Corrosion Protection of Reinforcing Steel in Concrete

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Cost of Corrosion

- Corrosion is the single most important cause of damage to concrete structures
- NACE estimates the cost of corrosion damage to concrete structures (in the USA) is approximately

$ 125 Billion per year!!!

Environmental Factors – Chloride Ion

Salting of Highways

Salt Dripping off Vehicles

Airborne Salt Deposition

Marine Exposure

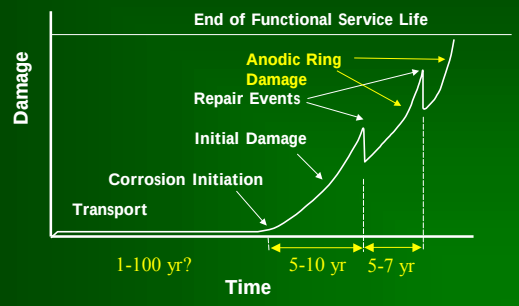
Environmental Factors - Carbonation

- Reduction of pH in cover concrete that causes loss of passive oxide layer
- Increased rate with increased w/cm
- Low pH caused by reaction of free lime ($Ca(OH)_2$) in concrete with atmospheric Carbon Dioxide (CO_2)

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

lime (soluble) pH 12-13 → (insoluble) pH < 9

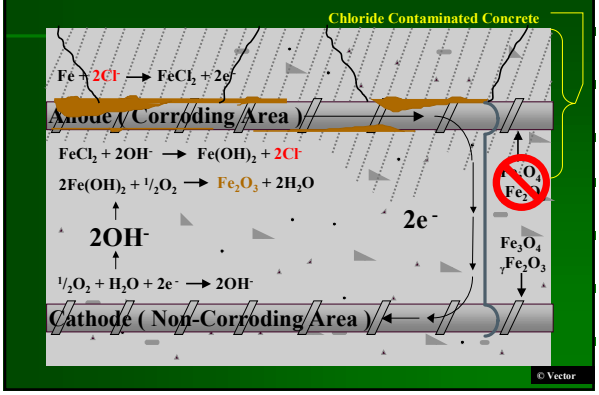
Corrosion Service Life

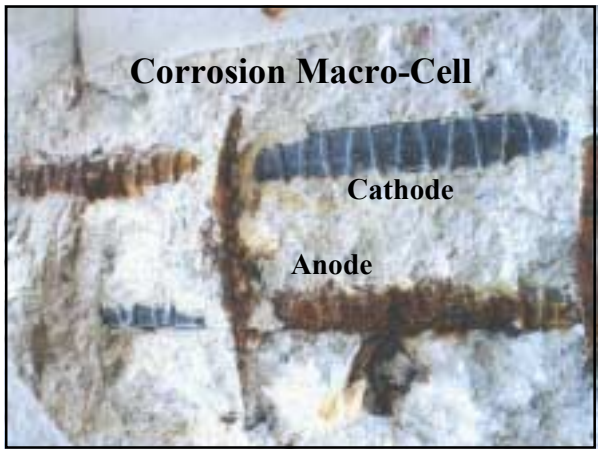


Requirements for Rebar Corrosion

- **1. Anode** (location where metal is lost)
  - pH < 11 and/or chloride ion initiate corrosion
- **2. Cathode** (steel surface)
  - Oxygen and water are consumed
- **3. Electrical connection** (steel)
  - Electron transfer from anode to cathode
- **4. Electrolytic connection** (moist concrete)
  - Ionic transfer from cathode to anode

