Corrosion Mitigation Systems for Concrete Structures

Vector Corrosion Technologies

Outline

- Concrete Corrosion
- Corrosion Evaluation
- Impressed Current Cathodic Protection
- Galvanic Protection
- Electrochemical Treatments

Concrete in Society

- Concrete is the most widely used man-made product in the world
- 6 Billion tons per year (3 - 4 Billion yd^3)
- Production of 1 ton of cement produces approx 1 ton of CO_2
  - (CO_2 Production ~ 1 Billion tons / yr)
- Production of 1 ton of steel produces ~ 2 tons of CO_2
  - (CO_2 Production ~ 200 Million tons / yr)

Responsible Use of Concrete

- Despite the environmental impact, concrete is one of the most environmentally friendly materials available if it is used properly.
- Concrete is extremely durable and has the ability to last for many years.
  - Design of long lasting structures
  - Repair/rehabilitate to maintain in service

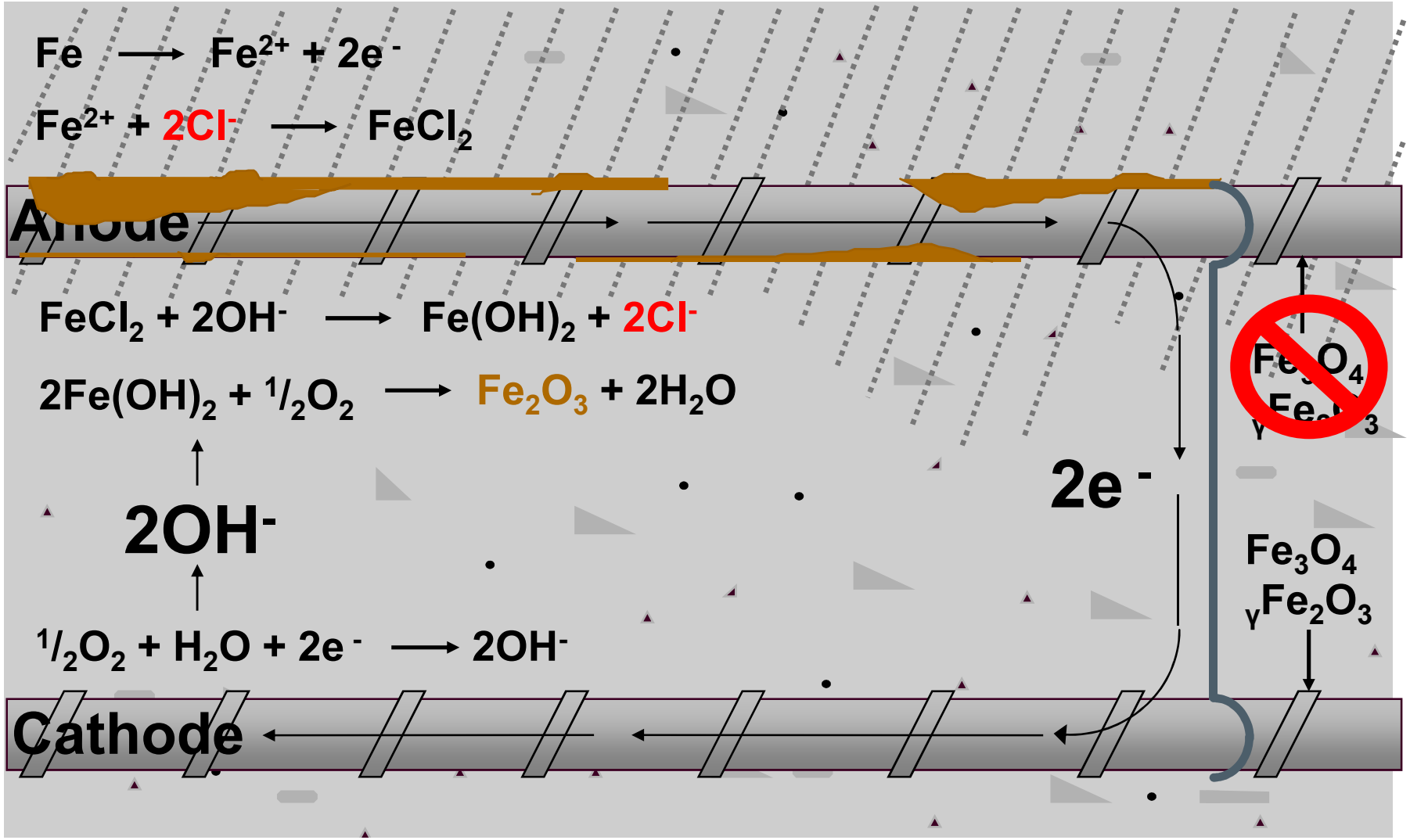
Corrosion in Reinforced Concrete

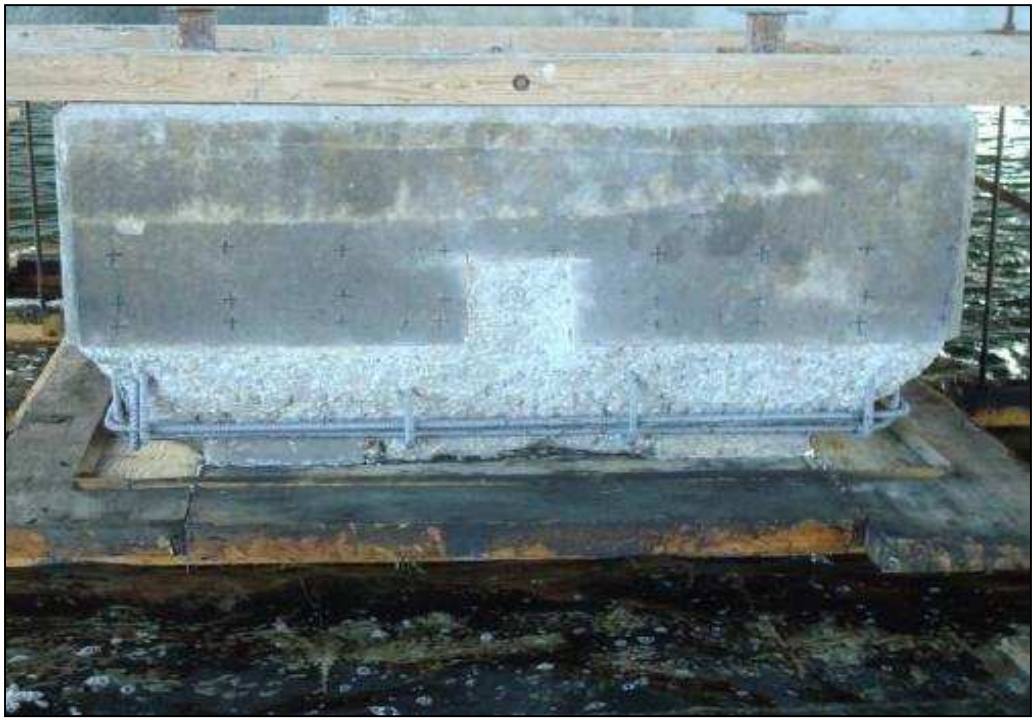
- Corrosion is the single most important problem in concrete structures
- NACE estimates the cost of corrosion (in the USA) to be approximately

  400 Billion!!!

- It's estimated that 25-30% of this cost is attributed to corrosion of concrete structures

Corrosion Cell in Concrete

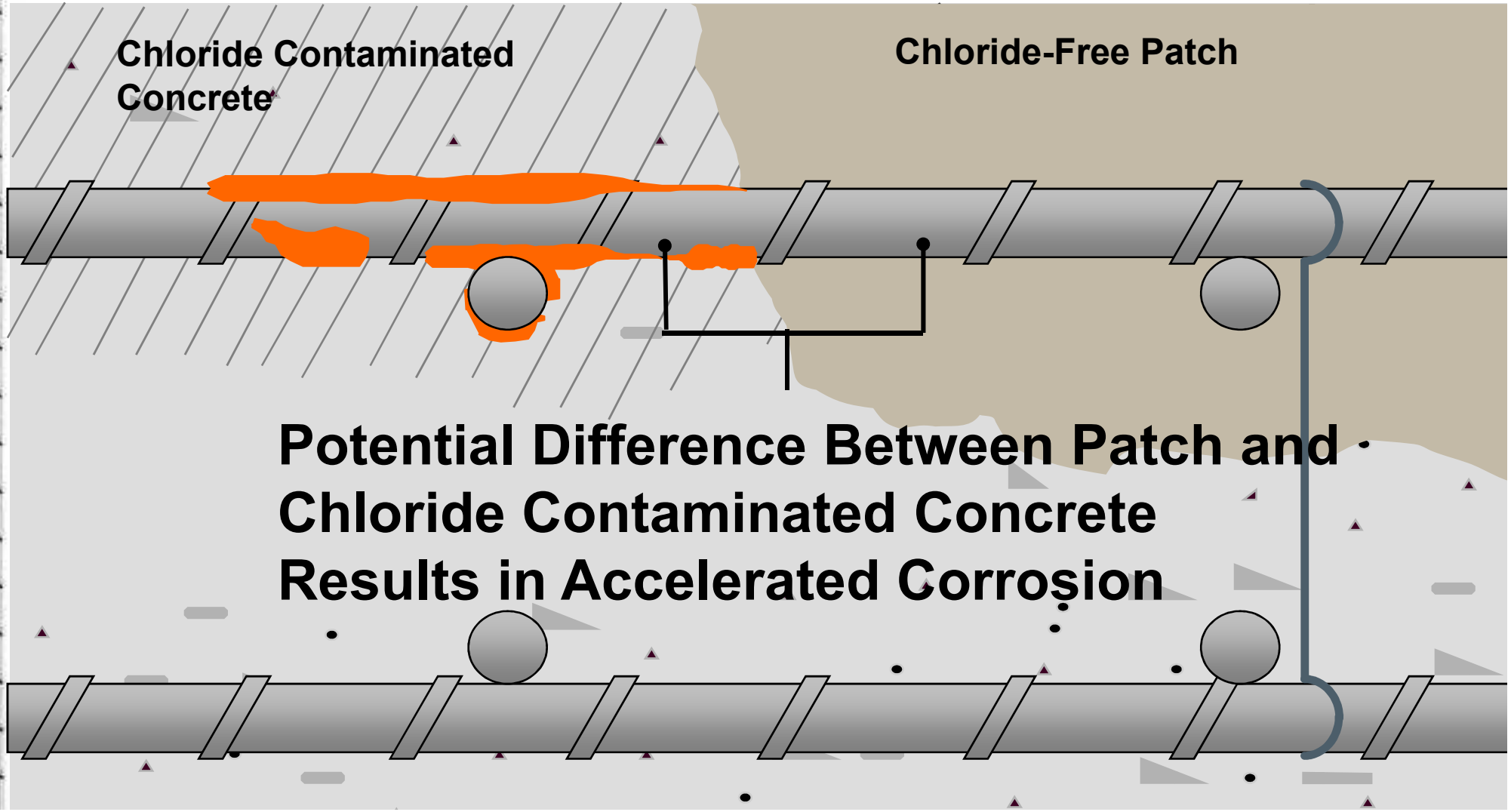




Corrosion Ravaged Columns
Chicago, Illinois


30
MPH

Patch Accelerated Corrosion



New Corrosion Sites

Underside of Parking Deck

Bridge Deck

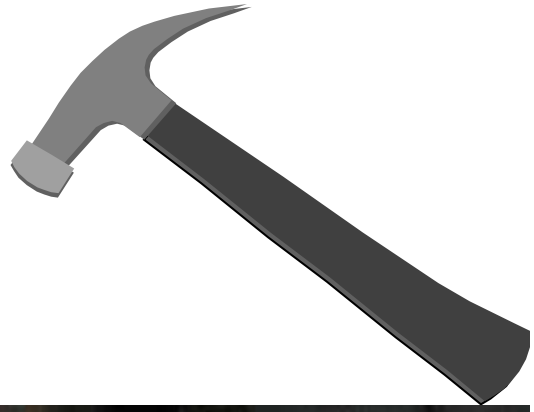
Corrosion Services

- Evaluation and Testing
- Monitoring
- Technical Site Services
- CP System Design
- System Installation

