

Corrosion Issues in Repair

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Epoxy Interest Group of CRSI

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Outline

- Introduction
- Corrosion mechanisms
 - Methods to reduce corrosion
- Epoxy-coated bars
- Repair and corrosion
 - The ring anode

Why is corrosion important?



Corrosion can be stopped!

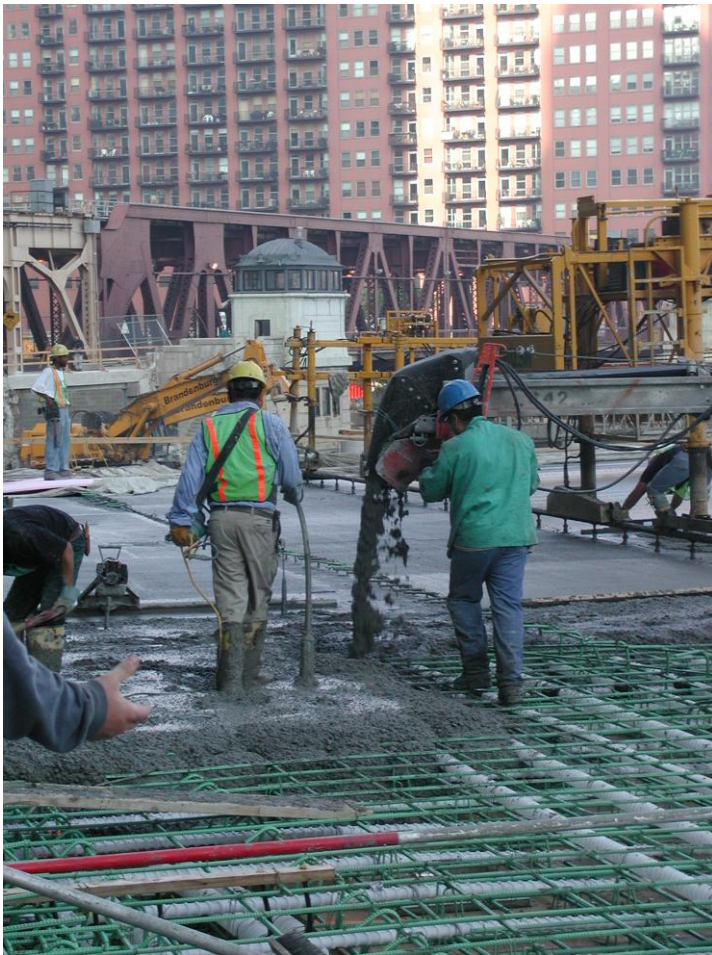
- Use alternate deicing methods
 - Heated structures, alternate chemicals
- Provide bars immune to corrosion
 - Titanium or Type 316 stainless steel
- Provide active cathodic protection throughout
 - And staff to maintain it
- Prevent contact between concrete and chloride
 - Impermeable coatings



Slowing down the process

- Reduce ingress
- Increase threshold
- Reduce reaction rates
- Provide alternate reactions

High Performance Concrete



Material	Amount
Cement – Type I/II	525 lb/yd ³
Fly ash– Class F	53 lb/yd ³ (10%)
Silica Fume	27 lb/yd ³ (5%)
GGBFS	79 lb/yd ³ (15%)
Limestone	1800 lb/yd ³
Sand	1140 lb/yd ³
Water	30.5 gal (w/cm= 0.37)
Other Admixtures (HRWR, Mid-range, AEA)	Varied

- Strict Specifications Req'd

HPC Mix Proportions (Wacker Drive)

Sealers



Surface sealers:

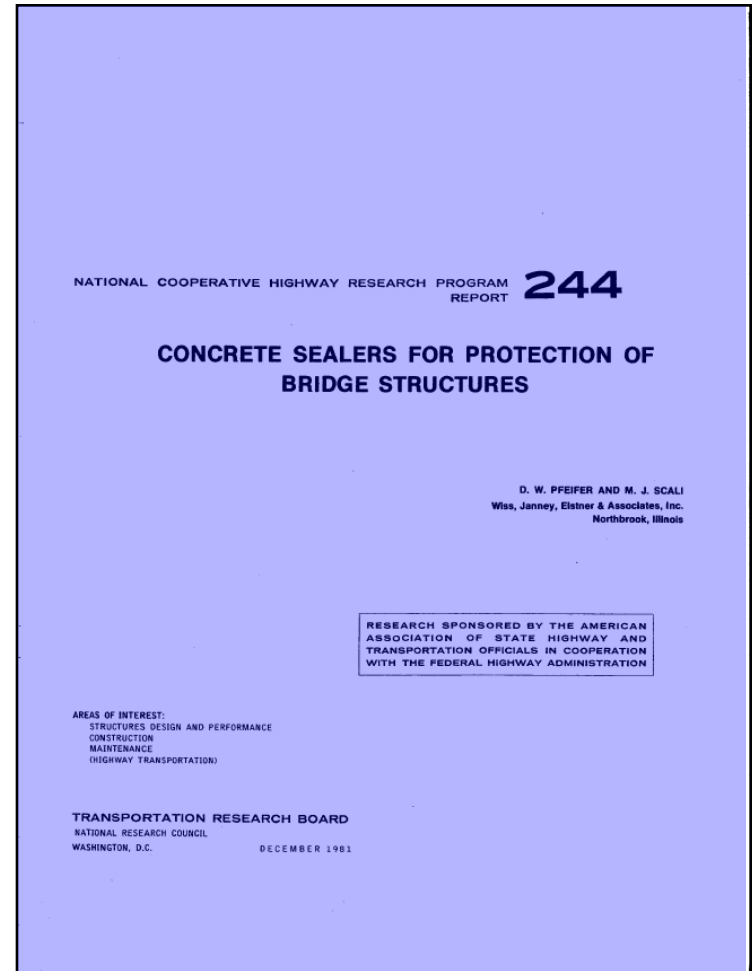
Linseed oil

Epoxies

Urethanes

Silanes/Siloxane

...



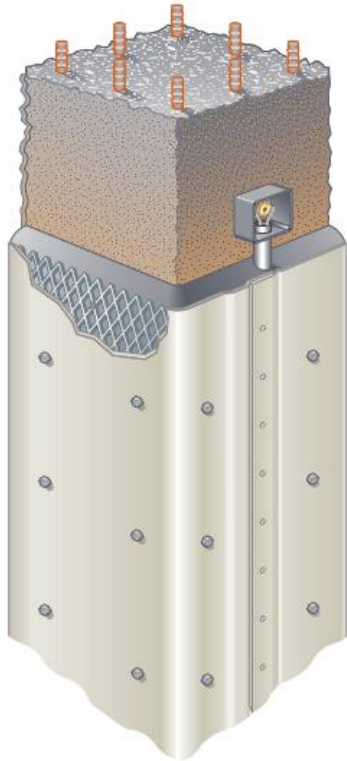
Increased Chloride Threshold

- Corrosion-resistant rebar
 - Stainless
 - Galvanized
 - Epoxy-coated (?)
 - Non-metallic
- Corrosion inhibitors



Cathodic protection

- Impressed current (active)
- Sacrificial anode (passive)



