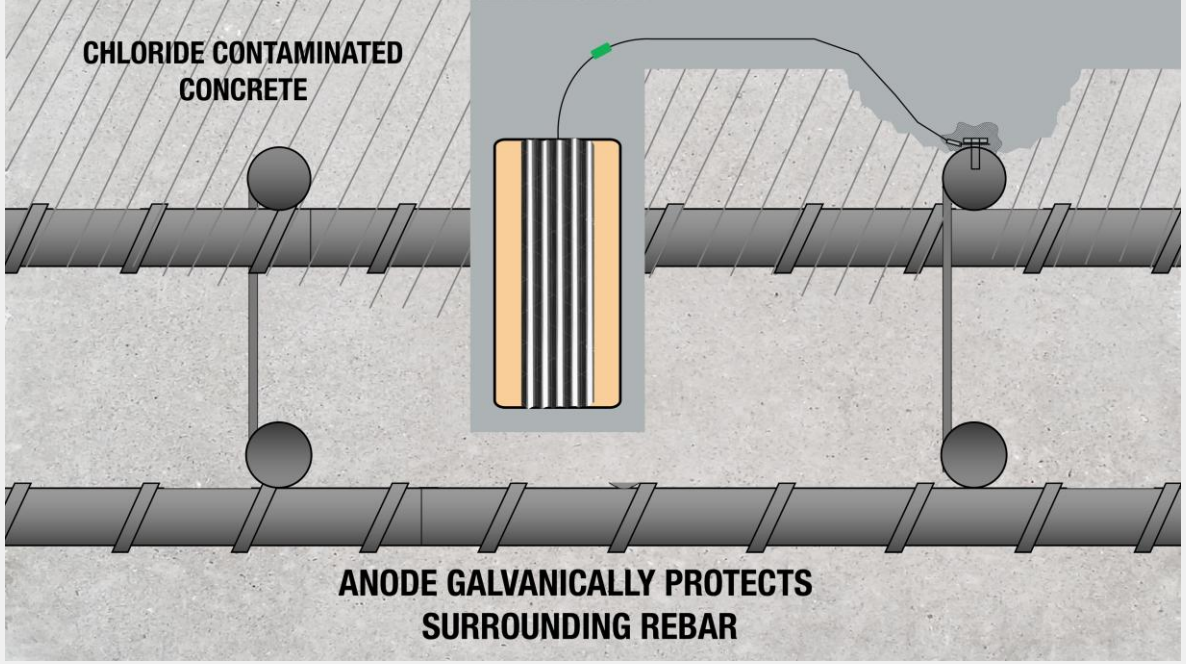


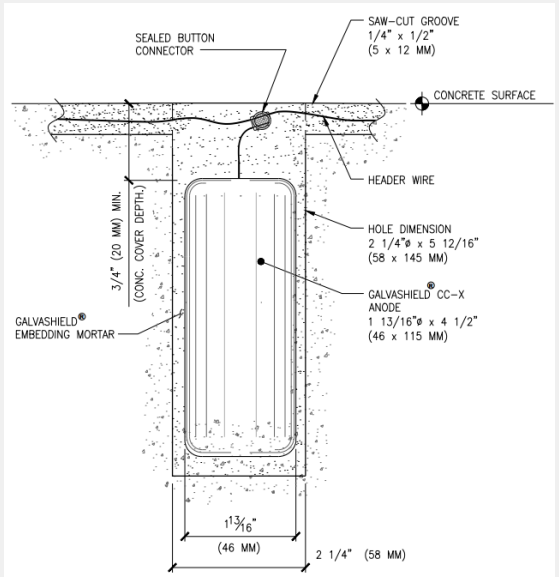


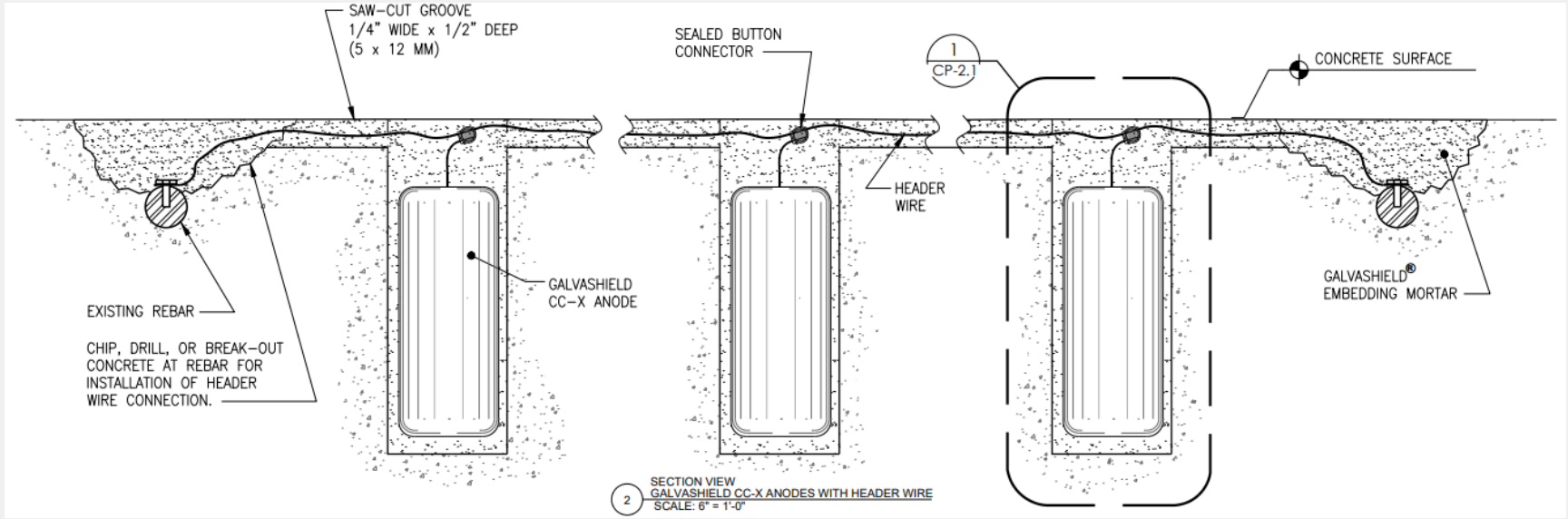
- **Issue:**
  - Active Corrosion in concrete
  - Not yet cracked/ Spalled
  - Future Spalling
- **Need:**
  - *Proactively protect steel from corrosion*
- **Solution:**
  - ***Type 2** Galvanic Anodes*