Visual Inspection

- Identify areas of visual damage
  - Rust stains on surface
  - Cracks
  - Spalls
  - Exposed steel
- Note exposure conditions and other observations

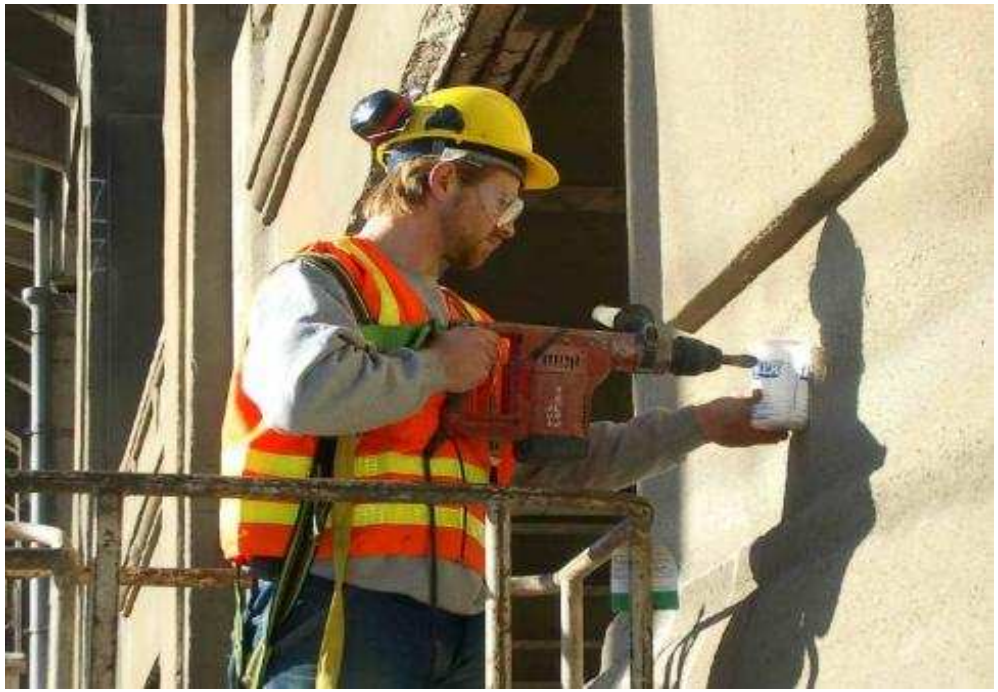
Delamination Survey



- Performed as per ASTM D4580
- Locate areas where concrete has lost bond with rebar and delaminated concrete which has not yet spalled
- Also known as “Sounding”
  - Hammer test
  - Chain drag

Chloride Sampling and Analysis

- To determine chloride content at various levels within the concrete
- Chloride content can be performed on concrete cores or dust samples



Chloride Thresholds

- 0.2% by weight of cement (ACI)
- 0.031% by weight of concrete
- 1.2 lb Cl^-/yd^3 of concrete (0.71 kg/m^3)
- These code guidelines are rather simplistic
- Different concrete conditions have different thresholds: wet or dry concrete, prestressed, etc.
- In reality corrosion activity is progressive and based on the Chloride / Hydroxyl Ratio (Cl^-/OH^-)

Chloride Limit for New Construction (ACI 222R)

	Acid Sol.	Water Sol.	Water Sol.
Test Method	ASTM C1152	ASTM C1218	Soxhlet
Prestressed	0.08	0.06	0.06
Reinforced Wet	0.10	0.08	0.08
Reinforced Dry	0.20	0.15	0.15% by weight Cement

Section 1

pH Testing

- Mainly to determine amount of carbonation
  - Can also be used to determine some types of chemical contamination
- 1% phenolphthalein in alcohol or 50/50 mixture of distilled water and alcohol
- Generally perceived to indicate pH of > 9.5
- “Rainbow” types also available

Depth of Cover Survey

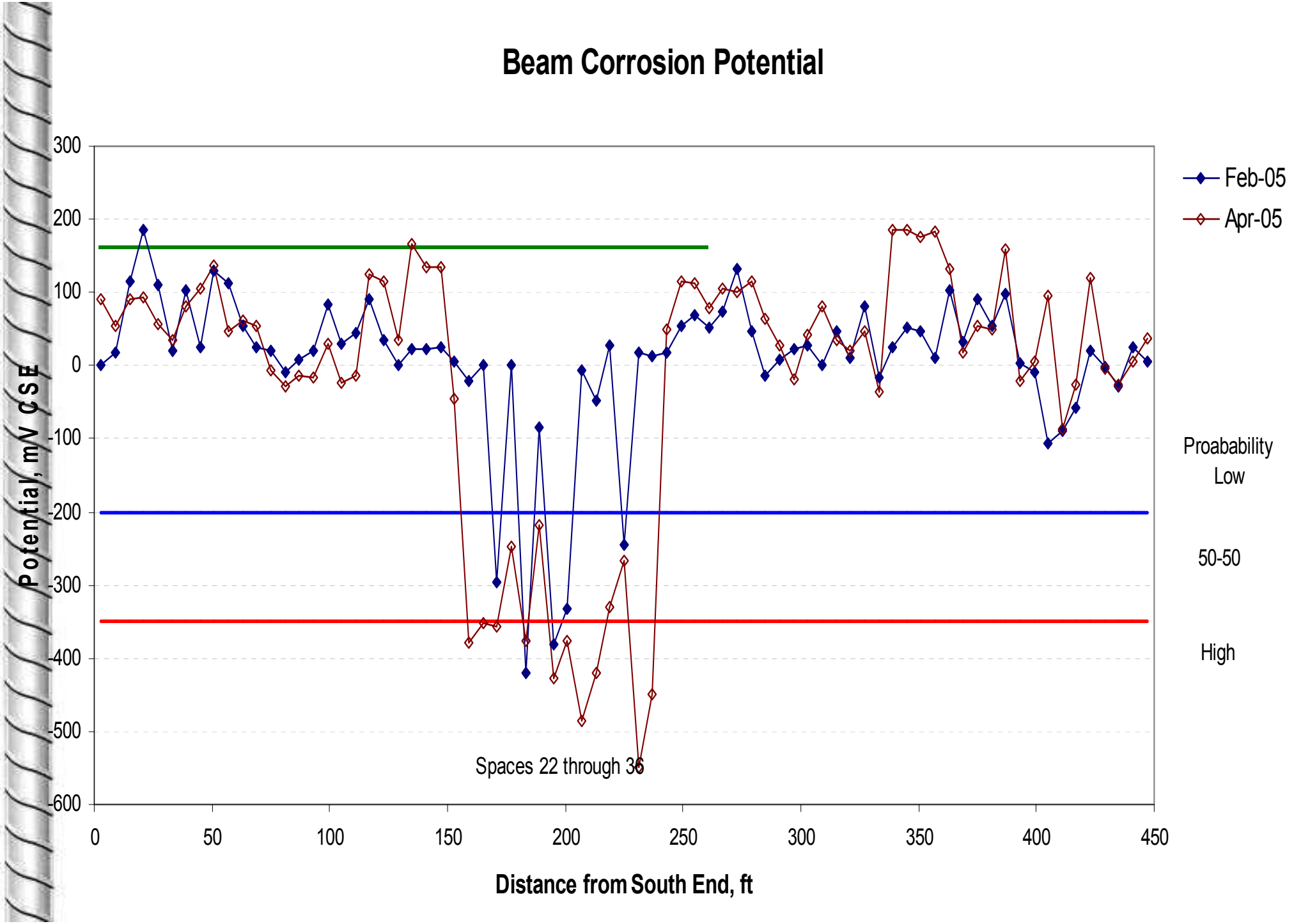
- To determine the average depth of concrete covering the rebar within the structure
- Compare depth of rebar with results of chloride and carbonation testing
- Performed using Micro Covermeter

Rebar Continuity

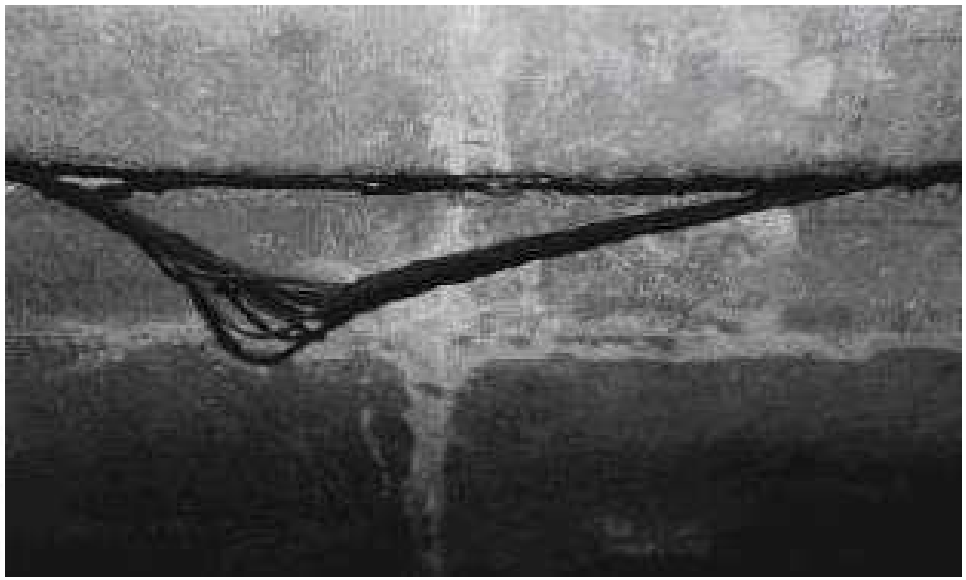
- Verify electrical continuity of the steel
  - Discontinuous steel may pose problems for cathodic protection
- Typical Criteria
  - Less than 1 mV or
  - Less than 1 ohm resistance

Corrosion Potential

- To determine the probability of corrosion by measuring the potential (voltage) of the reinforcing steel
- Uses a reference electrode:
  - copper-copper sulfate
  - silver-silver chloride
- Performed as per ASTM C876-91