Corrosion Macro-Cell in Concrete

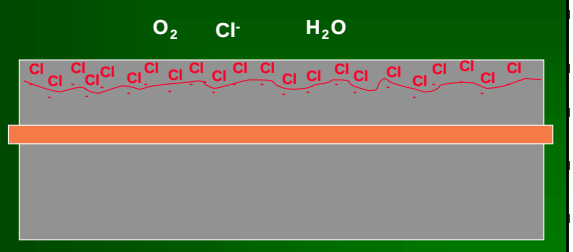




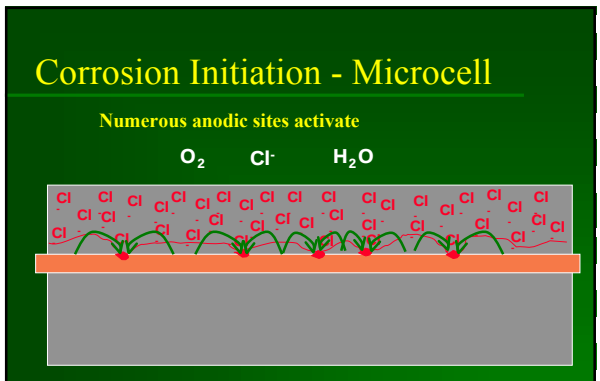
Anodic Ring (Halo Effect)

- Anodic ring phenomena are associated with a repair area that is surrounded by "new" corrosion sites.
- Anodic ring phenomena are one of the primary reasons for short-lived repairs.