Limitations of various systems

- Cost
- Maintenance
- Cracking
- Long-term performance
- Lack of field data

CORROSION MECHANISMS

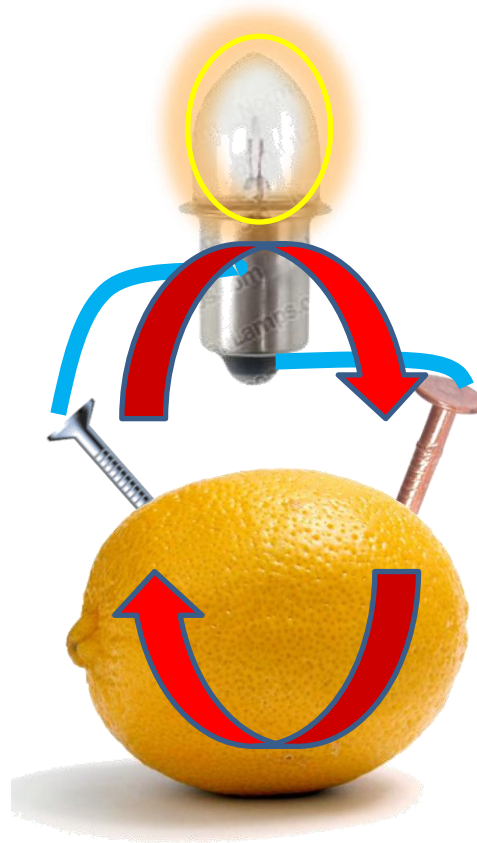
Rebar in Fresh Concrete

$\text{pH} > 13$

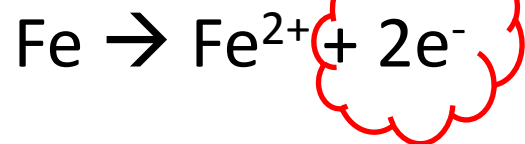


Passive film develops on the bar surface

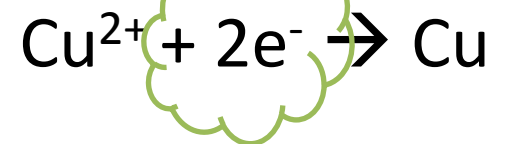
Corrosion Battery



ANODE



CATHODE



Corrosion

Anode



Cathode



Corrosion

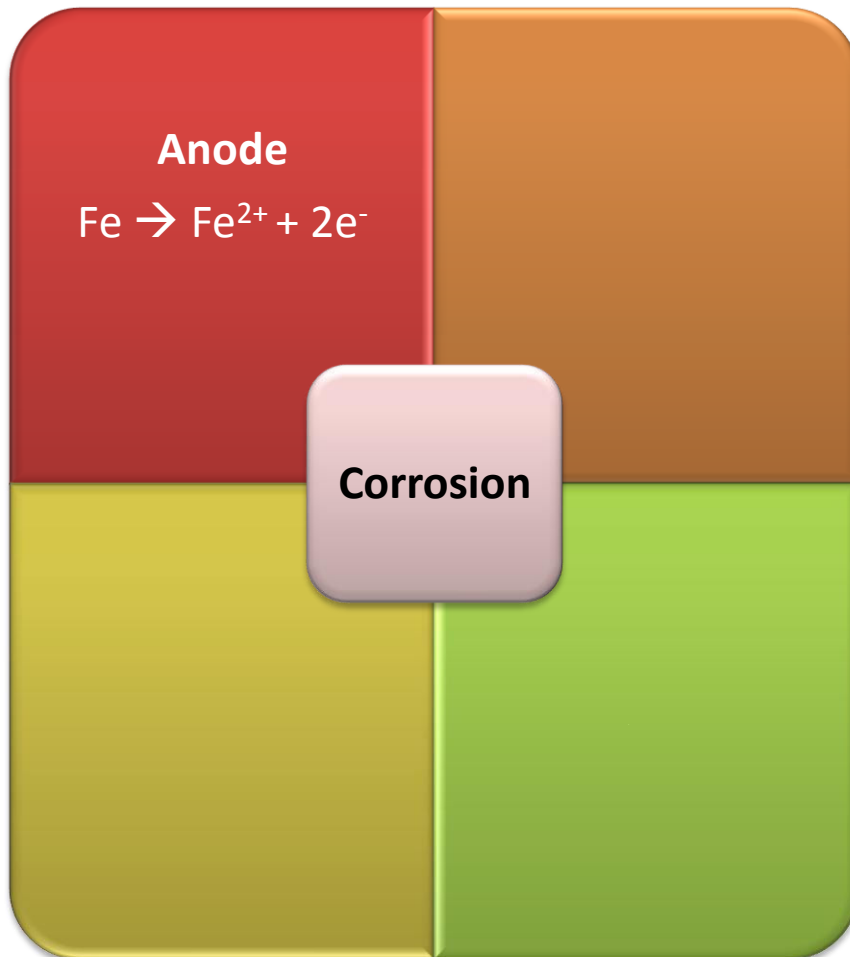
Electrical Connection

- between anode and cathode

Ionic path

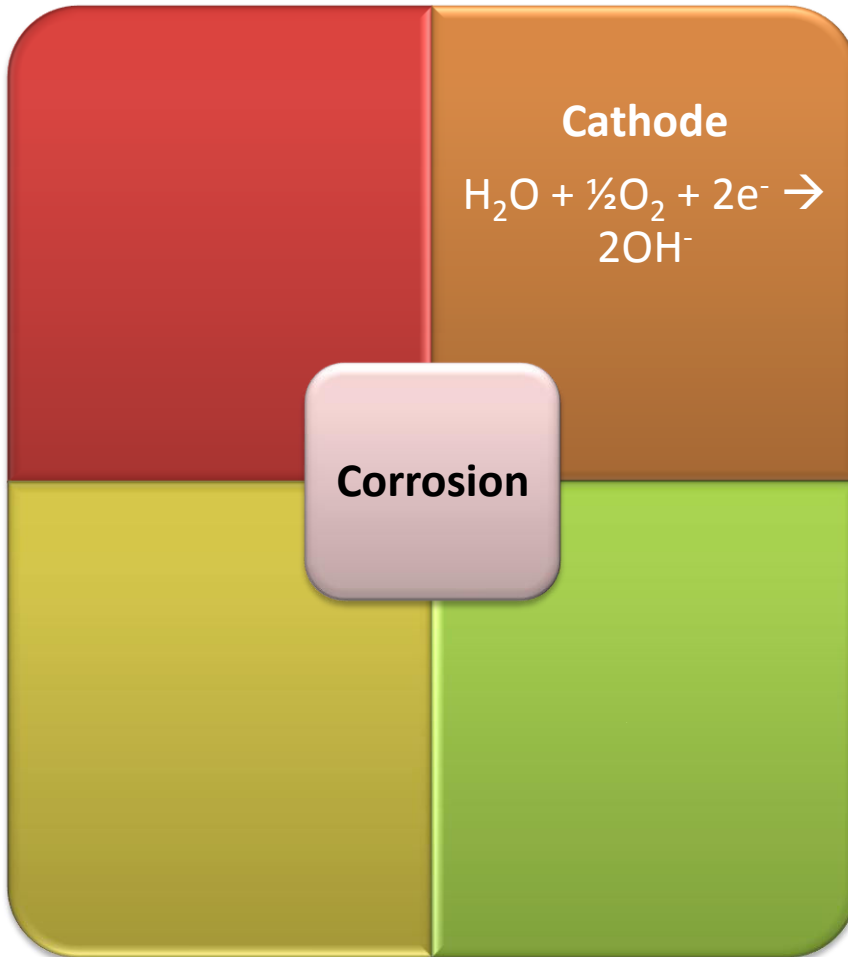
- To prevent buildup of charged ions

Anode



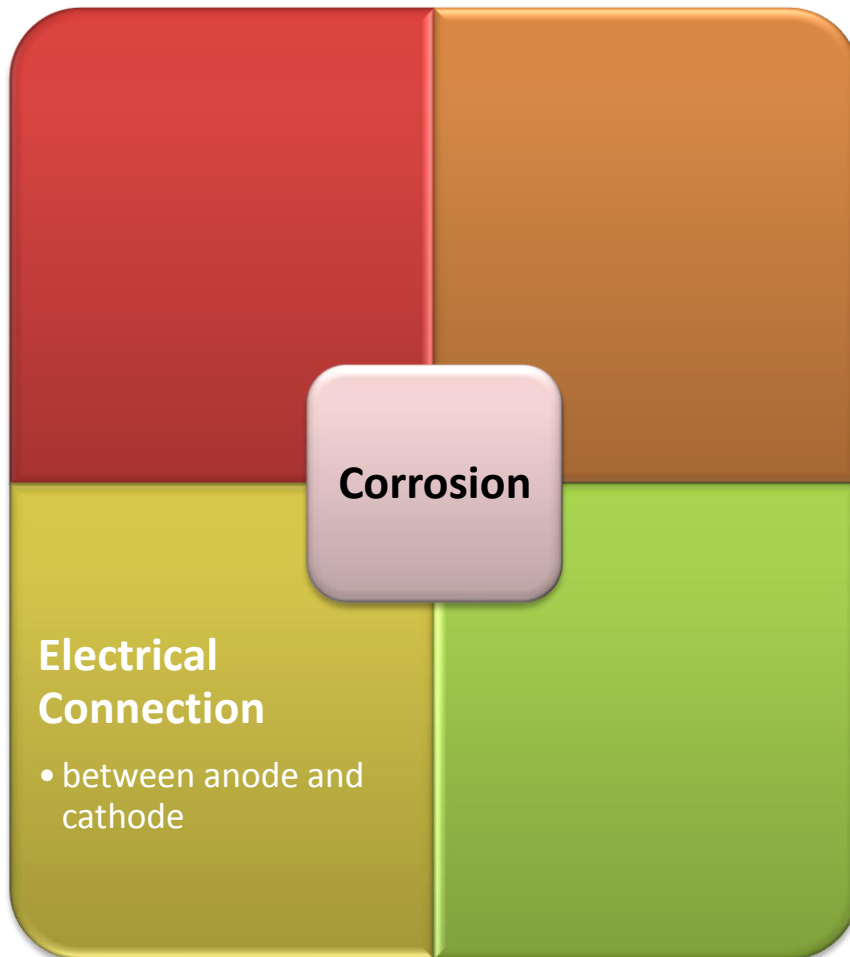
- Concrete permeability
 - w/c, pozzolans, chemical additions
 - Membrane, silane
- Chloride threshold