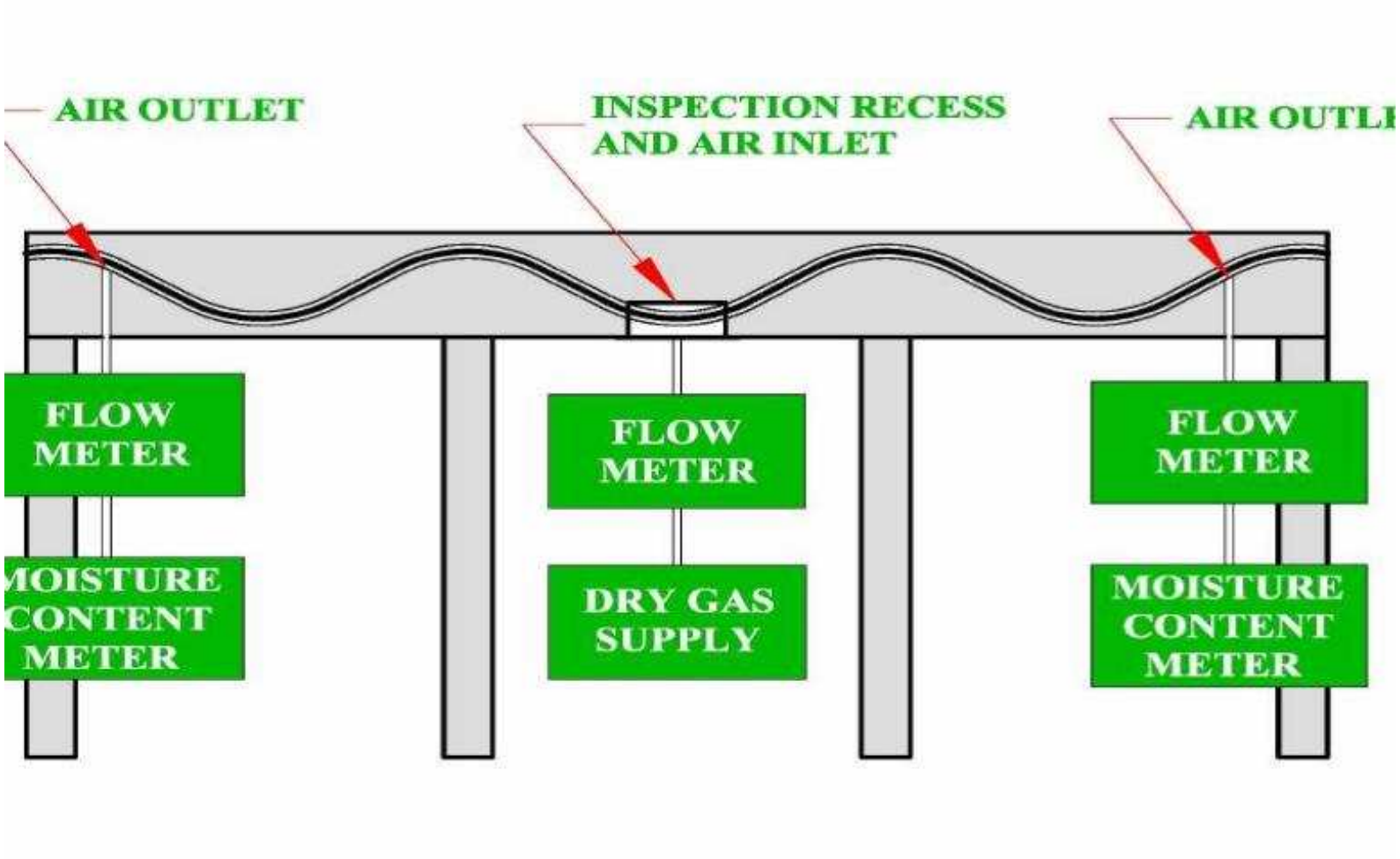

Beam Corrosion Potential
300
200
100
0
-100
-200
-300
-400
-500
-600
Potential, mV CSE
0
50
100
150
200
250
300
350
400
450
Distance from South End, ft
Spaces 22 through 36
Feb-05
Apr-05
Proabability
Low
50-50
High

Damaged Post-Tension Cables




VECTOR

PT Corrosion Evaluation

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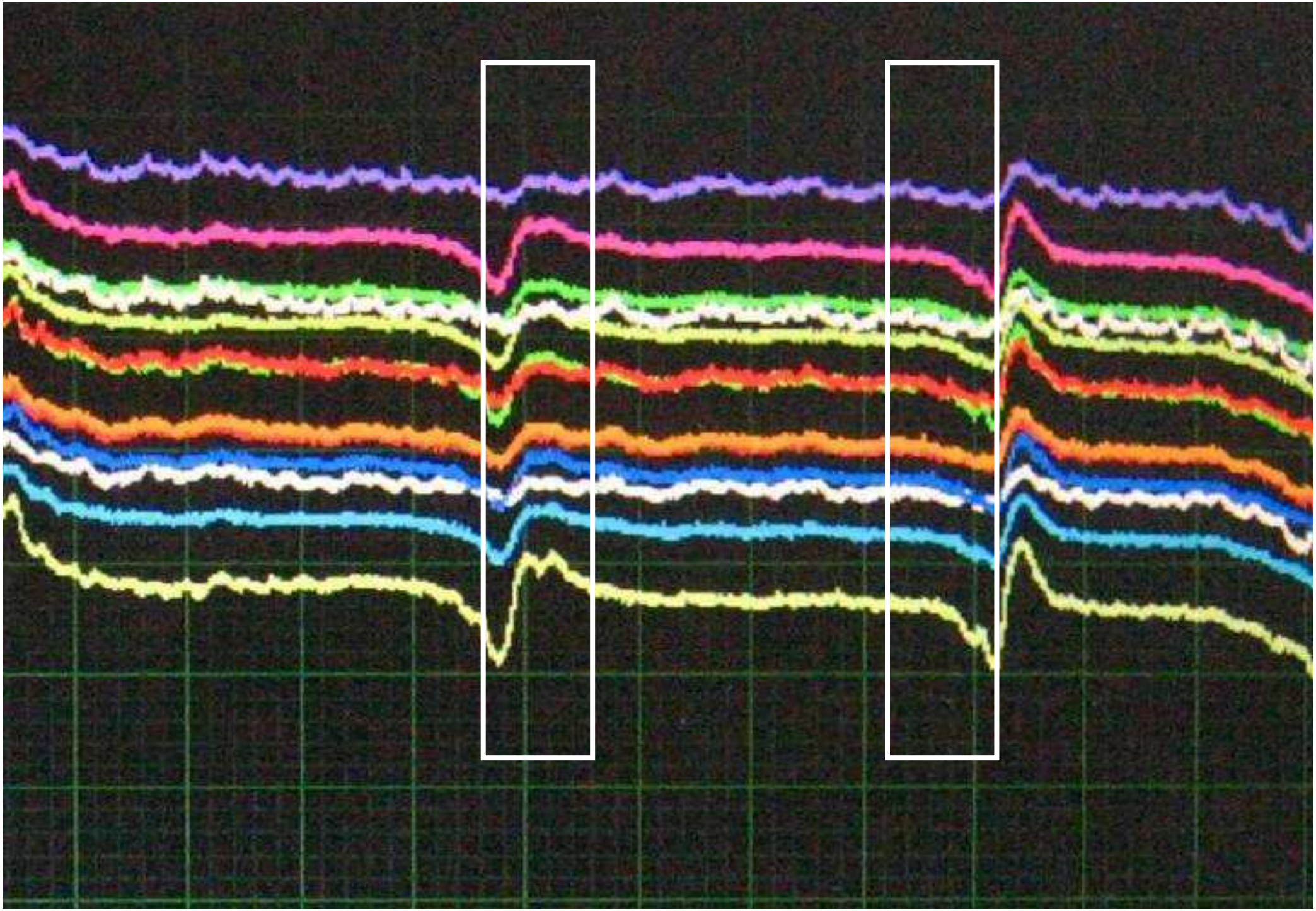
PT Corrosion Evaluation

	Classification Code	Potential for Corrosion	Moisture Content (kg/kg)
	1	Very Low (Very Dry)	< 0.001
Dry	2	Low (Dry)	0.001 < 0.003
	3	Moderate (Dry/Wet)	0.003 < 0.007
Wet	4	High (Wet)	0.007 < 0.010
	5	Very High (Very Wet)	> 0.010

Post Tech Cable Break Detection

Impulse Magnetization
with Scanner

Bridge Deck Scan



ICRI No. 310.1R–2008 Guideline for Surface Preparation for Repair of Concrete Deterioration Resulting from Reinforcing Steel Corrosion

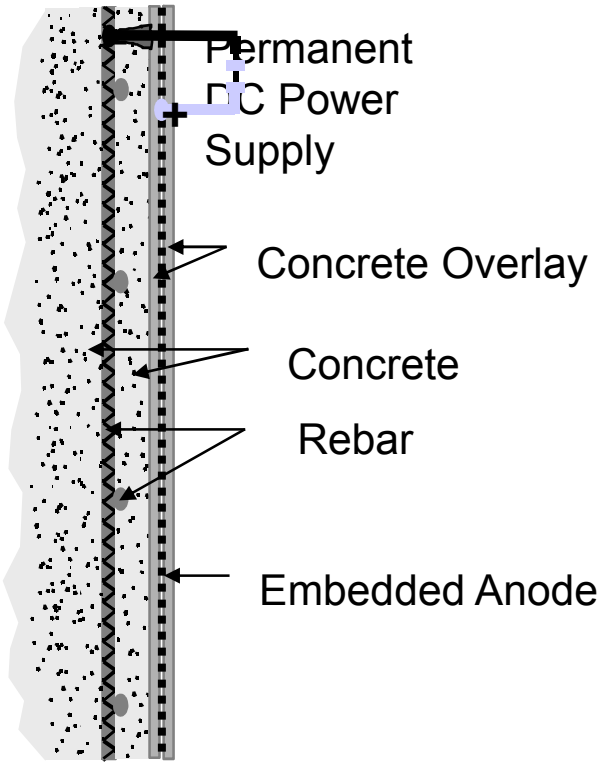
Key Issues Re Corrosion

- Remove concrete from full circumference of all reinforcing steel.
- Remove corrosion by-products from steel
- Expand area of patch outs area of active corrosion (clean steel).

Electrochemical Corrosion Mitigation Systems

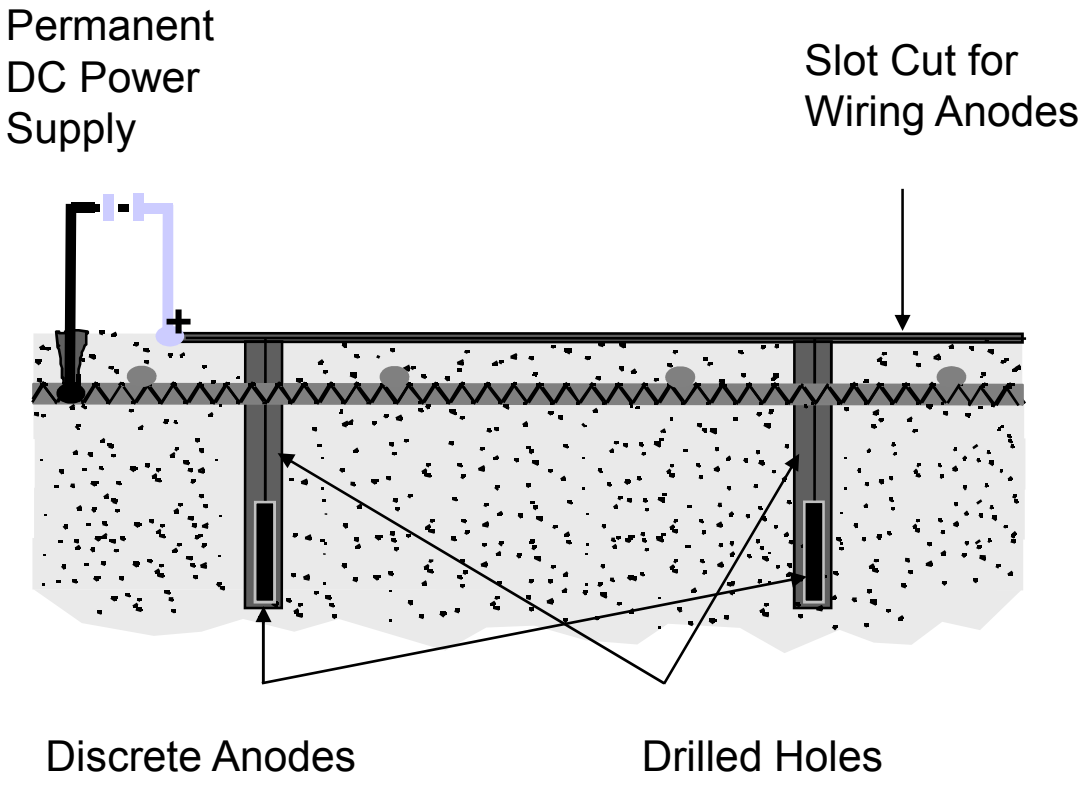
- **Impressed Current Systems**
  - Permanent D.C. power supply forces current flow from anode to reinforcement (cathode)
- **Galvanic Systems**
  - Sacrificial metal corrodes to provide protective current
- **Electrochemical Treatments**
  - Temporary D.C. power supply and anodes
  - Passivate corrosion by changing the environment around the reinforcement
  - Electrochemical Chloride Extraction or Re-alkalization