Chloride Transport



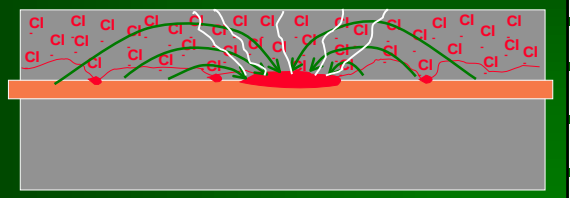
Corrosion Initiation - Microcell



Corrosion Damage - Macrocell

Primary anodic site cathodically protects smaller sites

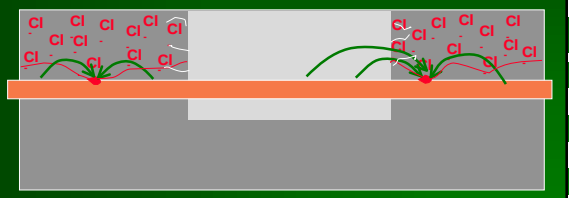
O_2 Cl^- H_2O



Structure after Repair

Secondary anodic sites activate

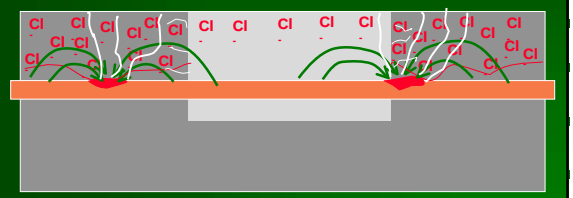
O_2 Cl^- H_2O



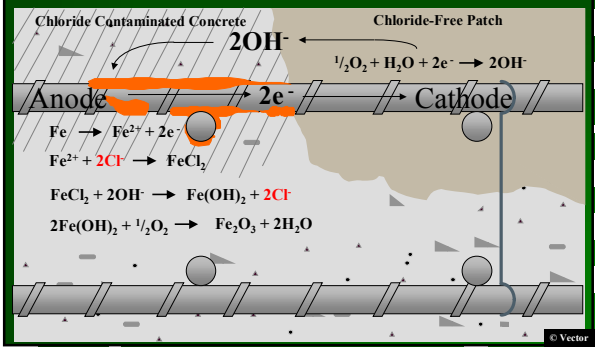
Anodic Ring Damage

Secondary anodic sites grow

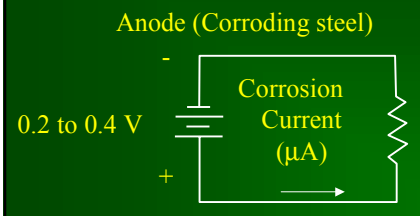
O_2 Cl^- H_2O

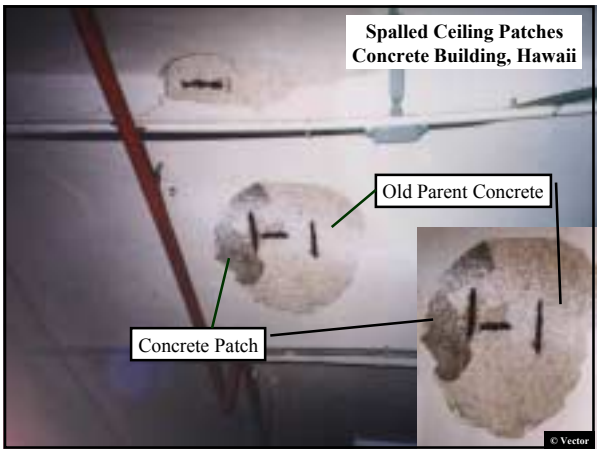


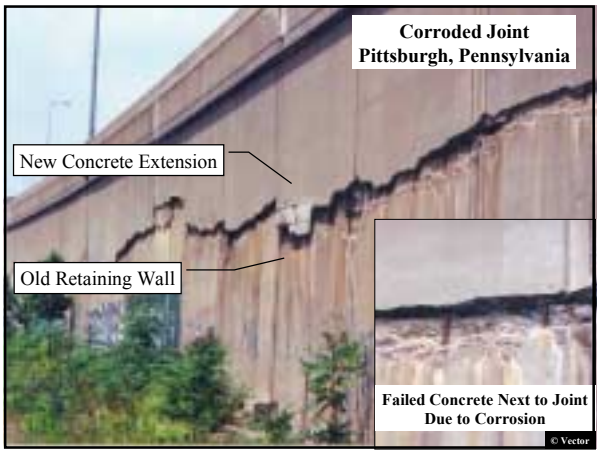
Corrosion Cell at Repair Edge



Steel Corrosion "Battery"







Corrosion Mitigation Options

- Address Cause for Corrosion Activity
- Remove Contaminated Concrete
  - Partial or full-depth repairs
- Dry the concrete
- Localized protection along interface
- Cathodic protection of entire element
- Electrochemical treatments

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Corrosion Management Strategies

Levels of Corrosion Protection

Corrosion Prevention	Preventing new corrosion activity from initiating
Corrosion Control	Significantly reducing on-going corrosion activity
Cathodic Protection	Highest level of protection intended to stop on-going corrosion activity
Corrosion Passivation	Stopping active corrosion by changing the environment around the steel

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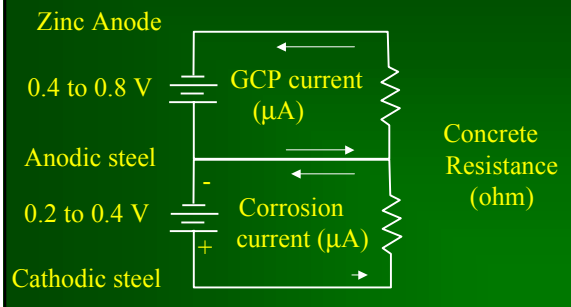
Galvanic Corrosion Protection Diagram



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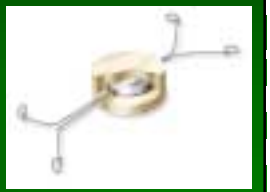
Corrosion Prevention in Concrete Repairs Using Discrete Galvanic Anodes

- Corrosion prevention
  - Use to prevent corrosion sites from initiating next to concrete repairs (ICRI Guideline 03730)
  - At joints between new and existing chloride-contaminated concrete
- Alkali activated
  - Contains no constituents corrosive to rebar
- Patented installation technique
  - Quick and easy
- Wide range of applications
  - Suitable for conventionally reinforced, prestressed and post-tensioned concrete structures