 - Inhibitor
 - Change metal (stainless)
- Reduce reactive surface
 - Coatings
- Reduce corrosion rate
 - Dry out concrete
- Force opposite reaction
 - Cathodic protection

Cathode



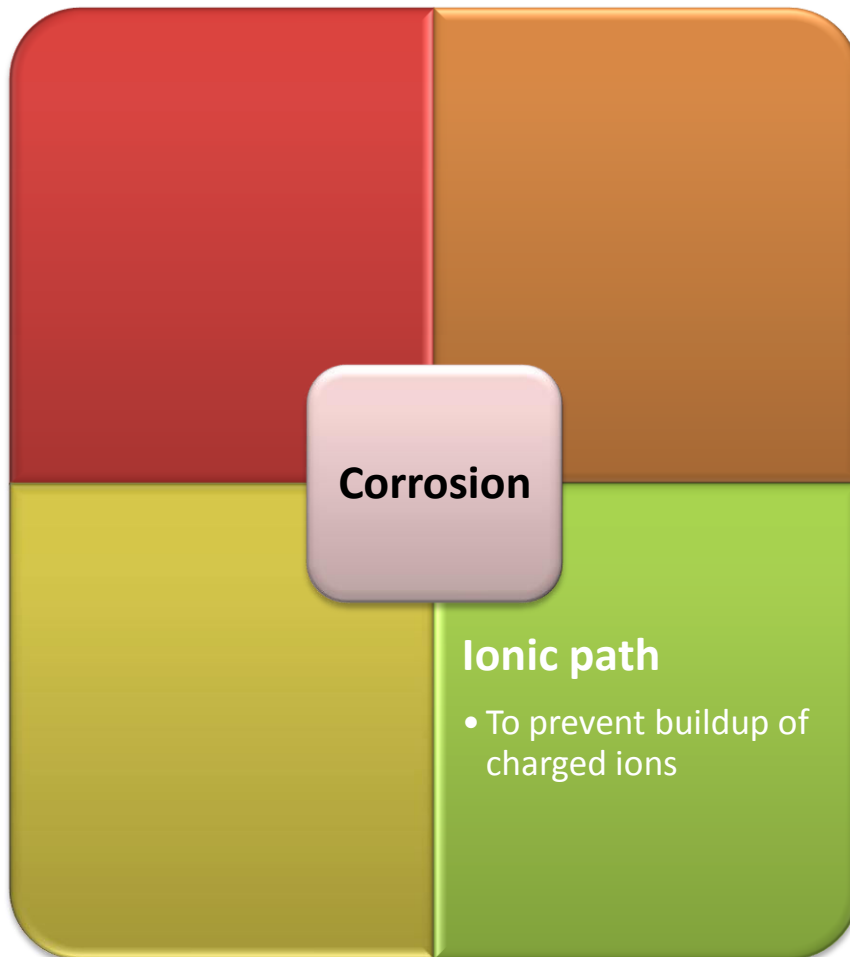
- Reduce area of reactive surface
 - Coatings
- Dry concrete
- Reduce oxygen
- Reduce cathode effectiveness
 - Inhibitors

Electrical continuity



- Disconnect anode and cathode
- Electrical separation of bars
 - Coatings
 - Electrical separation

Ionic Path



- Make pathway between anode and cathode more difficult
 - High resistivity concrete
 - Low moisture content

EPOXY-COATED BARS

Use

- 2nd most common strategy
 - Following increased concrete cover
- 65,000 bridges in the US alone
- USA, Canada, Middle East, Japan, and India