Impressed Current Cathodic Protection



Distributed Anodes

Point Anodes



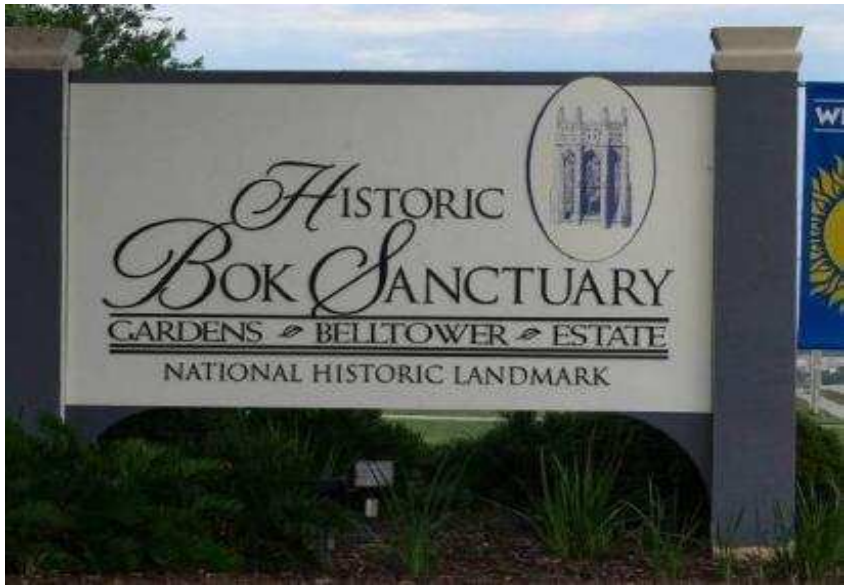
Impressed Current CP

- Outside power source required
- High level of control
- System monitoring and maintenance required

Bok Tower

Lake Wales, FL

- Historic Bell Tower
- Dedicated in 1929 – by President Calvin Coolidge
- Masonry encased steel frame
- Marble and coquina exterior



Bok Tower

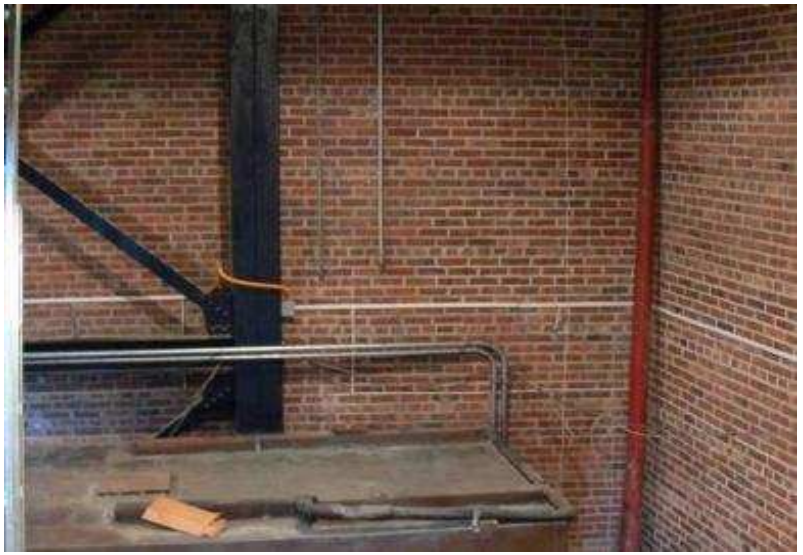
- Moisture intrustion caused corrosion of steel beams
- Corrosion damage of exterior stone
- ICCP with discrete anodes installed to protect steel frame

Bok Tower

- Discrete anodes placed in ½ in. diameter holes
- 32 in. spacing above and below beams
- Installed from the interior through brick masonry

Bok Tower

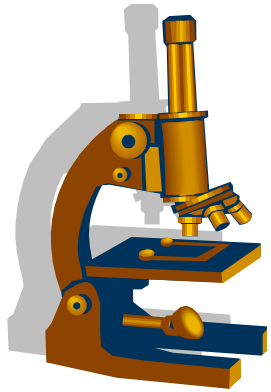
- Remote monitoring and control of power
- Minimal disruption
- Minimal impact on appearance



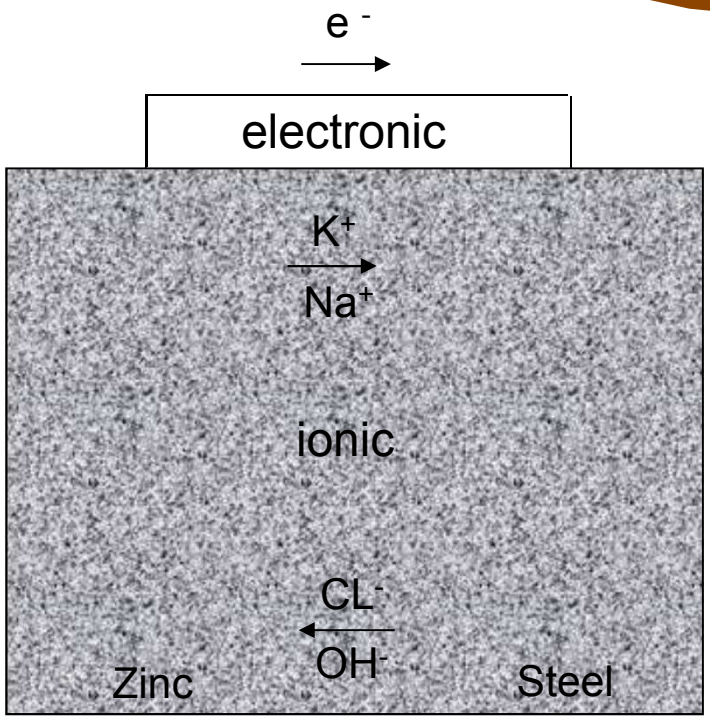
Galvanic Protection Systems

- Two different metals are connected in same electrolyte (concrete)
- More “active” metal = anode
- More “noble” metal = cathode
- Anode corrodes to protect cathode
- Natural reaction
  - no external power required
- Safe for prestressed concrete

Potentials and Current Flow



Partial Galvanic Series	
Metal	Voltage
Zinc	-1100 mV
Steel in concrete	-200 mV to -500 mV
*Typical potentials measured with respect to copper-copper sulfate electrode	

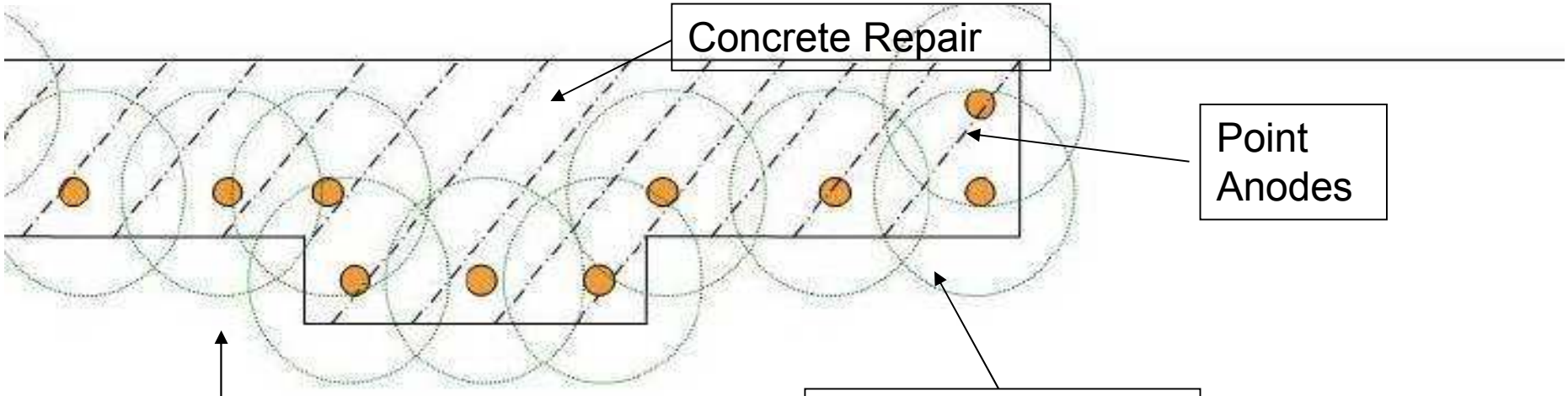


Types of Galvanic Systems

- Embedded Discrete Anodes
- Embedded Distributed Anodes
- Externally Applied Anodes
  - Zinc Sheets
  - Zinc Metalizing

Point Anodes

Point Anodes Protection (Typically for Halo Effect)

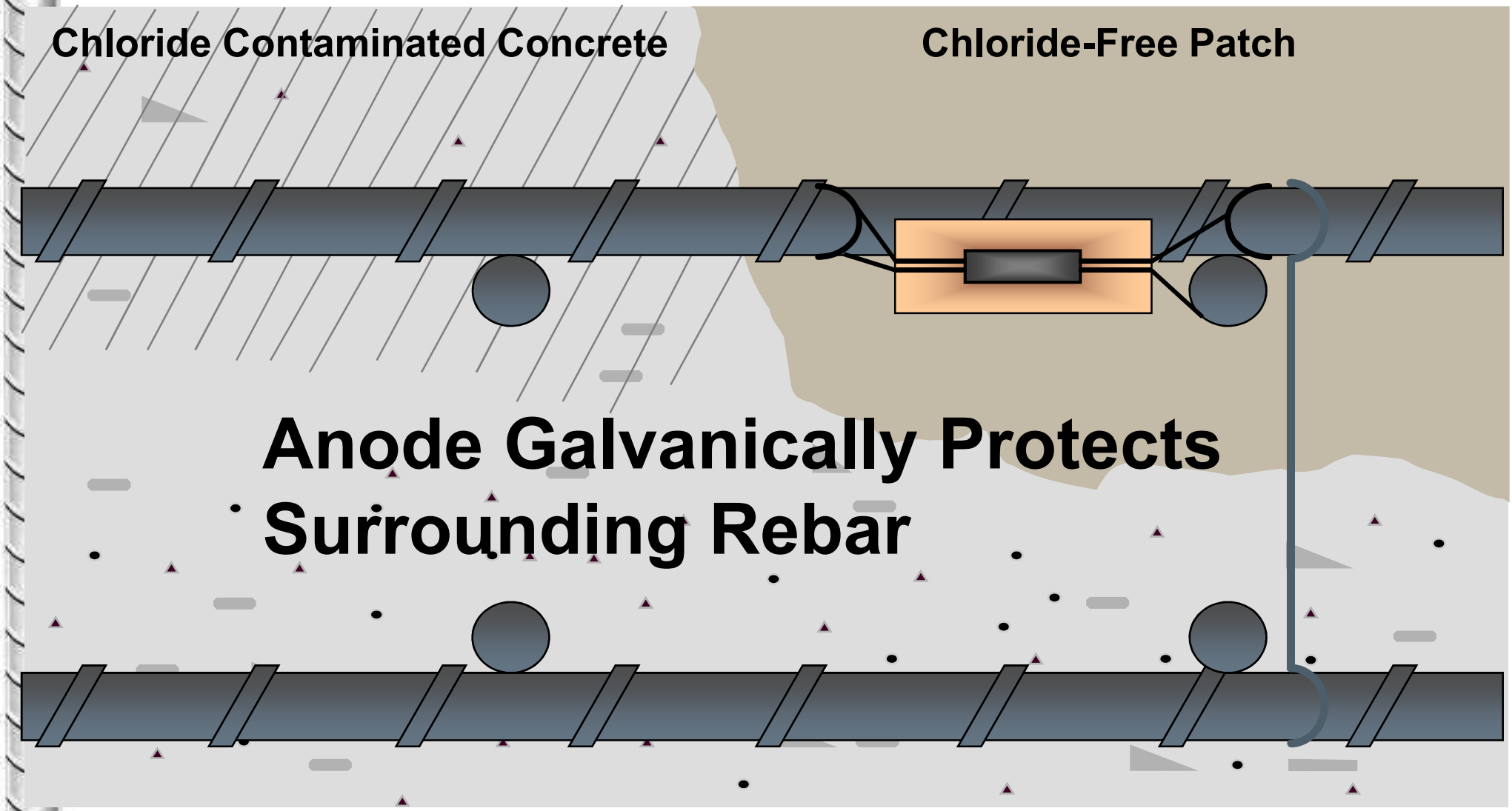


Activation Technology

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



Discrete Galvanic Anodes

Installing anodes around the perimeter of the repair.