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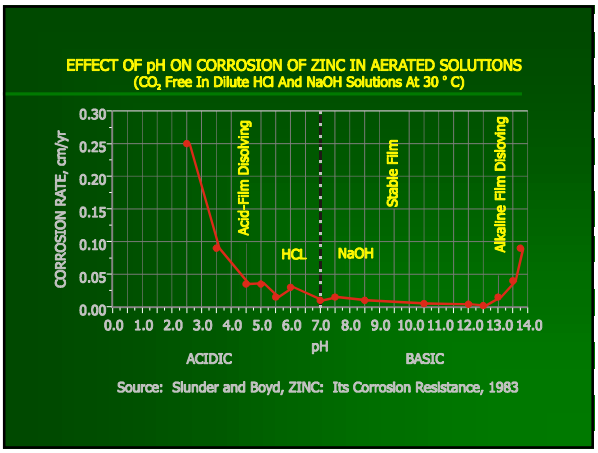
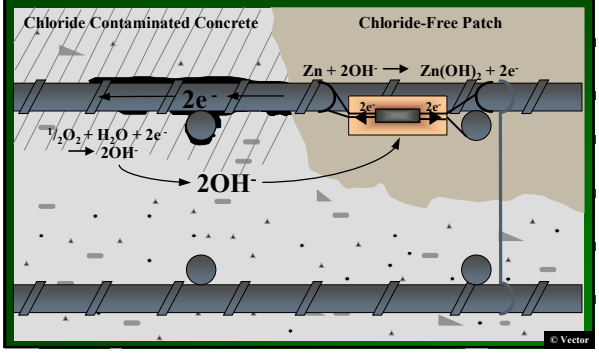
What is the purpose of the mortar shell around the anode?

- Mortar is specially formulated to keep the zinc active over time.
  - pH ≈ 14
- Mortar accepts corrosion by-products from the zinc core.



Repair with Discrete Galvanic Anode



Galvanic Corrosion Prevention
Parking Garage, North York, Ontario

Galvanic Corrosion Prevention
Port Mann Bridge: Deck Widening


Post Tension Anchor Repairs
Watergate Complex, Washington, D.C.
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Anode Installation
with Rebar Coating
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Corrosion Control in Sound Concrete
with Discrete Galvanic Anodes
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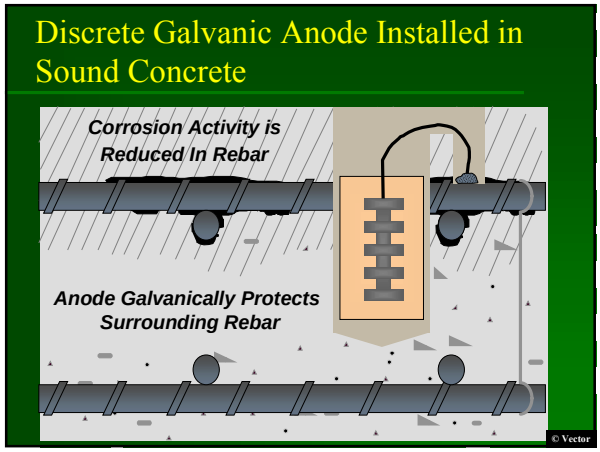
Discrete Galvanic Anode Installed in
Sound Concrete
Corrosion Activity is
Reduced In Rebar
Anode Galvanically Protects
Surrounding Rebar
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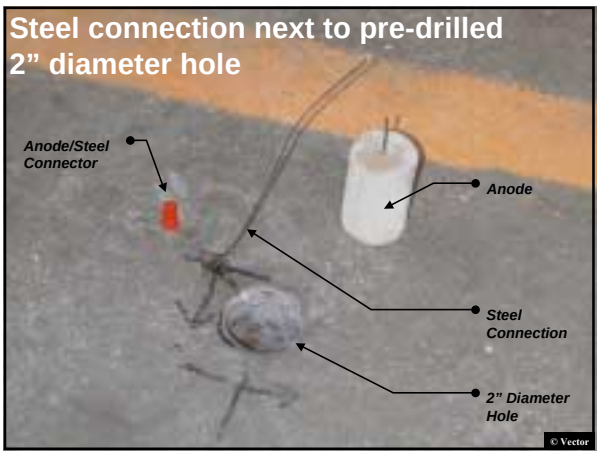
Steel connection next to pre-drilled
2” diameter hole
Anode/Steel
Connector
Anode
Steel
Connection
2” Diameter
Hole
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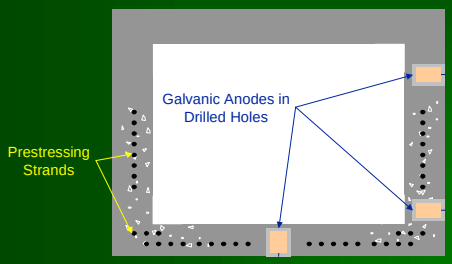
Localized Protection with Discrete Galvanic Anodes in Critical Areas