Type 2 Galvanic Anode for Sound Concrete



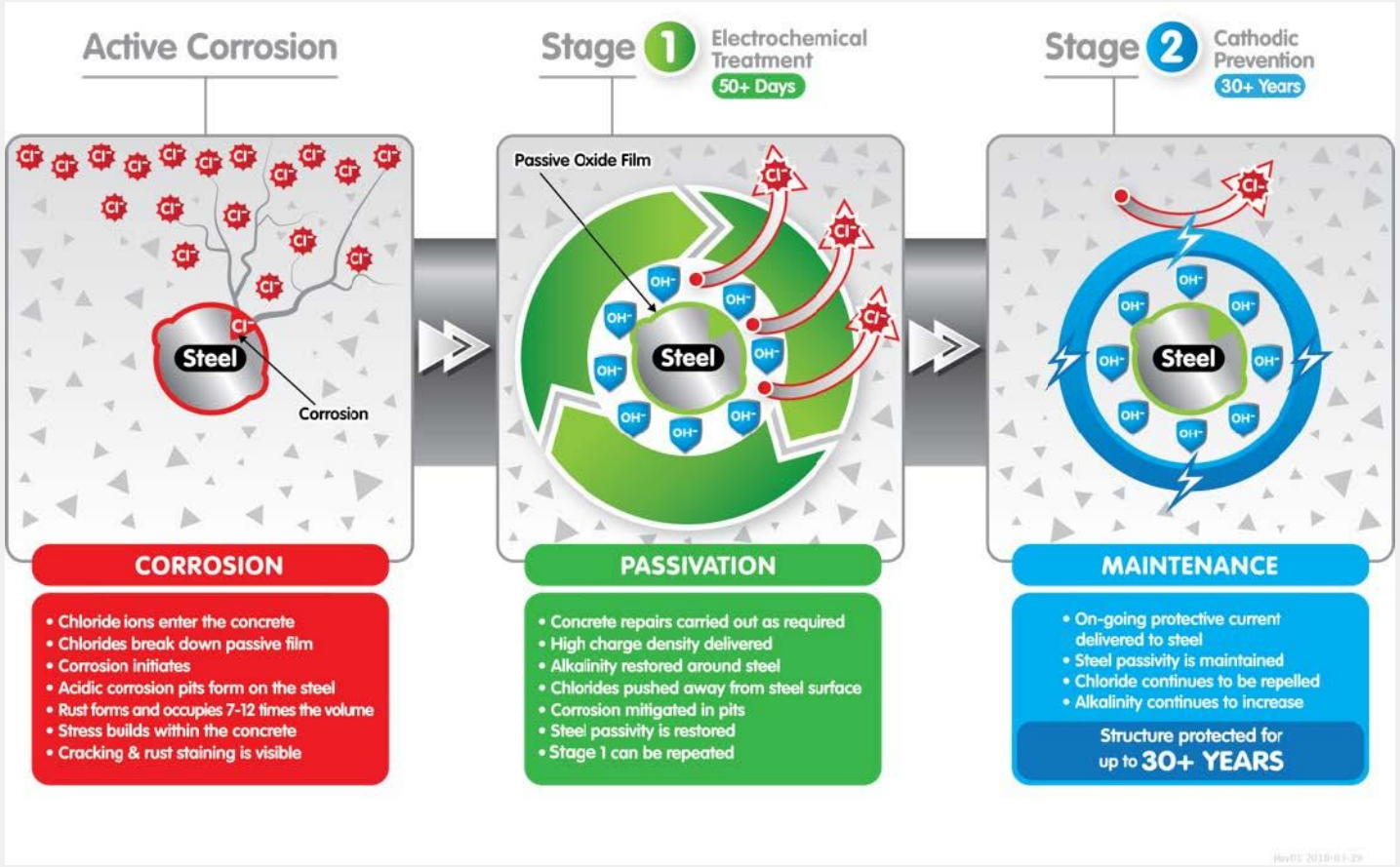


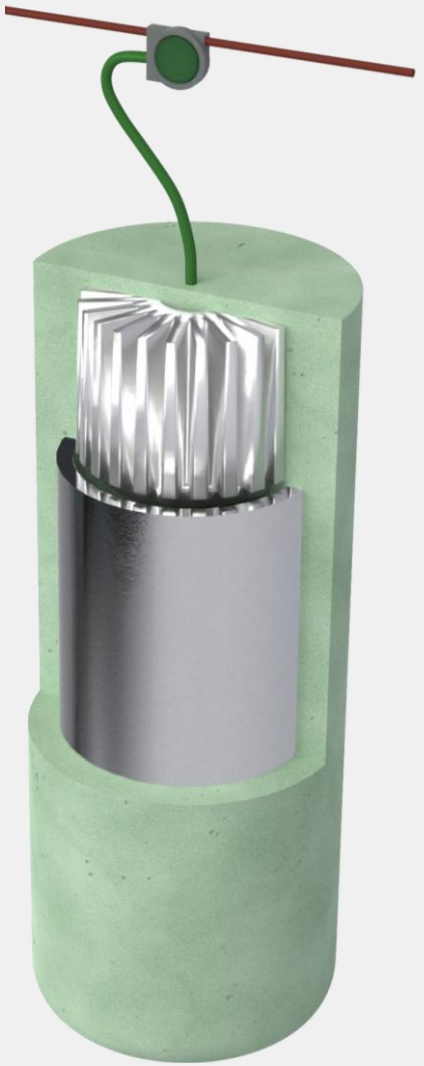


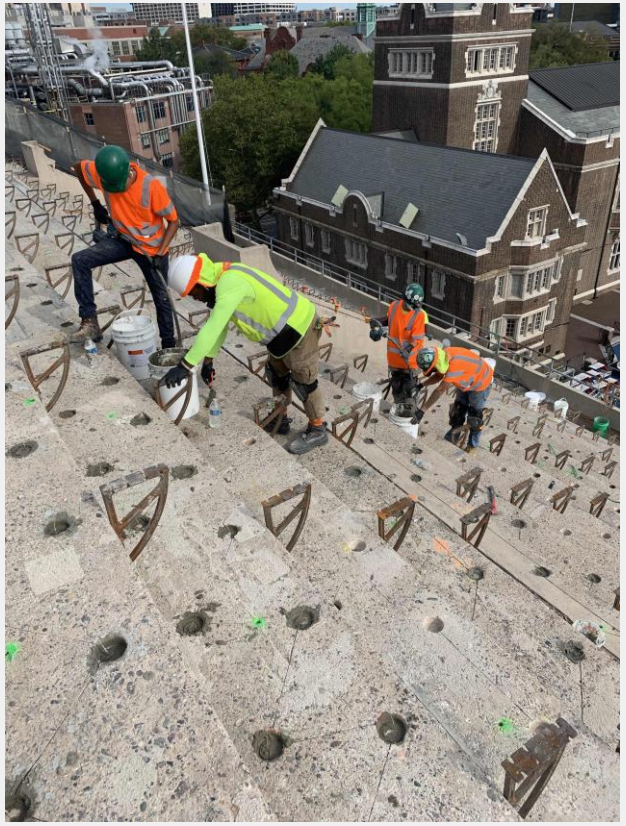


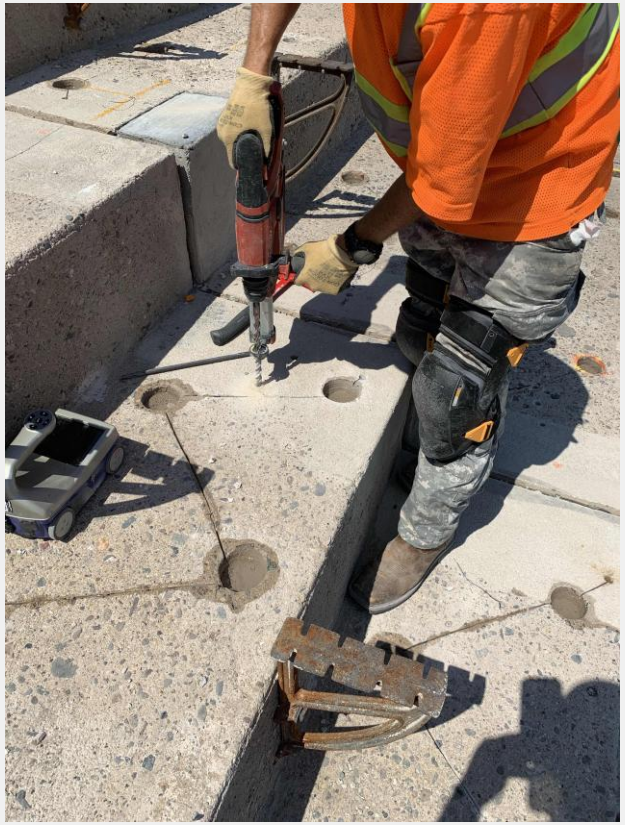
Hybrid Anodes

Phase 1: Impressed Current Cathodic Protection System (Battery)
Phase 2: Galvanic Cathodic Protection System (Zinc)



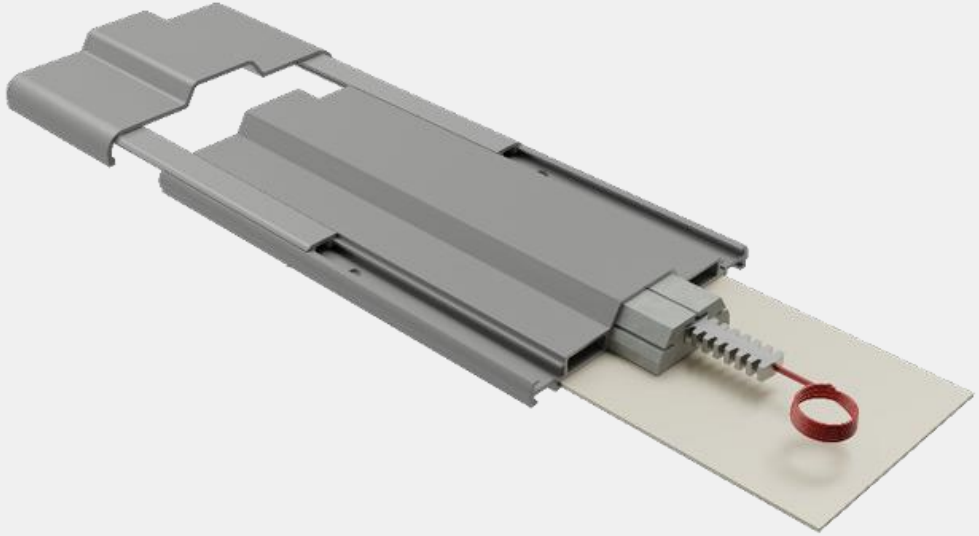







1:50PM

Surface Mounted System



Arc Sprayed Zinc

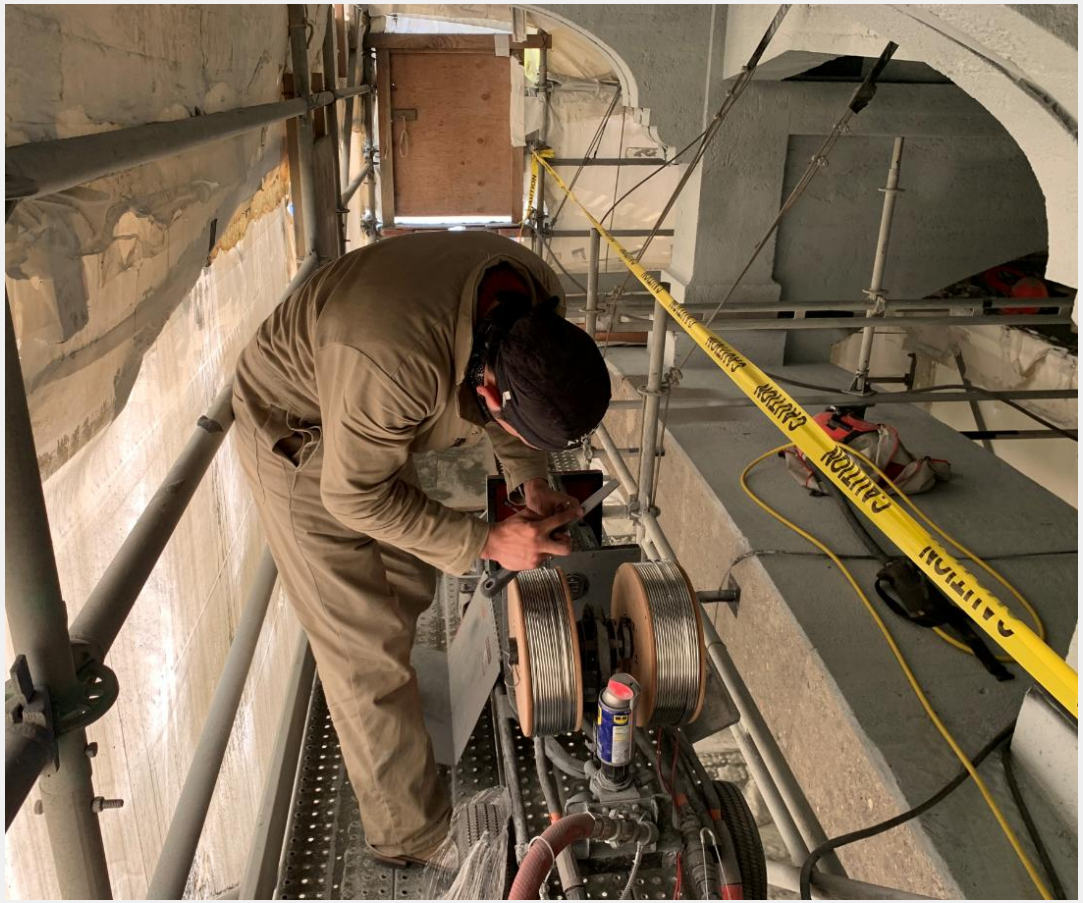
- Surface Applied Galvanic Anode -Typically Zinc
- Molten metal is sprayed directly onto the concrete surface using compressed air.
- Typical heat sources are Electrical Arc or Flame