Discrete Galvanic Anodes

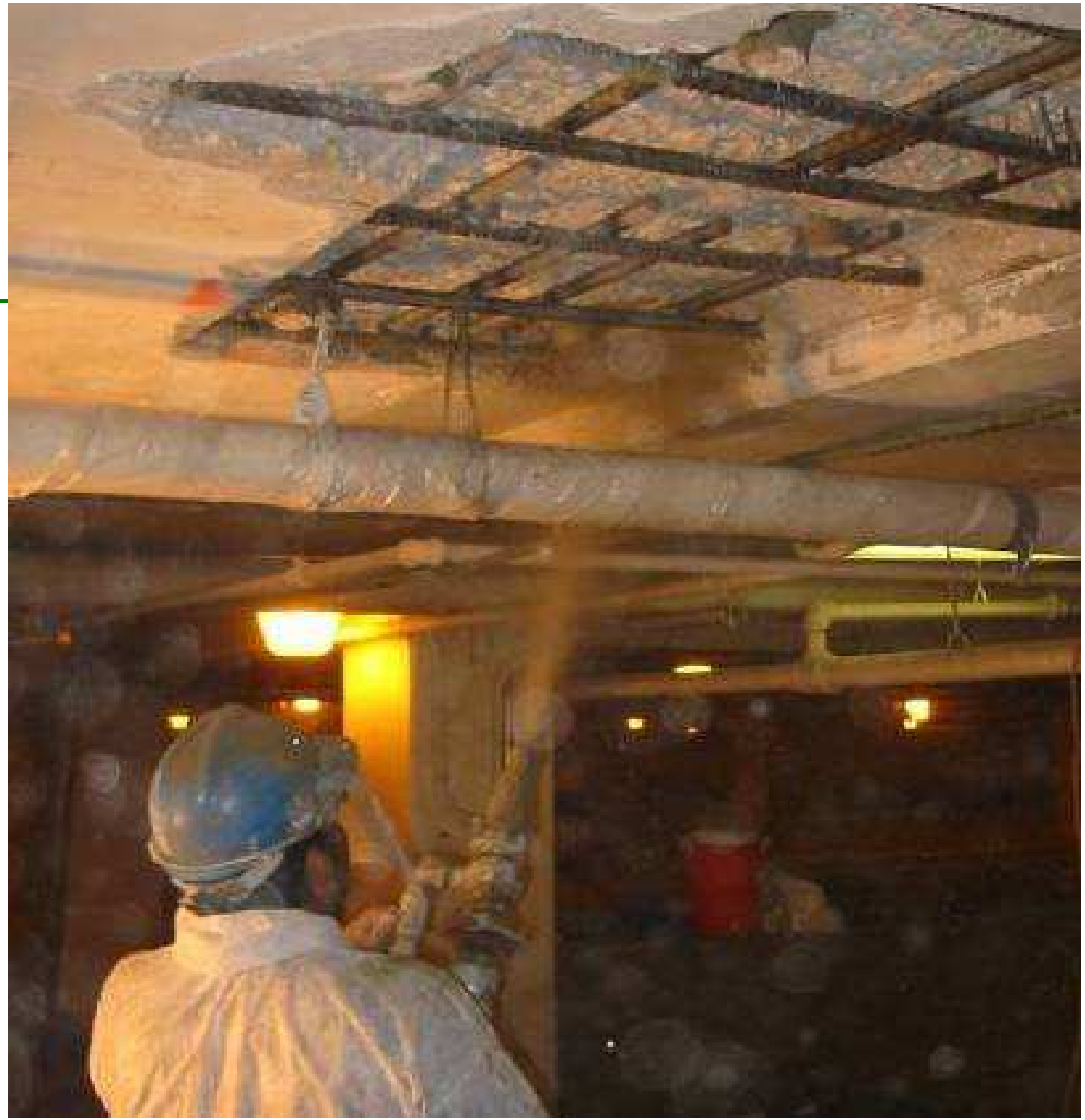
Bridge Deck - Chip and Patch Repairs.
Colorado DOT – Greeley, CO


NYSDOT Maintenance
Bridge Deck Repair

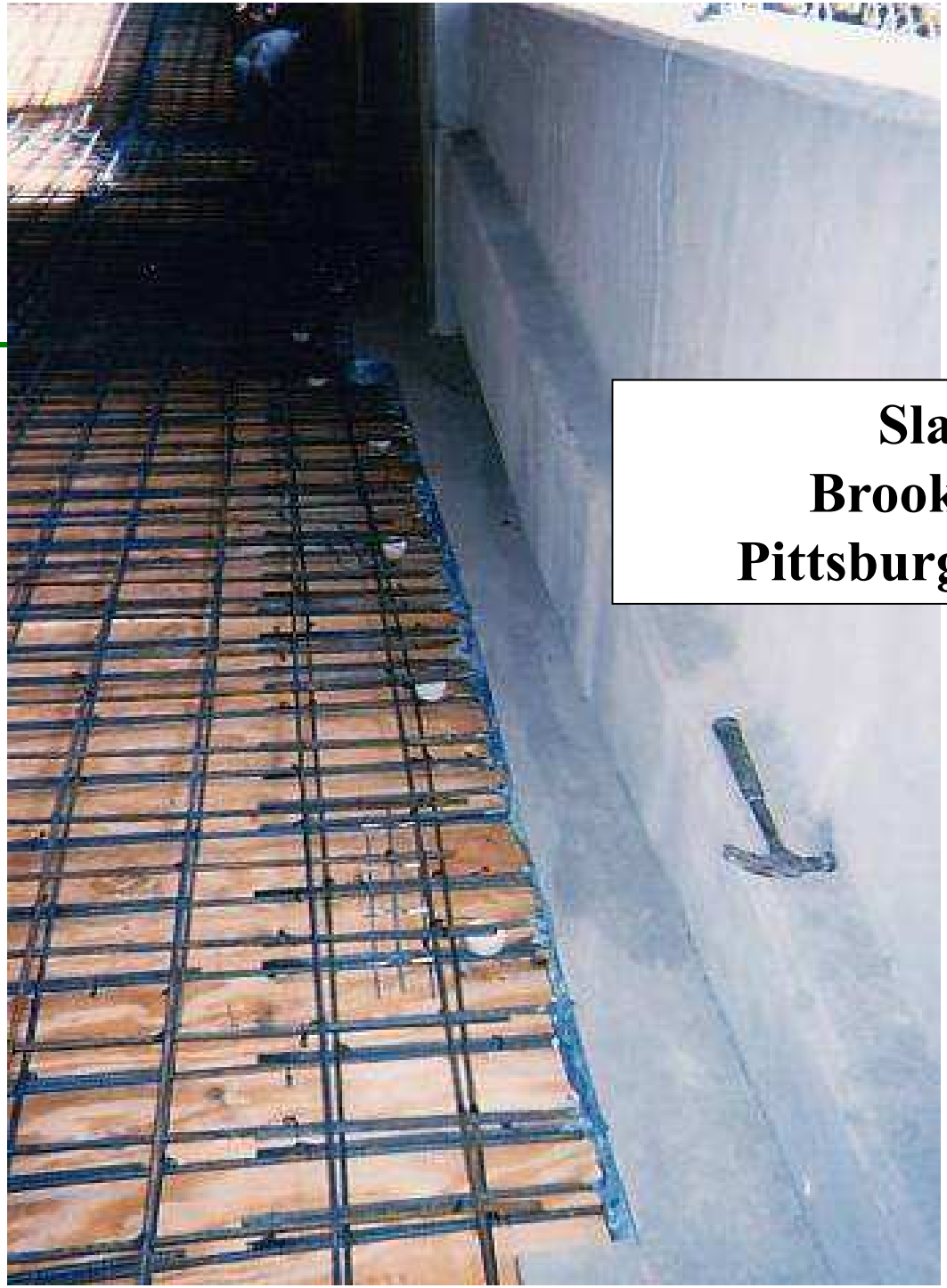

Patch Repair
Arch Bridge
20 07 2004

Bridge Widening Corrosion Prevention


© Vector



Post Tension Anchor Repairs
Watergate Complex, Washington, D.C.



Slab Replacement
Brookline Blvd. Garage
Pittsburgh Parking Authority

Bridge Widening Corrosion Prevention

Point Anodes for Sound Concrete

- Embedded anode for corrosion control
- Installed into drilled holes
- Protect sound but contaminated areas
- Corrosion “hot spots”

