Corrosion in Concrete Structures

Vector Corrosion Technologies, Ltd.
www.vector-corrosion.com

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Vector Construction Group

- Headquartered in Winnipeg, MB
- Started in the mid-1960's in the earth moving business
- Diversified into specialty concrete repair in the early 1980's.
- Involved in the corrosion business since the mid-1980's
  - Cathodic protection installation
  - Norcure ECE

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Vector Construction Group

- Construction Division
  - Specialty repair, protection, strengthening
  - 16 Branch offices (7 in Canada, 8 in US, 1 U.K)
- Corrosion Division
  - U.S., Canada, Latin America, Europe, Asia.
  - Research & Development
  - Manufacturing

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Vector Corrosion Technologies

- Involved in the corrosion mitigation business since the mid-1980's
  - Cathodic protection installation
  - Norcure Chloride Extraction
- Product Mix
  - Material supply
  - Corrosion mitigation system installation
  - Corrosion testing and evaluation
  - System design
  - On-site technical service

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Corrosion Basics

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Corrosion of concrete structures

- Corrosion is the single most important problem in concrete structures
- NACE estimates the annual 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

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Reinforced Concrete (Composite material)

Portland Cement Concrete .

- Portland Cement
- Fine Aggregate (sand)
- Coarse aggregate (gravel)
- Water

Steel .

Coefficient of thermal expansion is nearly the same

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Concrete is Alkaline

- The pore liquid of concrete has a pH >13
- Contains high ionic concentrations of
  - Hydroxyl (OH^-) 300mmol/L
  - Sodium (Na^+) 100mmol/L
  - Potassium (K^+) 250mmol/L
  - Calcium (Ca^{++}) 2mmol/L

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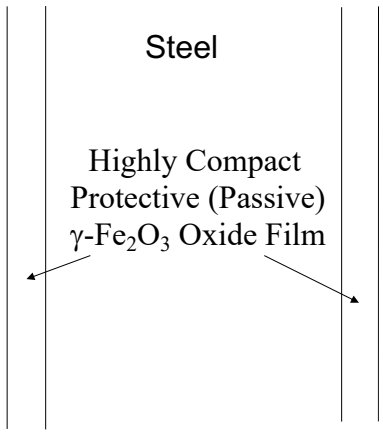
Steel Passivates in Alkaline Environment



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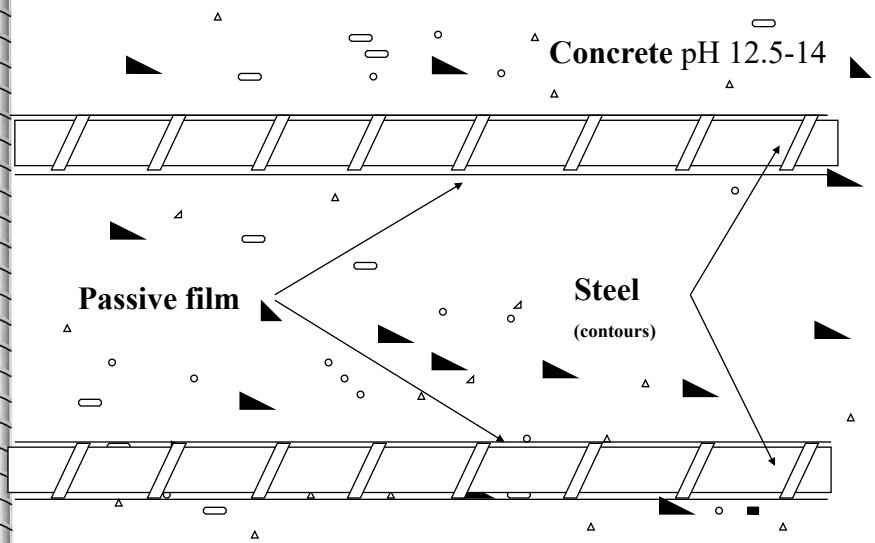
Concrete / Steel Protection



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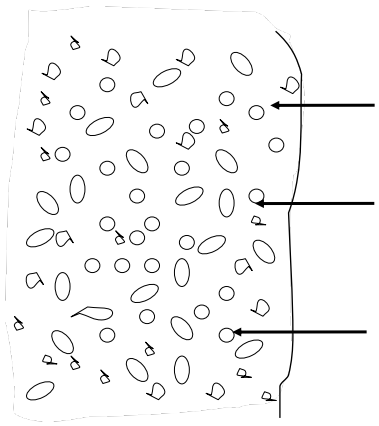
Corrosion of Reinforcing Steel in Concrete

Concrete is Porous



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Causes of Corrosion

- Chlorides
- Carbonation

Results in the Destruction of the Steel's Passive Oxide Layer

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Corrosion of Reinforcing Steel in Concrete

Chlorides in Concrete

External

- Seawater
- Deicing salts
- Other contaminants

Internal

- Calcium chloride additions for accelerated curing
- Contaminated aggregates, sand, water

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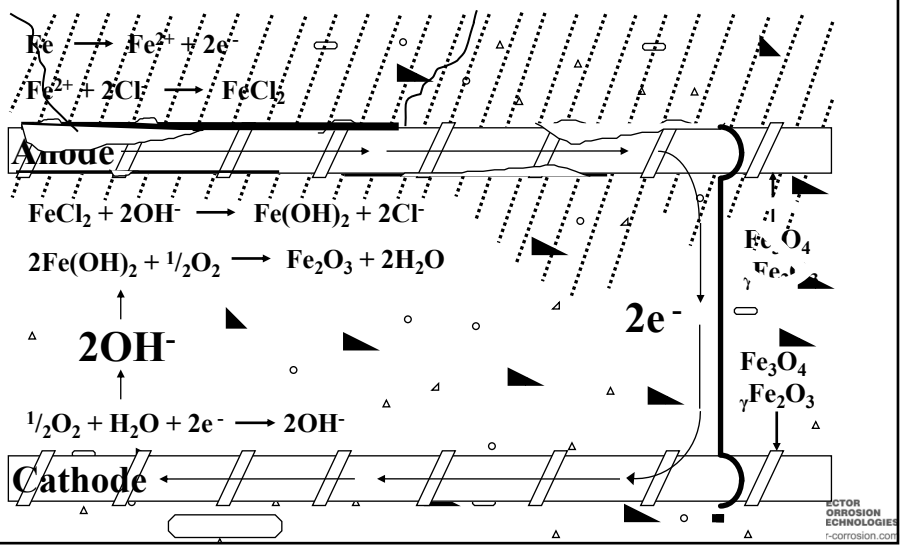
Corrosion Cell in Concrete



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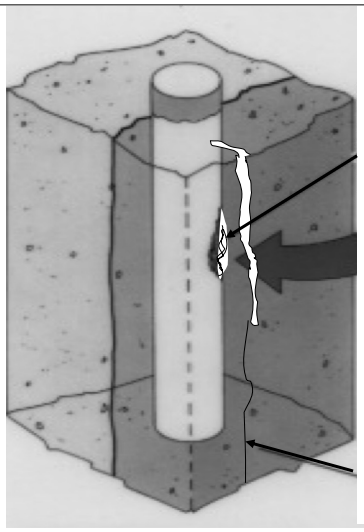
Corrosion of Reinforcing Steel in Concrete



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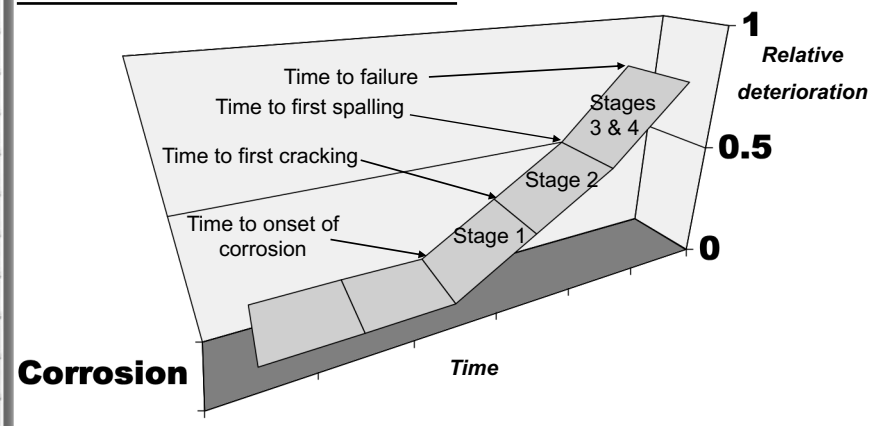
Corrosion of Reinforcing Steel in Concrete



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Corrosion of Reinforcing Steel in Concrete

Stage 1: Initially, the concrete appears to be sound with relatively little macroscopic cracking and no 'rusty' discoloration from corrosion product formation.

Four stages of corrosion of steel in concrete

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Corrosion of Reinforcing Steel in Concrete

Stage 2: Macroscopic cracks have appeared and the concrete surface is stained by reddish corrosion products.

Four stages of corrosion of steel in concrete

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Corrosion of Reinforcing Steel in Concrete

Stage 3: Spalling of the concrete cover over the reinforcing steel is clearly visible, due to the formation of voluminous corrosion products.

Four stages of corrosion of steel in concrete

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Corrosion of Reinforcing Steel in Concrete

Stage 4: Severe spalling of the concrete cover over the reinforcing steel is evident, leaving the reinforcing steel bars directly exposed to the atmosphere.

Four stages of corrosion of steel in concrete

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Chloride-induced Corrosion

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Carbonation

- Reduction of pH in cover concrete which causes loss of passive oxide layer
- 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) ⇨ (insoluble)

pH 12-13 pH < 9

Where steel is no longer passive

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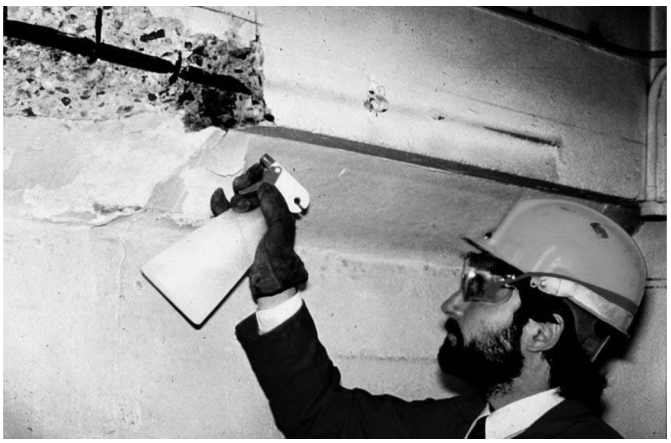
Carbonation Testing



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Carbonation-induced Corrosion

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Corrosion of Reinforcing Steel in Concrete

Typical low cover corrosion from carbonation

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Halo Effect in "Chip and Patch" Repair Method

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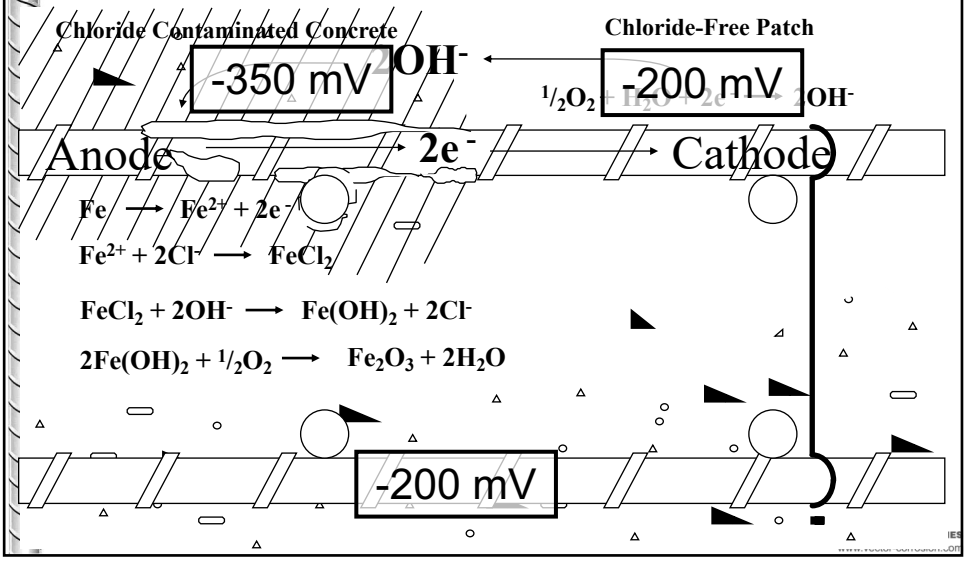
Patch Accelerated Corrosion



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Halo Effect

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Halo Effect

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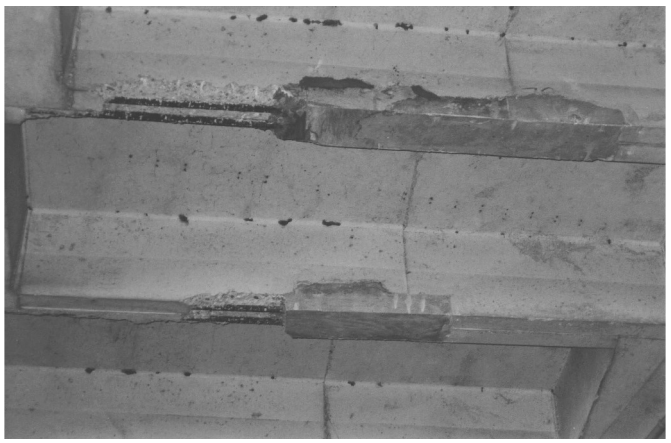
Halo Effect, Incipient anode or ring anode



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Corrosion Evaluation For Concrete Structures

Is important a correct diagnosis taking into account technical and economic considerations when we are dealing with a rehabilitation strategy for a corrosion steel embedded into concrete.

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Why evaluate corrosion?

- know causes of corrosion & Extension of the problem
- Allow us to offer economical corrosion mitigation solutions
- Save money by the correct application of existing corrosion protection technology and throughout the life of the structure.
- When problems are known, maintenance budgets may be spent wisely.

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Corrosion Testing and Analysis

- Visual Inspection
- Delamination Survey
- Concrete Cover Survey
- Chloride Sampling and Analysis
- pH Testing (Carbonation)
- Corrosion Potential Measurements

Less frequent measurements
- Resistivity of concrete
- Corrosion rate of steel

Assessment of condition of steel reinforcement

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Visual Inspection

- Identify areas of visual damage
  - Rust stains on surface
  - Cracks
  - Spalls
  - Exposed steel
  - Flat surfaces (formation of paddles)
  - Structure History

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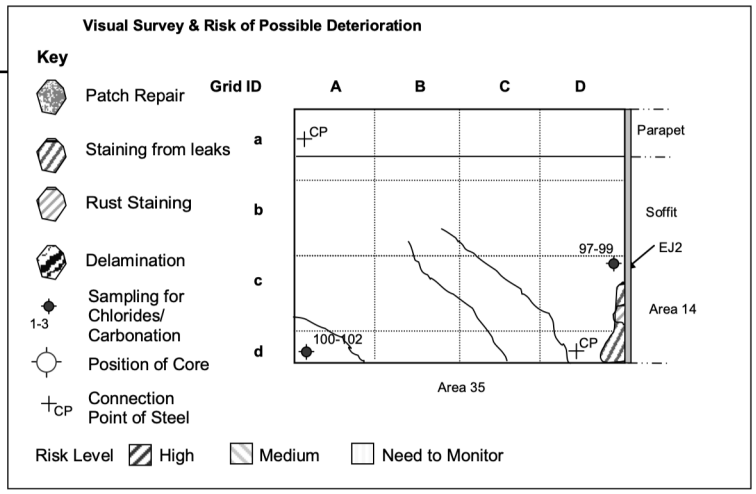
Corrosion of Reinforcing Steel in Concrete



Visual Survey

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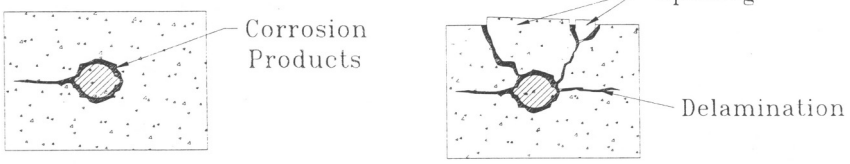
Delamination Survey

- Used to locate areas where concrete has lost bond with steel reinforcement, delaminated concrete which has not yet spalled
- Also known as "Sounding" or hammer test



Section 2

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Cover Meter Survey
(Average depth)

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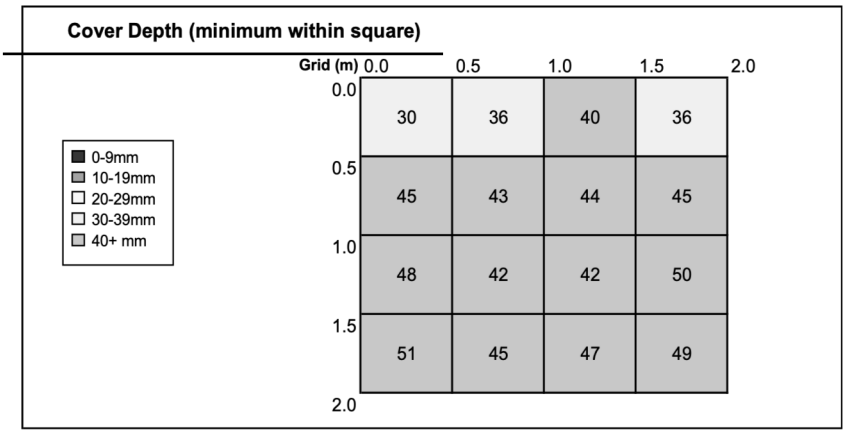
Corrosion of Reinforcing Steel in Concrete



Depth of Steel Cover

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Chloride Sampling and Analysis

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

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Chloride Measurements-Levels

- The American Concrete Institute states that when chloride levels exceed 0.2% by weight of cement {SHRP 1.2 lb Cl^-/yd^3 of concrete (0.71 kg/m^3 0.031% by weight of concrete)} steel will rust
- Different concrete conditions have different thresholds: wet or dry concrete, prestressed, etc.
- These code guidelines are rather simplistic
- In reality corrosion activity is progressive and based on the Chloride / Hydroxyl Ratio (Cl^-/OH^-)

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pH Testing

- Primarily to determine the carbonation of concrete
- 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

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Phenolphthalein Testing of Newly-Exposed Concrete

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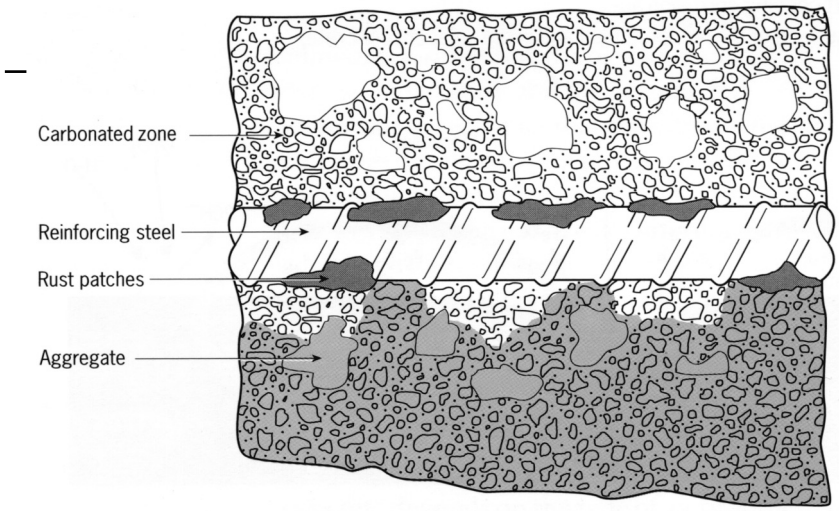
Corrosion of Reinforcing Steel in Concrete



Carbonated Concrete (colourless) leading to steel corrosion

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Corrosion Potential Measurements

- To determine the probability and extent of corrosion by measuring the potential (voltage) of the reinforcing steel inside the concrete at various locations
- Uses a half-cell reference electrode
  - copper-copper sulfate is most common, others are silver-silver chloride, calomel, and hydrogen
- Performed as per ASTM C876-91

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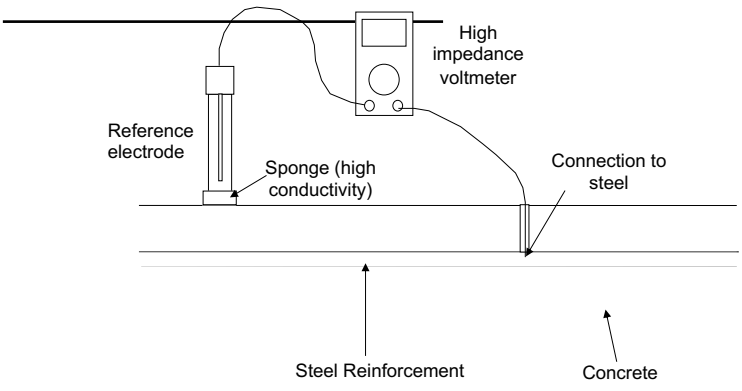
Corrosion of Reinforcing Steel in Concrete