Surface Preparation

- Clean surface with light abrasive blasting
- Achieve sufficient profile which maximizing the amount of cement paste in contract with the zinc coating
- Dry compressed air used to clean any residual dust and blast media

Access and Containment

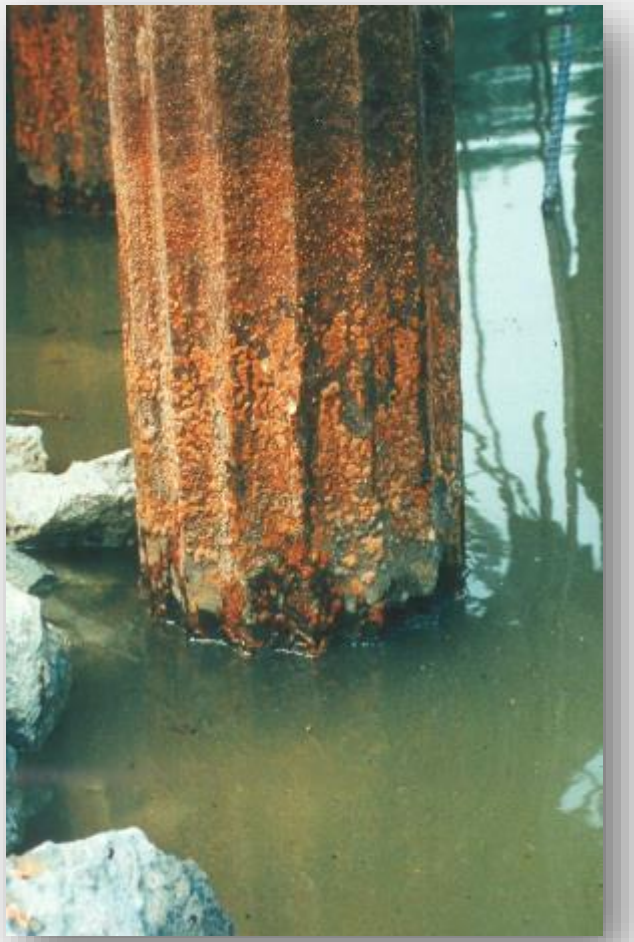
Metalizing Equipment



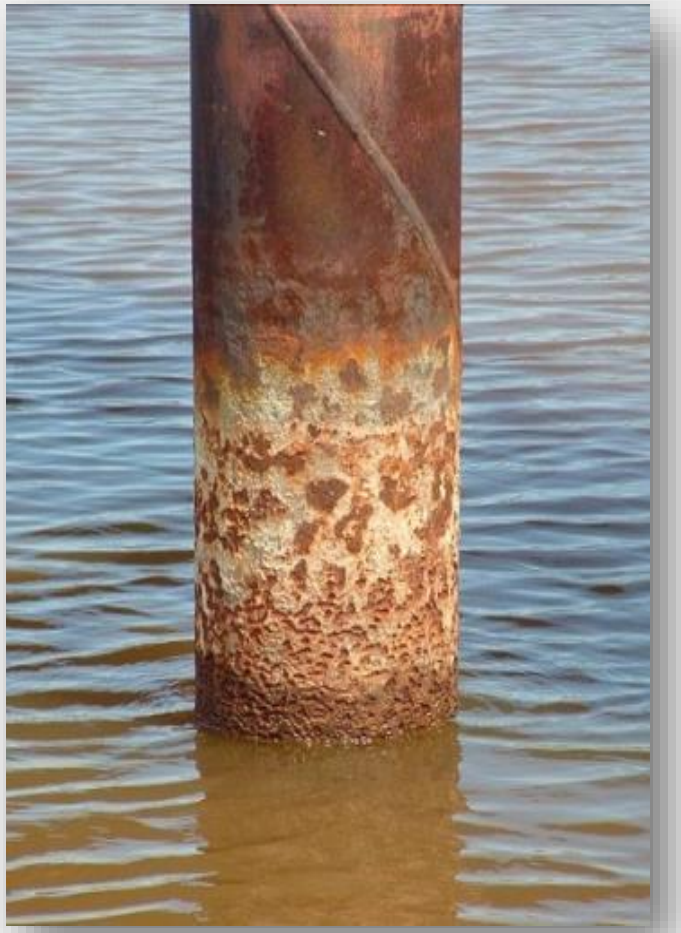
Marine Infrastructure

Corrosion Mitigation Solutions for Marine Infrastructure

Past Pile Corrosion Strategies



Uncoated Steel Pile



Coating Failure on Steel Pile

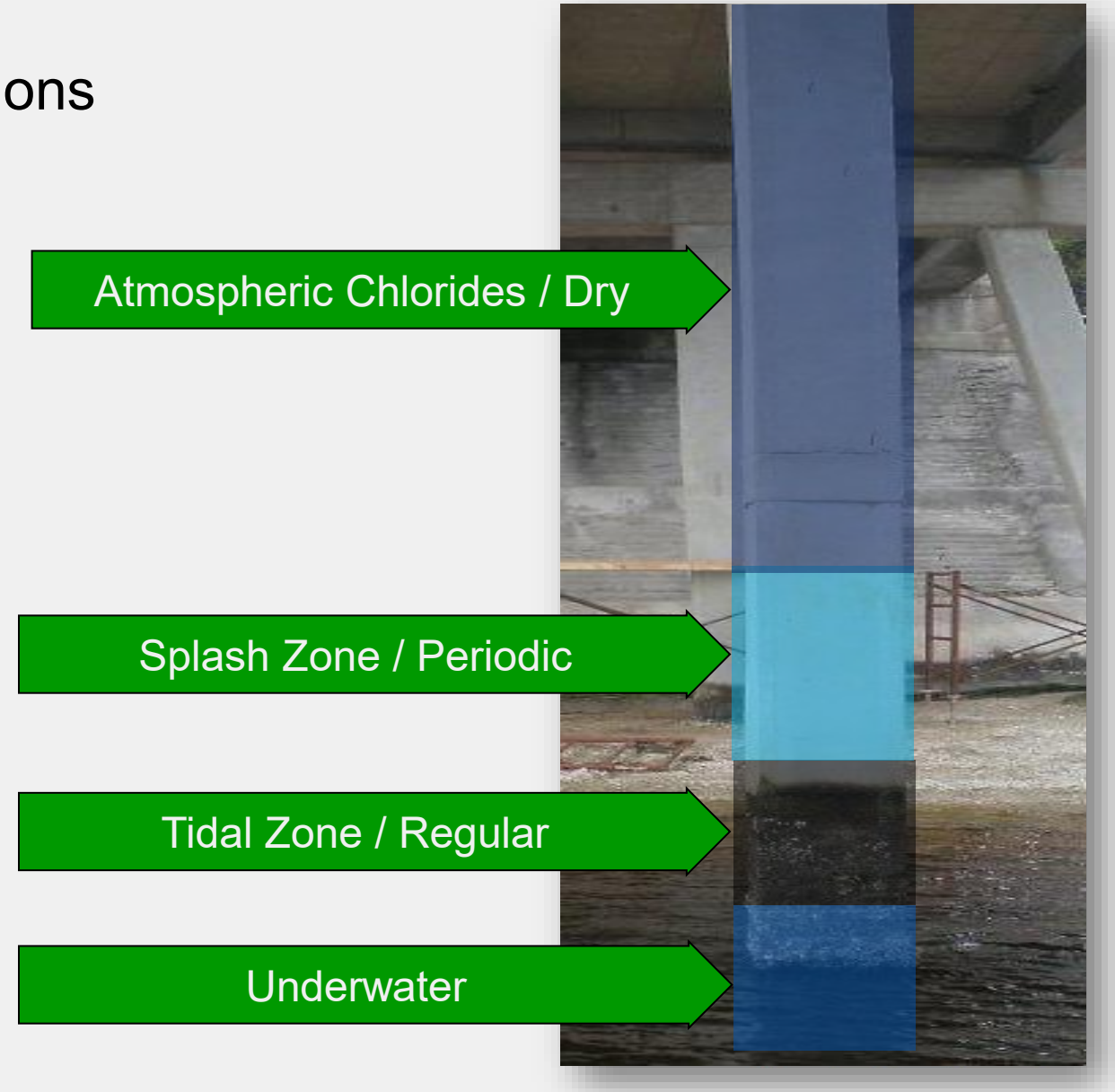
- Uncoated steel piles
- Coated steel piles
- Constant wetting cycle deteriorates coating
- Coating failures
- Corrosion continues
- Very difficult to apply / repair in the field.