700,000,000 sq ft of bridge deck

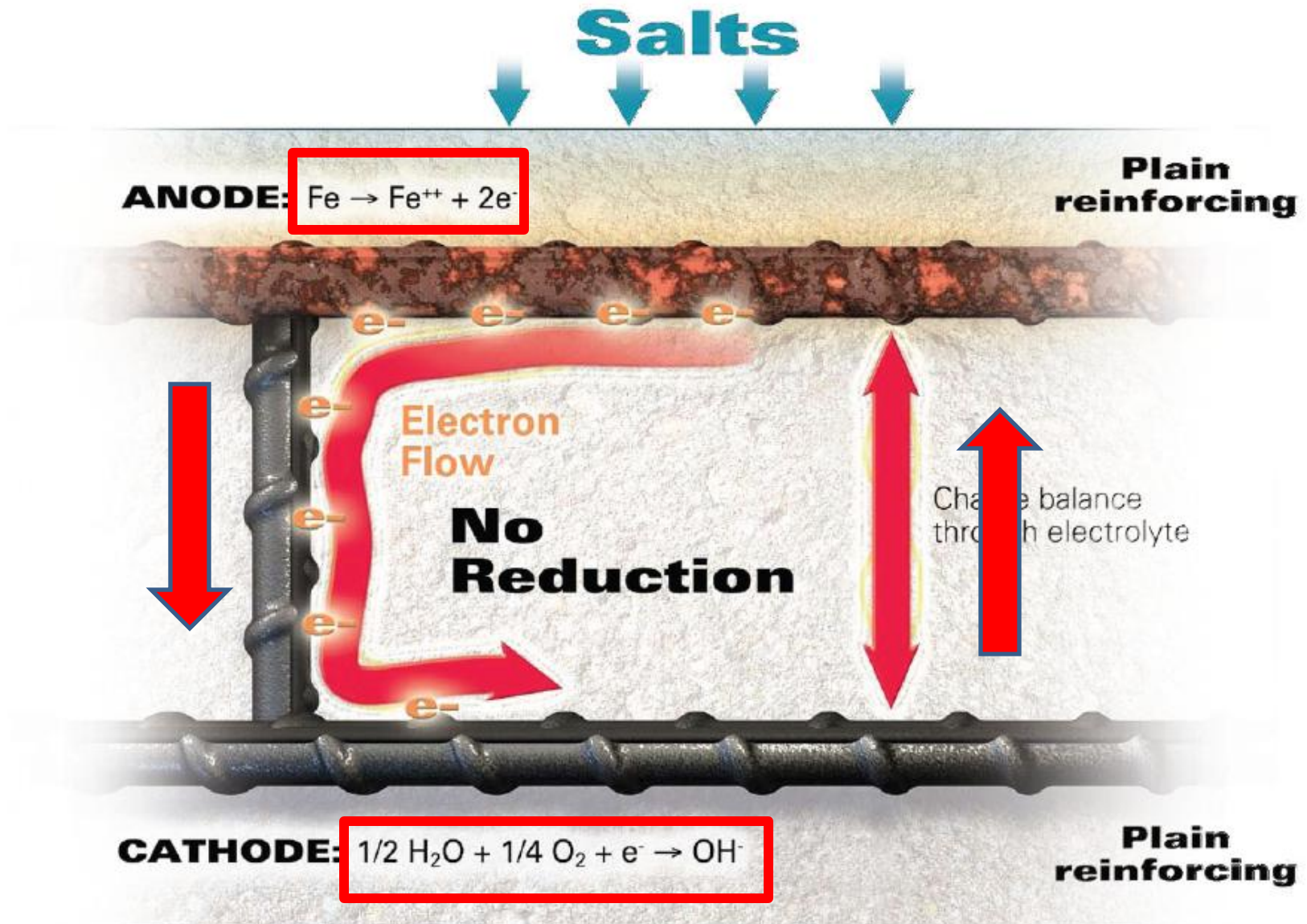


Research and Performance

- Over 200 research papers
- Widespread use by DOT's and Counties



Black bar in bridge deck



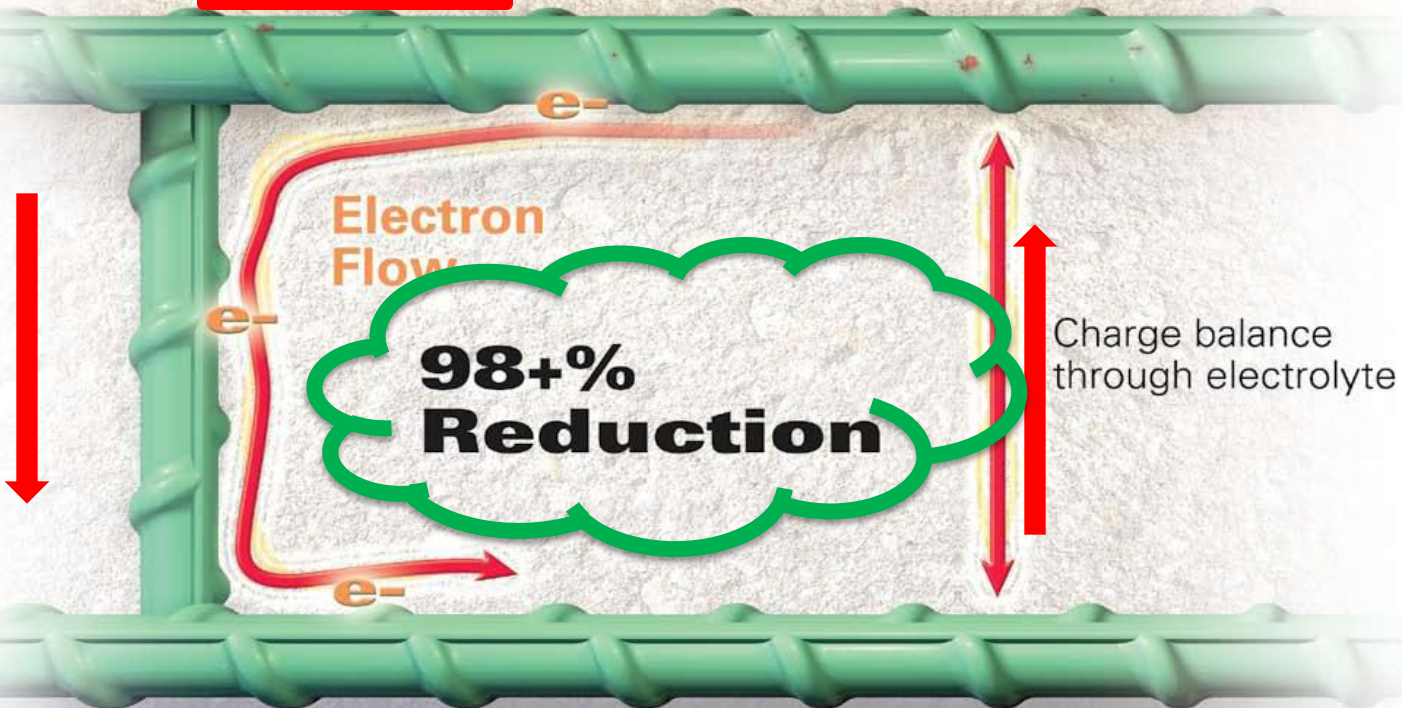
Epoxy-coated bar

Salts



ANODE: $\text{Fe} \rightarrow \text{Fe}^{2+} + 2\text{e}^-$

Epoxy-coated reinforcing



Electron Flow

**98+%
Reduction**

Charge balance through electrolyte

CATHODE: $\frac{1}{2} \text{H}_2\text{O} + \frac{1}{4} \text{O}_2 + \text{e}^- \rightarrow \text{OH}^-$

Epoxy-coated reinforcing

Epoxy-coated bars

Anode

Reduces anode area
Increases threshold*

Cathode

Reduces cathodic area

**Reduced
corrosion**

Electrical Connection

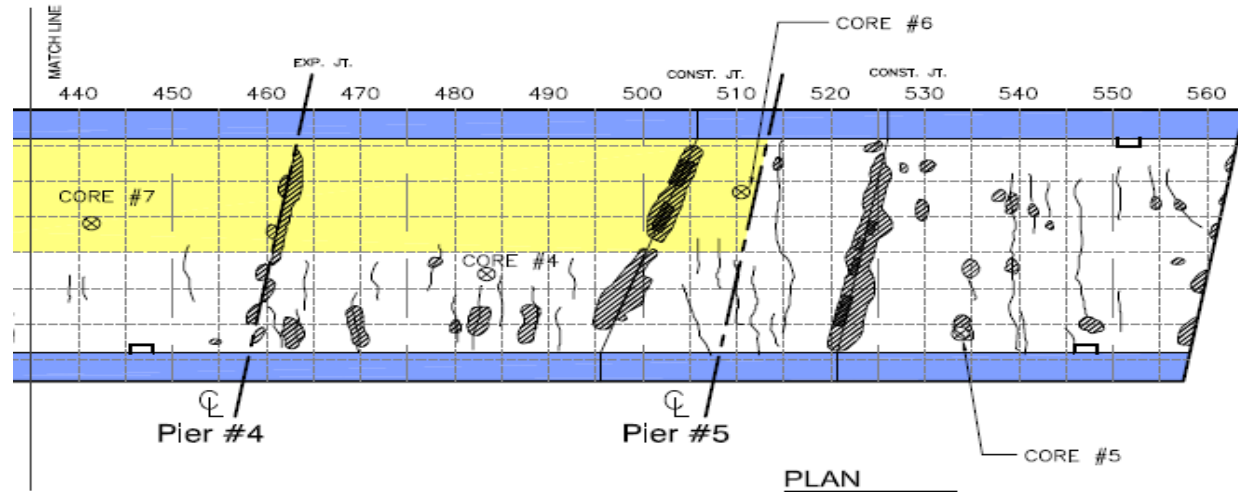
- Electrical path between anode and cathode