Potential Mapping

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Corrosion Potential Surveys

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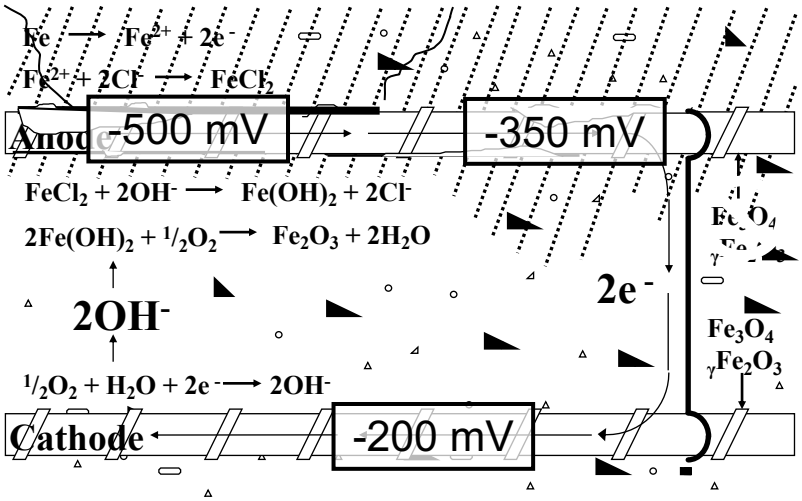
Corrosion Potentials Cell in Concrete



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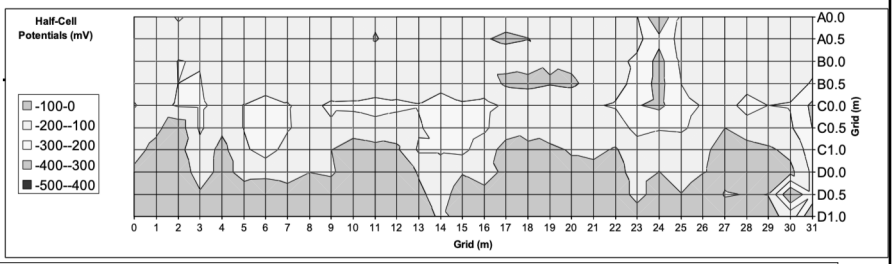
Corrosion of Reinforcing Steel in Concrete



Steel depth of Cover (mm)

Distance (m)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
A0.0	31	31	37	35	35	35	39	42	42	36	42	34	36	32	34	35	36	31	21	38	39	49	40	37	37	38	43	22	46	50	61
B0.0	37	39	36	36	38	30	35	26	38	33	39	40	36	33	37	38	36	38	38	37	38	47	38	36	34	44	33	38	37	36	35
C0.0												45	42	45	38	44	42	40	47	41	41	41	39	37	30	40	40	36	41	39	40
C0.5	47	47	44	43	33	43	60	56	56	40	32	45	44	40	33	37	35	38	36	38	39	37	40	36	32	51	49	56	37	38	37
C1.0	59	55	50	53	31	58	44	43	52	50	43	59	59	50	40	41	39	32	41	38	40	42	44	42	37	54	58	59	62	57	70
D0.0	50	49	40	32	36	46	38	32	35	52	47	34	41	39	54	54	50	41	47	46	58	53	39	41	46	49	42	39	43	44	42
D0.5	48	58	48	38	35	54	44	35	33	47	45	42	41	37	55	52	50	45	42	40	64	64	48	42	50	49	50	46	58	57	50

0-9mm
10-19mm
20-29mm
30-39mm
40+ mm

Potential Mapping & Depth of Steel Cover

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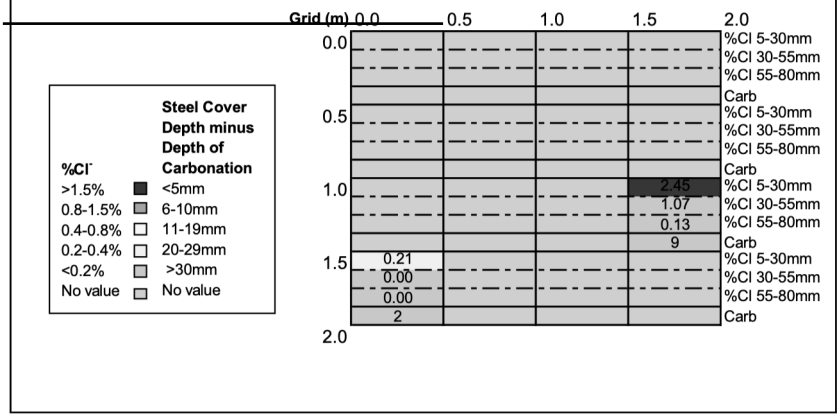
Corrosion of Reinforcing Steel in Concrete

Chloride Concentration and 'Effective' Carbonation Depth



Depth of Carbonation Relating to Depth of Steel Cover

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Corrosion Potential (Continued)

- Gives indication of likely corrosion activity when no other damage is visible
- Identifies areas for possible chloride investigation
- Mapping helps to identify hot-spots of likely corrosion, problem areas

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Corrosion Survey

- A combination of the assessment techniques described above, should give a fair indication of the present condition of the reinforcement.
- What happen into the structure
- What we can do (options)
- How to do it (Construction Bid documentation, Technical specifications)
- How much (Budget)

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Questions ?

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Corrosion Management Strategies

- Corrosion Prevention (Cathodic Prevention)
- Corrosion Control
- Cathodic Protection

levels of active corrosion protection

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System Selection

- Level of Chloride & Carbonation
- Amount of concrete damage
- Environment exposure conditions
- Extend of Corrosion Activity
- Cost & Design life
- Expected service life of the structure

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Levels of Corrosion Protection

Cathodic Protection	Reduce or eliminate on-going corrosion activity
Corrosion Control	Reduces on-going corrosion activity
Corrosion Prevention (Cathodic Prevention)	Mitigates initiation of new corrosion activity

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Cathodic Protection

- Almost certain corrosion protection
- Reduce corrosion rate to approximately zero
- Most widely used criterion: 100 mV potential shift
- Typical applied current: 5 to 15 mA/m^2

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Corrosion Control

- Significantly reduce corrosion rate
- May or may not see 100 mV potential shift
- Typical applied current: 1 to 7 mA/m^2
- Research has shown that as little as 1 mA/m^2 achieved 96% reduction in delamination growth

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Corrosion Prevention

- Purpose is to prevent corrosion from initiating in chloride-contaminated environment
- No criterion with regard to potential shift
- Current density necessary to prevent corrosion from initiating is lower than amount necessary to stop on-going corrosion activity
  - Research has shown that 0.25 to 2 mA/m^2 is sufficient to prevent corrosion initiation

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Galvanic Corrosion Protection Systems

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Galvanic Protection Systems

- Provide DC using dissimilar metals (Galvanic Anodes)
- Anode is more active (electronegative) and corrodes in preference to steel
- No outside source of electricity needed
- Low driving voltage avoids hydrogen embrittlement of prestressed steels

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Vector® Galvashield® XP Embedded Galvanic Anode for Corrosion Prevention

- Developed in the late 1990's
- Designed to provide corrosion prevention (cathodic prevention) in concrete
- Typical Design
  - 10 - 20 years service life

75

Electrochemical Potentials

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	

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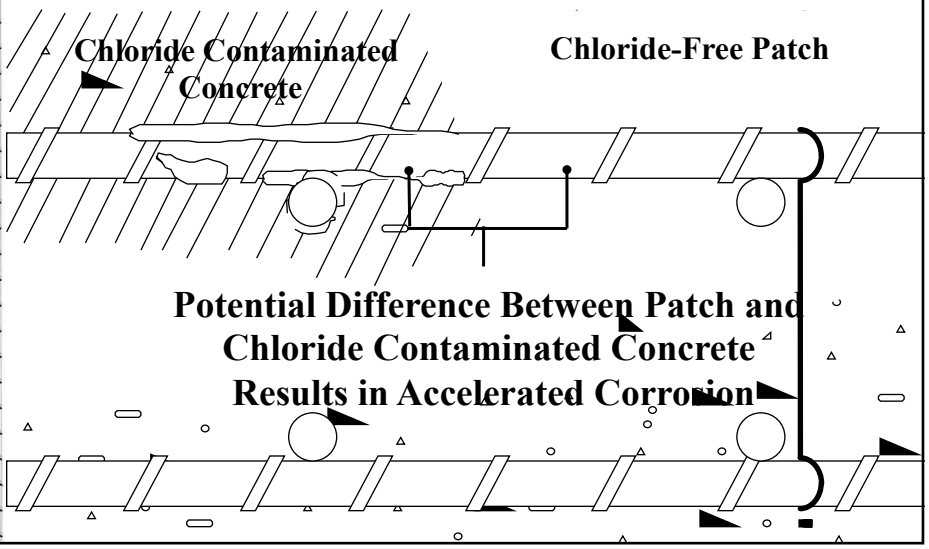
Patch Accelerated Corrosion



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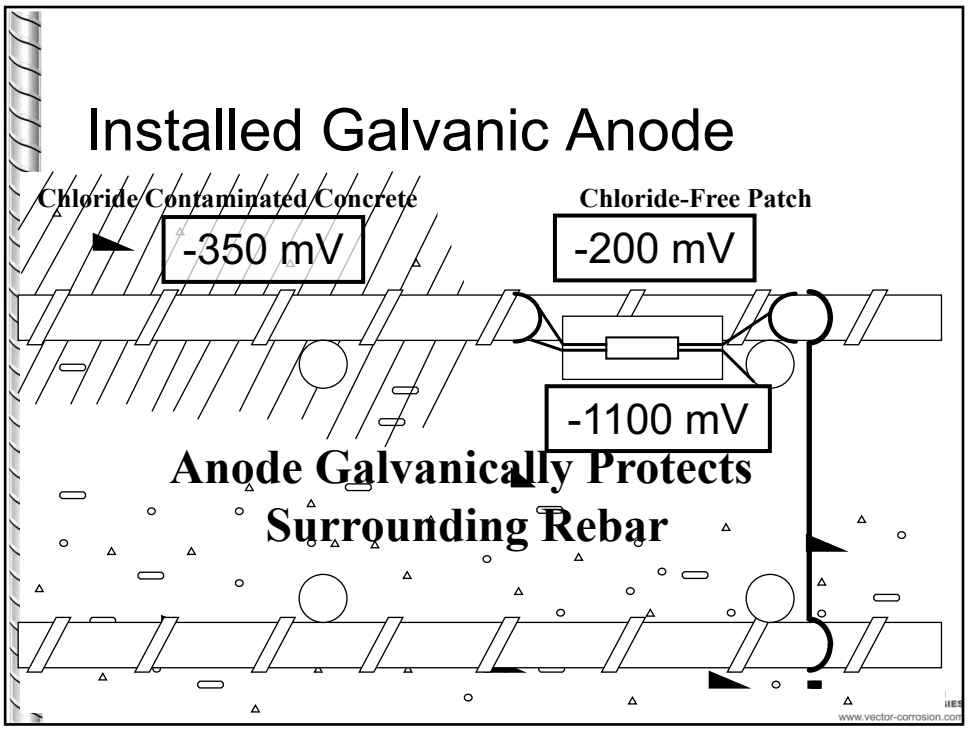
Installed Galvanic Anode
Chloride Contaminated Concrete
-350 mV
Chloride-Free Patch
-200 mV
-1100 mV
Anode Galvanically Protects
Surrounding Rebar
www.vector-corrosion.com

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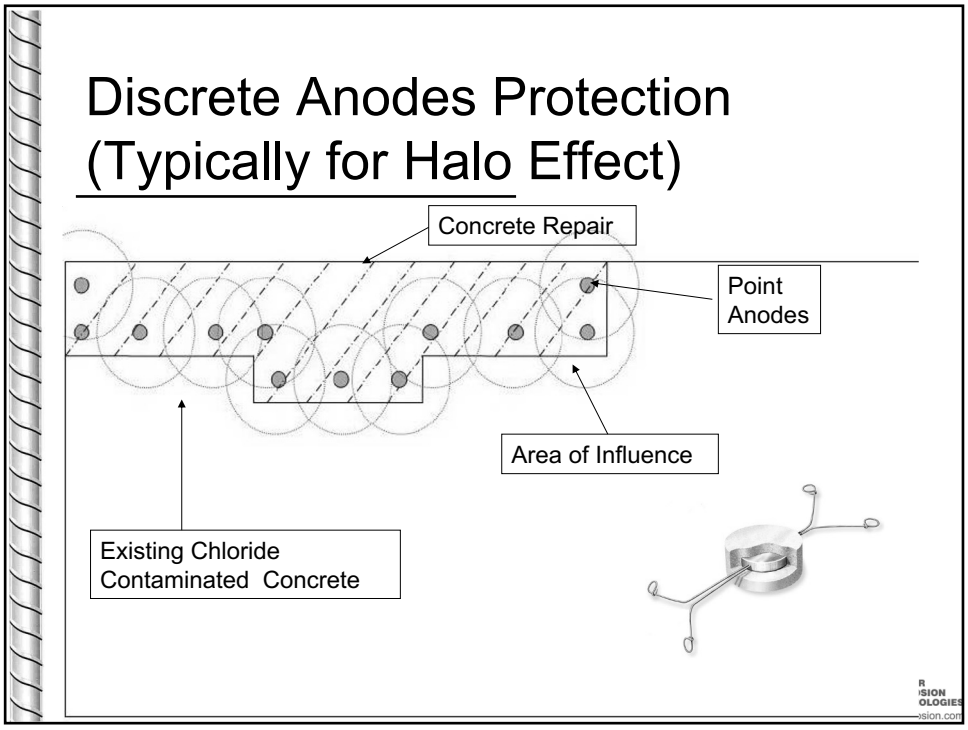
Discrete Anodes Protection
(Typically for Halo Effect)
Concrete Repair
Point
Anodes
Area of Influence
Existing Chloride
Contaminated Concrete

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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.
  - High pH
- Mortar accepts corrosion by-products from the zinc core.

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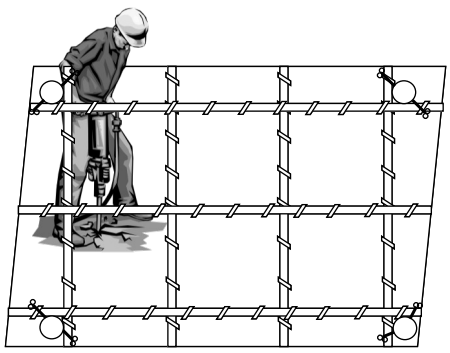
Installation of Galvanic Anodes



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Anode Installation

Saw cut and cleaned repair area.

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Anode Installation

Anode is tied to reinforcing steel quickly and easily.

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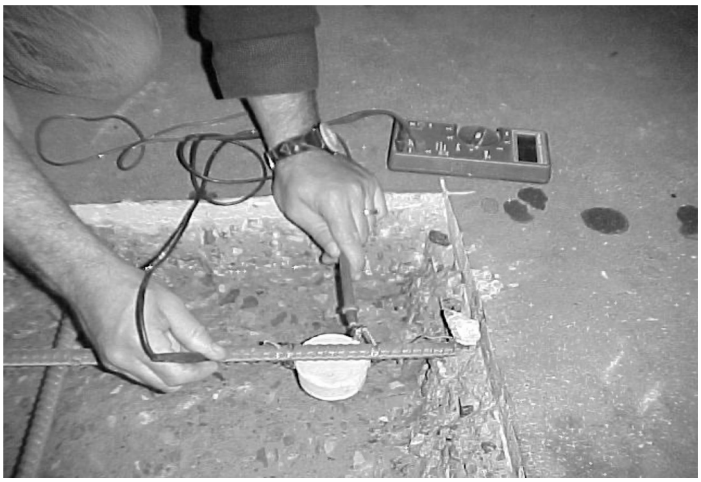
Anode Installation



Testing anode connection to reinforcing steel.

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Anode Installation

Installing anodes around the perimeter of the repair.

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Anode Installation

Embedding anodes with repair material.

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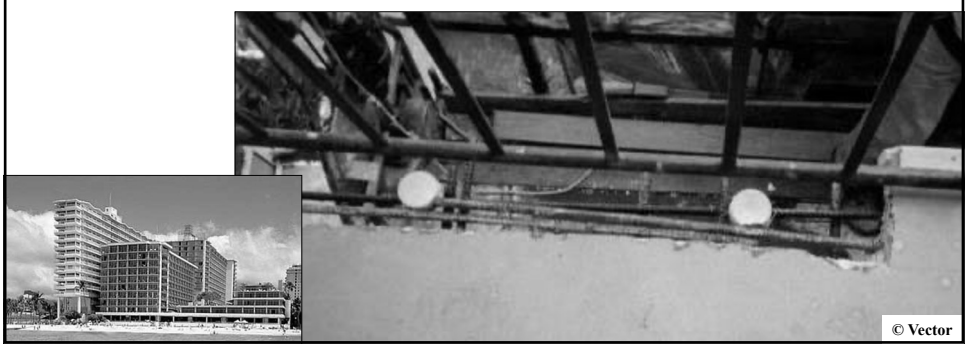
Prestressed Concrete Girders in Parking Garage
Southern Ontario, Canada

88

Bridge Deck Repair

89

Balcony Repairs
Outrigger Reef Hotel, Waikiki, Hawaii



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Spandrel Beam Repairs with Galvanic Anodes Chicago, IL

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Prestressed Beam Ends

92

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

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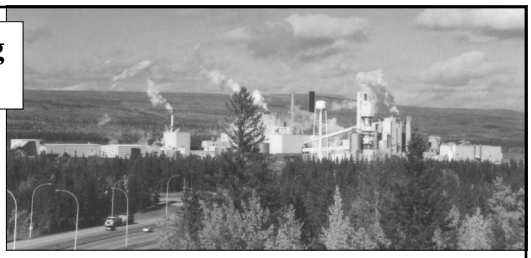
Repairs in Industrial Building
Pulp Mill, Northern Alberta



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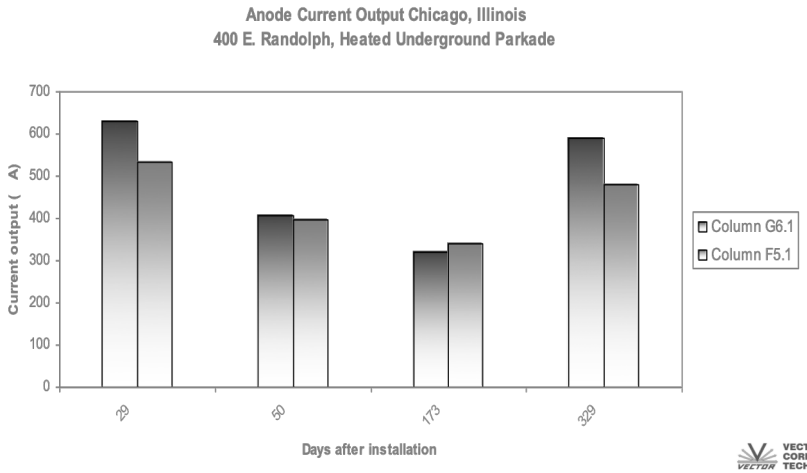
400 Randolph Parking Garage,
Chicago, Illinois

95

Anode Current Output



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Joints and Interfaces

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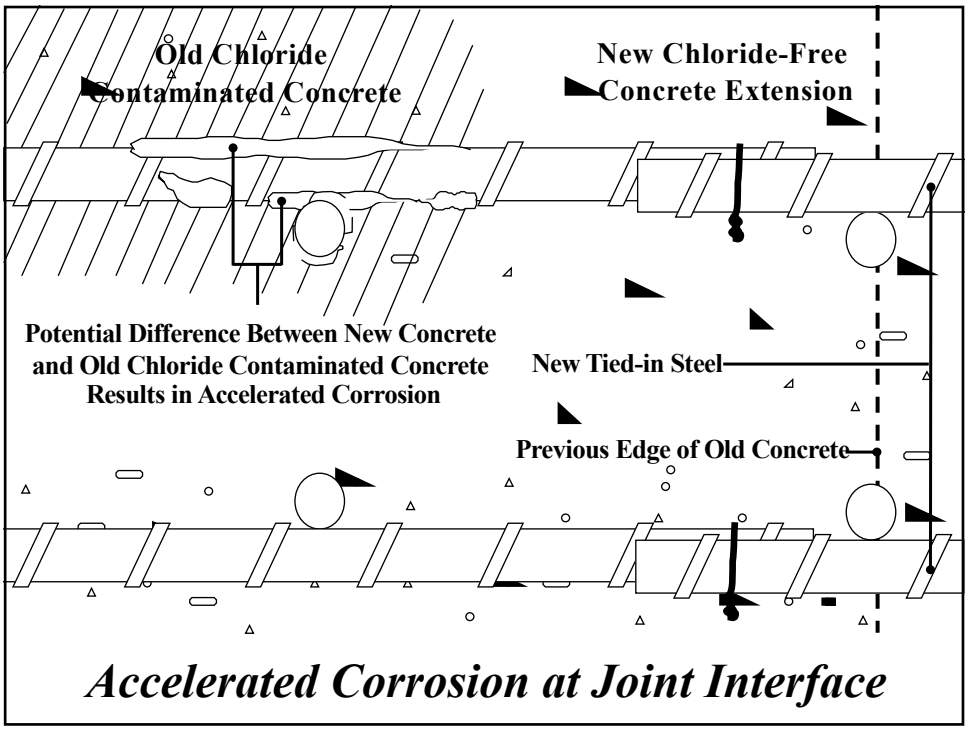
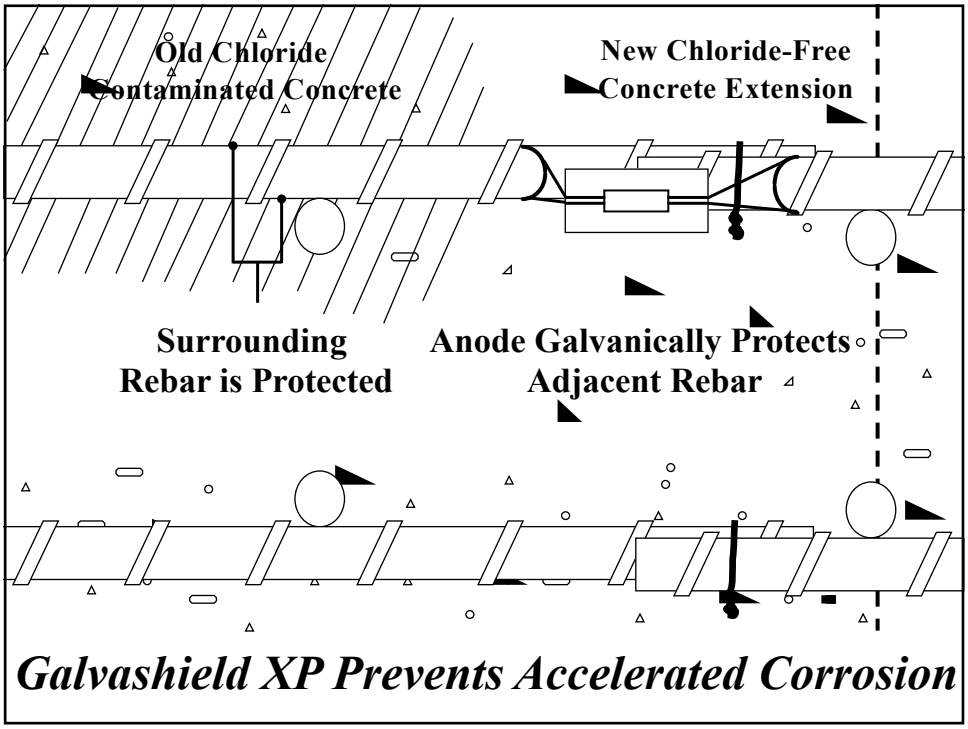

Old Chloride
Contaminated Concrete
New Chloride-Free
Concrete Extension
Potential Difference Between New Concrete
and Old Chloride Contaminated Concrete
Results in Accelerated Corrosion
New Tied-in Steel
Previous Edge of Old Concrete
Accelerated Corrosion at Joint Interface

98


Old Chloride
Contaminated Concrete
New Chloride-Free
Concrete Extension
Surrounding
Rebar is Protected
Anode Galvanically Protects
Adjacent Rebar
Galvashield XP Prevents Accelerated Corrosion

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Balcony Replacements
Satellite Beach, FL

100

Balcony Replacements
Cocoa Beach, FL

101

Bridge Widening
Port Mann Bridge, Vancouver, British Columbia

102

Grid versus Point / Line Installation

Jubilee Overpass, Winnipeg, Manitoba

103

Questions ?