Pile Exposure Conditions

- A pile can be exposed to multiple conditions
- Varying from
  - submerged (underwater)
  - Tidal (Daily wet / dry)
  - Periodic (Storm / Wind)
  - Atmospheric (Dry)

Saltwater is not always present at every location

All conditions can be corrosive!



Past Pile Corrosion Strategies

Expanded Zinc Mesh / FRP Jacket and Bulk Anode

Zinc Mesh CP Jacket -

Developed in 90's by FDOT

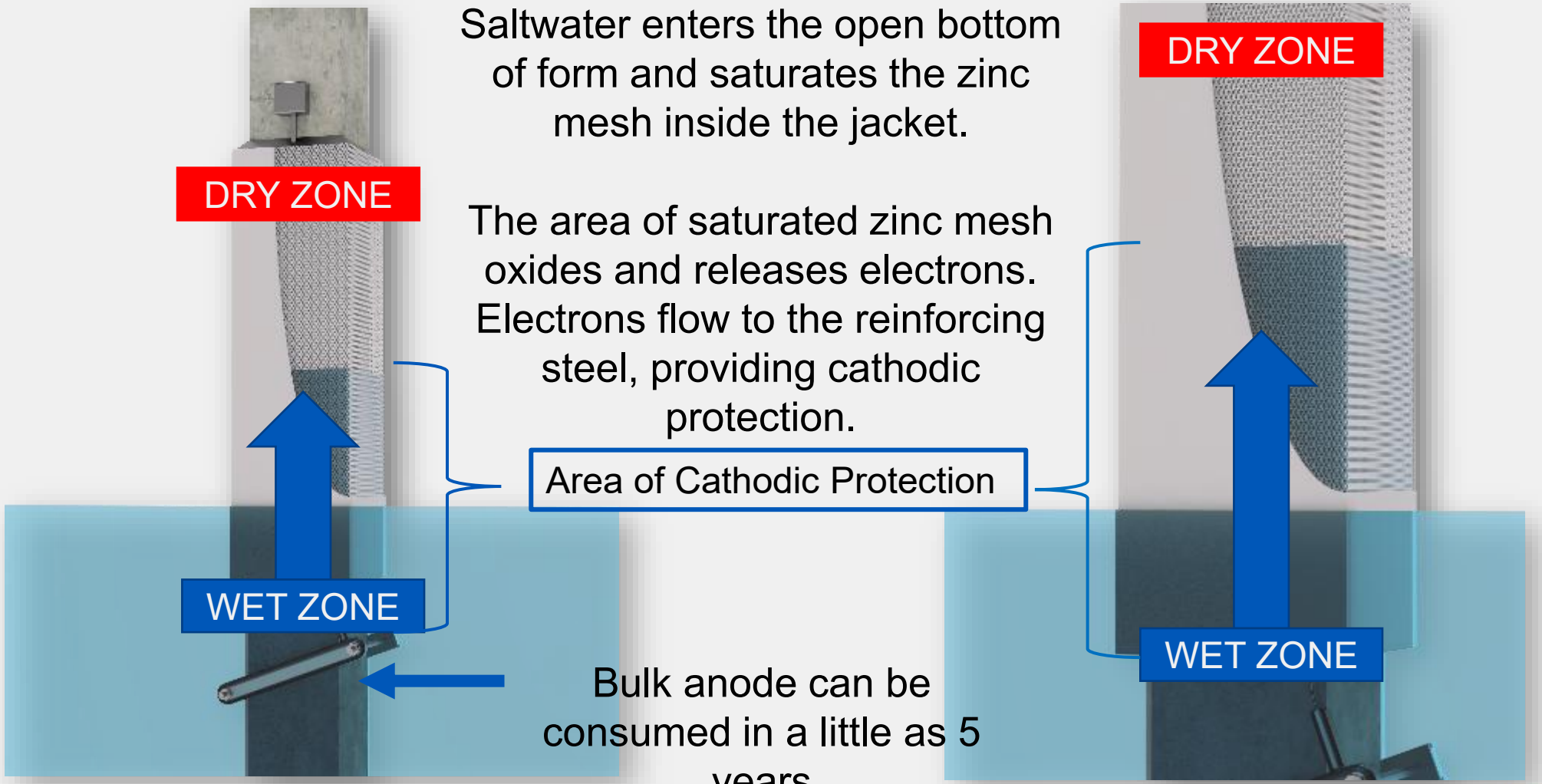
Tidal zone protection

- Zinc mesh anode attached to FRP stay-in-place form
- Open bottomed FRP Jacket
- Allows saltwater inside
- Off the shelf bulk zinc hull anode for underwater protection

Past Pile Corrosion Strategies

Saltwater enters the open bottom of form and saturates the zinc mesh inside the jacket.

The area of saturated zinc mesh oxides and releases electrons. Electrons flow to the reinforcing steel, providing cathodic protection.

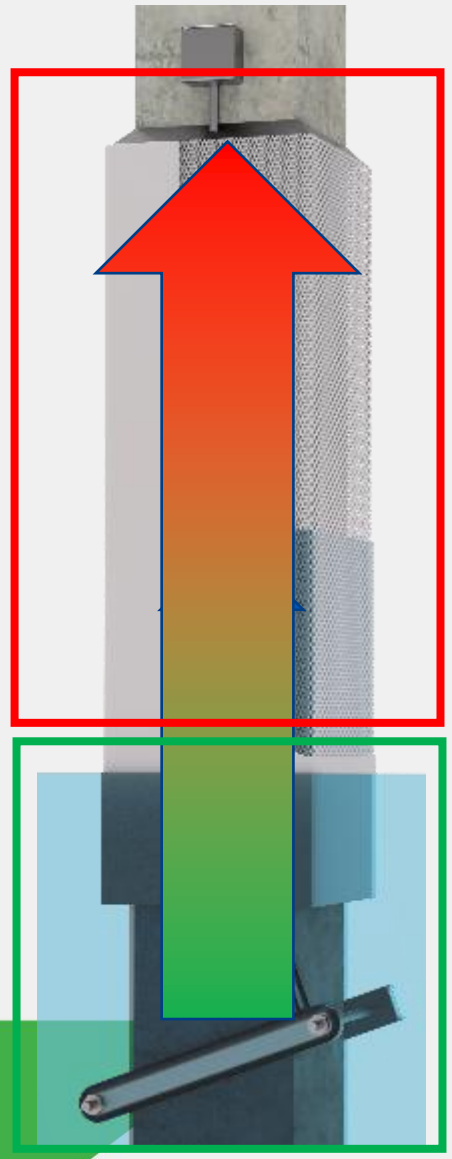


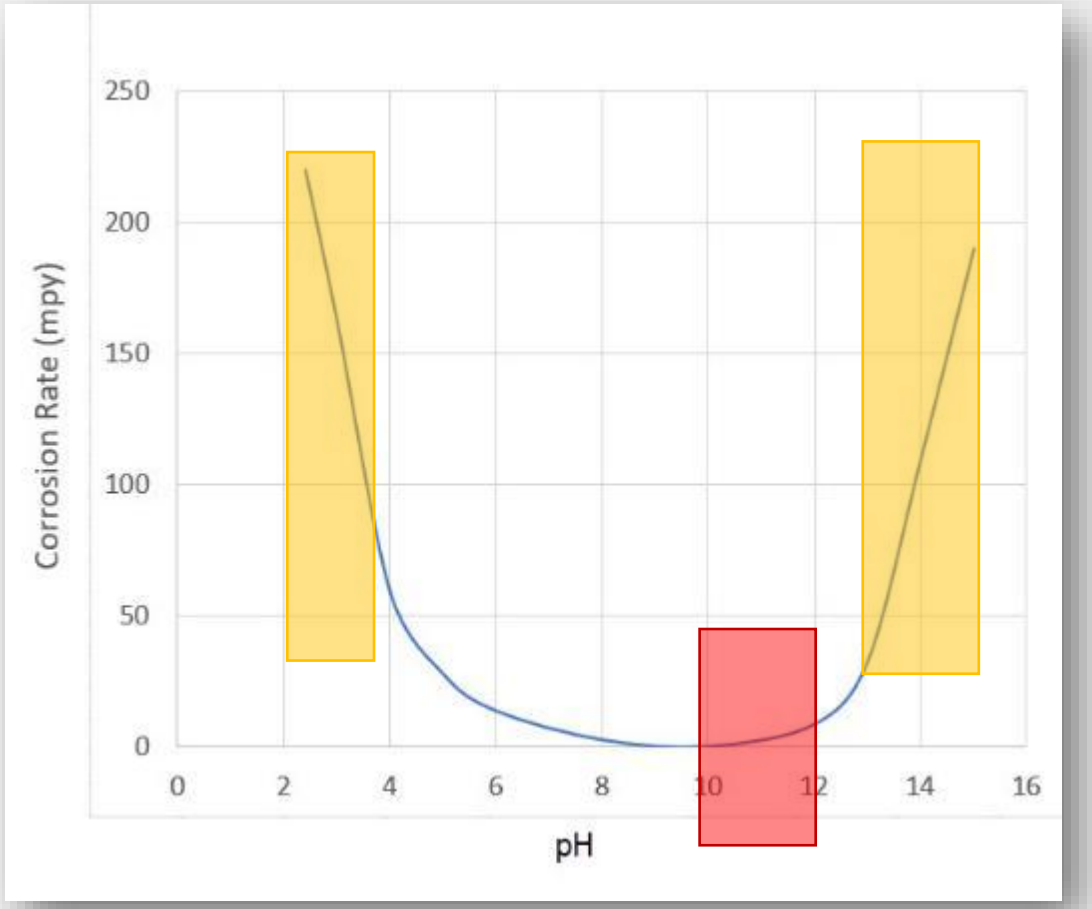
Bulk anode can be consumed in a little as 5 years

Past Pile Corrosion Strategies

Dry portions of the jacket receive limited or no protection from lack of saltwater and direct contact with low pH concrete. Zinc Mesh passivates reducing galvanic current.