Galvanic Protection with FRP Strengthening, Coastal Condominium

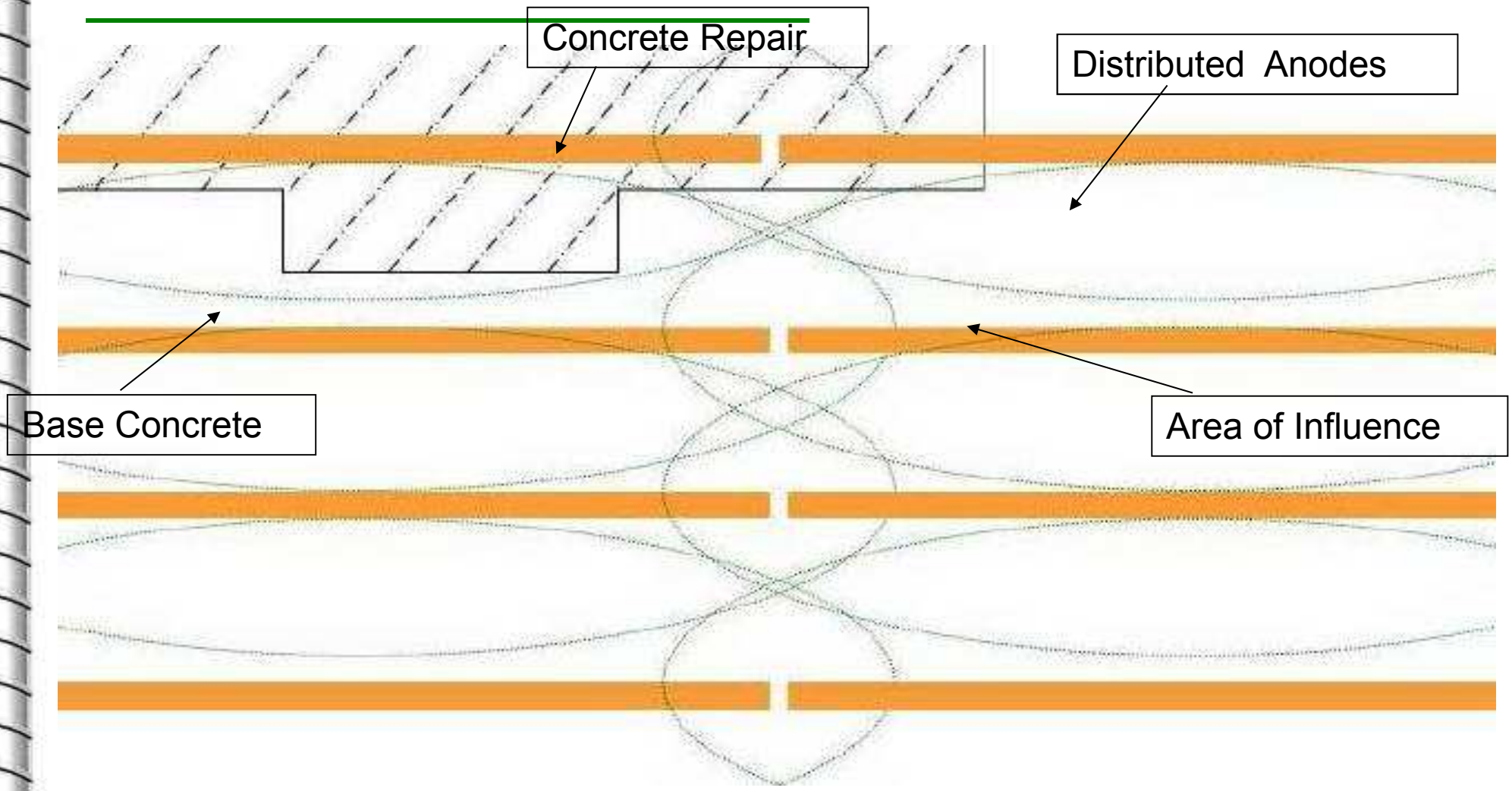

NYSDOT Bridge Maintenance
Fort Covington, NY


NYSDOT Bridge Maintenance
Fort Covington, NY

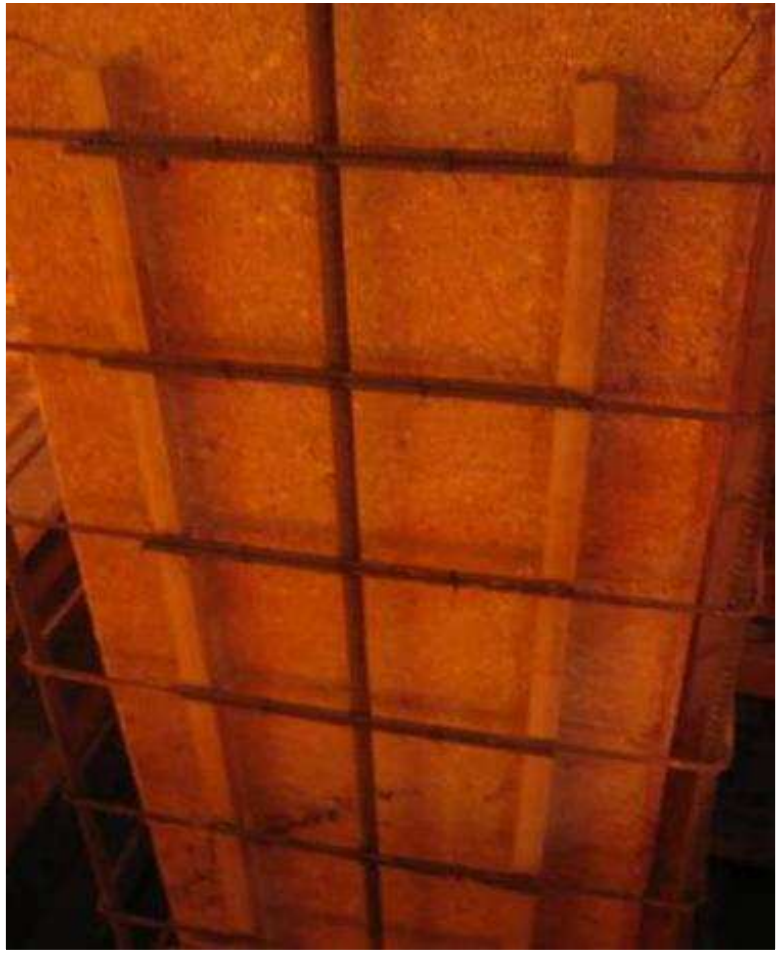

NYSDOT Bridge Maintenance
Fort Covington, NY


NYSDOT Bridge Maintenance
Fort Covington, NY

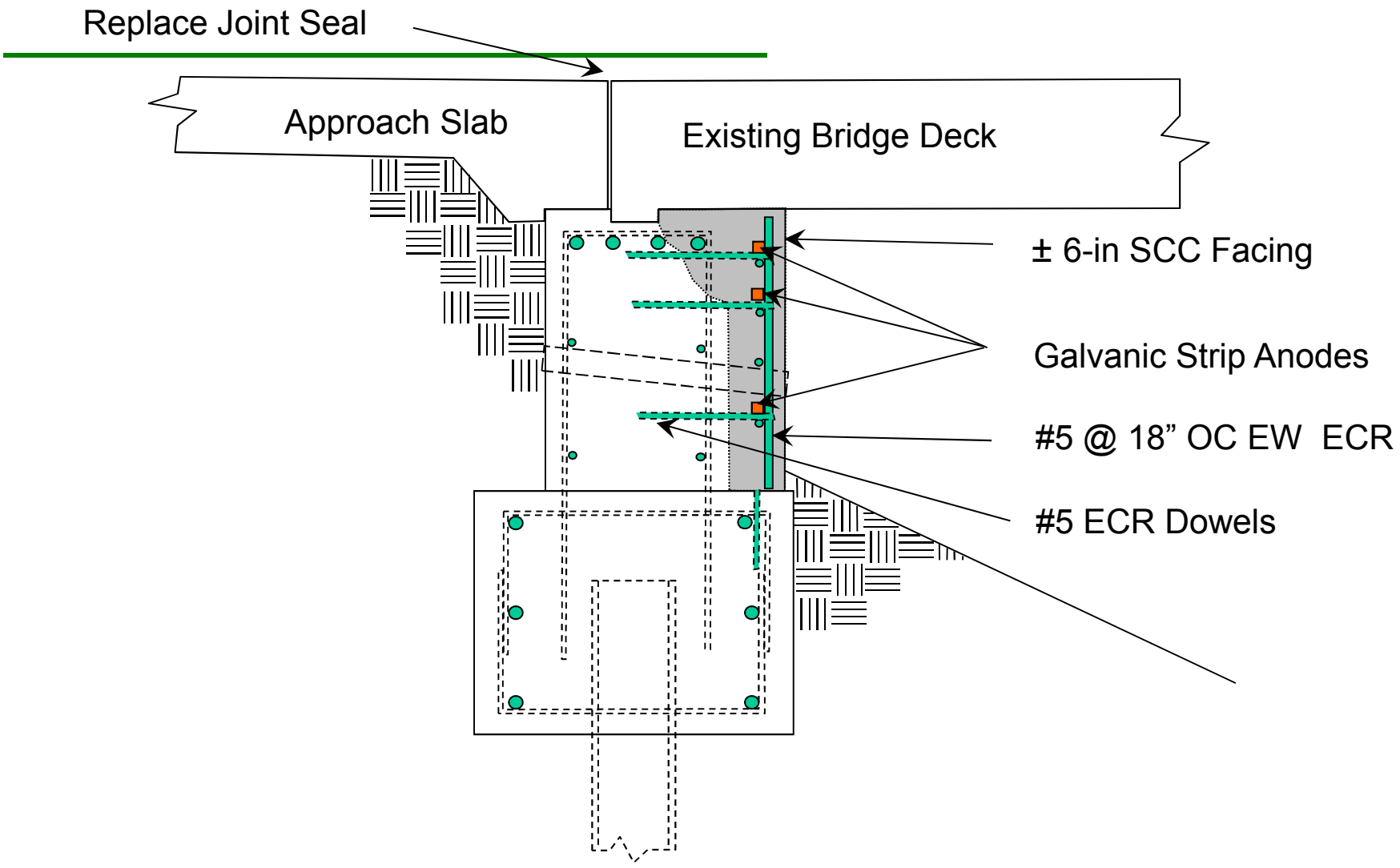
Distributed Anodes



Distributed Anode System



Abutment Repair Detail With Galvanic Protection



Past Practice for Repairs

- Slab would be temporarily supported
- Abutments would be replaced
- Requires closure or part-width construction

Options

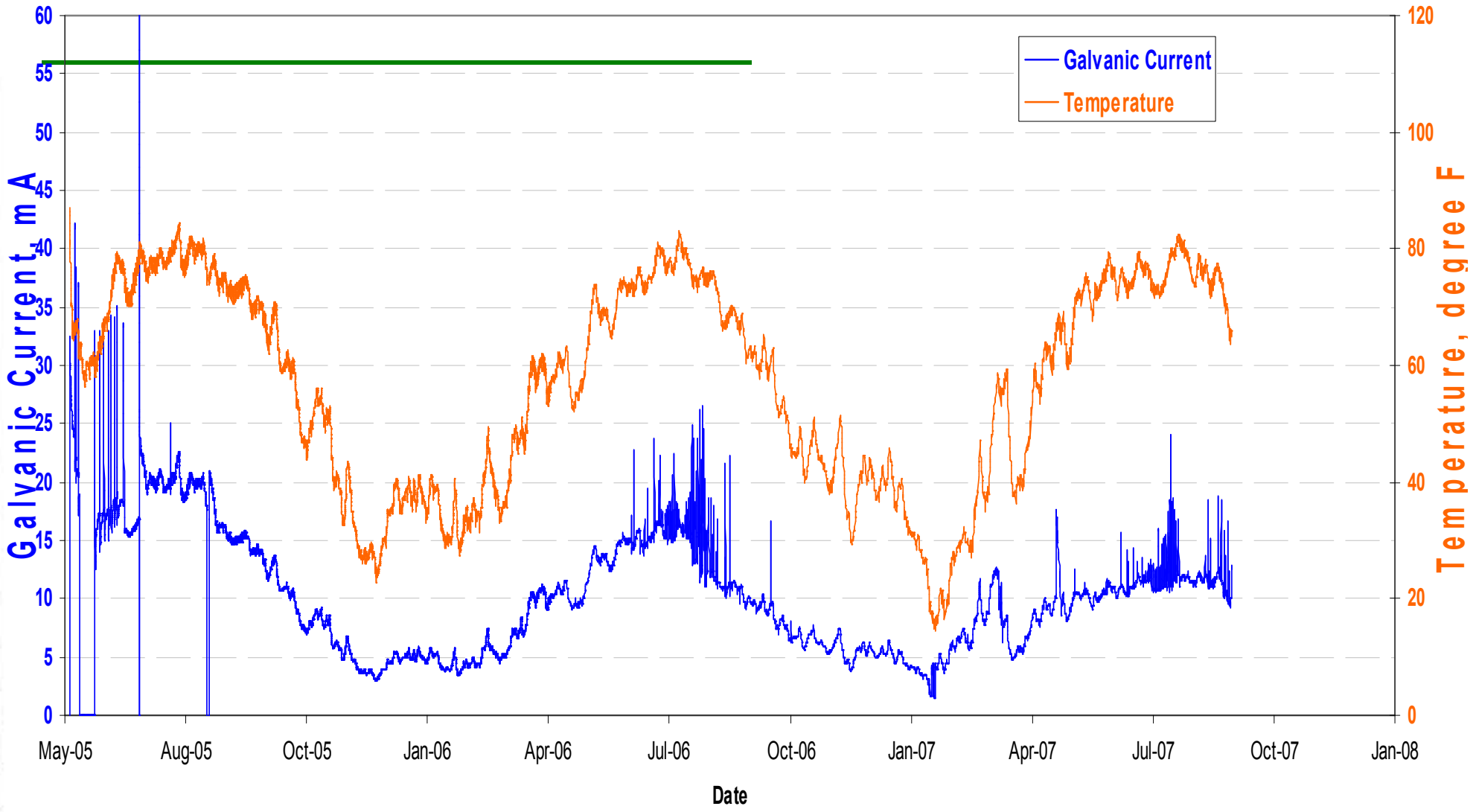
- Do Nothing
  - Not a feasible alternative for bridges on the in ers
- Repair bridge
  - With appropriate repair, most of these bridges have remaining service life
- Replace bridge
  - Not cost-effective to remove a good slab