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Leister Bridge Cross Beam

– Completed in 1999
– Monitored for 10 years

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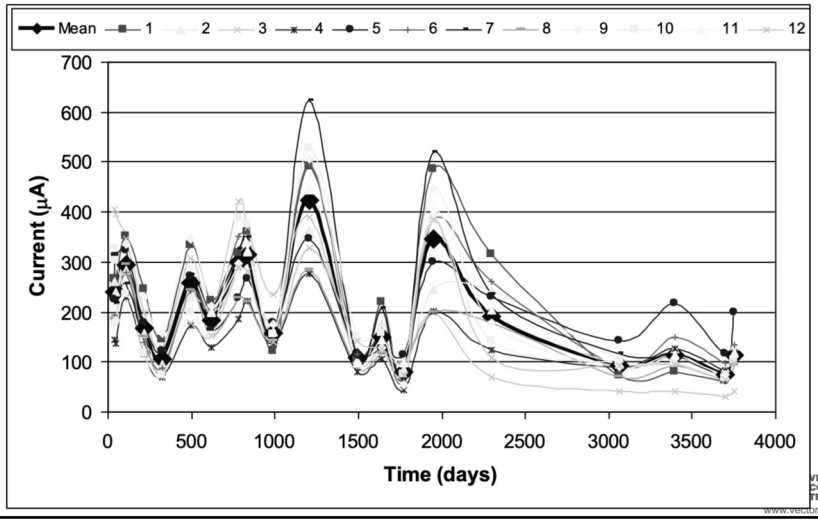
10 Year Monitoring - Current



106

Current Density

- Cathodic Prevention
  - European Standard EN 12696
  - Current Density 0.2-2mA/m^2
  - No polarization criteria
- Leister Bridge
  - Ranged 0.6 mA/m^2 and 3.0 mA/m^2
  - Overall mean of around 1.4 mA/m^2

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Polarization Measurements

No. of days from switch-on	Beam soffit within the repaired area, midway between anodes (mV)	West vertical face of beam at shown distance from edge of repair (mV)	
		50mm	300mm
21	56	58	56
41	27	47	31
50	22	55	28
112	24	48	11
3400	95	184	Not determined

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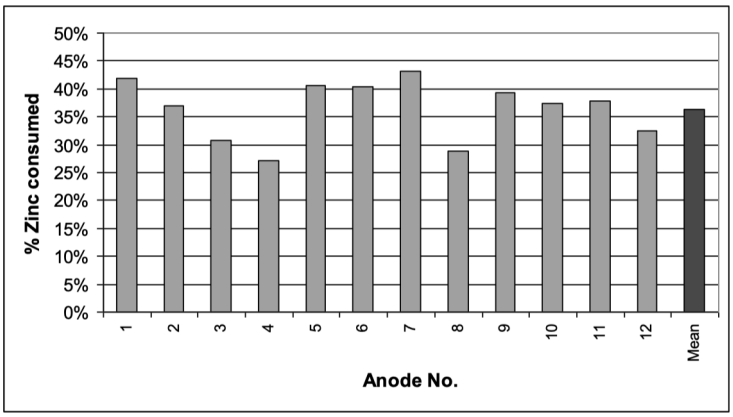
Approximate Zinc Consumption



- Calculated based on current output and 85% utilization

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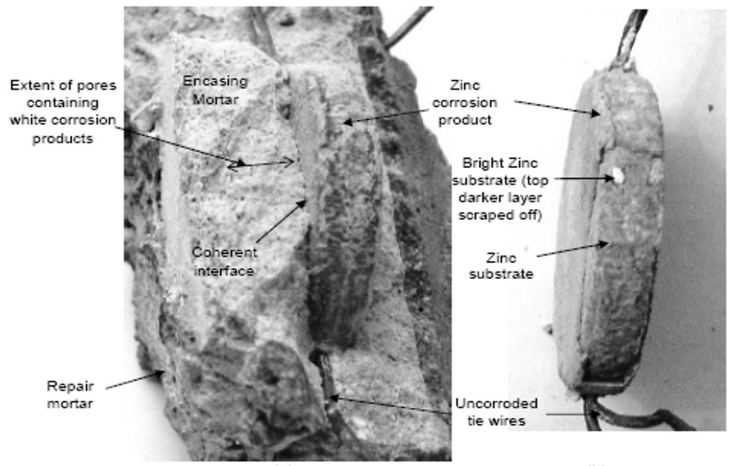
Galvashield's Performance after 10 years



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More Recent Developments

- 2G Technology™ additive
  - Increased current output
  - 40-100% versus original XP
- BarFit ™ groove
  - Available on XP2 and XP4
  - Secure anode placement

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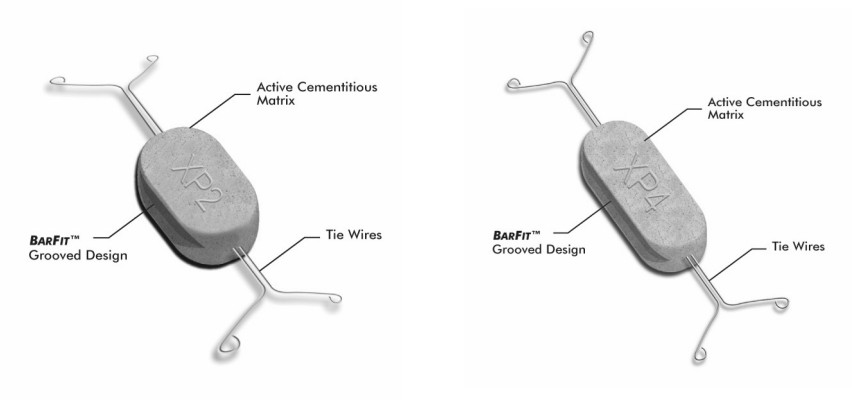
Galvashield XP2 and XP4



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Galvashield XP2 and XP4

- Greater surface area
  - –XP2 = 2x XP4 = 4x
- Greater zinc mass
- Higher output and increased capacity

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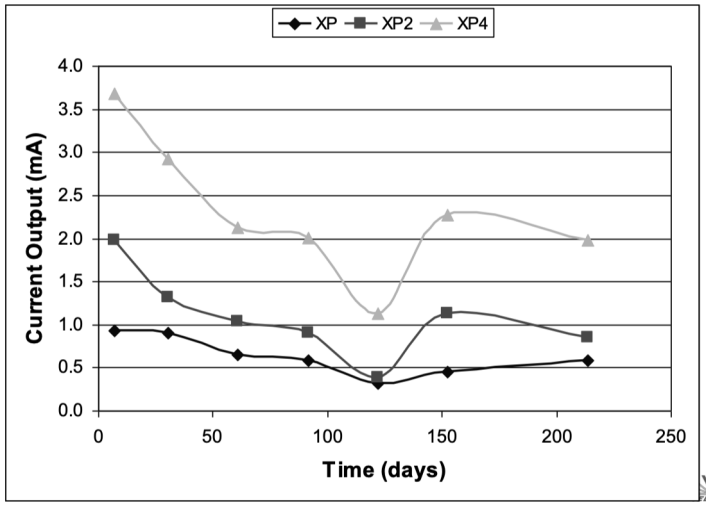
Galvashield XP-Type Anodes



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Anode Comparison

Average current per anode over the seven month test period:

Anode	Current	Change vs XP
Galvashield XP	0.6 mA	n/a
Galvashield XP2	1.1 mA	1.8x
Galvashield XP4	2.3 mA	3.8x

Based on this information, the Galvashield anodes are performing similar to the design capacity ratio of the anodes of 1:2:4.

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Galvashield XP2 / XP4

Examples of Use:

- Providing a higher level of protection in areas where active corrosion may exist after the repair (corrosion control vs. corrosion prevention)
- Providing a higher level of protection for high corrosion risk (high chloride) structures,
- Reducing the number of anodes required in high steel density installations,
- Providing increased zinc mass for a longer anode life.
- Suitable for conventionally reinforced, prestressed and post-tensioned concrete structures

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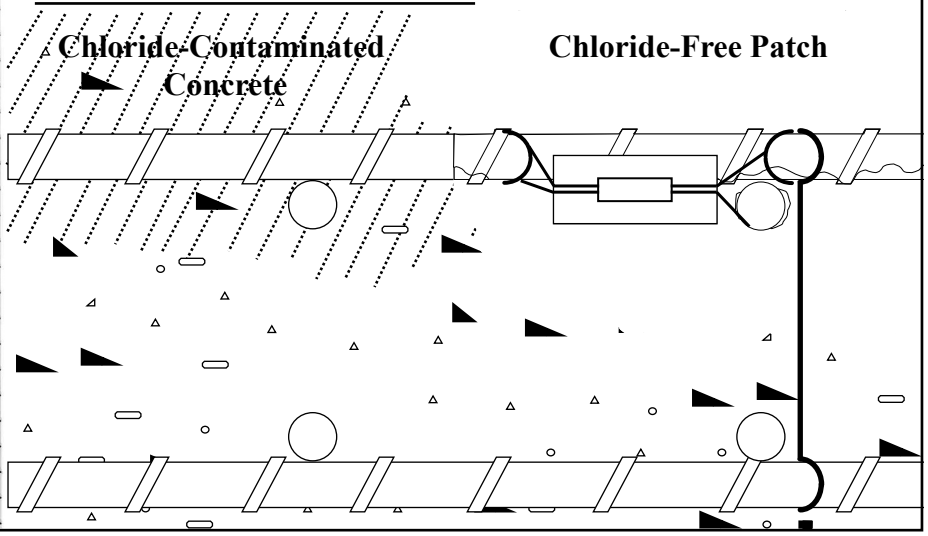
Can you coat the rebar inside the patch area?



120

Perimeter Highway (PTH 100) over Red River, Winnipeg, Manitoba
Manitoba Department of Highways and Transportation

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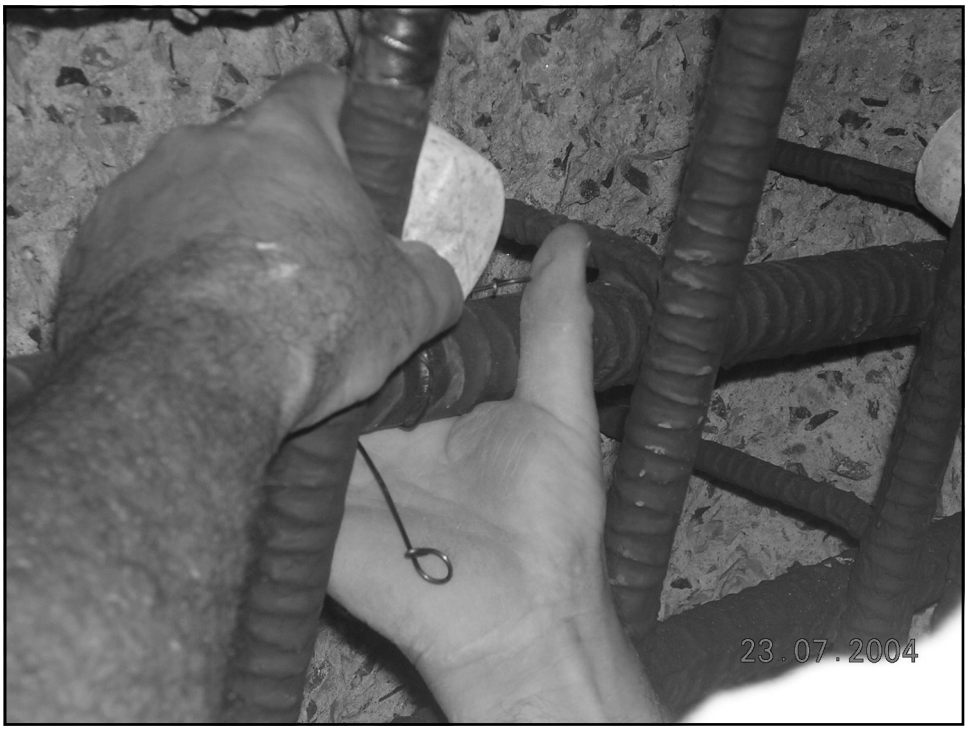

123

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Concrete Resistivity

- Higher repair concrete resistivity will reduce anode current output
- Maximum recommended resistivity is 15,000 ohm-cm. This is intended to match normal concrete which may be contaminated.
- If higher resistance materials are used:
  - Provide low resistivity contact with substrate.
  - Use special Mortars for this application.
  - This approach may be preferable in many cases to get additional current into the substrate.

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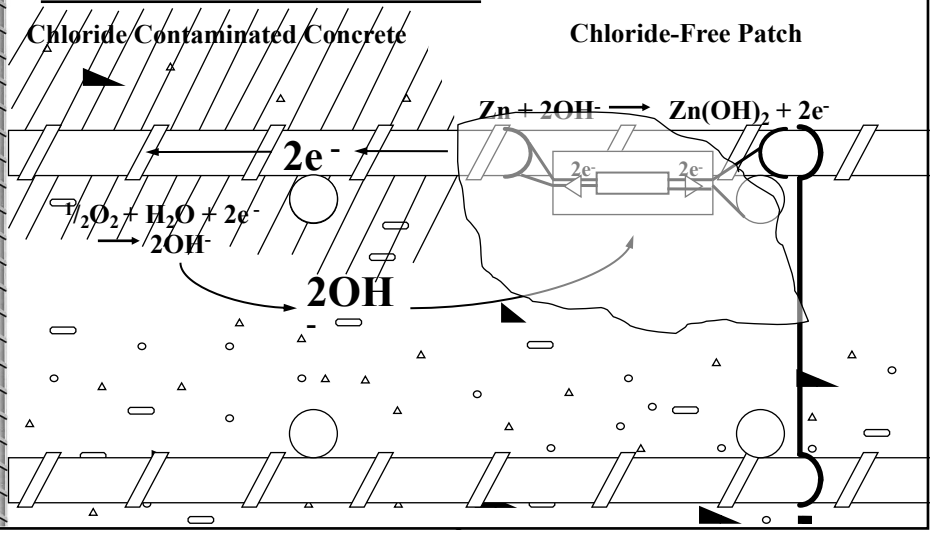
Installation with Low Resistivity Embedding Mortar



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Embedding Mortar Installation

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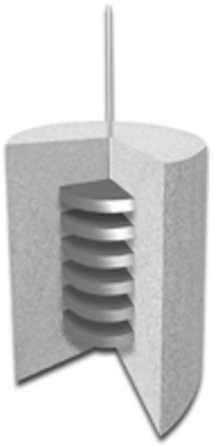
Vector® Galvashield® CC
Embedded Galvanic Anodes for Corrosion Control



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Vector® Galvashield® CC

- Significantly reduces or stops on-going corrosion activity
- Proactive solution for areas that are contaminated but have not spalled or delaminated
- Suitable for conventionally reinforced, prestressed and post-tensioned concrete structures
- Can be used with Vector® Galvashield® XP to provide global protection

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Galvashield CC Applications

- Mechanically sound concrete that requires localized corrosion protection
  - Structures that require repair, but can't chip around steel for structural reasons – may not be able to use XPs
  - May be more cost-effective or practical to protect before physical deterioration realized

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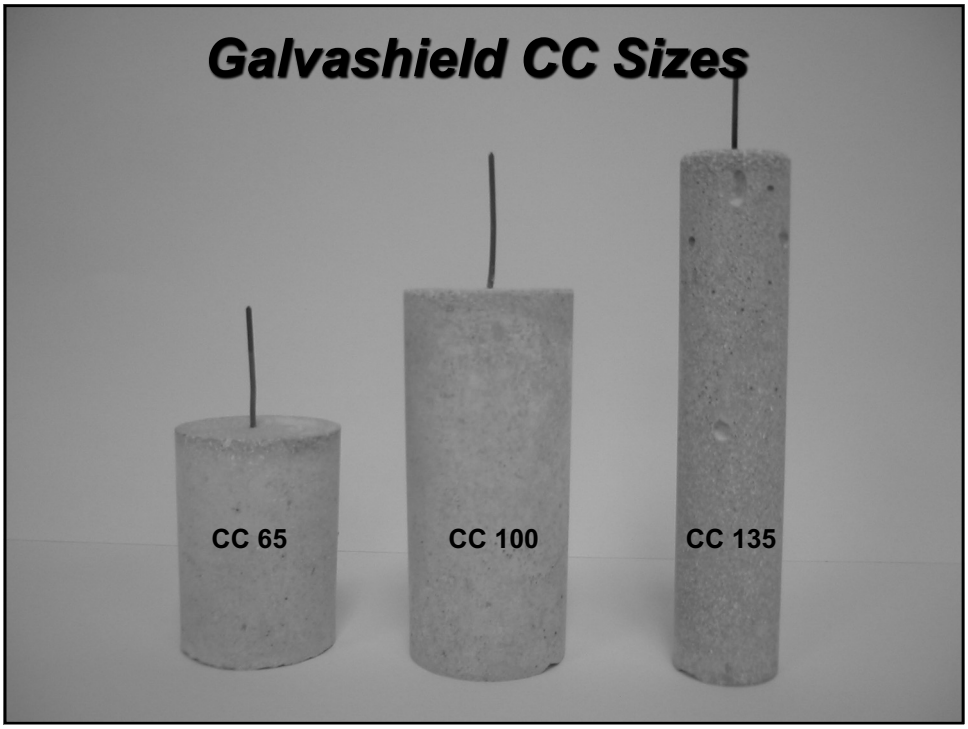
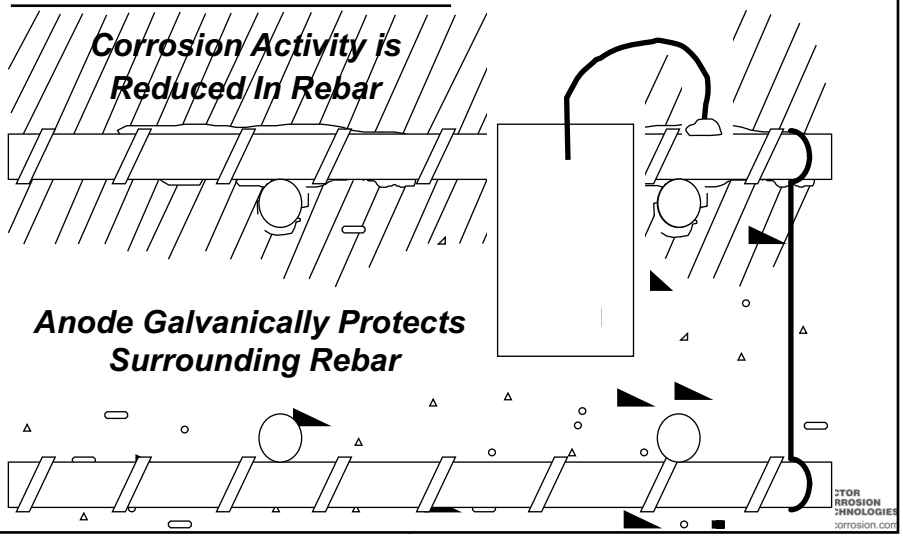