Embedded Galvanic Anodes in Prestressed Box Girder Repair



- Galvanic Corrosion Control
- NYSDOT: Prestressed Concrete Beam Repair

Galvanic Anodes in Prestressed Box Girder

Cathodic Protection Systems

- Work by applying sufficient current to reinforcing steel to overcome the corrosion process
- Galvanic Systems: Sacrificial metal corrodes to provide protective current
  Impressed Current Systems: D.C. power supply provides current (rectifier or battery)

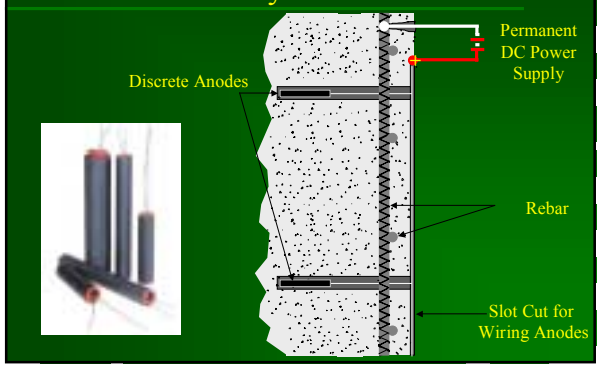
Galvanic Cathodic Protection with Distributed Anodes

- Galvanic Cathodic Protection Deck Overlay
- Ontario Ministry of Transportation

Galvanic Cathodic Protection in Pile Jackets

Galvanic Cathodic Protection with Activated Arc-Sprayed Zinc

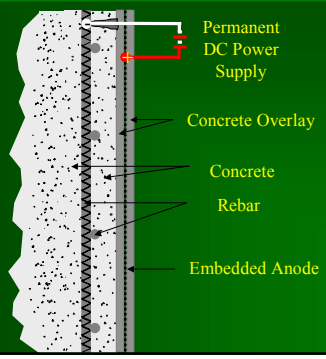
Impressed Current Cathodic Protection Discrete Anode System



Installation of Discrete Anode ICCP System Winnipeg, Manitoba

Installation of Discrete Anode System Winnipeg, Manitoba

Impressed Current Cathodic Protection Using Distributed Anode System



Corrosion Passivation

- Modify the chemistry of the concrete to create a passive environment around the reinforcing steel.