I-75 Ohio DOT


Forms installed


Completed repair

Kirkwood Road – Protective Current



Kirkwood Road Performance

Date	Temp	mA/m2	Polarization	Instant Off
5/6/05		37.7		654*
7/20/05		13.9	346	1000
8/16/05	87	12.9	333	987
10/26/05	54	5.4	394	1048
12/7/05	51	3.2	339	993
5/1/06	57	7.5	335	989
12/20/06	40	4.3	500	1154
5/30/07	79	7.5	446	1100
9/20/07	75	9.7	484	1138

* Native Potential Cathodic Protection Criteria: Polarization > 100 mV or Inst. Off > 850 mV

Galvanic Strips In 8 Bridge Deck Overlays Lake County, OH


2008/01/30

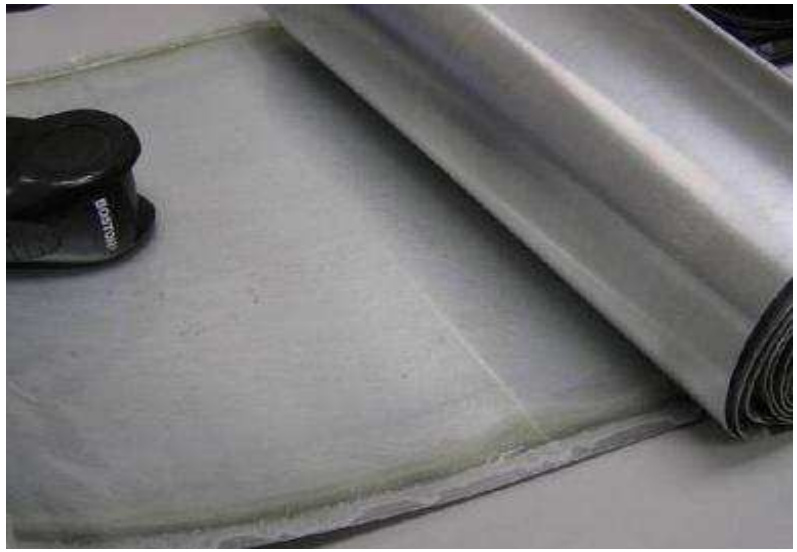

2008/02/13


2008/04/02


20E
21W

Surface Mounted Zinc Anode

- High purity zinc foil
- Conductive adhesive
- Supplied in rolls
- Applied to concrete surface and connected to reinforcing steel



Surface Applied Zinc Sheet Application

ZincSheet Column Protection

Galvanode Zinc Tape

NY DOT

I-890 E over Little Circle


RONG WAY

Prestressed Concrete Balcony Protection

Clearwater Beach, FL

Activated Arc Spray Zinc
Hospital Parking Garage

Galvanode ASZ+
Activated Arc Spray Zinc

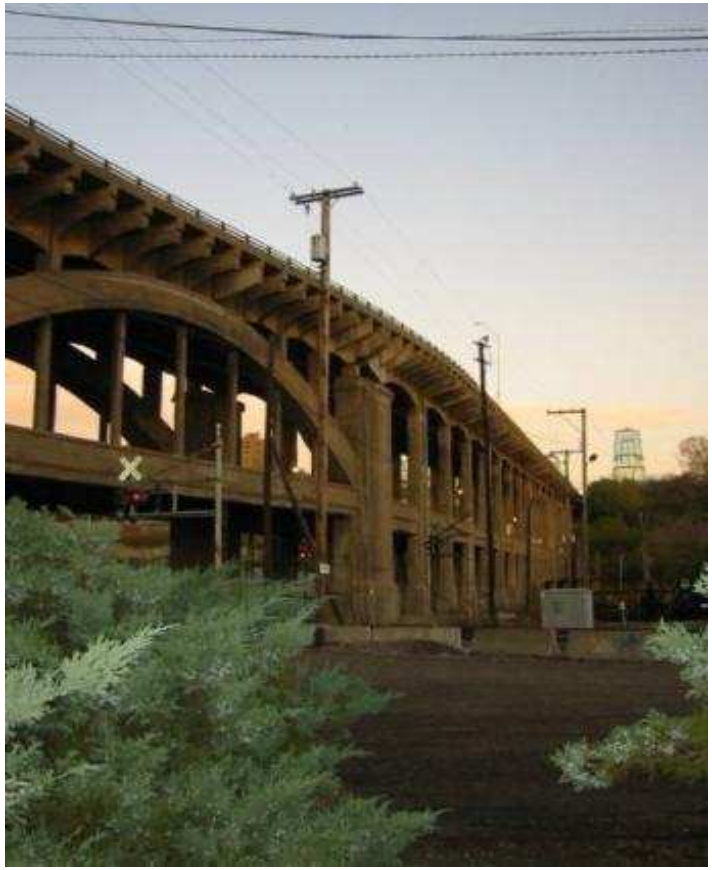
ICCP Jackets

Galvanic Jackets


2CH|1CH
NOTICE

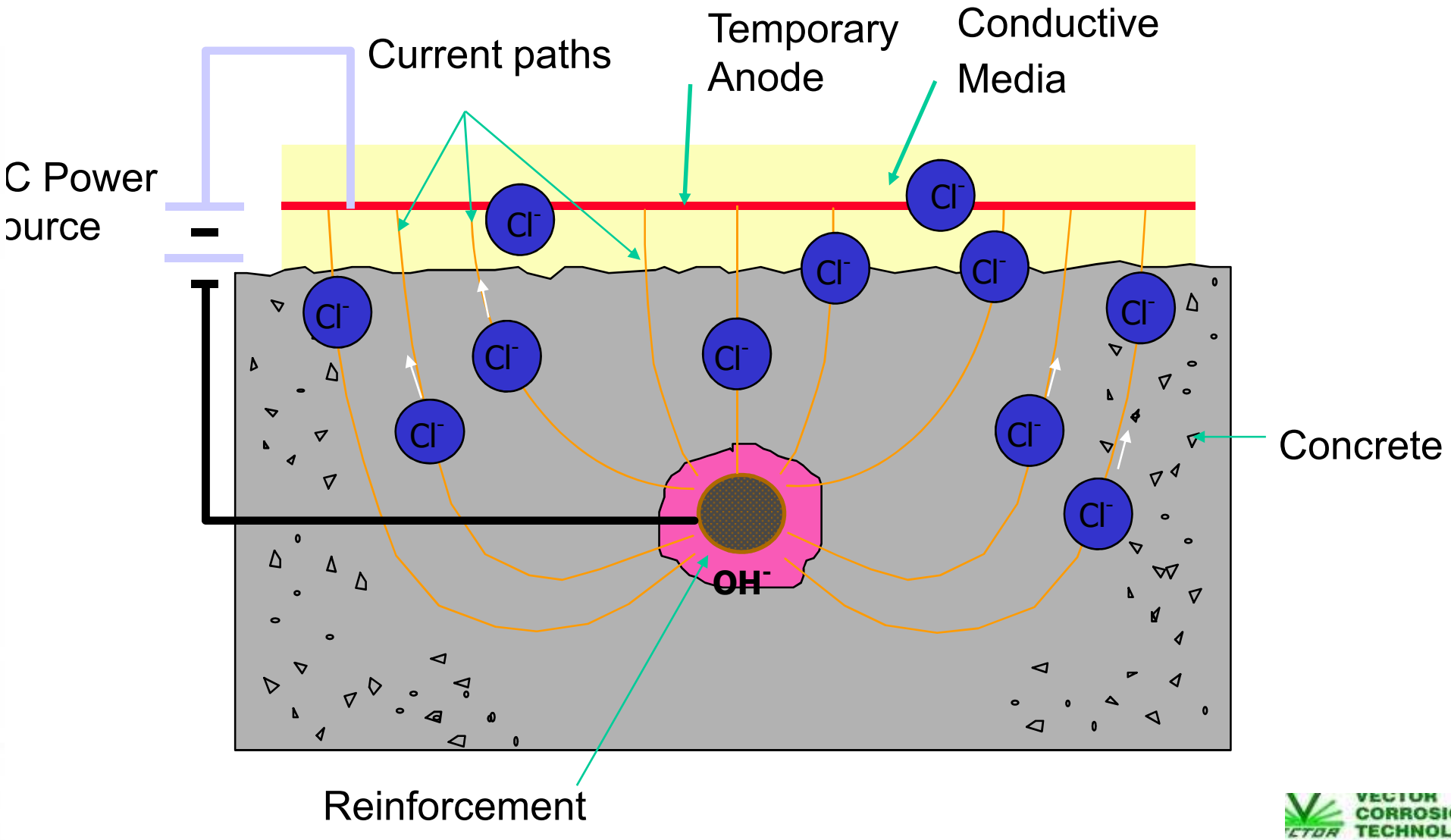
Electrochemical Treatments

Electrochemical Treatments



- Address the cause of the problem
- Passivates active corrosion
- Temporary treatment process
- No system left in place to maintain