134

Galvashield CC Installation



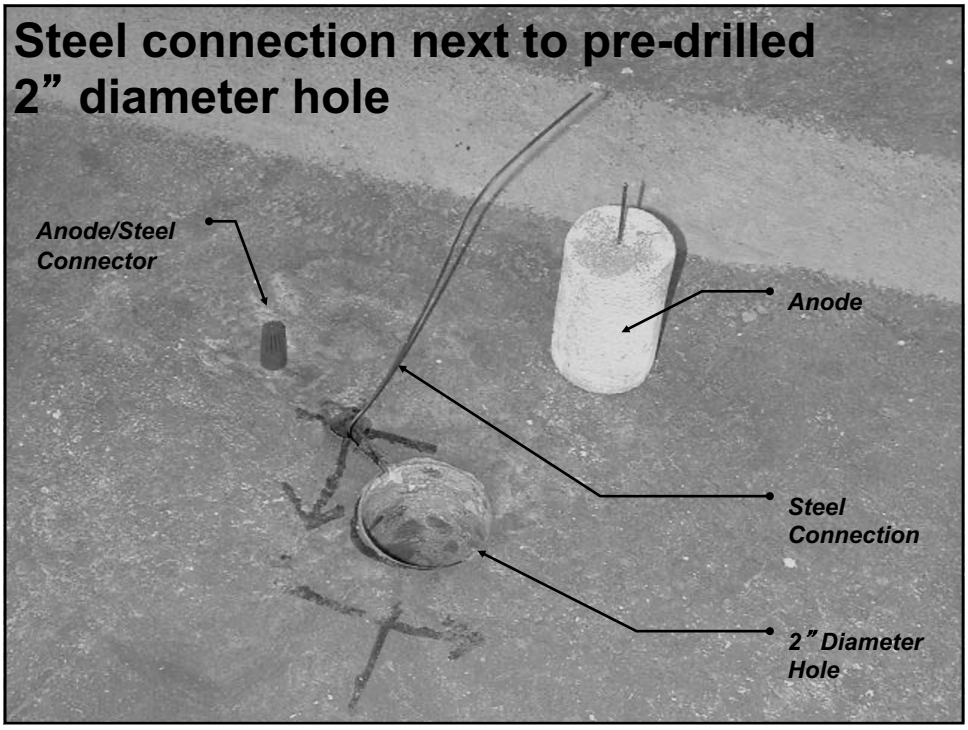
135

Installation Process
Locating Steel Reinforcement

136

Predrilled Holes for CC Installation
Parking Garage Deck

137



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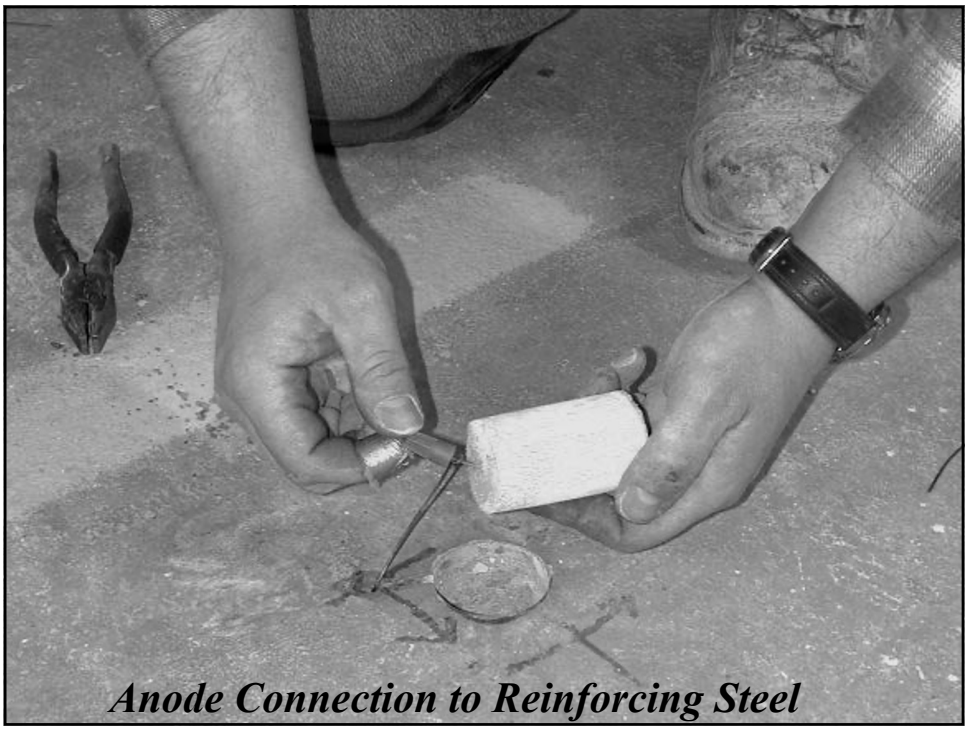

Anode Connection to Reinforcing Steel

139

Pouring Grout for Galvashield CC Installation

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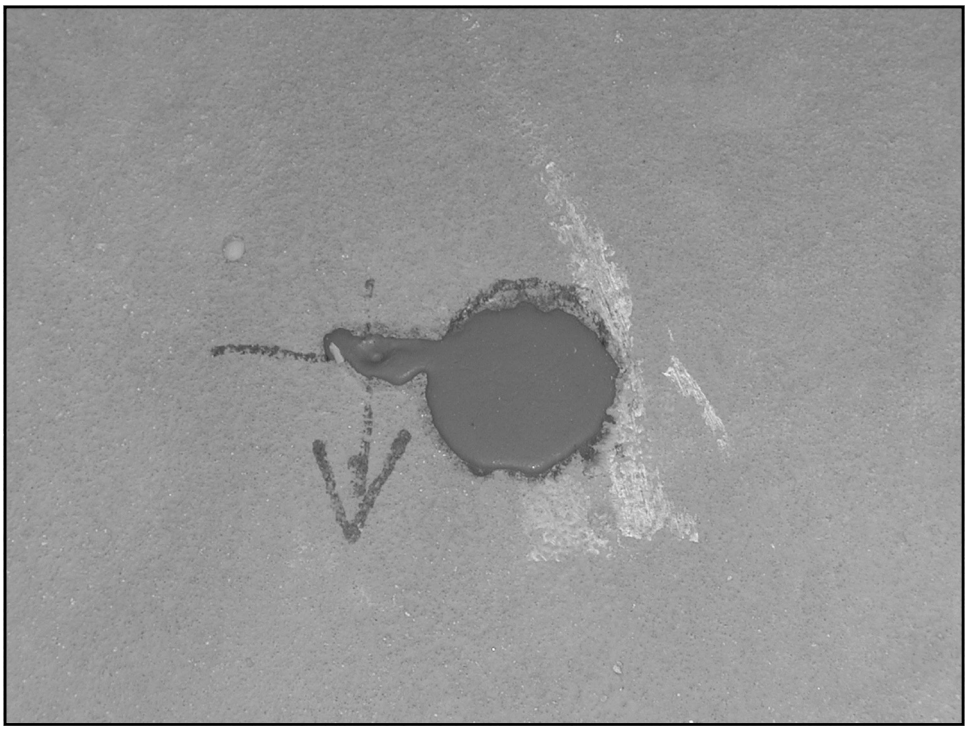

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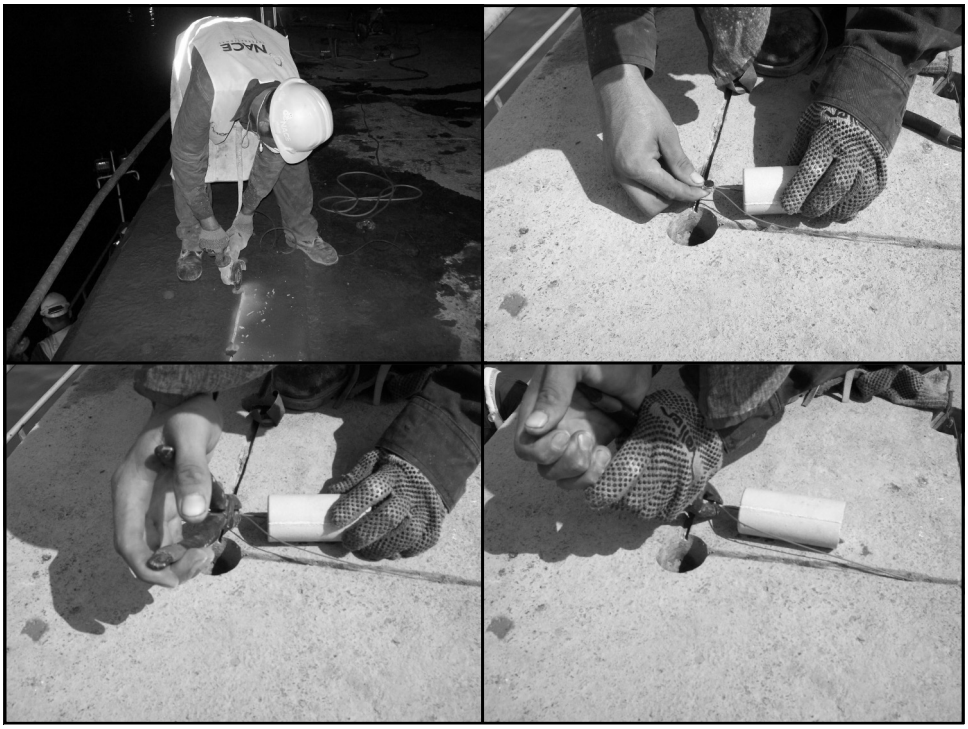

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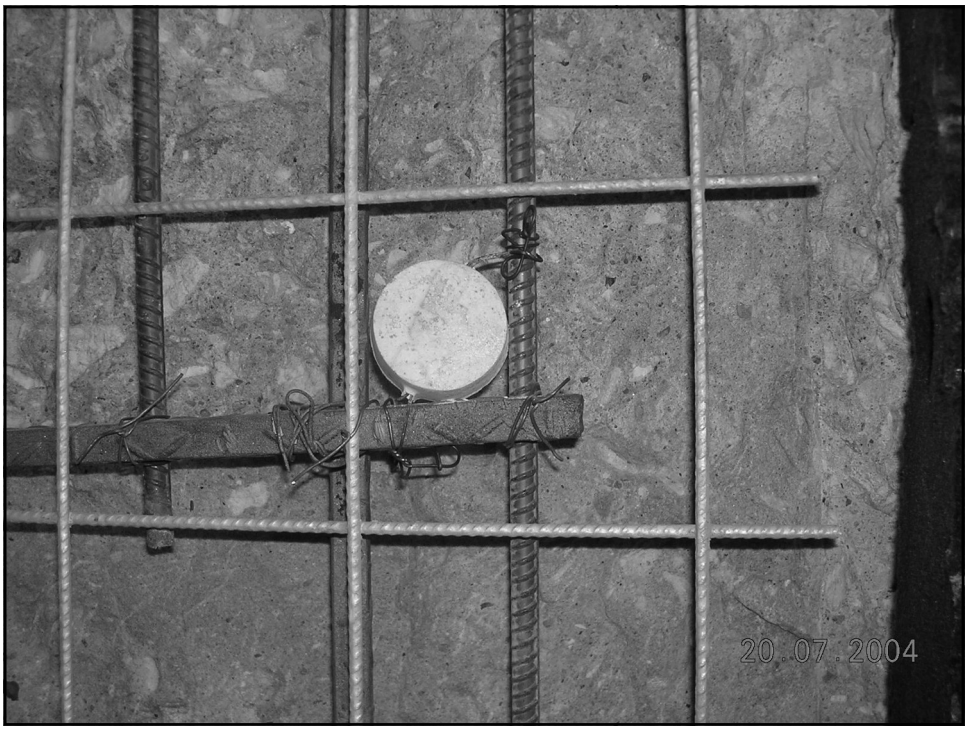

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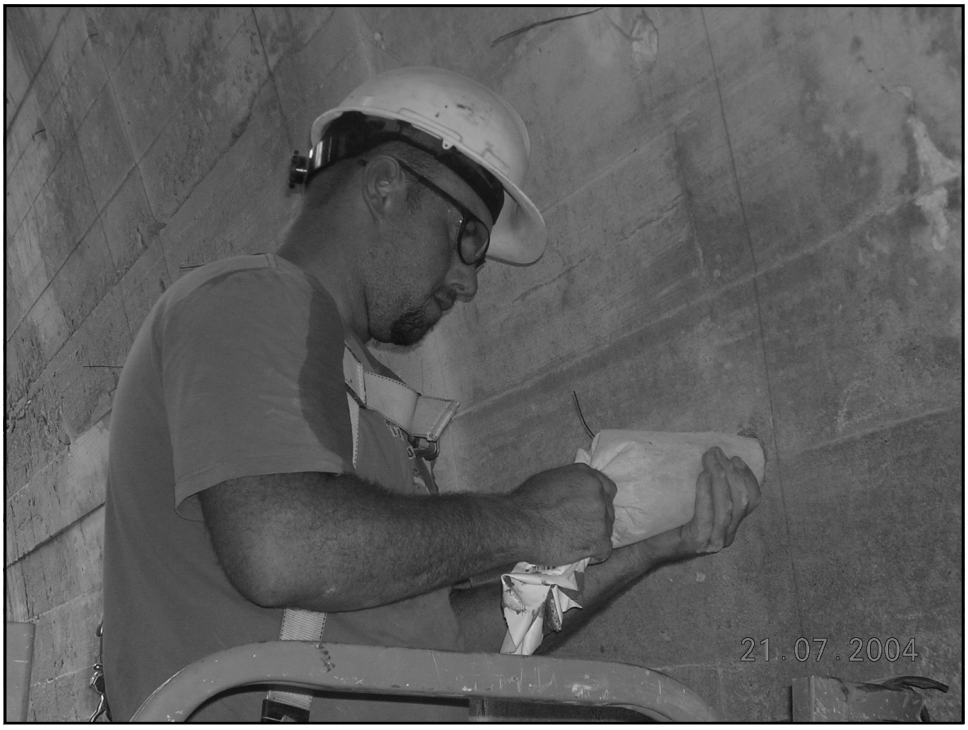

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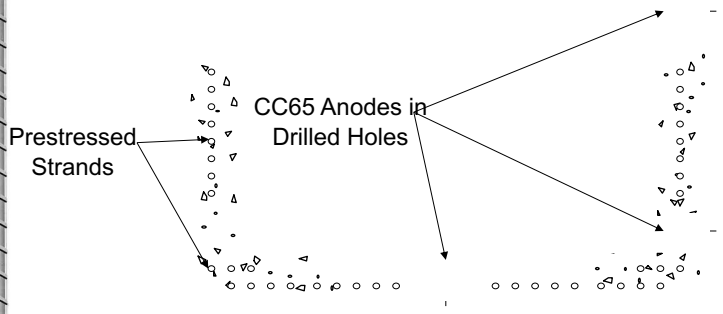
Galvanic Anodes in Prestressed Box Girder



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Galvanic Anodes in Prestressed Box Girder

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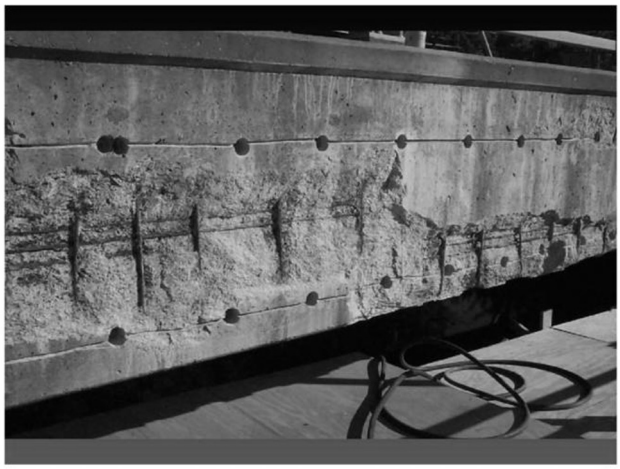
Galvanic Anodes in Prestressed Box Girder



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Galvanic Anodes in Prestressed Box Girder

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Galvanic Anodes in Prestressed Box Girder

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Galvanic Anodes in Prestressed Box Girder

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Iowa 192 Viaduct, Council Bluffs, Iowa
Iowa DOT

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Galvashield® CC65 Anodes
Balcony Protection

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Galvashield CC65 Anodes
Balcony Protection

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Balcony Protection

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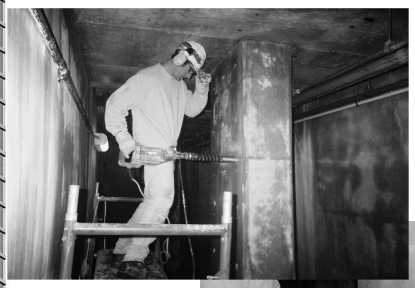
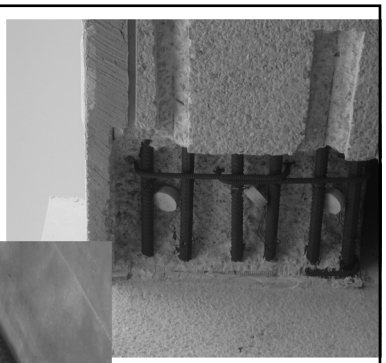
Column Protection



161

Column Protection



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Galvashield CC65 and CC135

Steel density ratio (steel surface area/ concrete surface area)	Maximum grid dimensions in. (mm)
< 0.2	28 in. (700 mm)
0.21 – 0.4	24 in. (600 mm)
0.41 – 0.54	20 in. (500 mm)
0.55 – 0.67	18 in. (450 mm)
0.68 – 0.80	16 in. (400 mm)
0.81 – 0.94	15 in. (380 mm)
0.95 – 1.07	14 in. (355 mm)
1.08 – 1.2	13 in. (335 mm)

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Galvashield CC100 Spacing

Steel density ratio (steel surface area/ concrete surface area)	Maximum grid dimensions in. (mm)
0.55 – 0.94	20 in. (500 mm)
0.95 – 1.17	18 in. (450 mm)
1.18 – 1.41	16 in. (400 mm)
1.42 – 1.64	15 in. (380 mm)
1.65 – 1.88	14 in. (355 mm)
1.89 – 2.11	13 in. (335 mm)

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Distributed Anodes for Corrosion Control

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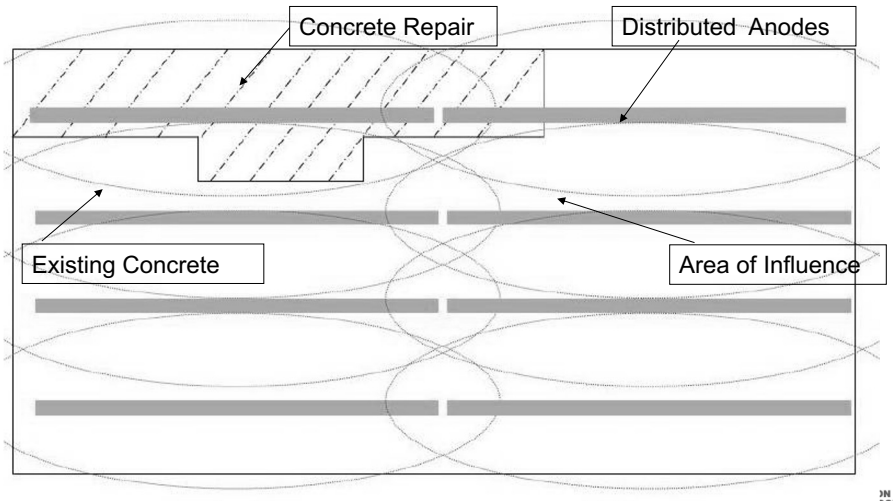
Distributed Anodes Protection



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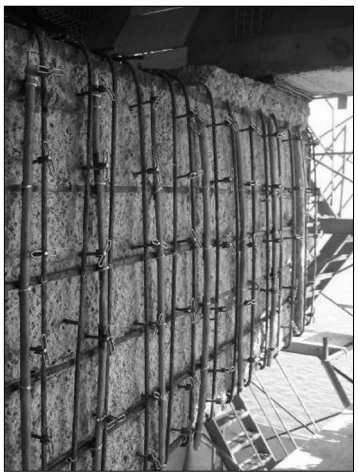
Distributed Anode System



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2008/01/30

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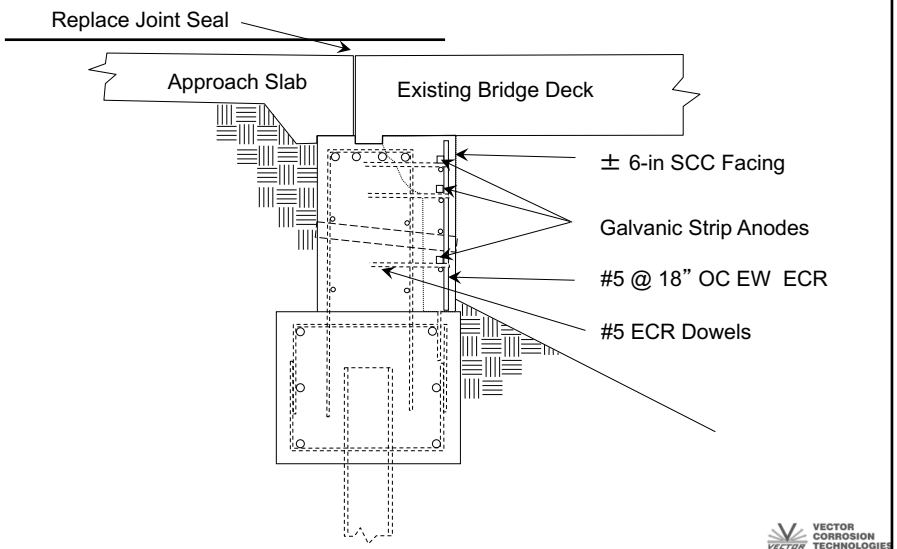
Abutment Repair Detail With Galvanic Protection