Ionic path

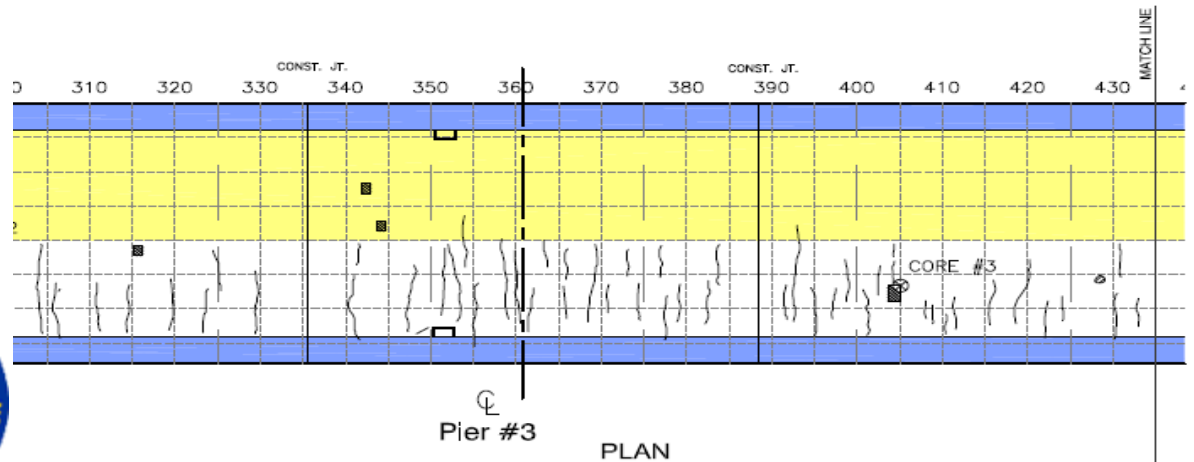
- Makes ionic pathway longer

FIELD PERFORMANCE

Bridge 2930, West Virginia, 2009



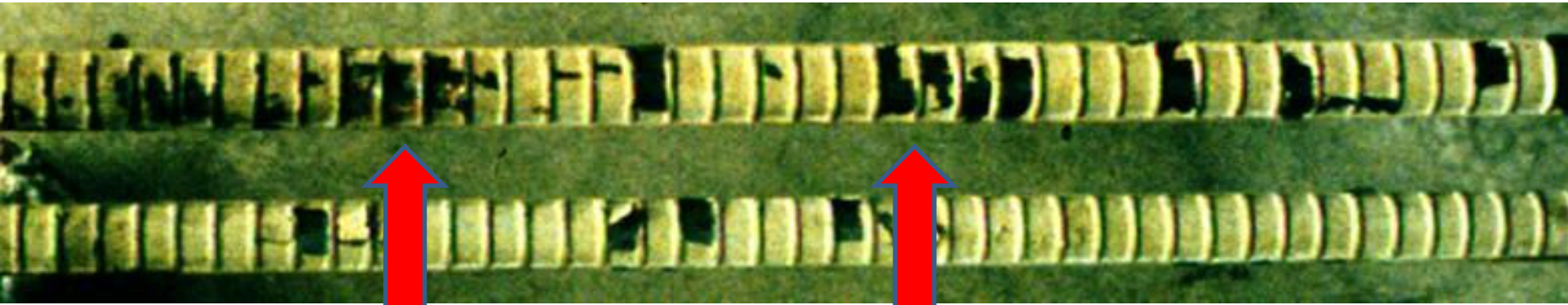
Black Bars, 1st repair 1993



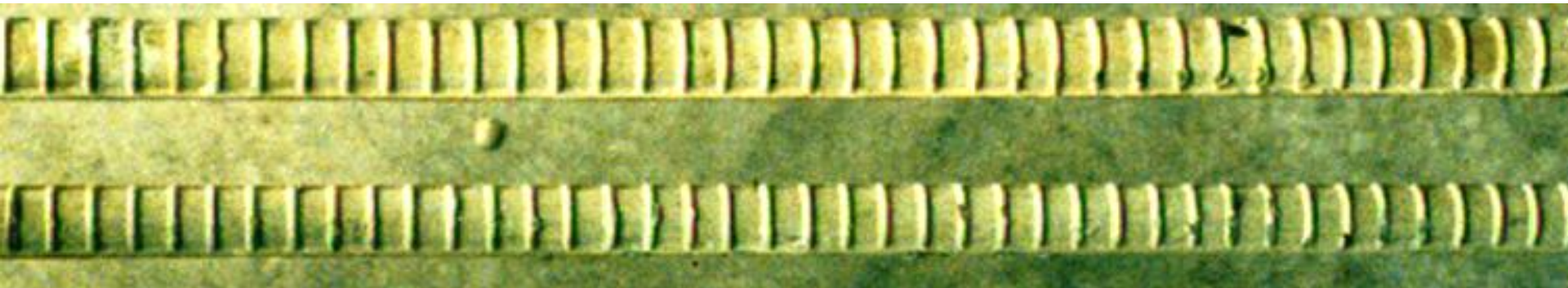
Epoxy-coated bars

Oregon Piles

4 – 5 mil - inadequate surface profile



9 – 10 mil - adequate surface profile

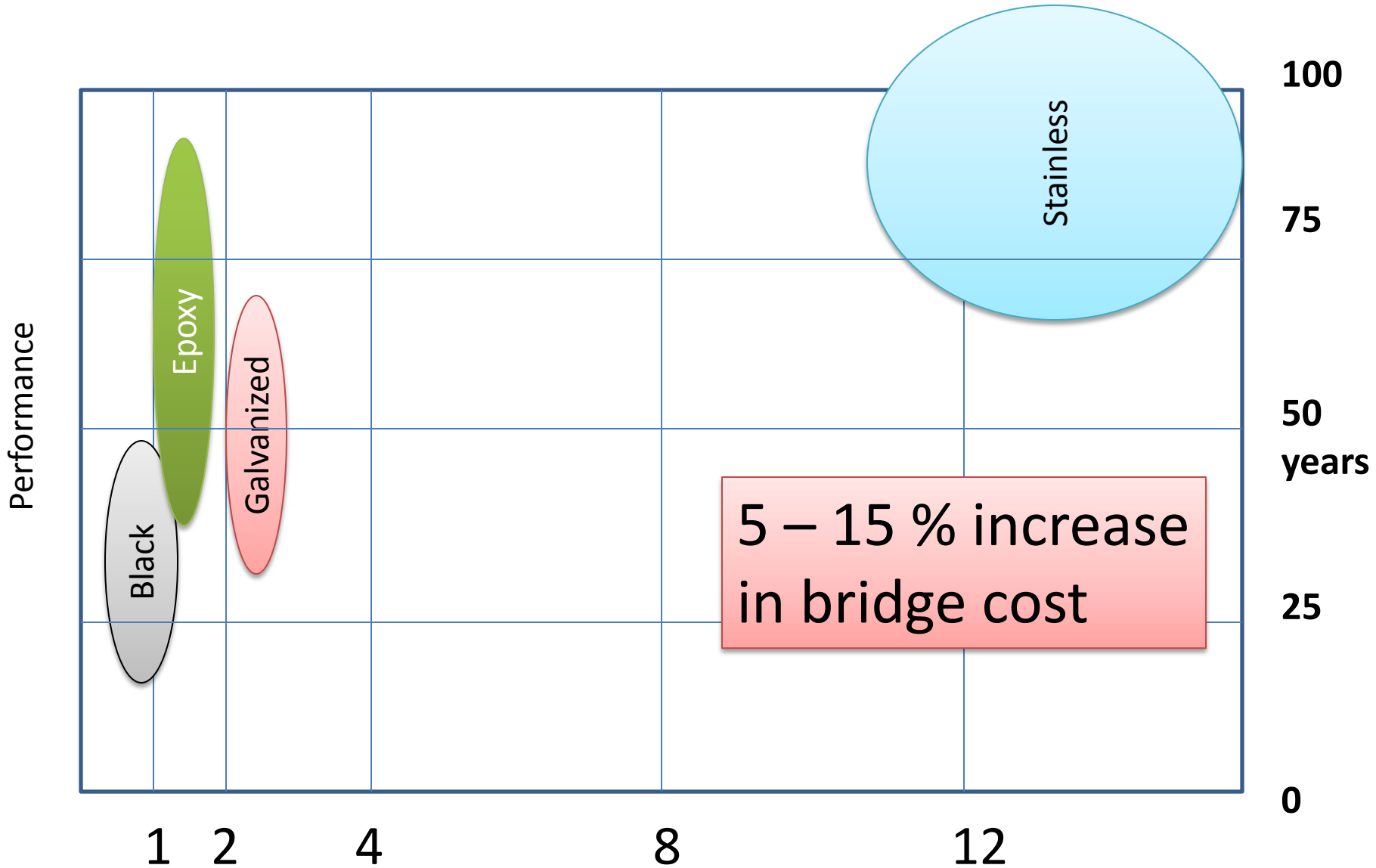


Modified Criteria – 1980s - 2007

- Anchor profile
- Delay after blasting
- Backside contamination
- Chloride contamination
- Coating thickness
- Holidays
- Flexibility
- Cathodic debonding
- Repair of jobsite damage
- Vibrators