Lower portions receive most of the cathodic current because of the continuous wetting with saltwater.

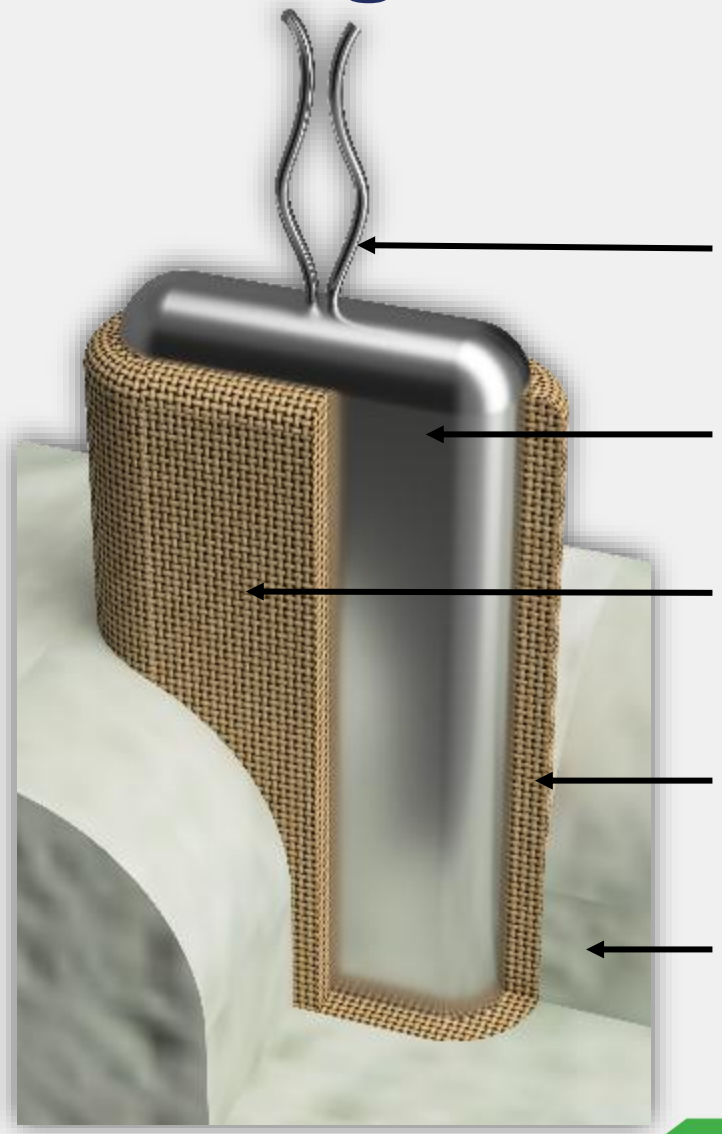




Zinc passivates in direct contact with concrete without saltwater

CP Jacket Improvements

Wicking Anode



Anode wires cast Inside full length of anode. Reliable connection for the entire life.

Cast zinc anode.

Wicking Fabric for increased saltwater capillary action.

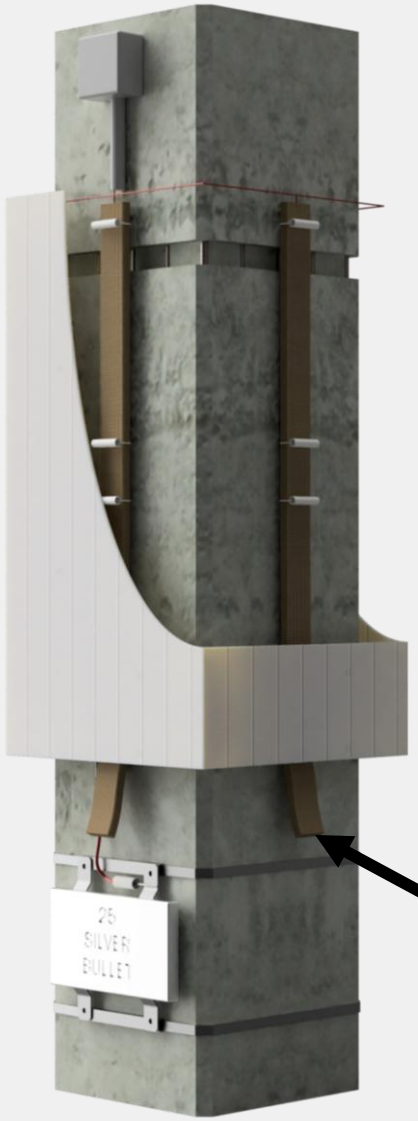
Protective barrier between zinc and low pH concrete.

Concrete

WICKING BARRIER MAINTAINS SALTWATER ACTIVATION

Solid zinc anode with integrated wire

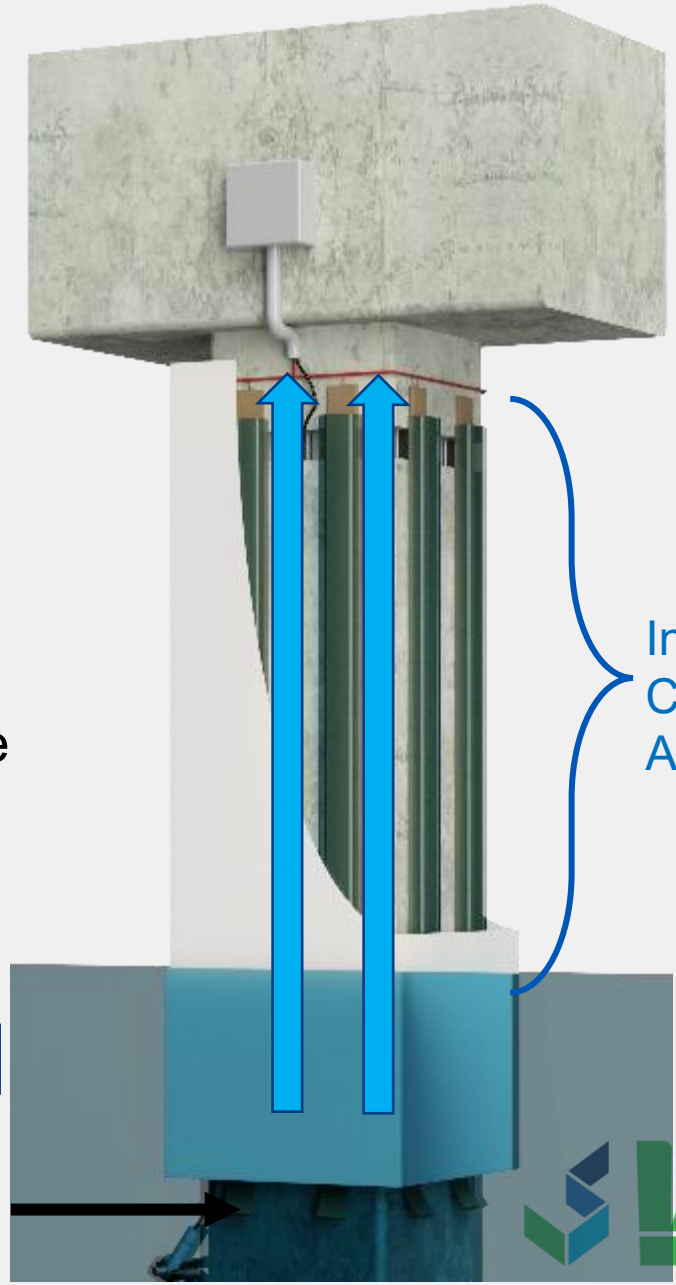
How does it work?



Saltwater wicks up the wicking fabric tail and completely saturates the zinc anode inside the wicking fabric.

Fabric isolates the zinc from being passivated by the concrete mortar.