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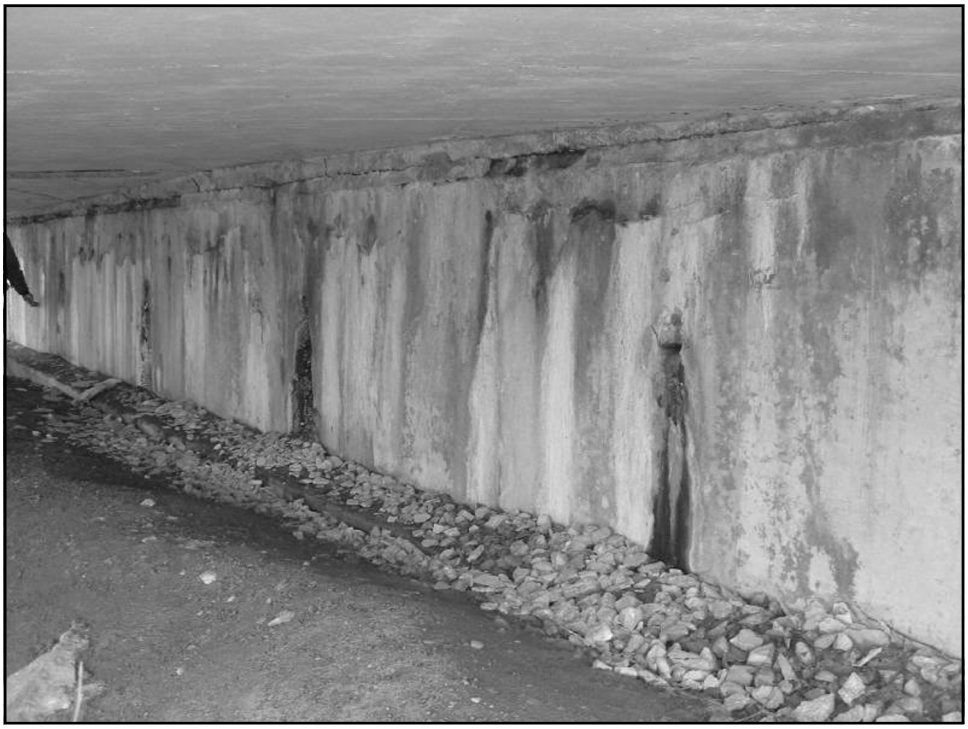

179

I-75 Ohio DOT

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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	31	12.9	333	987
10/26/05	12	5.4	394	1048
12/7/05	11	3.2	339	993
5/1/06	14	7.5	335	989
12/20/06	4	4.3	500	1154
5/30/07	26	7.5	446	1100
9/20/07	24	9.7	484	1138
12/09/08	4	3.3	470	1124
7/9/09	23	3.3	475	1129

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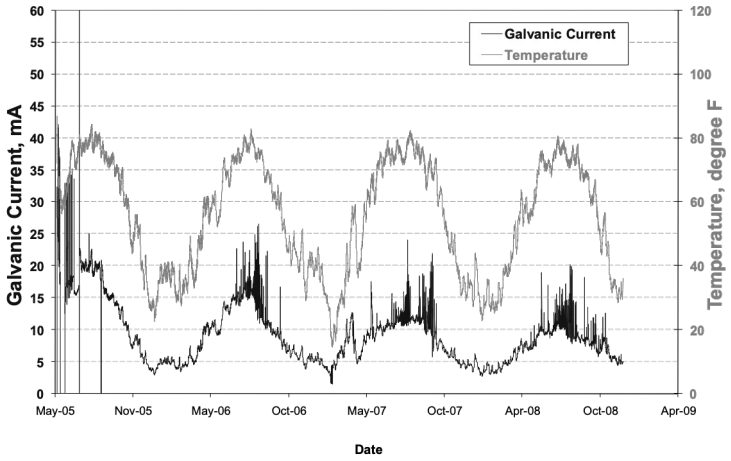
Kirkwood Road – Protective Current



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Thank You

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Cathodic Protection Systems

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Cathodic Protection Systems

- Work by applying current to reinforcing steel to overcome the corrosion process
- Impressed Current Systems: D.C. power makes electrons flow from anode to reinforcement (cathode)
- Galvanic Systems: Sacrificial metal corrodes to provide electrons

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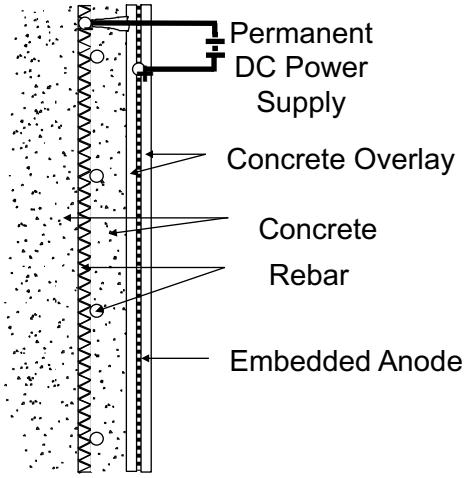
Distributed Anode ICCP System



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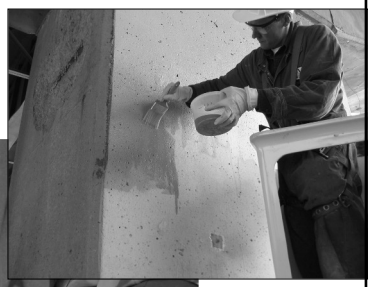
Arc Sprayed Zinc



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- Galvanic CP Deck Overlay
- Ontario Ministry of Transportation

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Galvanic Mesh Overlay

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Galvanic Strip Anodes for Cathodic Protection of Plaza Deck

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- Galvanic Strip Deck Protection
- Ontario Ministry of Transportation

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- Galvanic Strip Deck Protection
- Ontario Ministry of Transportation

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- Galvanic Strip Deck Protection
- Ontario Ministry of Transportation

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Vector® Ebonex® Discrete Anodes for ICCP

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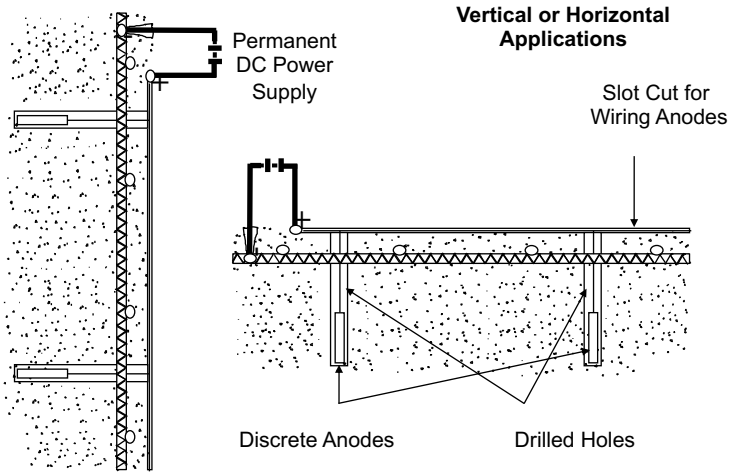
200

Cathodic Protection for Concrete and Masonry Structures – Ebonex® Discrete ICCP Anodes



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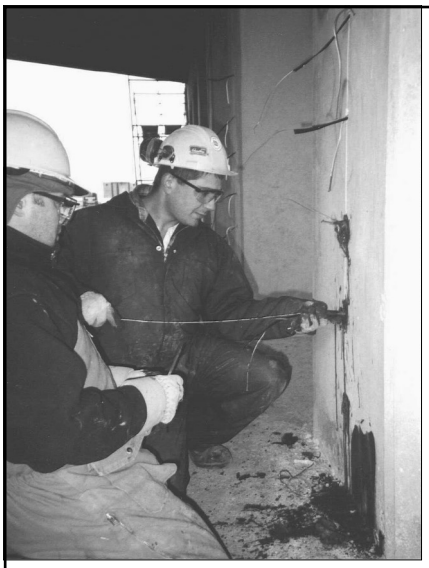

Installation of Ebonex Anode System
Winnipeg, Manitoba

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Installation of Ebonex Anode System
Bridge Substructure

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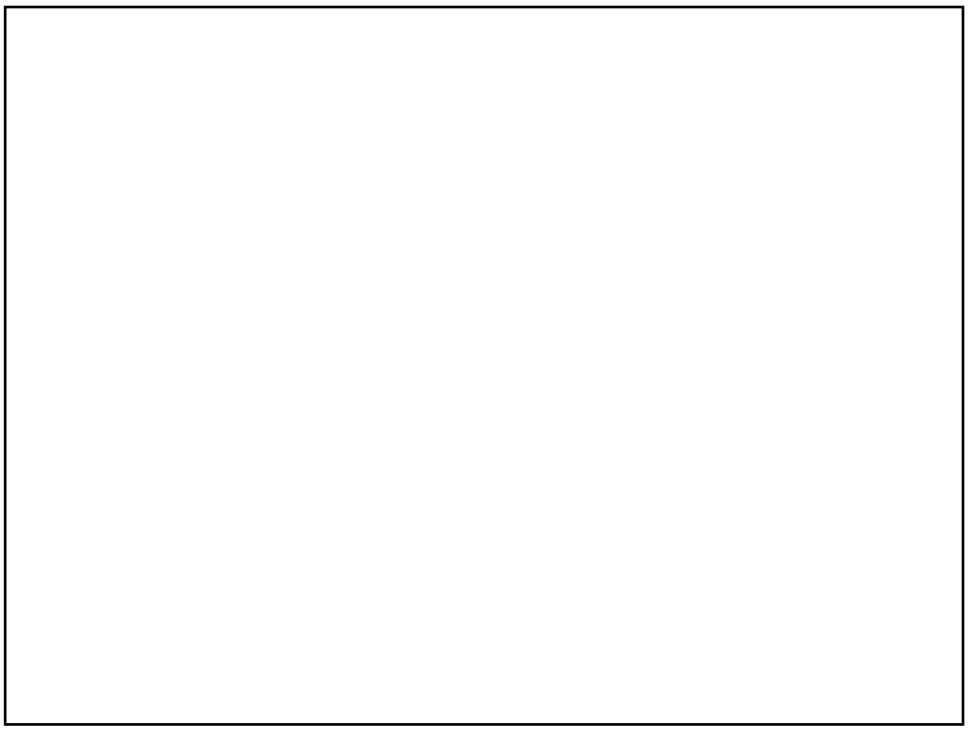
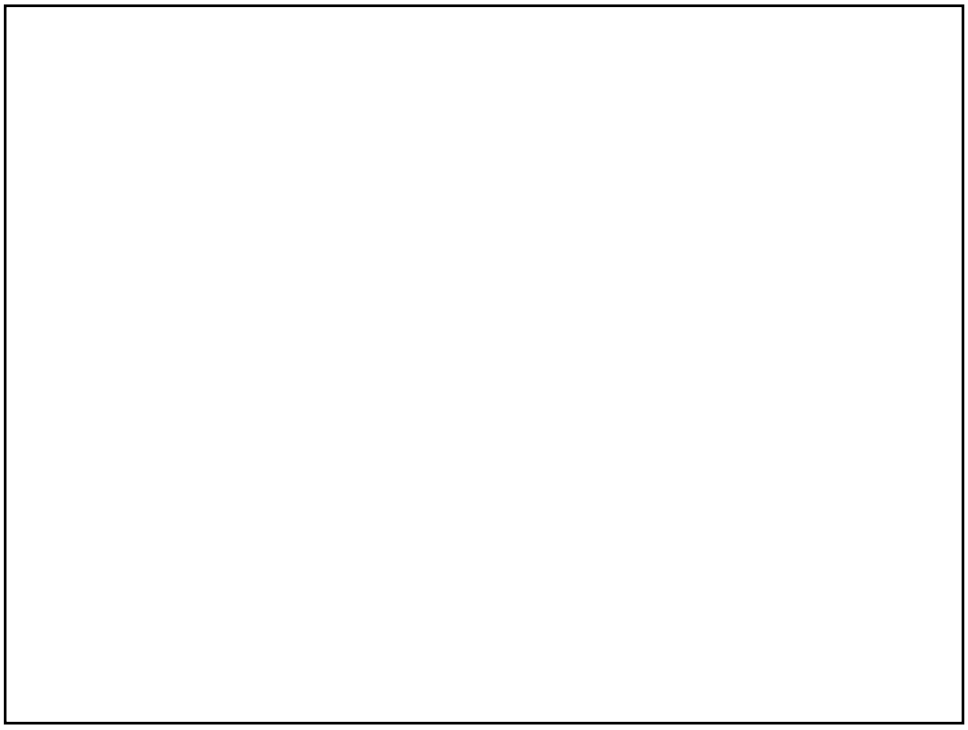


205



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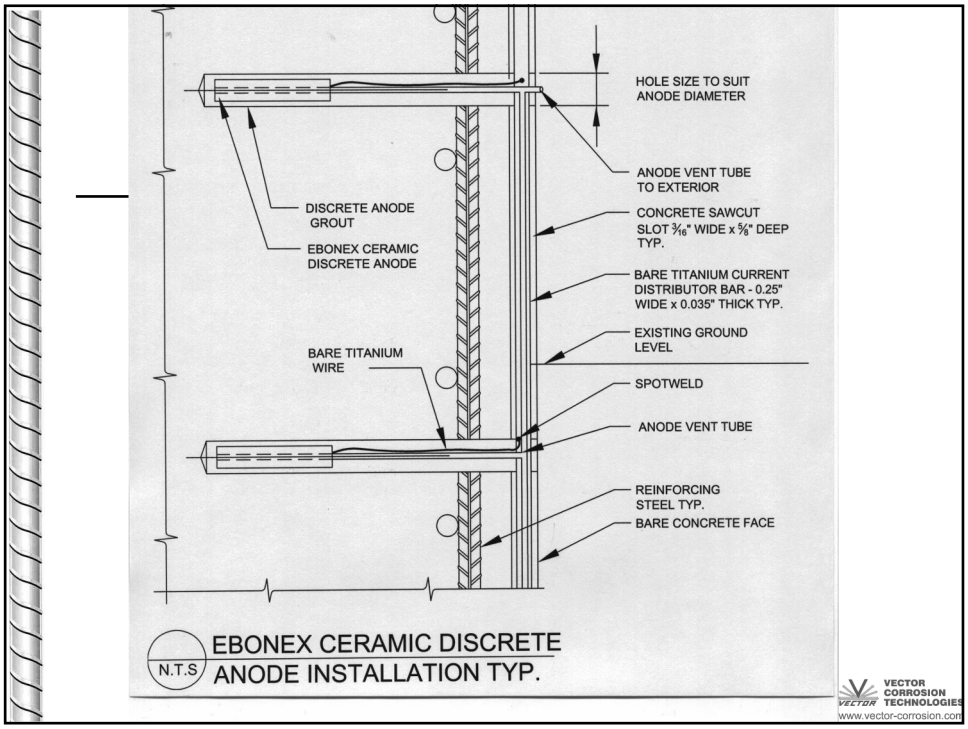
HOLE SIZE TO SUIT
ANODE DIAMETER
ANODE VENT TUBE
TO EXTERIOR
CONCRETE SAWCUT
SLOT 3/16" WIDE x 5/8" DEEP
TYP.
BARE TITANIUM CURRENT
DISTRIBUTOR BAR - 0.25"
WIDE x 0.035" THICK TYP.
EXISTING GROUND
LEVEL
SPOTWELD
ANODE VENT TUBE
REINFORCING
STEEL TYP.
BARE CONCRETE FACE
DISCRETE ANODE
GROUT
EBONEX CERAMIC
DISCRETE ANODE
BARE TITANIUM
WIRE
N.T.S
EBONEX CERAMIC DISCRETE
ANODE INSTALLATION TYP.
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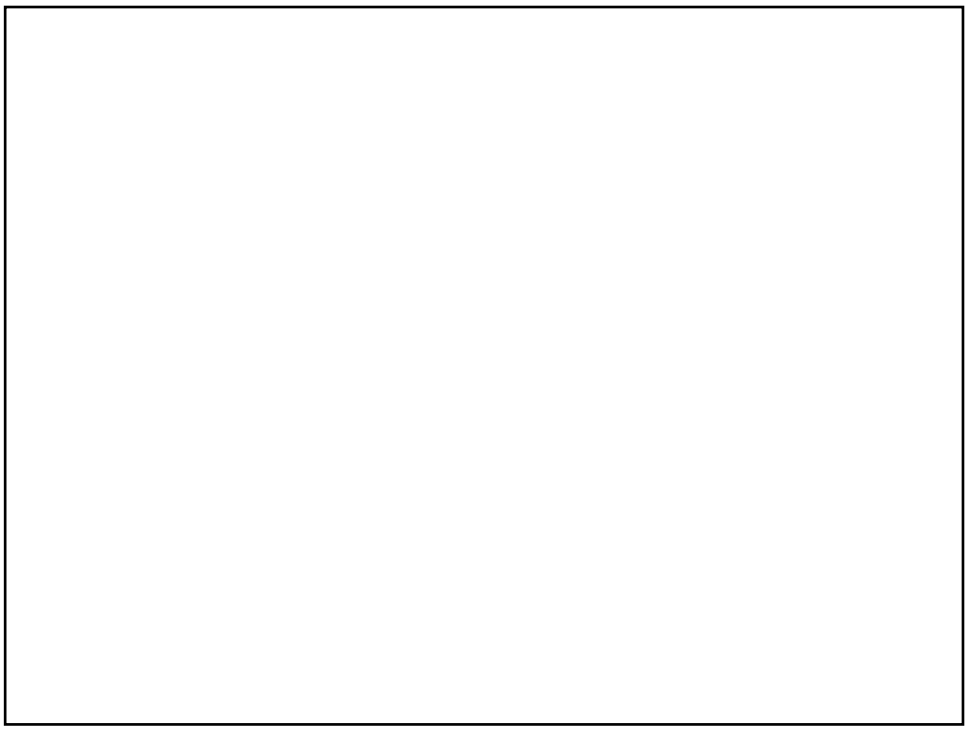

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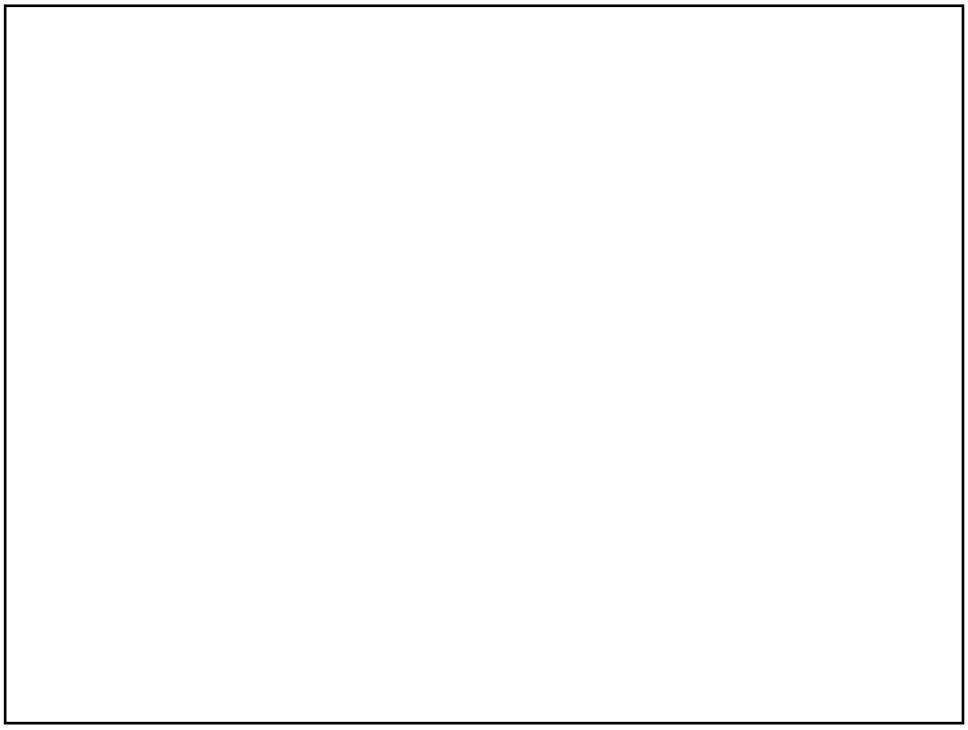