Performance vs. Cost

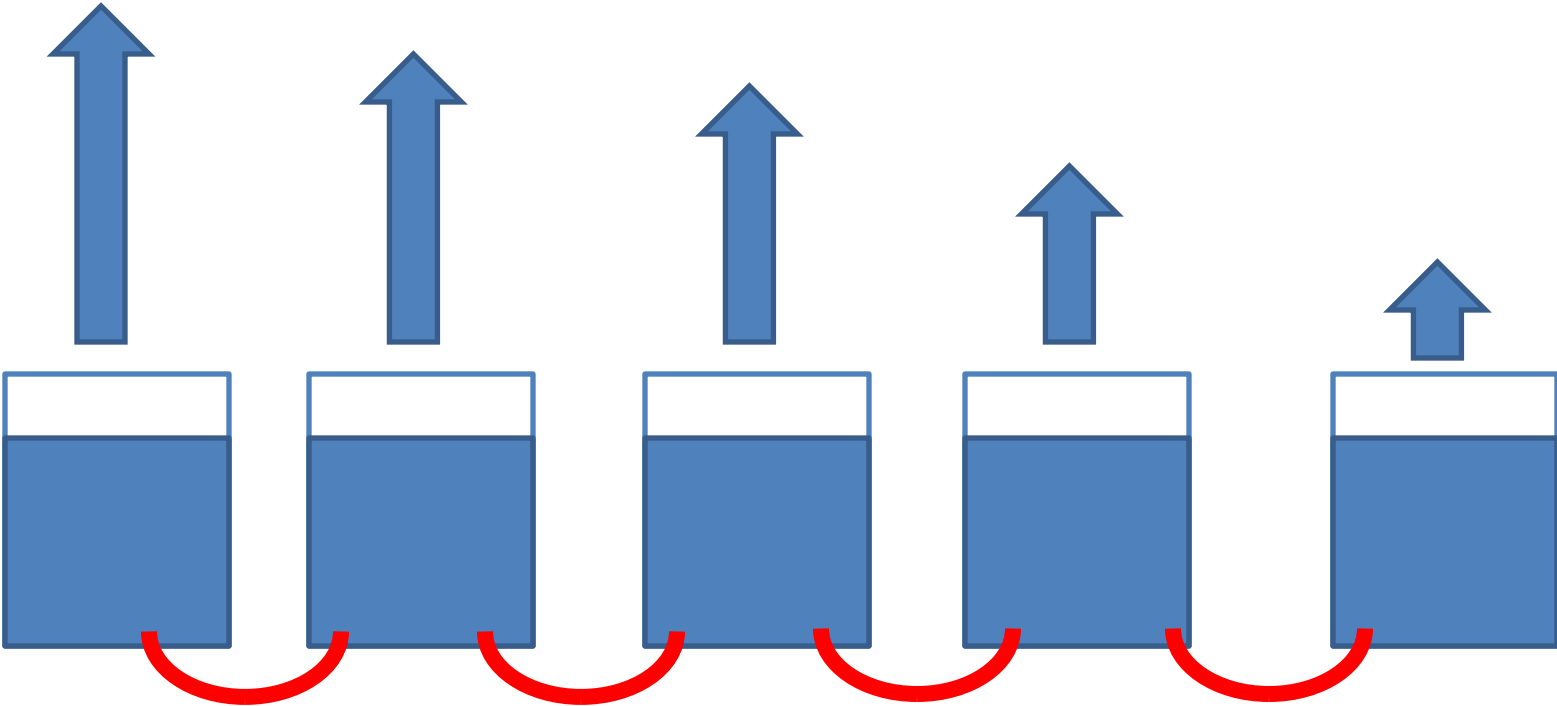


CONCRETE REPAIR

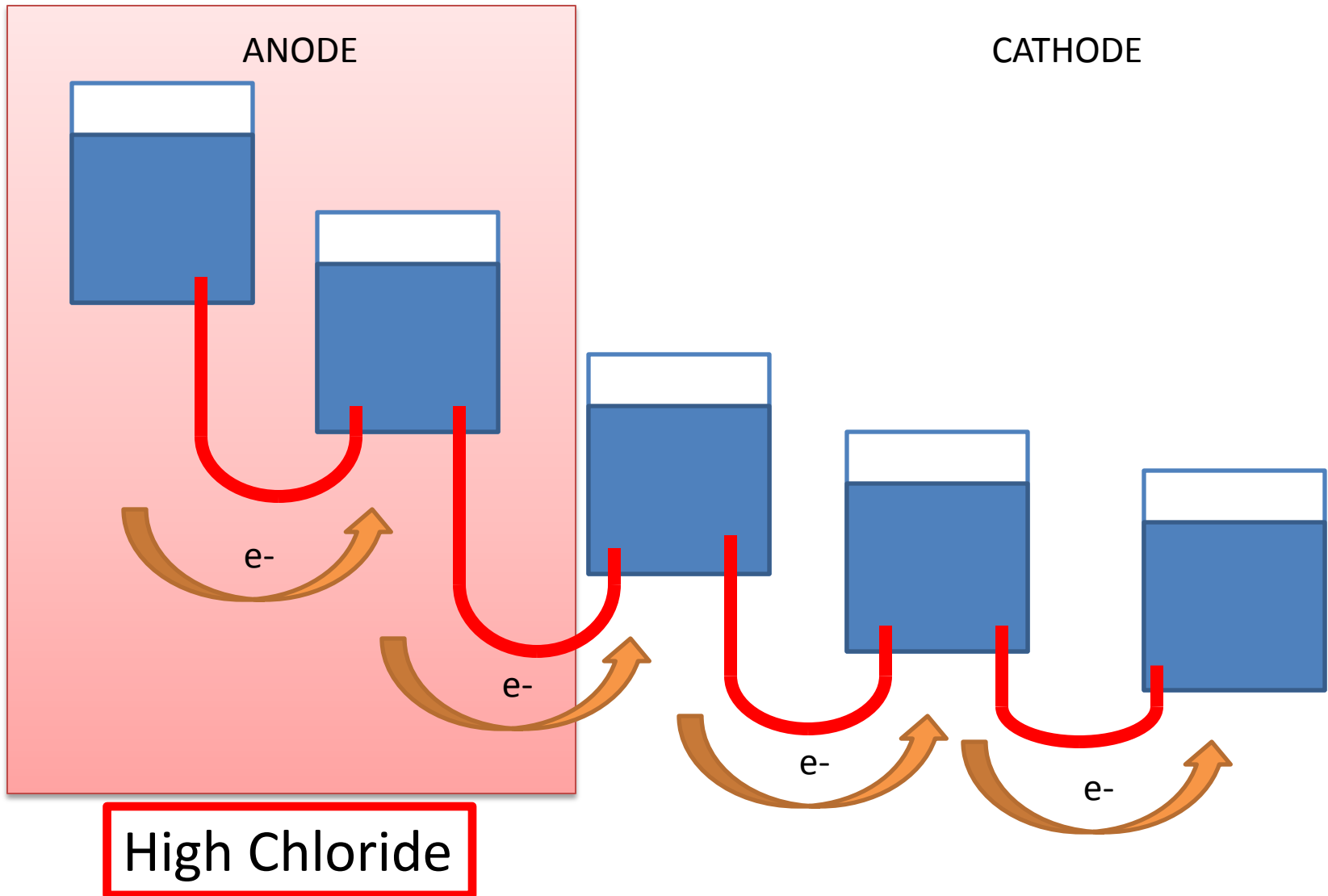
Repair outline

- Stopping the cycle of corrosion and repair
- Corrosion
- Ring anode
- Methods to stop ring anode and future reduce corrosion