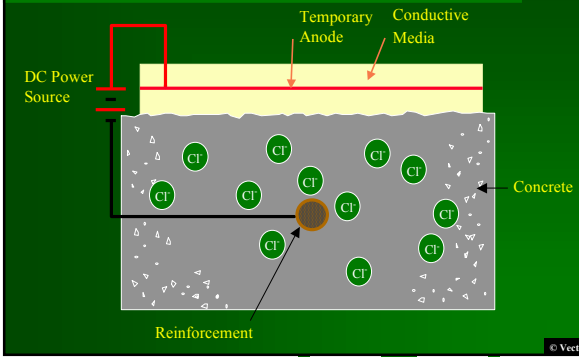
Electrochemical Treatments

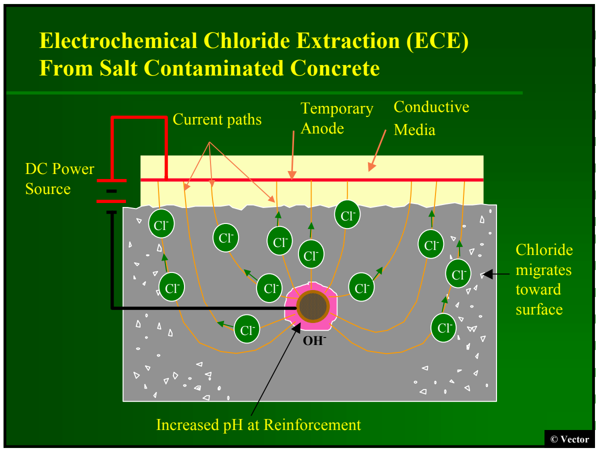
- Proven long term performance
- Measurable criteria:
  - ECE: Chloride content before and after 700 to 1500 A*hr/m^2 (SHRP)
  - Realk: pH before and after (phenolphthalein) 100 to 250 A*hr/m^2

Electrochemical Chloride Extraction SHRP Research

- Extensive ECE Testing Undertaken (SHRP)
- Confirmed ECE's Ability to:
  - Halt Corrosion
  - Restore Passive Oxide Film on Rebar
- No Adverse Chemical or Mechanical Effects
- ECE Deemed one of the Most Valuable Technologies Evaluated
- Long Term Data Shows Rebar Still Passive

Electrochemical Chloride Extraction (ECE) From Salt Contaminated Concrete




Electrochemical Chloride Extraction (ECE)
From Salt Contaminated Concrete
Current paths
Temporary Anode
Conductive Media
DC Power Source
Chloride migrates toward surface
Cl^-
OH^-
Increased pH at Reinforcement
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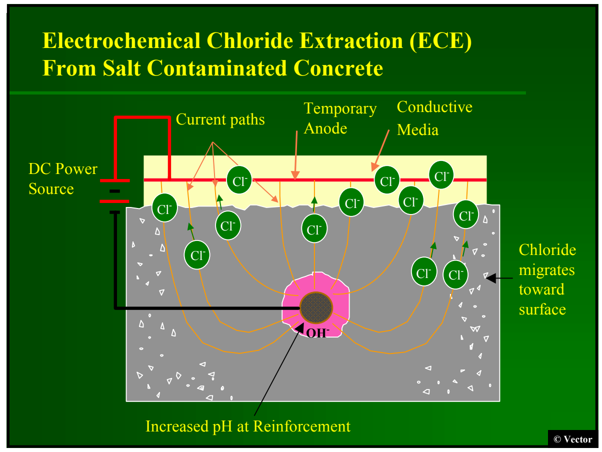
Electrochemical Chloride Extraction (ECE)
From Salt Contaminated Concrete
Current paths
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Chloride migrates toward surface
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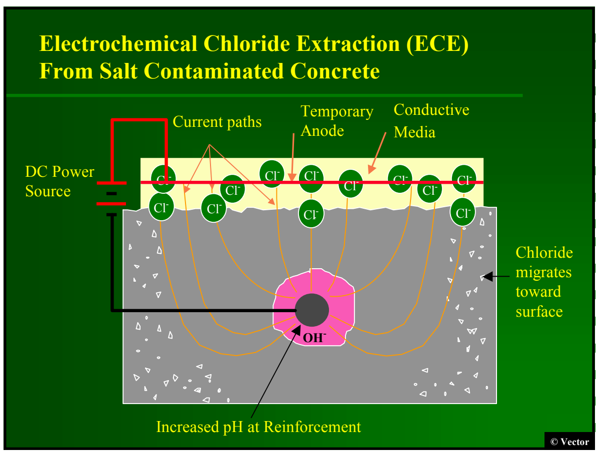
Electrochemical Chloride Extraction (ECE)
From Salt Contaminated Concrete
Current paths
Temporary Anode
Conductive Media
DC Power Source
Chloride migrates toward surface
Cl^-
OH^-
Increased pH at Reinforcement
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Step 1 : Concrete Repair
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Step 2 : Install Battens
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Step 3 : Install Temporary Anode