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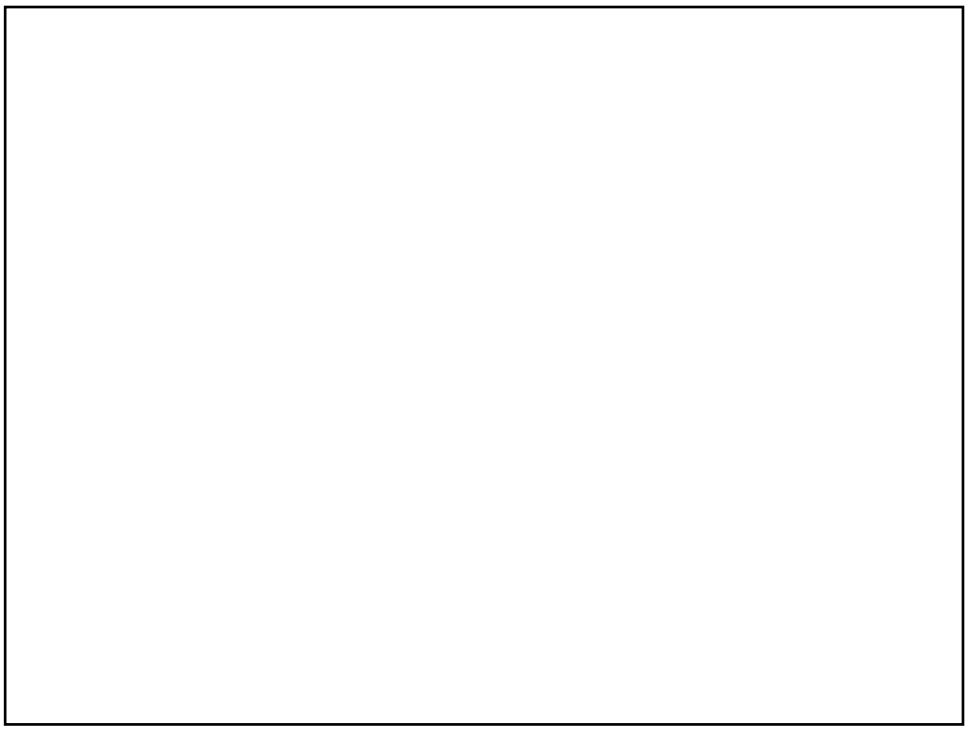

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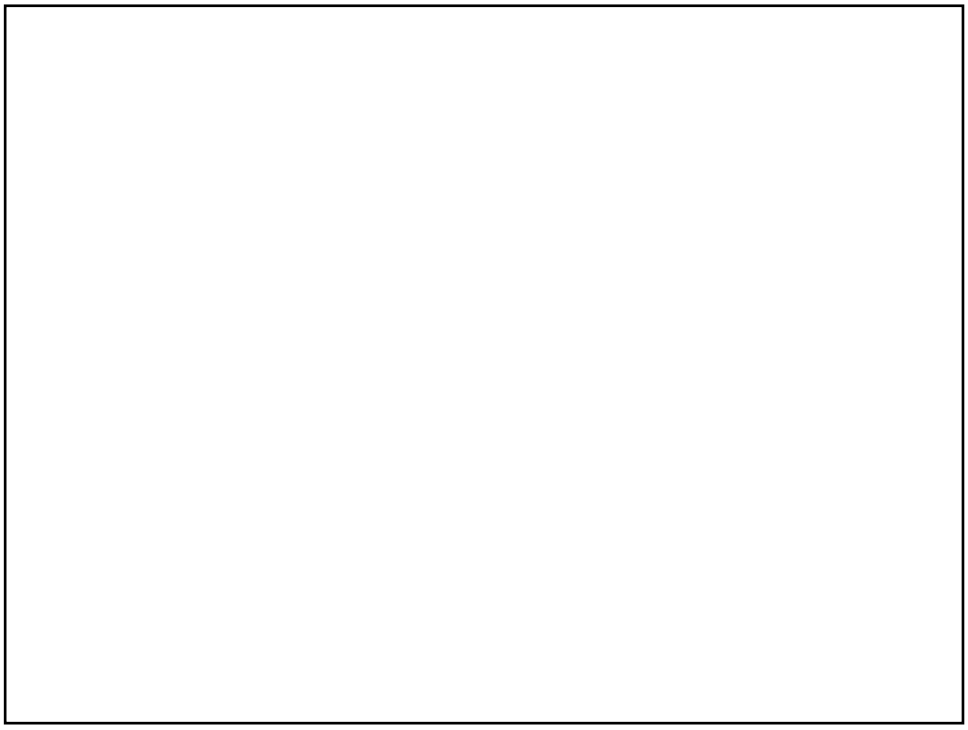

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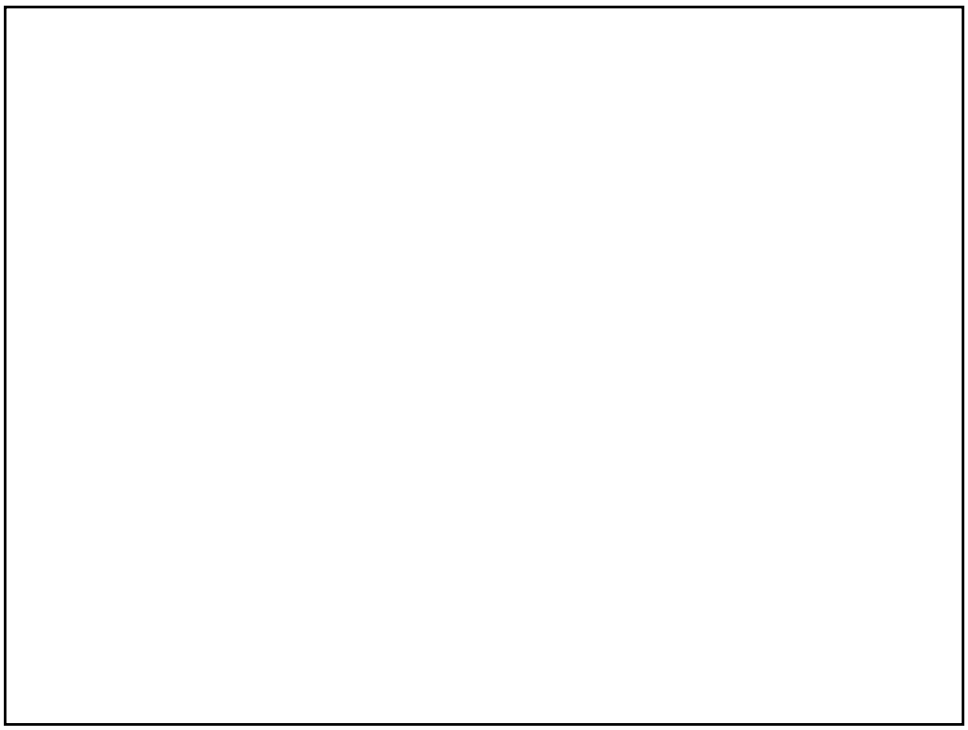

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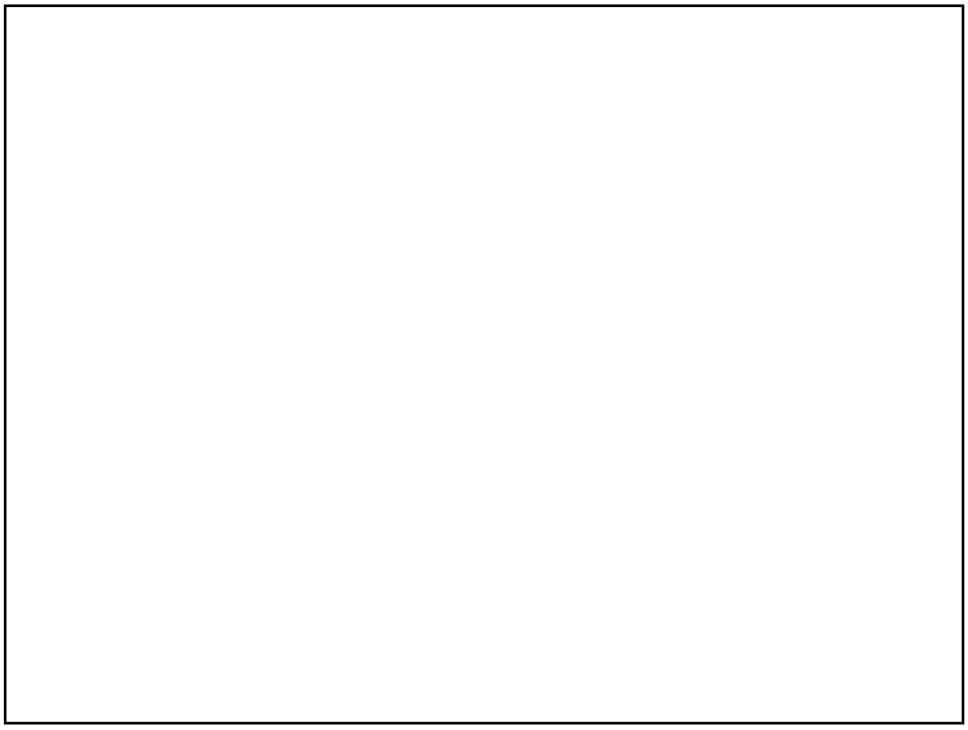

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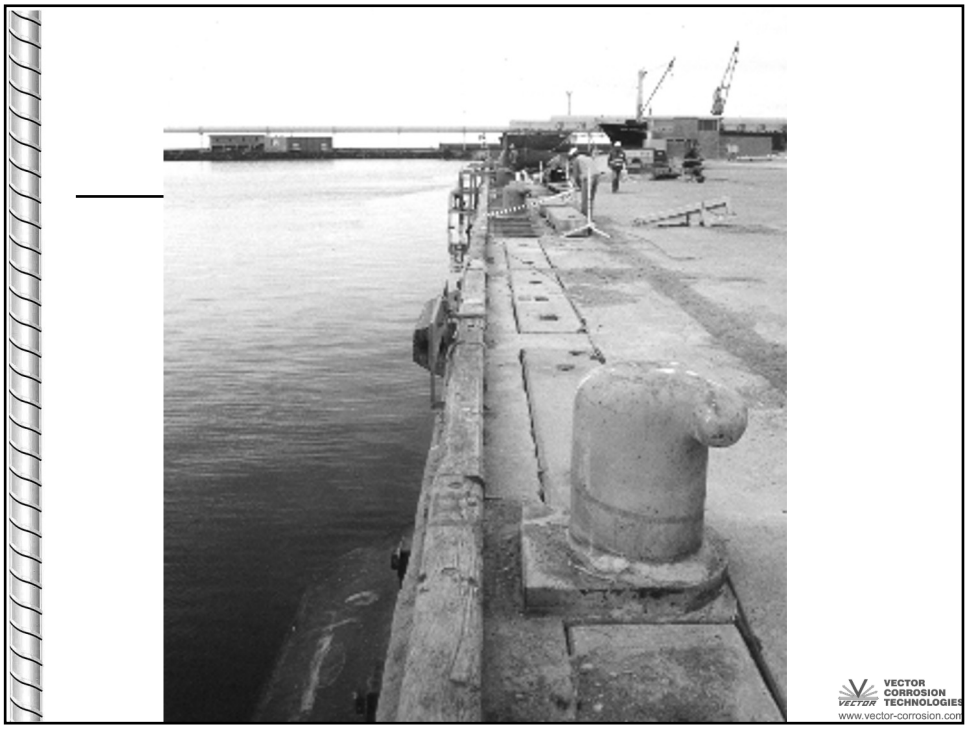

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Corrosion of Masonry-Clad Steel Frame Buildings

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Corrosion of Steel Frame

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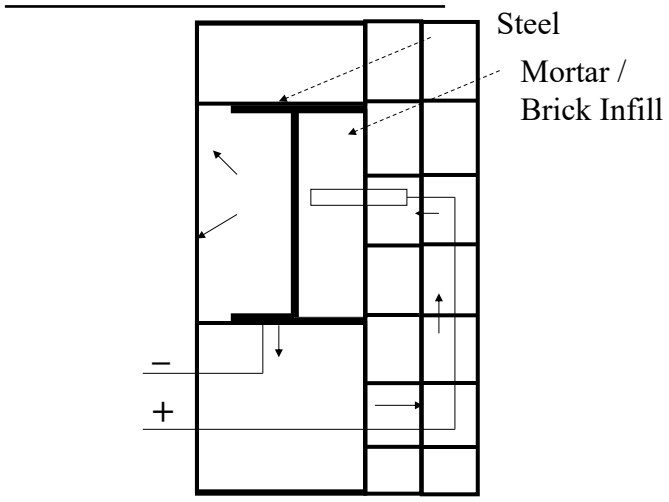
Steel Frame ICCP



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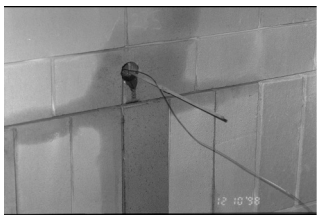
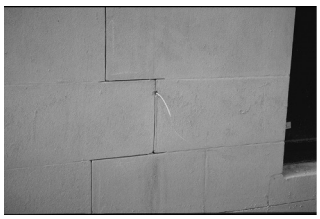
ICCP to the Steel Frame

- Anodes and Reference Electrode designed to protect and monitor beams and columns
- Titanium feed wire routed through chases in the brickwork joints and re-pointed
- Gas vent tube cut flush with the surface on completion





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Arkwright House, Manchester, UK

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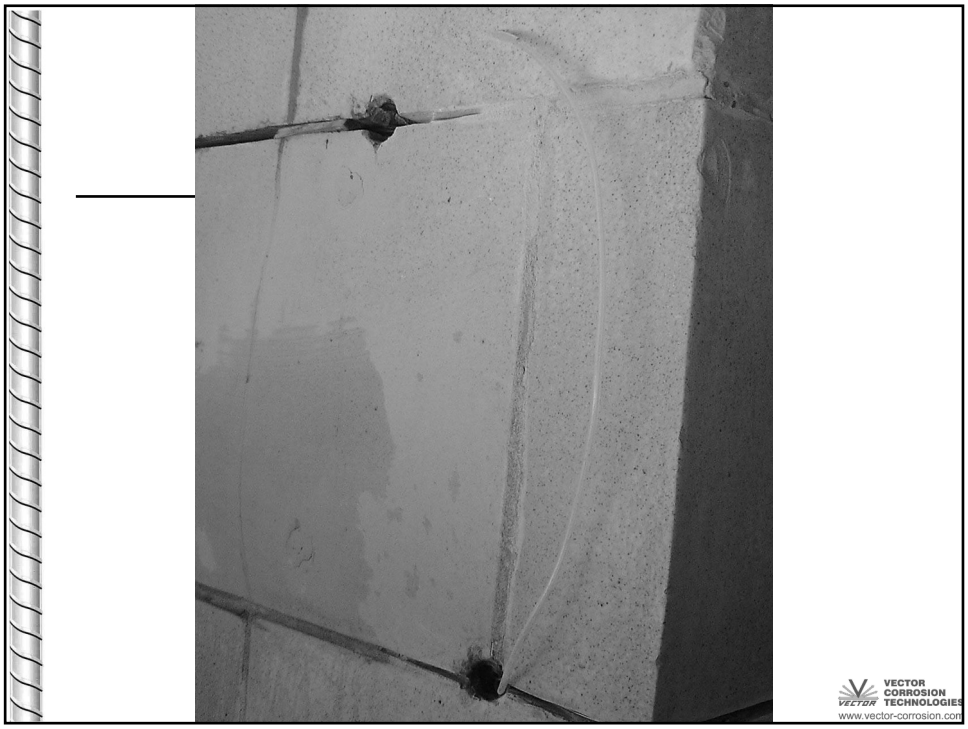

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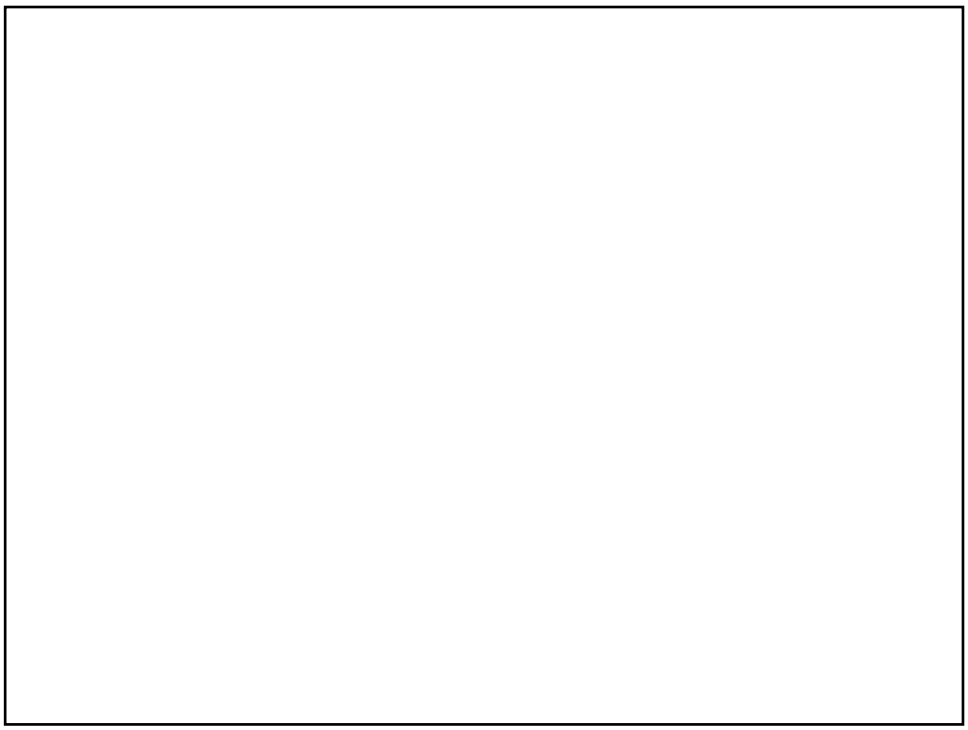

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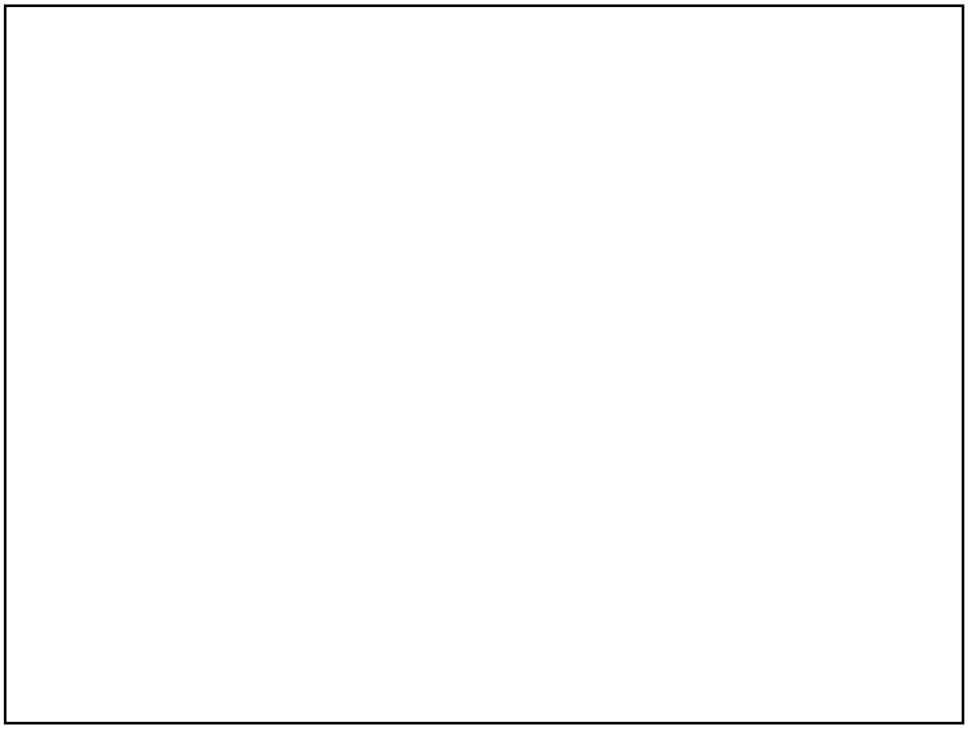

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Vector® Ebonex®

- ICCP - intended to stop on-going corrosion activity
- High current capacity
- Protects deeply embedded steel
- Built-in ventilation system
- Ideal for concrete columns, beams, and steel frame masonry buildings

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Electrochemical Treatments

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Electrochemical Treatments

- Norcure® Chloride Extraction (ECE)
- Norcure® Re-alkalization

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Norcure® Chloride Extraction

- Addresses the cause of corrosion
- Chloride levels are significantly reduced
- Alkalinity is increased at the level of the steel
- Reinforcing steel is returned to a passive, non-corroding state

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How does ECE work?