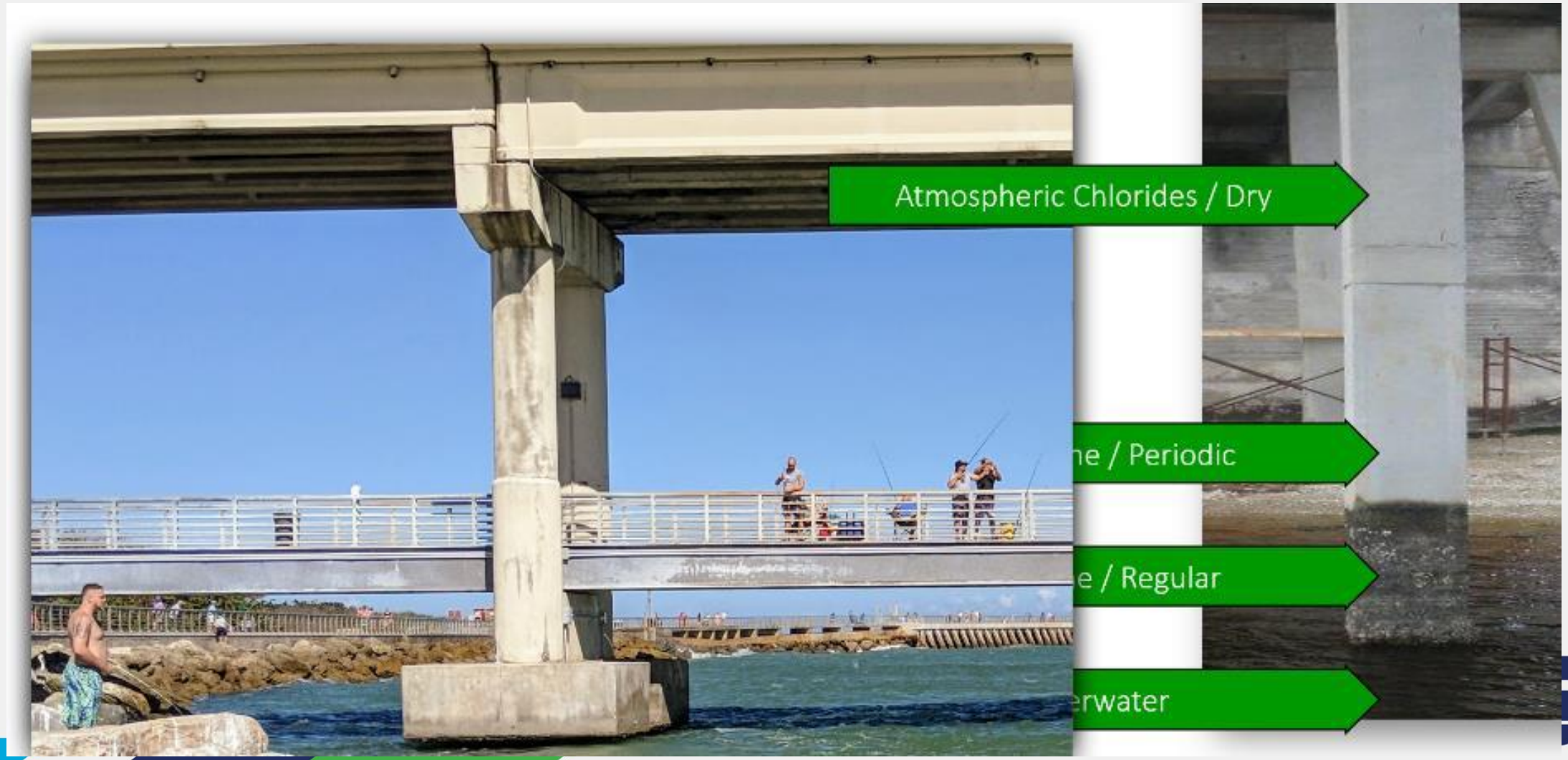
Wicking Tail



Wicking Anode Jacket System Installation

Alkali Activated Jacket

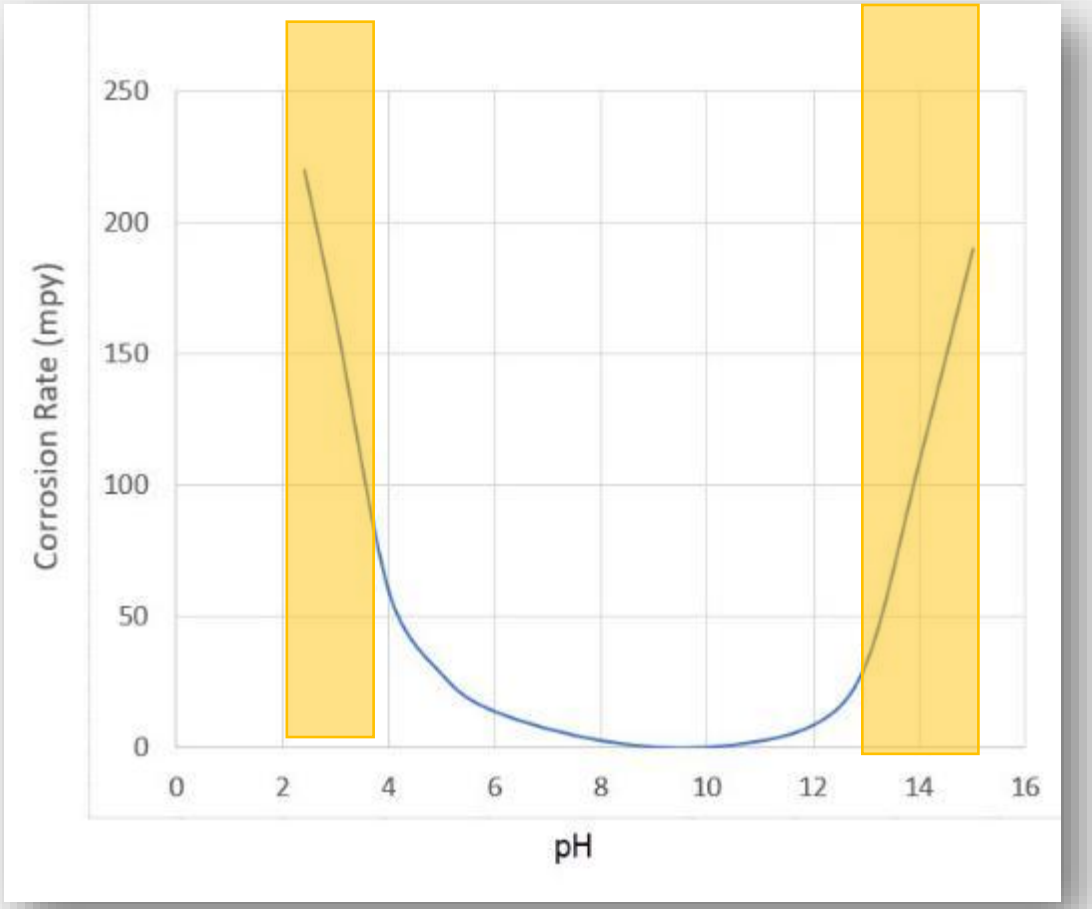
Dry Atmospheric – Saltwater Not Required - Galvashield® DAS