Step 4: Spray Cellulose Fiber

Several Piers Wrapped and Undergoing ECE Treatment
Omaha, Nebraska

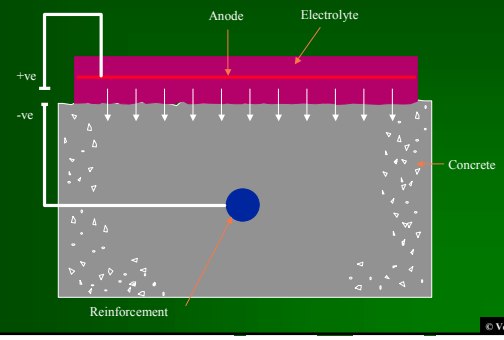
Piers after ECE Treatment
Cleaned and Sealed

St. Adolphe Bridge over Red River
St. Adolphe, Manitoba
Manitoba Highways and Transportation

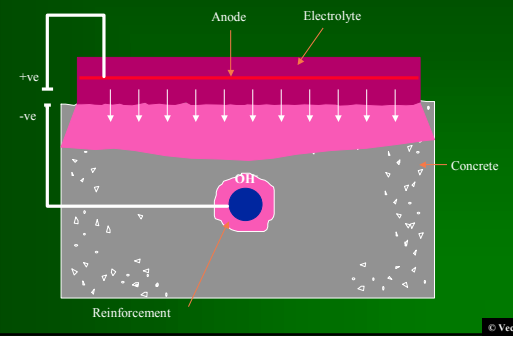
Realkalization

- Draws highly alkaline electrolyte to the reinforcing steel to restore lost alkalinity to carbonated concrete
- Alkalinity around reinforcing steel is maintained over time, will not re-carbonate
- Lower cost, less disruptive than mechanical removal and replacement of carbonated concrete

Realkalization



Realkalization



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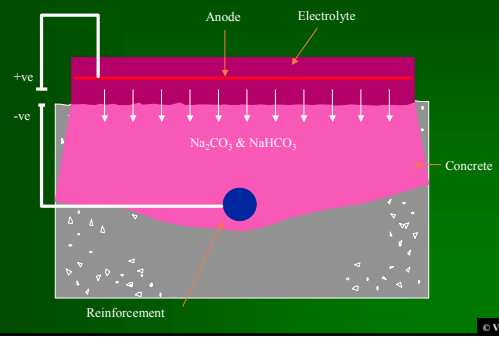
Realkalization



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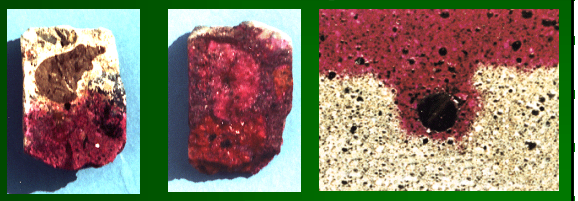
Phenolphthalein Testing

- Testing on Cores
  Before After
- The affects of realkalization: increased pH around steel



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Summary

Level of Protection	Description	Typical Solution
Corrosion Prevention	Preventing new corrosion activity from initiating	Discrete Galvanic Anodes
Corrosion Control	Significantly reducing active corrosion	Discrete Galvanic Anodes
Cathodic Protection	Stopping active corrosion by applying on-going electrical current	Distributed Galvanic Anodes or Impressed Current Cathodic Protection (ICCP)
Corrosion Passivation	Stopping active corrosion by changing the concrete environment around the steel	Electrochemical Treatments (ECE or Realkalization)