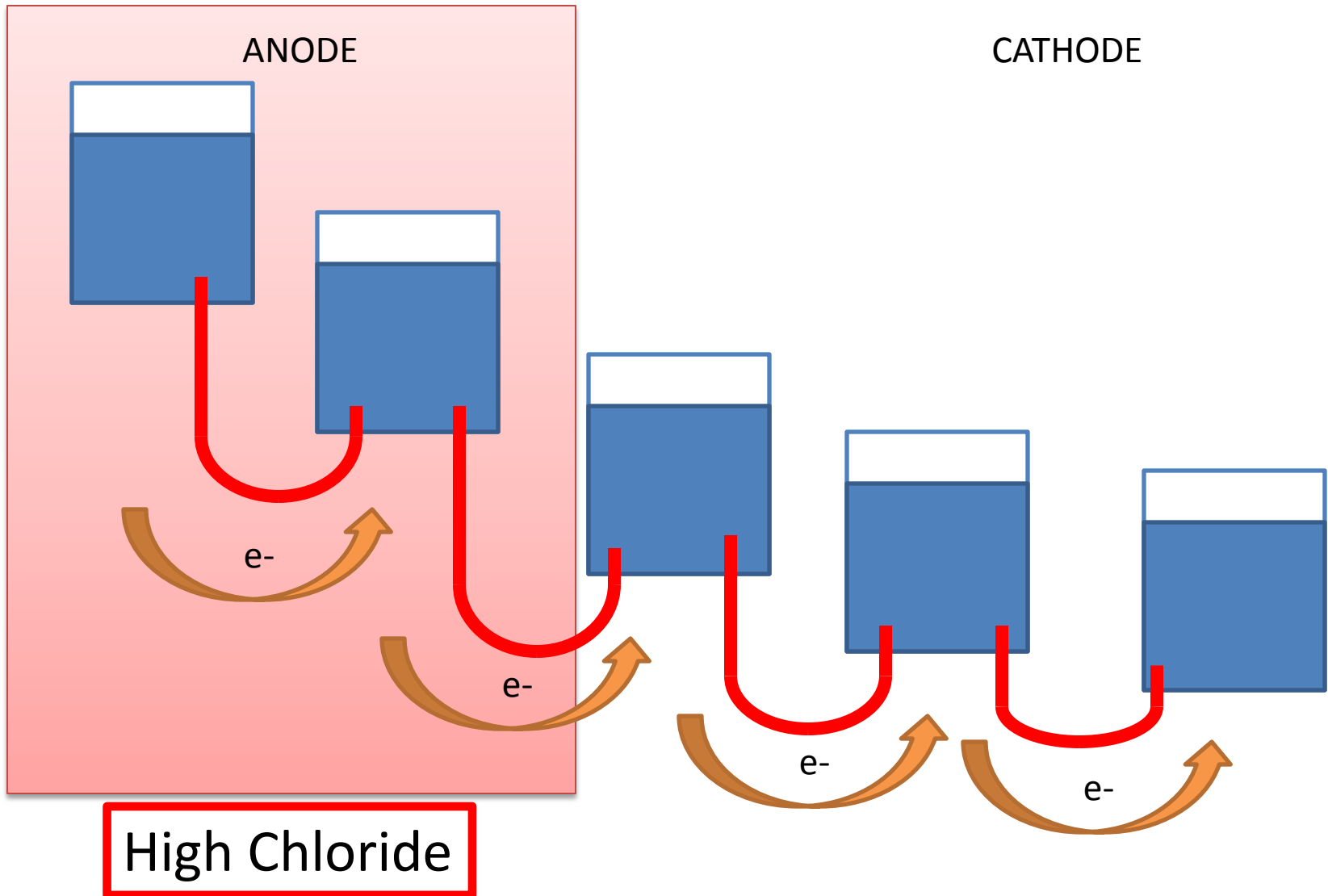
Water Analogy Newly Constructed



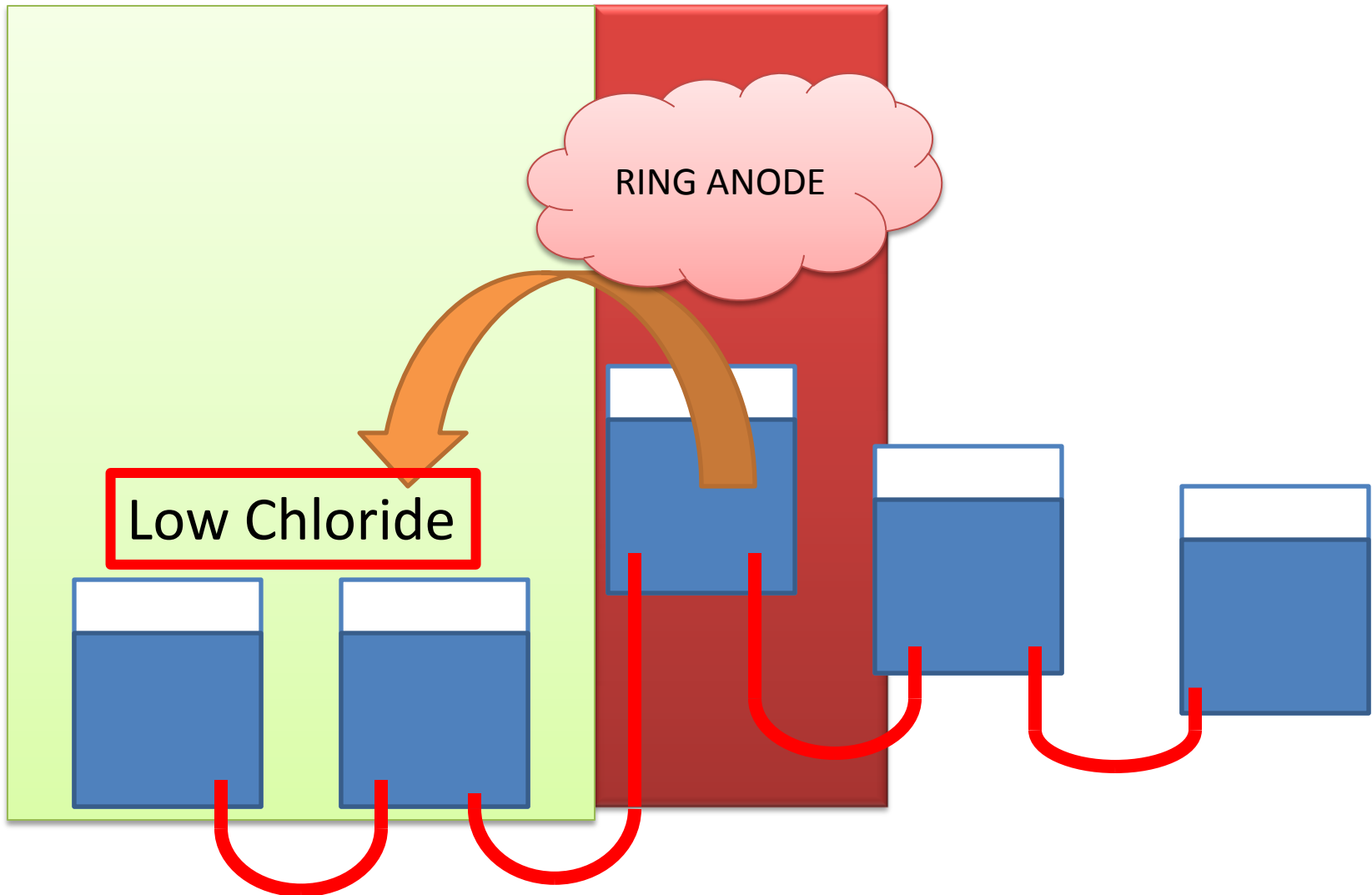
Water Analogy – Before Repair



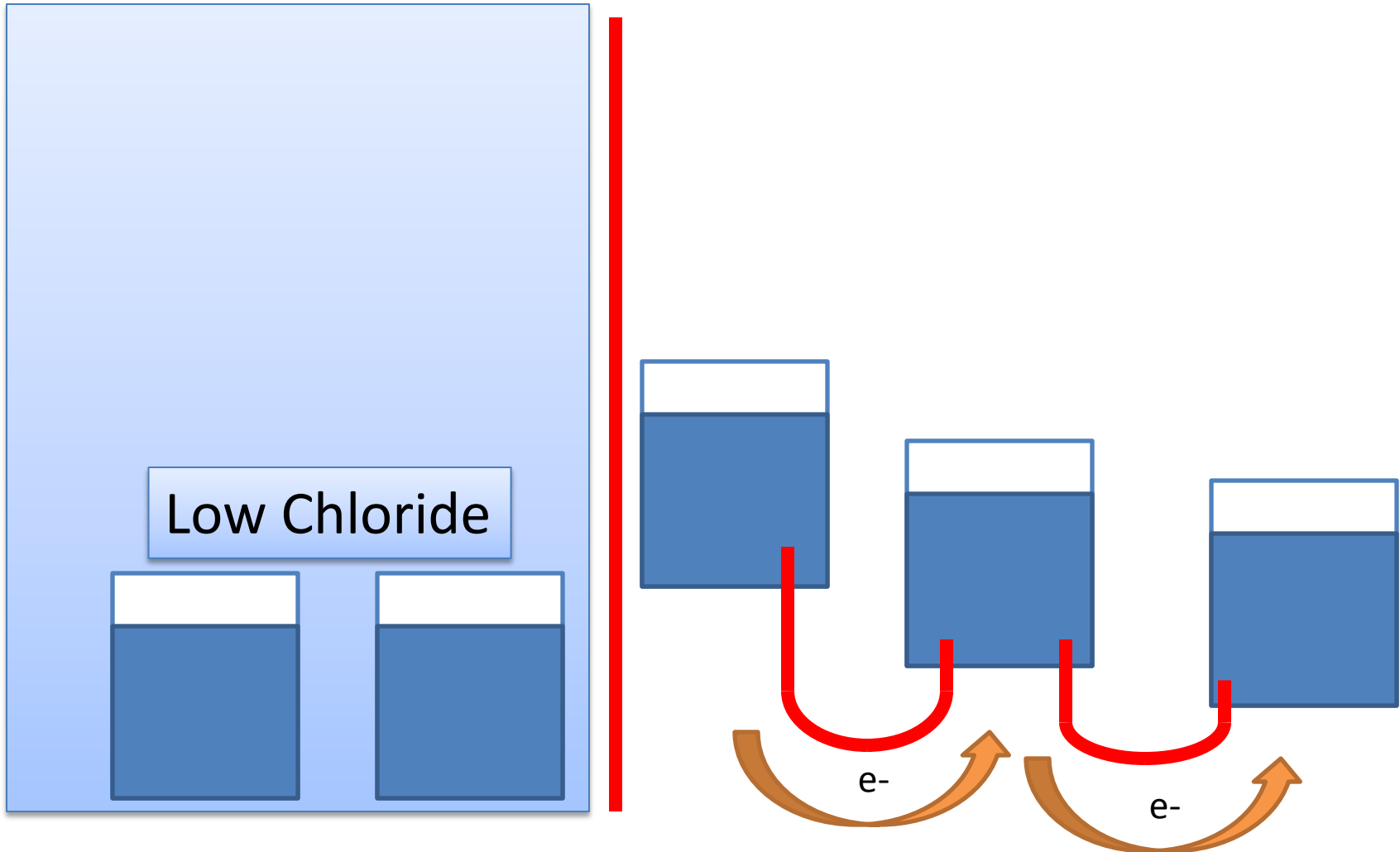
Water Analogy – Before Repair



Water Analogy – After Repair



Water Analogy



Reducing Ring Anode

Anode

Dry the concrete

Provide cathodic protection

Migrating inhibitors **

Cathode

Dry the concrete

Coated bars or bar coatings (2 coats)

Cathodic inhibitors

Provide local cathodic protection

Corrosion

Electrical Connection

- ???

Ionic path

- Use high electrical resistivity concrete in patch

Summary

- We can stop corrosion , but cannot afford it
- Corrosion is a battery
 - anode
 - cathode
 - electrical connection
 - ionic path
- Epoxy-coated bars work on all mechanisms of corrosion
- In repair, ring anodes need to be considered and mitigated
- Multiple methods need to be used to reduce future deterioration

Questions?