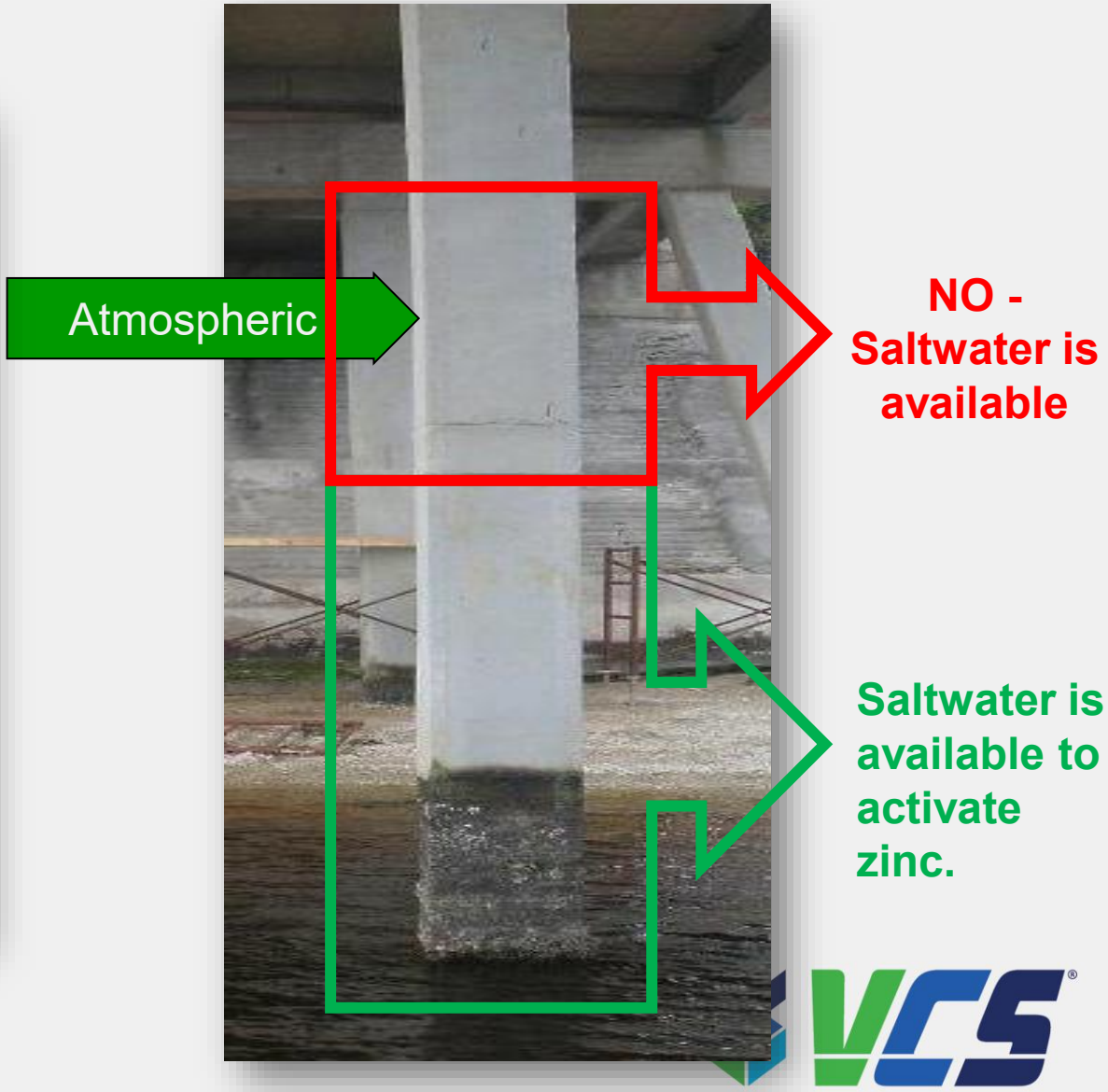


Dry Atmospheric – No Saltwater

Alkali Activated Jacket

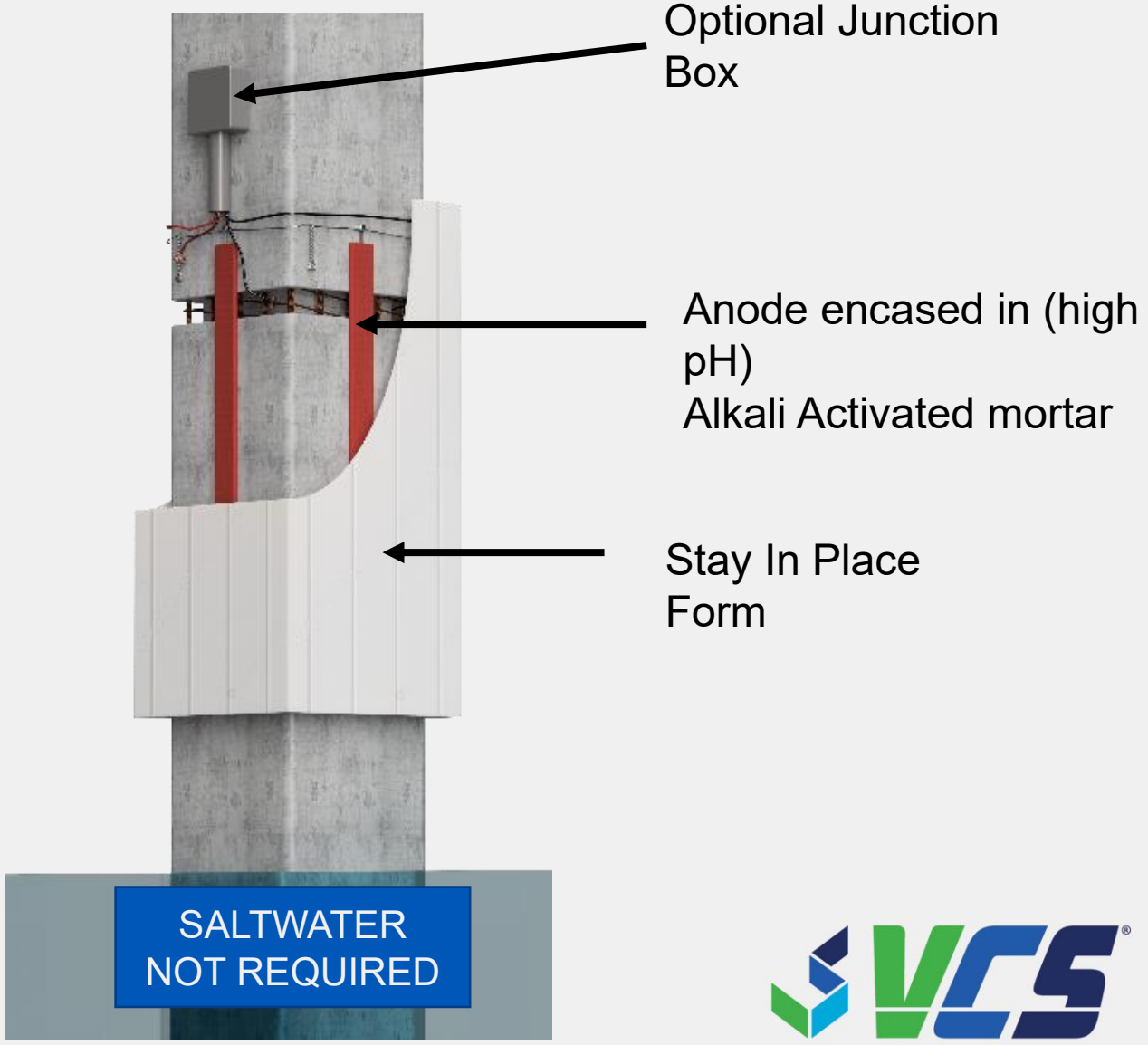
Corrosion Rate of Zinc vs pH



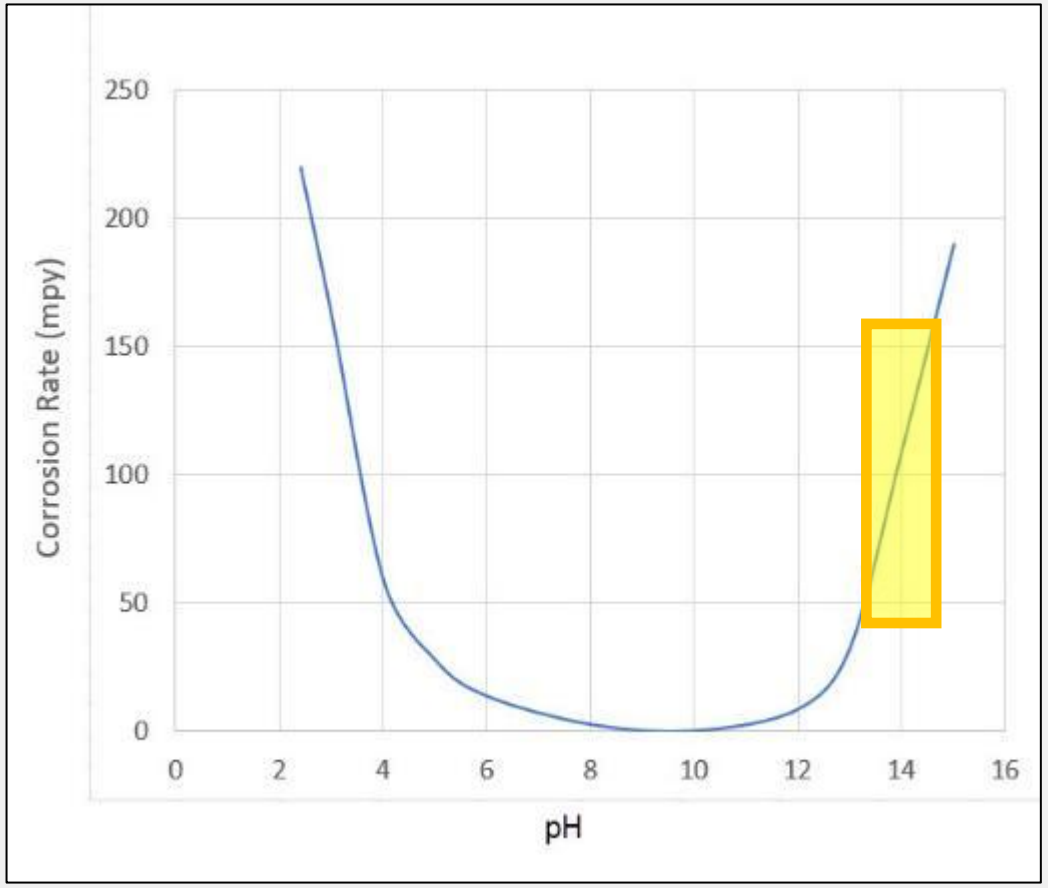


Alkali Activated Jacket

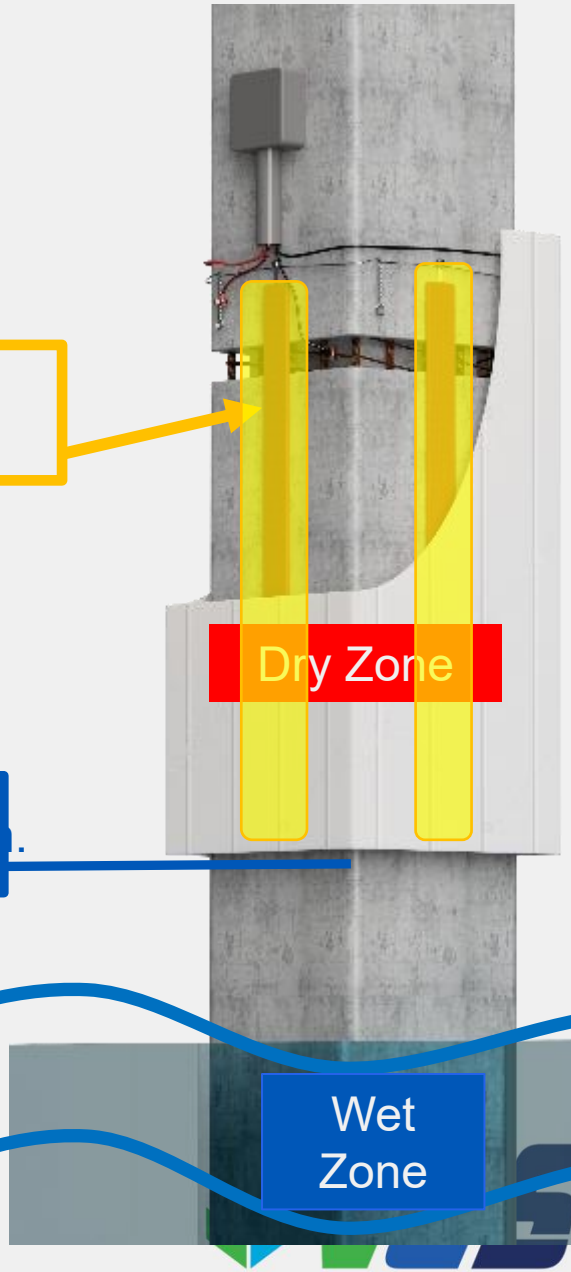
- DAS Technology introduced in 2004
- Saltwater not required!
- Alkali activating technology keeps the zinc active allowing for continued galvanic current without saltwater in
    - Saltwater
    - Brackish water
    - Fresh water and
    - Dry land applications.
- Use appropriate bulk hull anode for underwater protection when required.