Electrochemical Chloride Extraction (ECE) From Salt Contaminated Concrete




CONSTRUCTION
LeROI

ECE Treatment Process

ECE Treatment Process

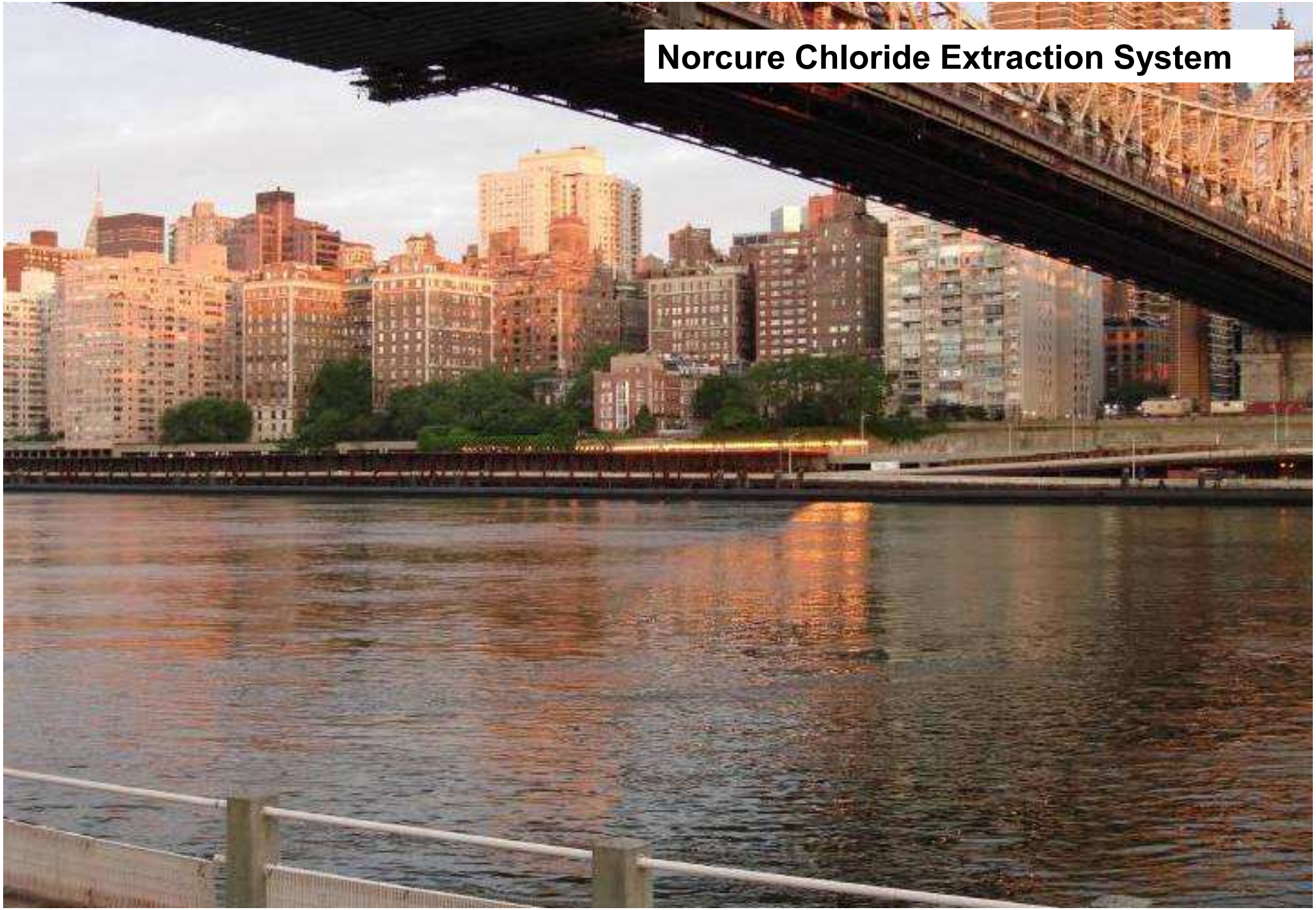
ECE Treatment Process

ECE Treatment Process

ECE Treatment Process

ECE Treatment Process

Norcure Chloride Extraction System



Historic Bridge (1933)

- Idaho's Largest single span (210') conc. arch bridge
- Cost $74,000 to build
- Corrosion Evaluation in 2004
  - Concrete Arches & Main Piers (below drains) had most severe corrosion
  - Corrosion Potential between -.1 to -.45 V
  - Chlorides between .2 to 5.3 lbs/cy
  - Recommended ECE for Arches & Piers

MAIN OBJECTIVES

- Preserve & Protect historic structure for future generations

- Improve Safety for traveling motorists

Potential Mapping Grid

Electrochemical Chloride Extraction

- Began July 20, 2006
- Completed September 14, 2006
- Treated Approximately 8,000 sf
- Temporary process, so no system left in place
- Addressed the source of the problem by reducing chlorides & increasing pH around rebar
- Minimal Aesthetic Impact
- Allowed structure to be rehabilitated rather then replaced.
- Also placed discrete XP+ anodes in patches


Work
Platform
Installed

Electrical Cathodic Connections to Steel Reinforcing

2007 Awards Program

Project of the Year

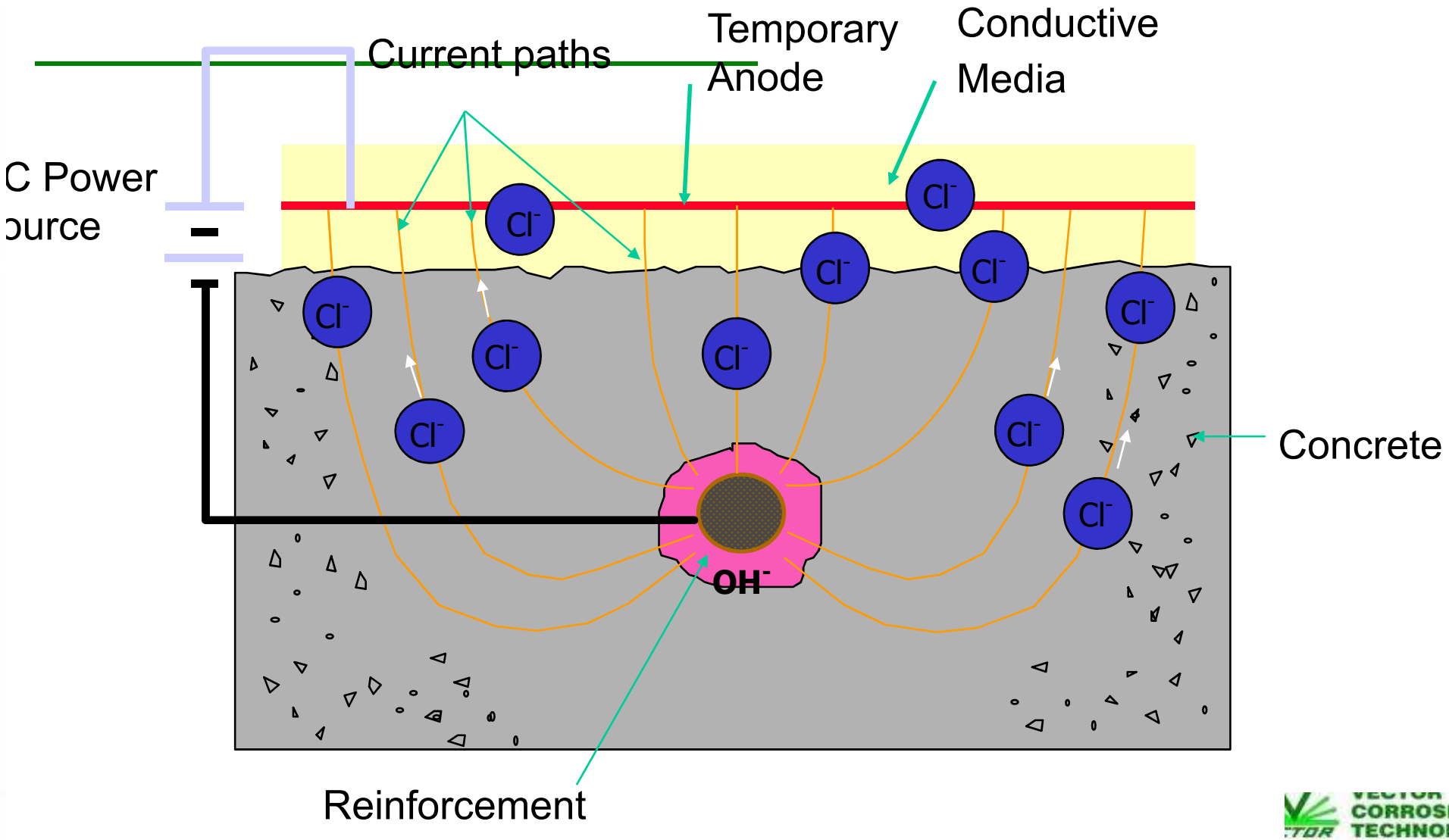
Repair and Preservation of the Historic Rainbow Bridge

Valley County, Idaho

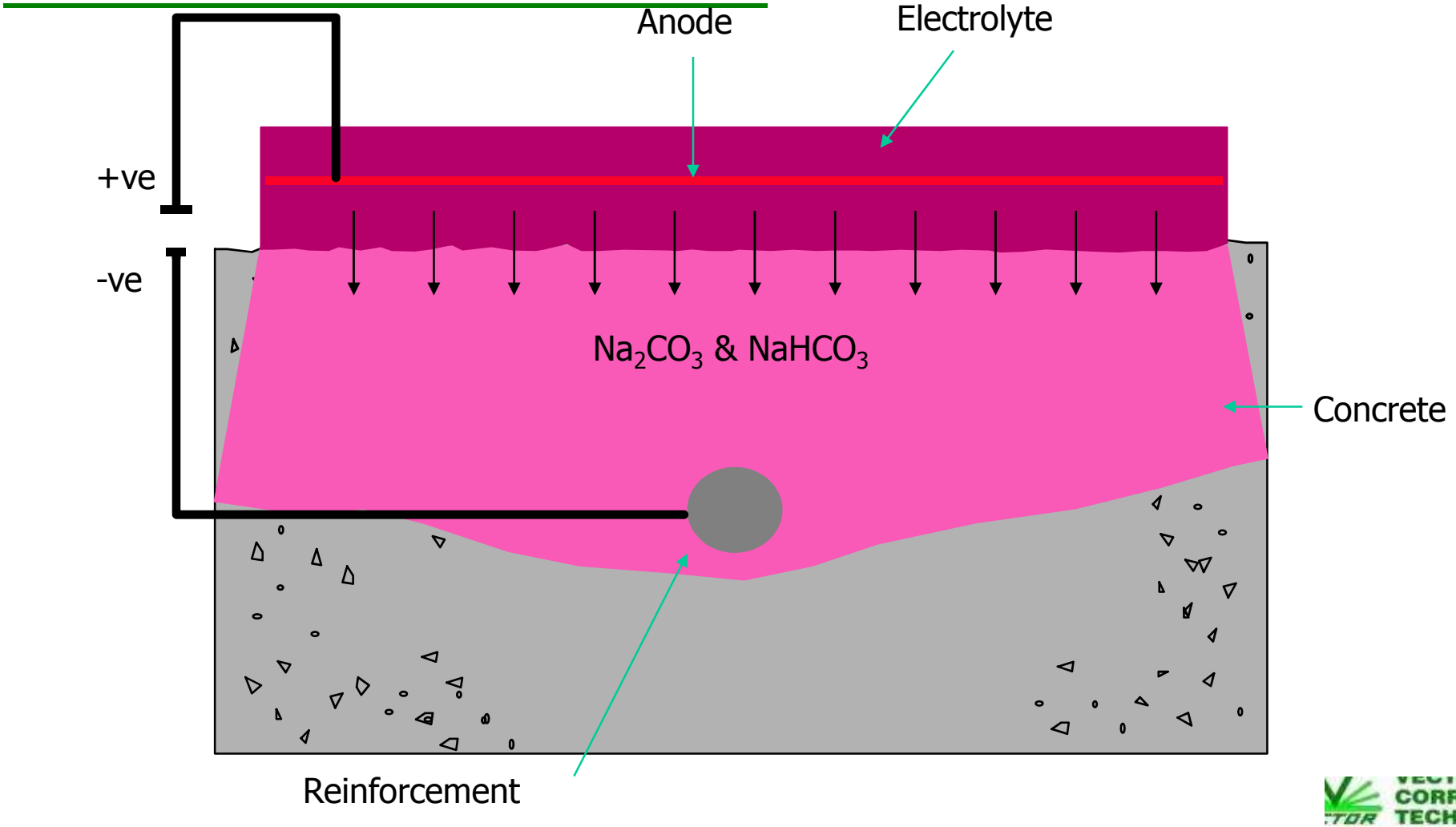
Vector Corrosion Technologies

Wesley Chapel, Florida

Electrochemical Chloride Extraction (ECE) From Salt Contaminated Concrete



Re-alkalization of Carbonated Concrete



Norcure® Re-alkalization & ECE

Reagan National Airport Facade
Washington, DC

Summary

- Large Range of Options Available for Marine Structures
- Mitigation strategies can be
  - Global, targeted, or localized in nature
- Final system selection
  - Existing condition, exposure conditions, service life requirements, maintenance considerations, budget

Thank you!