- Removes Chlorides from the Concrete
- Regenerates the Protective Passive Layer around the Reinforcing Steel

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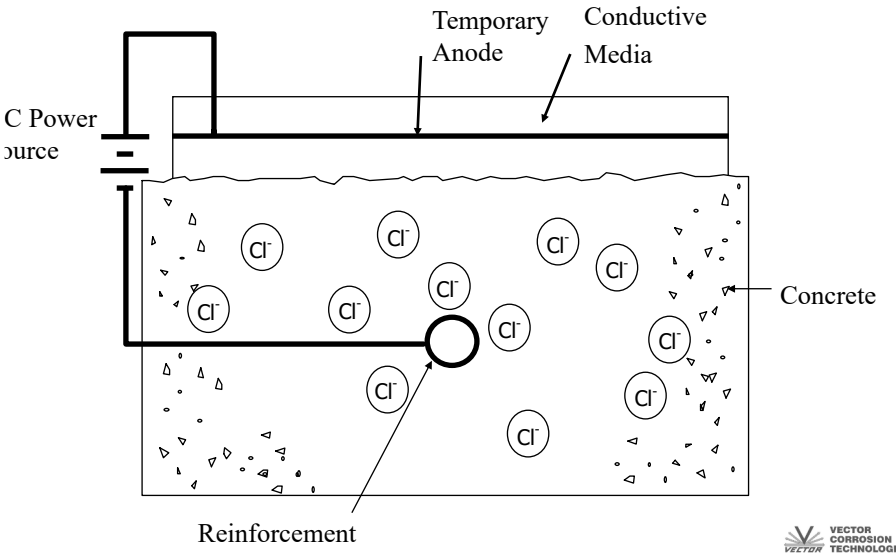
Electrochemical Chloride Extraction (ECE) From Salt Contaminated Concrete



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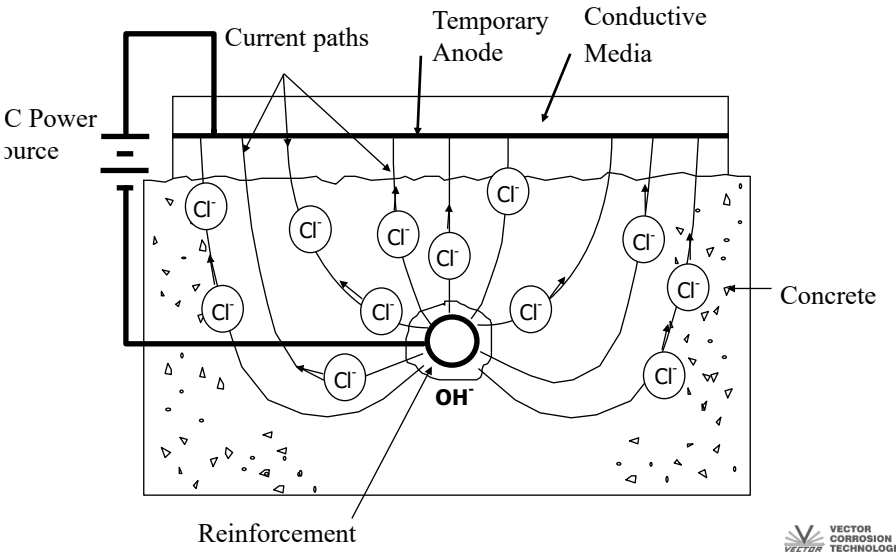
Electrochemical Chloride Extraction (ECE) From Salt Contaminated Concrete



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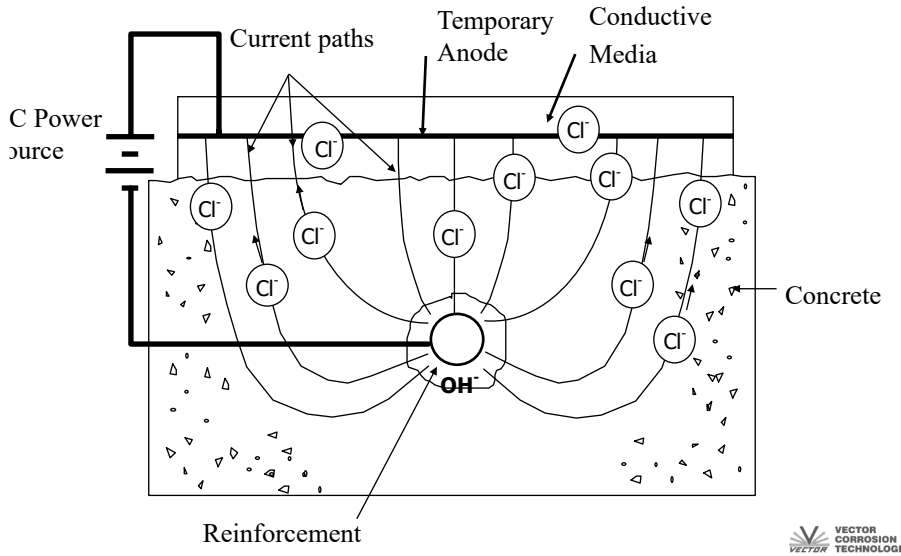
Electrochemical Chloride Extraction (ECE) From Salt Contaminated Concrete



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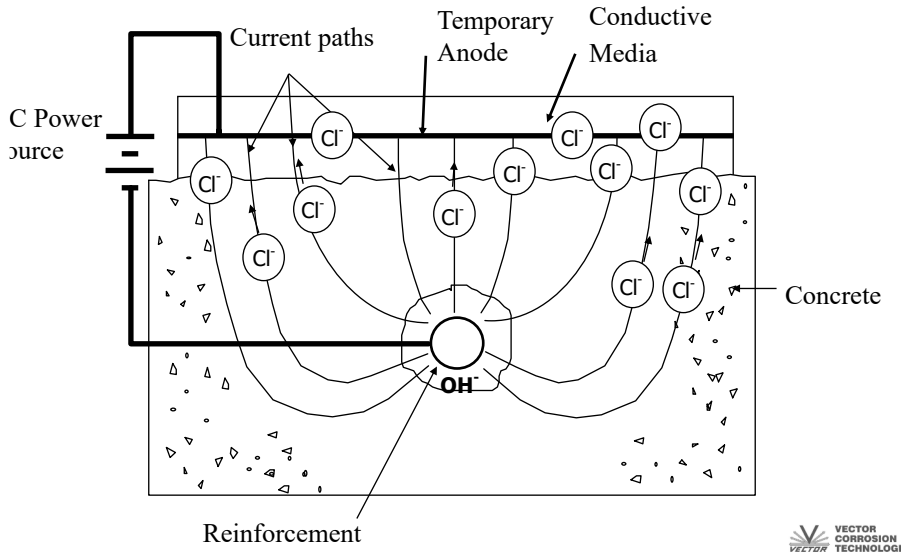
Electrochemical Chloride Extraction (ECE) From Salt Contaminated Concrete



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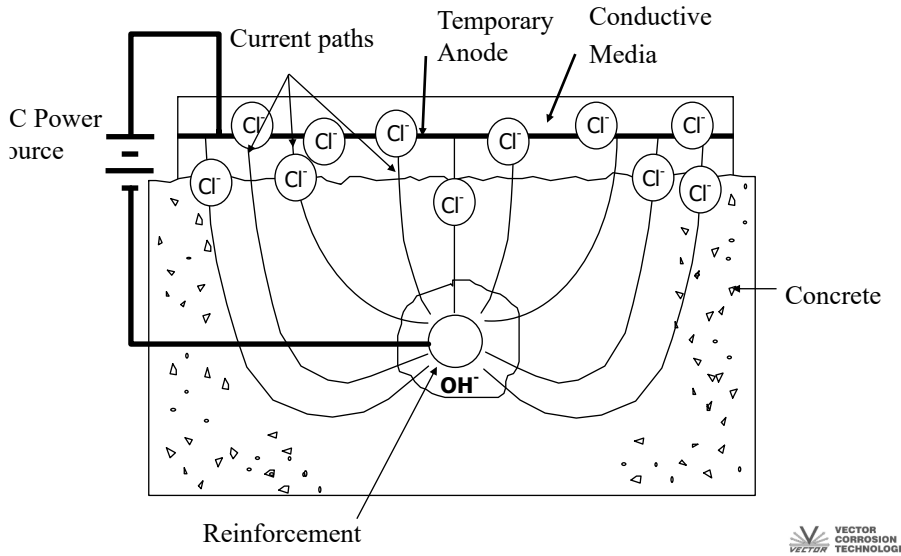
Electrochemical Chloride Extraction (ECE) From Salt Contaminated Concrete



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SHRP Research

- Extensive ECE Testing Undertaken
- 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

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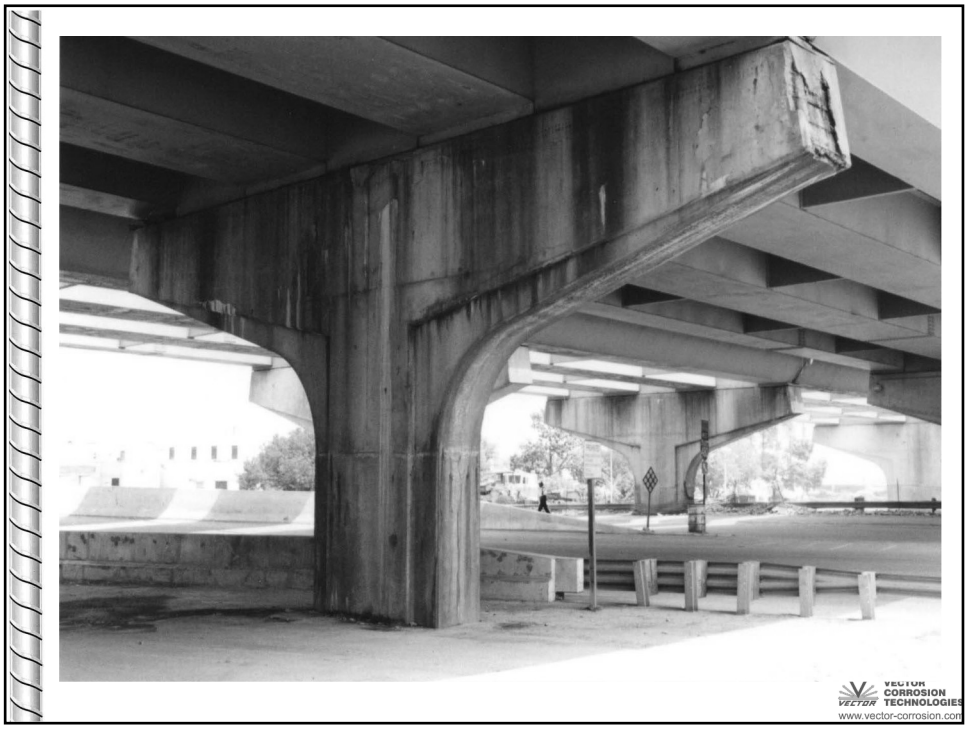

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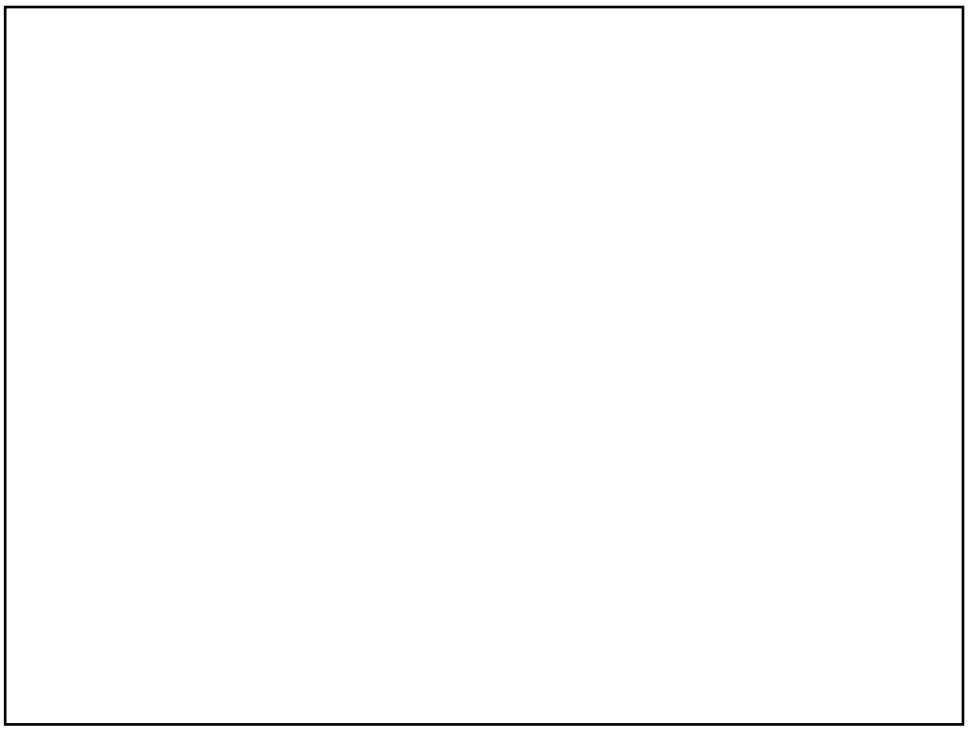

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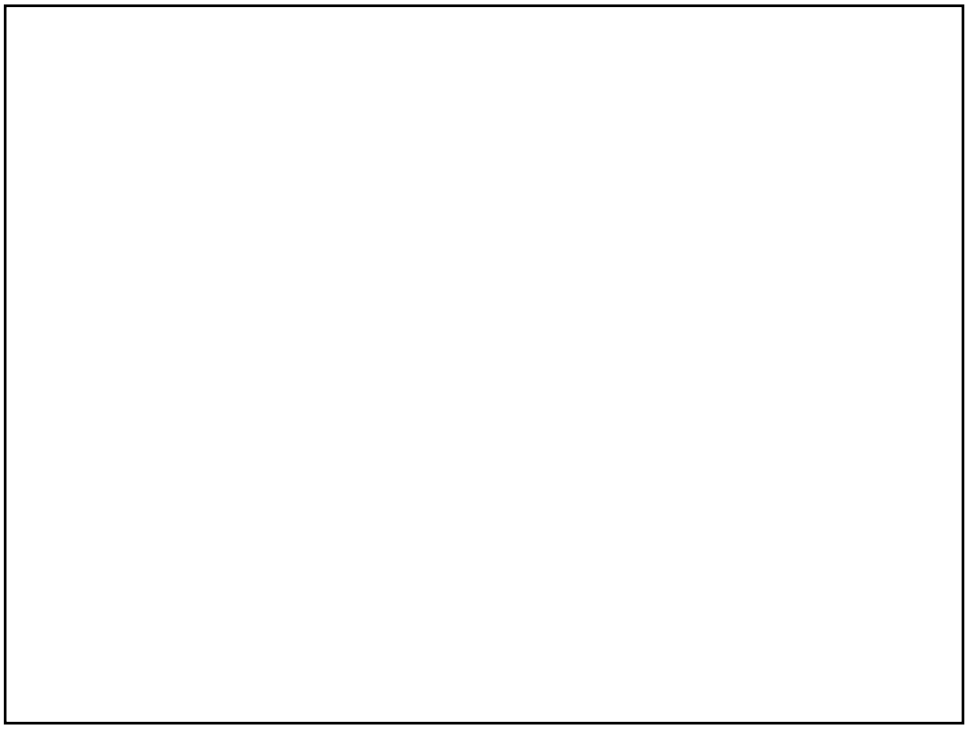

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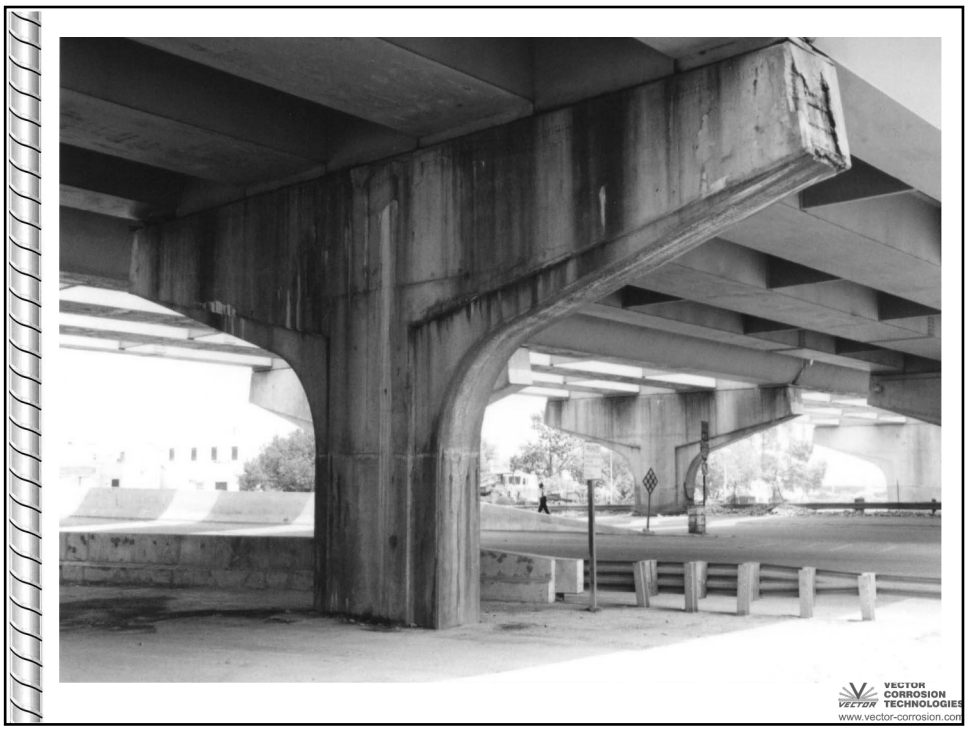
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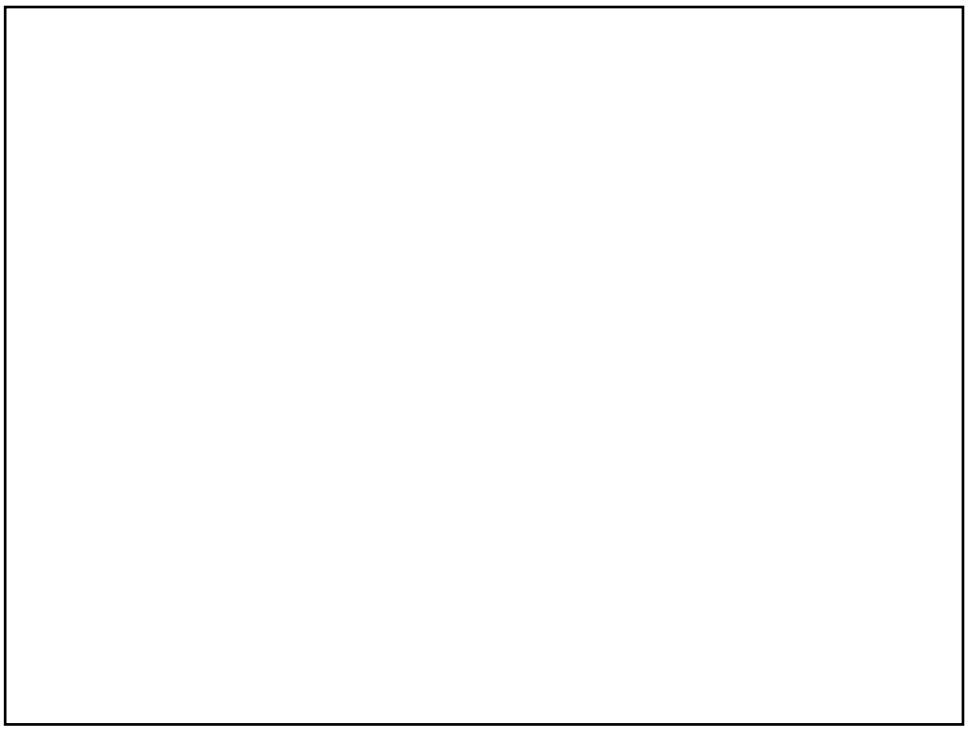

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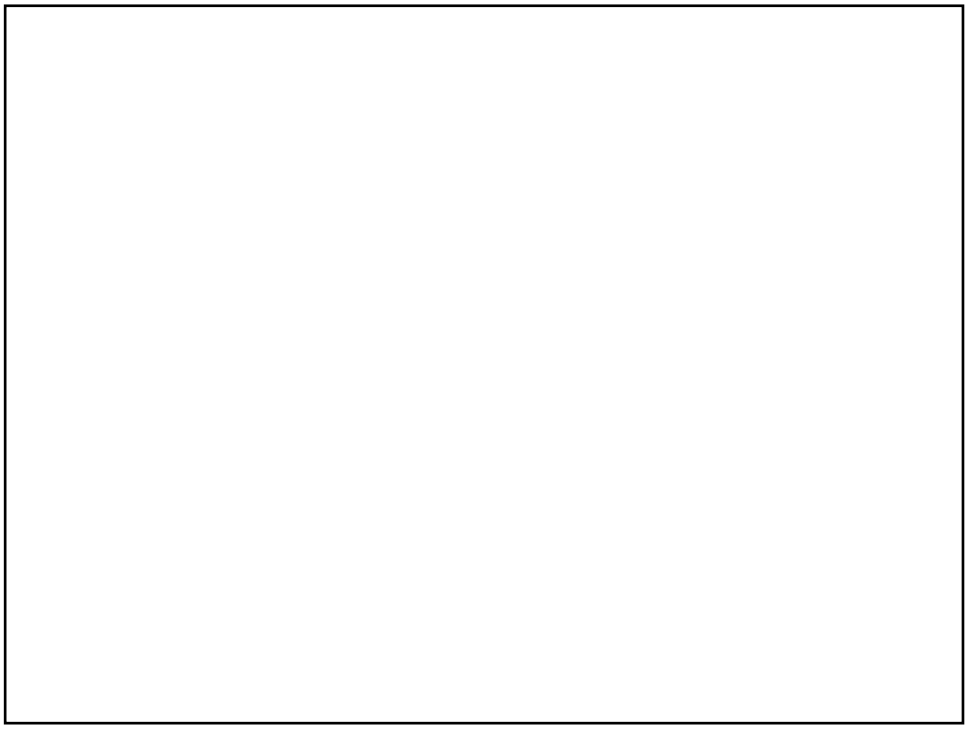