Alkali Activated Jacket



High Alkaline Mortar keeps Zinc Anodes Activated



NO Saltwater enters bottom.

High Tide

Low Tide

ALKALINE MORTAR ACTIVATES ZINC

Alkali Activated Jacket

- Alkali Activated Anodes pre-installed on to the FRP Forms
- FRP forms placed around column and filled with grout.
- Use appropriate bulk anode for underwater protection when required.

Alkali Activated Anodes pre-installed in stay in place FRP. Florida DOT

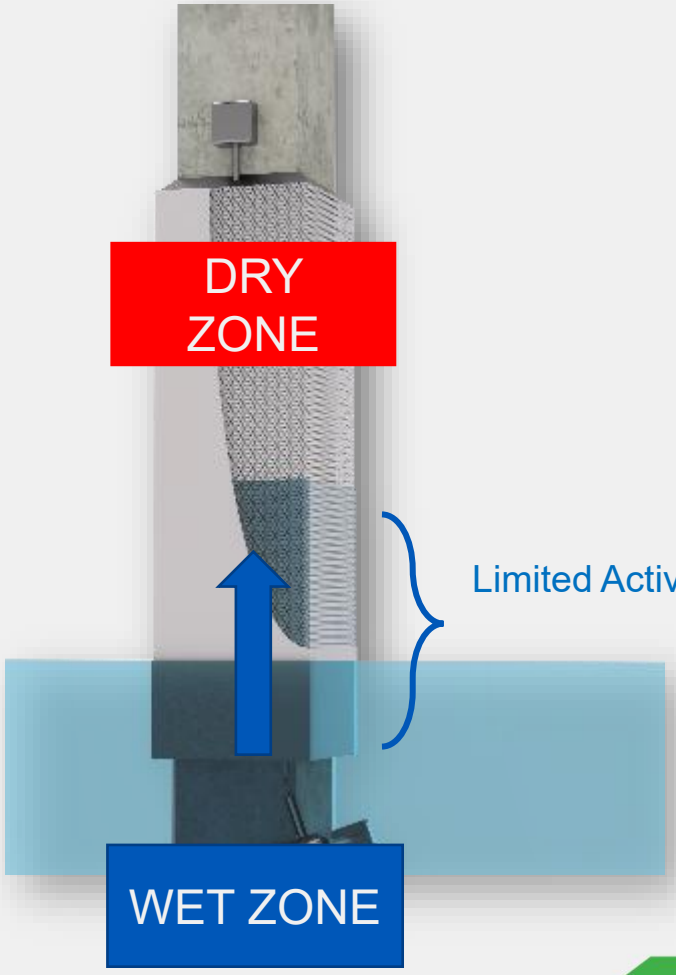
Alkali Activated Jacket

Lake Worth, FL

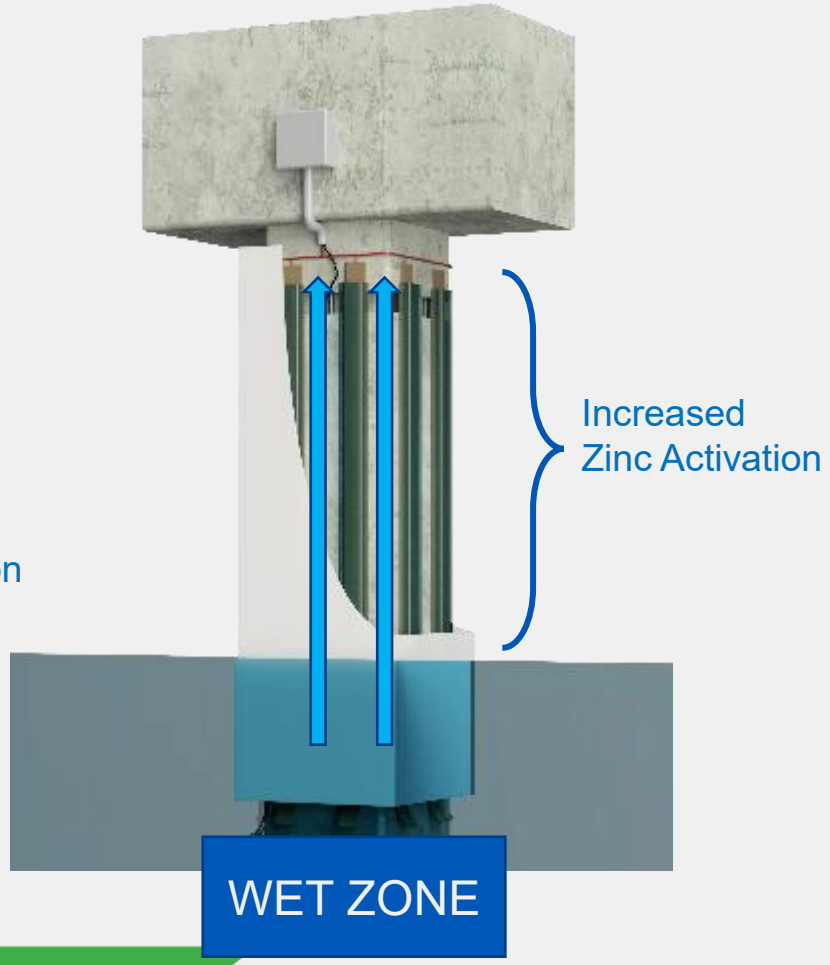
FDOT – Lake Worth Alkali Activated Jackets providing full CP in the dry zone.

Conclusion - Jacket Selection?

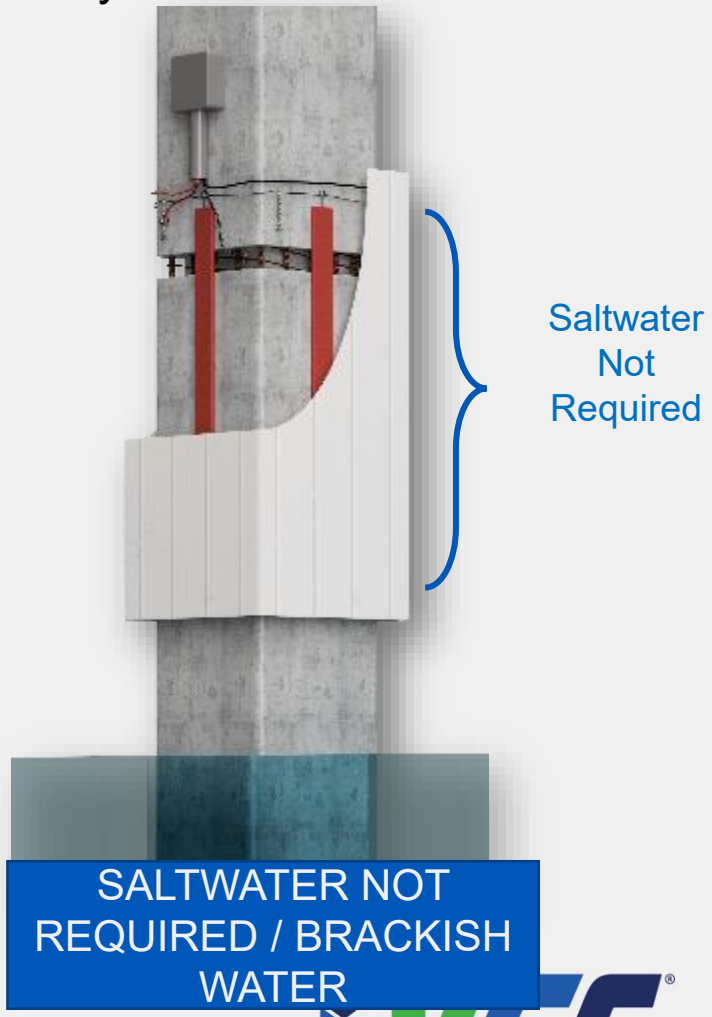
1st Gen Tidal (Mesh)
Tidal Protection



Improved Tidal (Wicking)
Elevated Tidal Protection



Alkali Activated
Dry Areas Land / Marine



Summary

- **Corrosion is inevitable | Can be slowed or delayed**
- Corrosion evaluation can provide valuable information about the existing conditions and the remaining service life of the structure
- Timely application of corrosion mitigation measures will extend the service life of the concrete structure
- Some of the corrosion mitigation options
  - Concrete Repairs: Type 1A Anodes
  - Targeted Concrete: Type 2A Anodes
  - Global Protection
    - Passive Systems
      - Electrochemical Chloride Extraction (ECE)
      - Electrochemical Realkalization (ECR)
    - Cathodic Protection System
      - Zinc Metallizing
      - Conductive Coatings
      - Impressed Current Cathodic Protection System (ICCP)

Thank You!

QUESTIONS?

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