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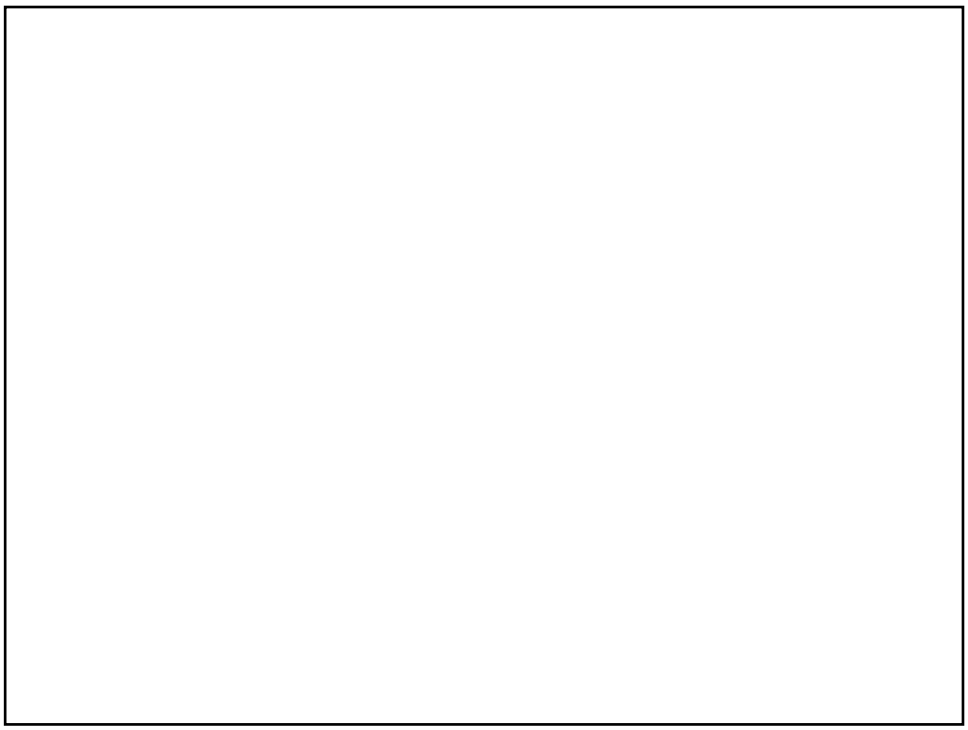

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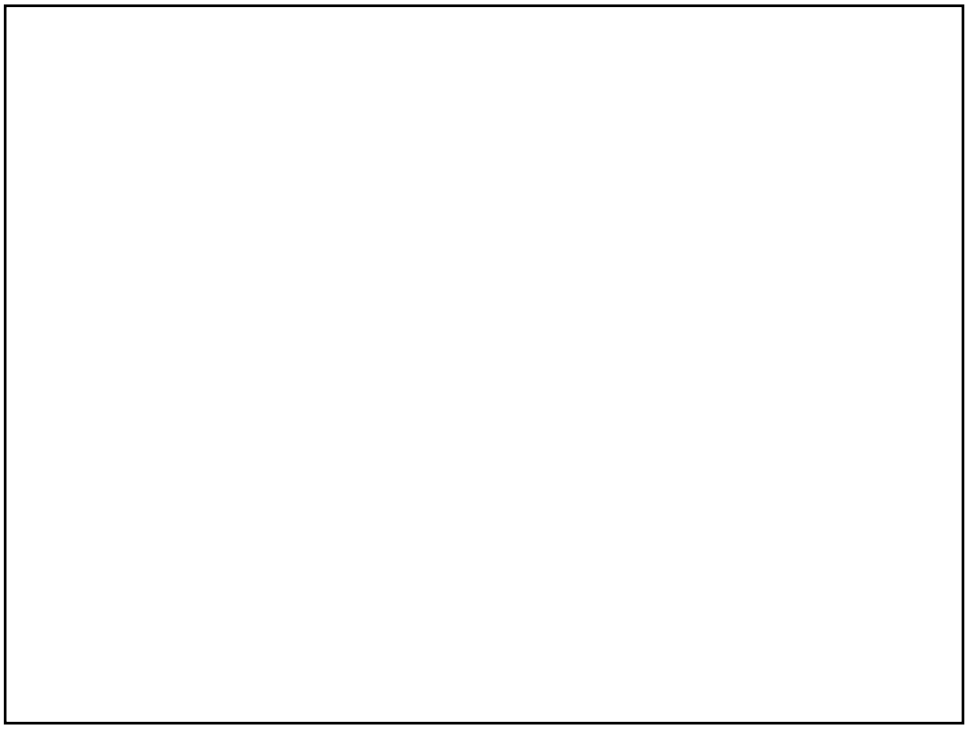

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Norcure® ECE Treatment Process

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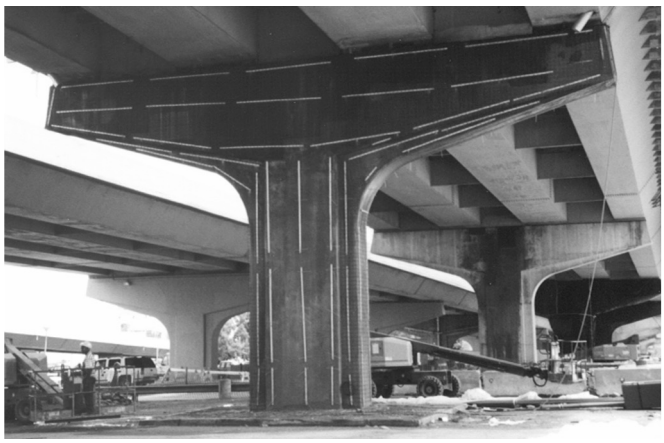
Norcure® ECE Treatment Process



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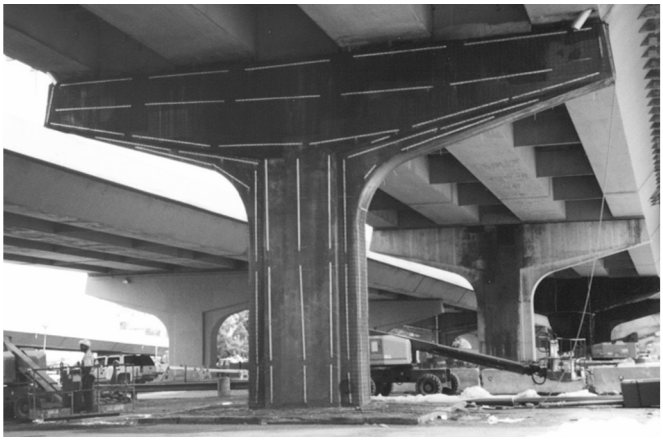
Norcure® ECE Treatment Process



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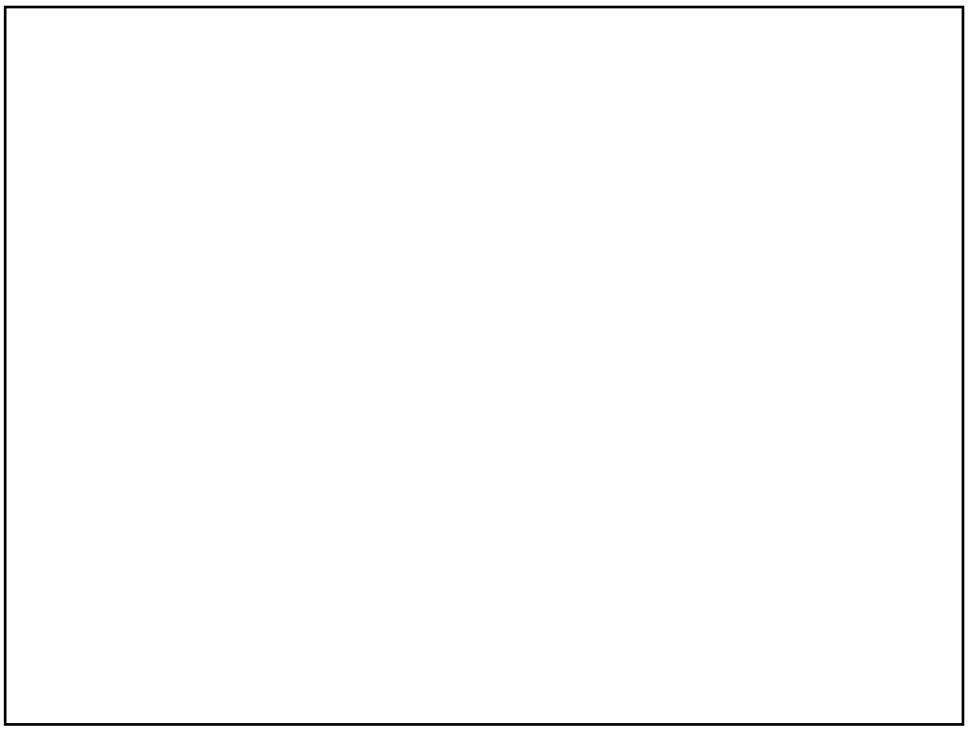

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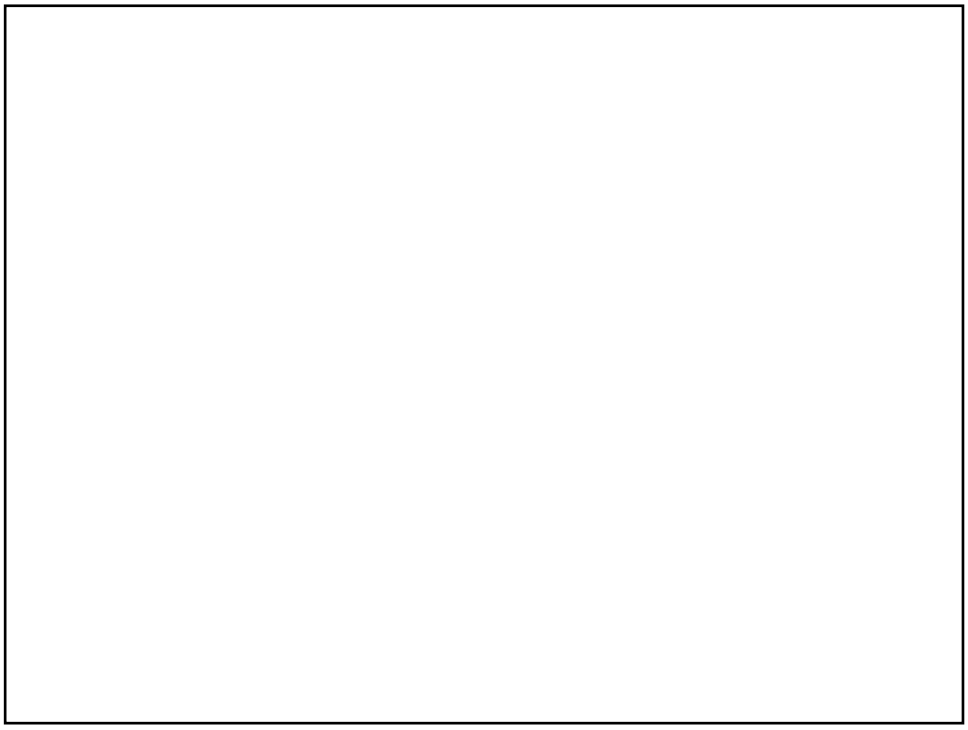

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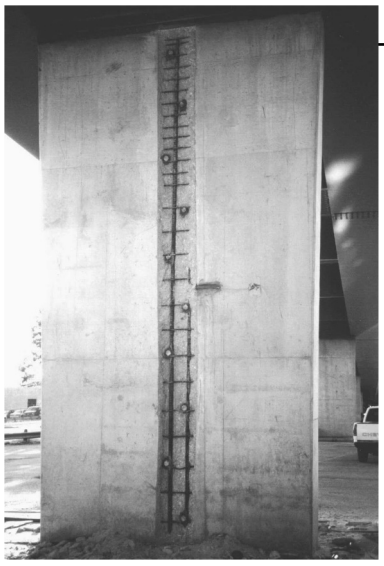
I-480 Pier 2B in Omaha, Nebraska



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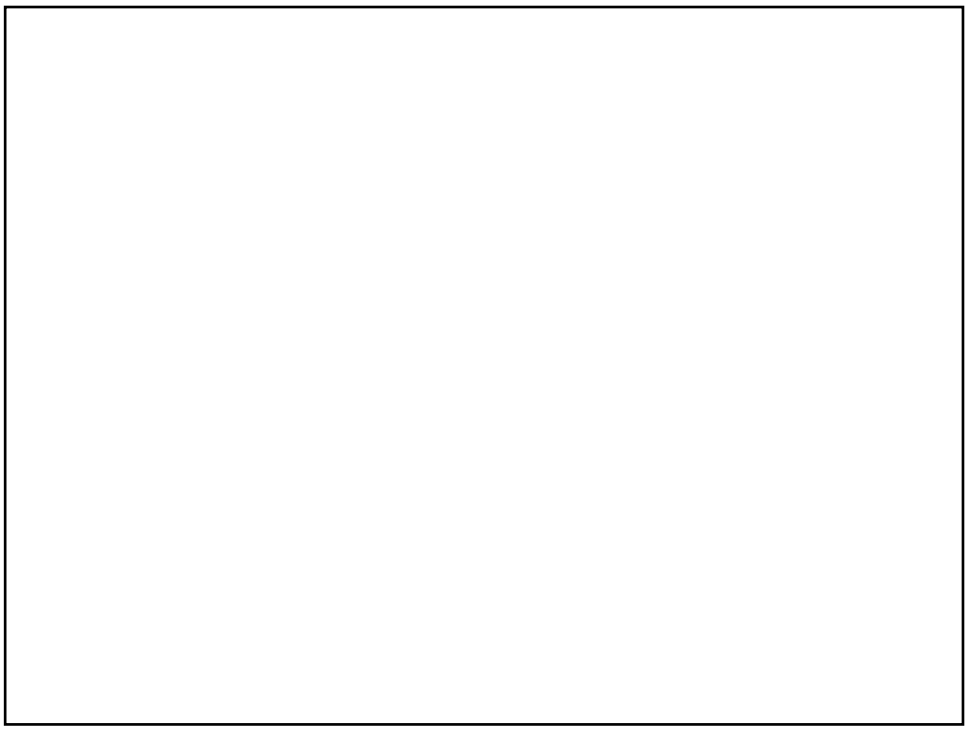

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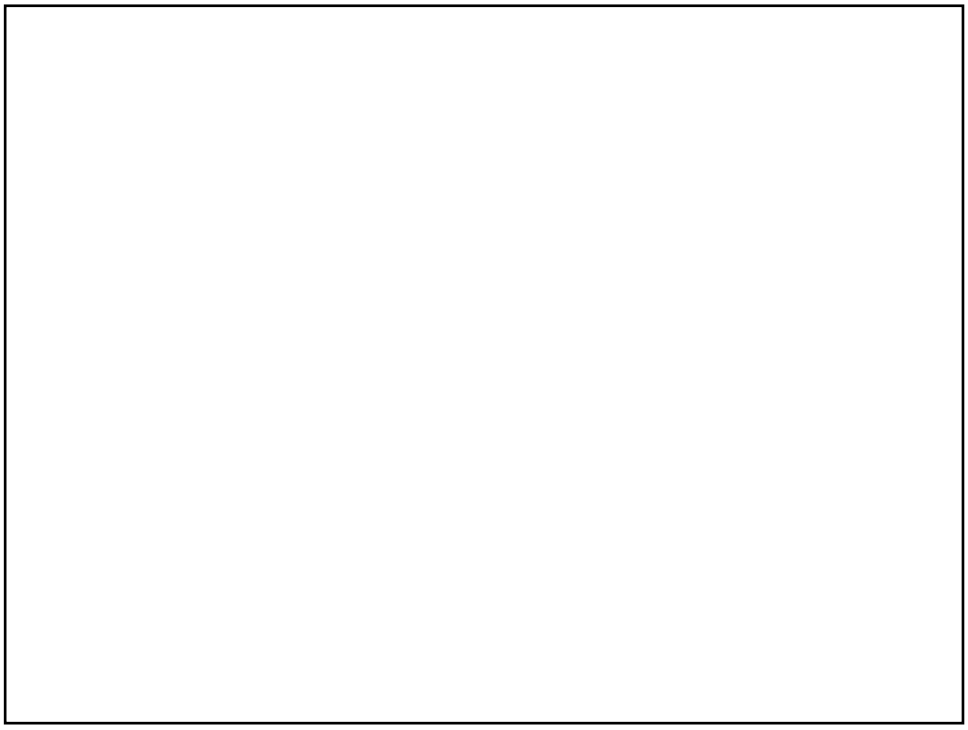

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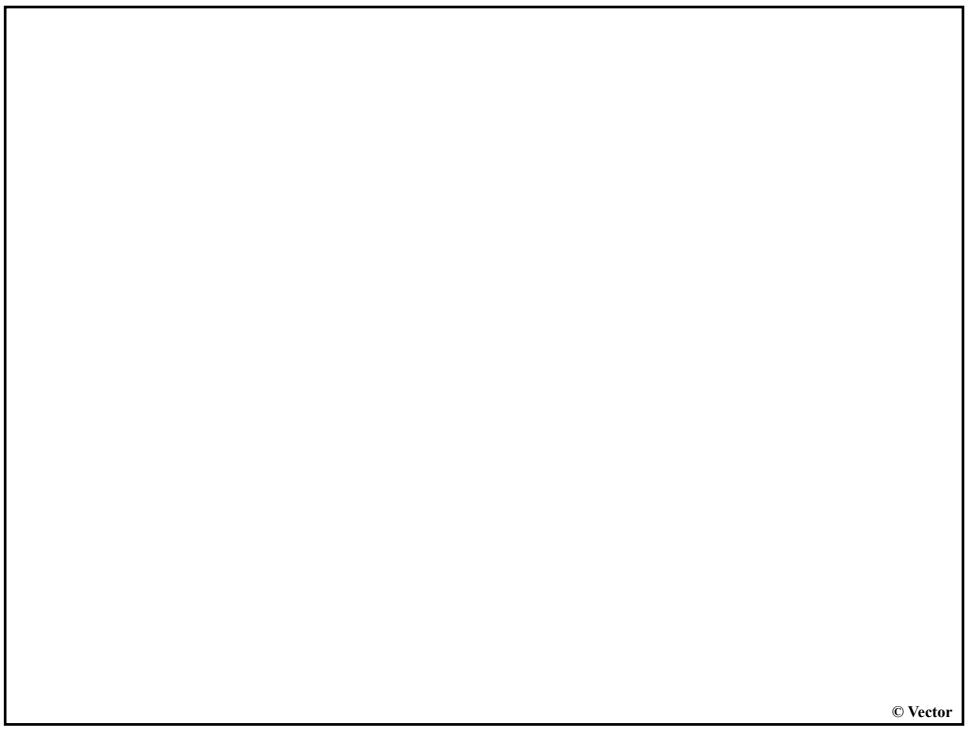

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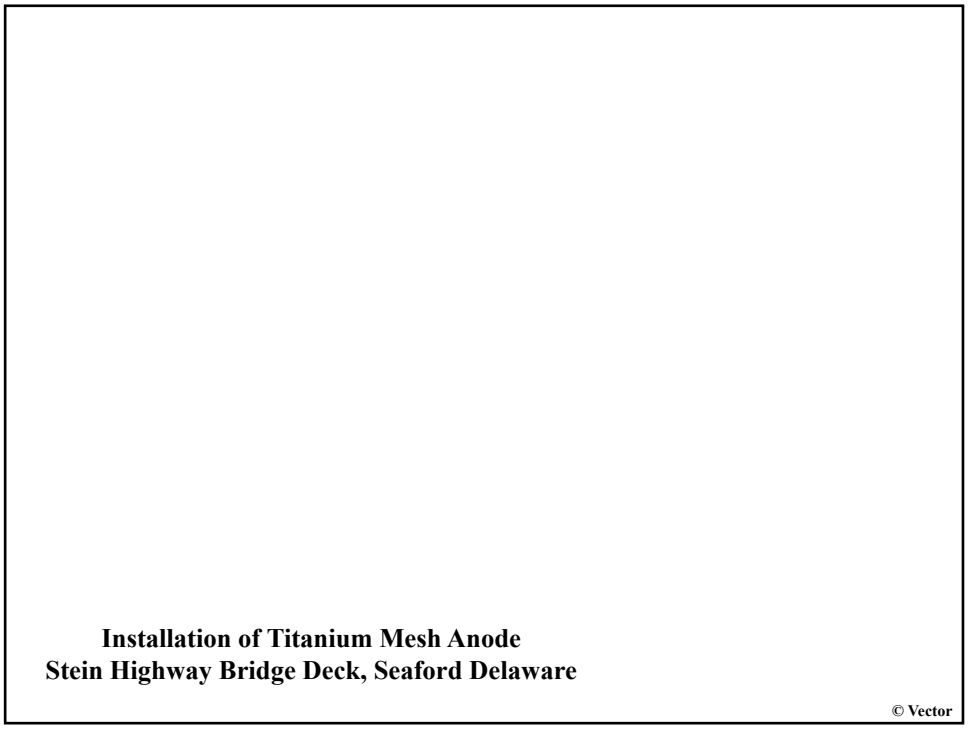

Installation of Titanium Mesh Anode
Stein Highway Bridge Deck, Seaford Delaware

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System Fully Installed and Running
Stein Highway Bridge Deck, Seaford Delaware

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Norcure® ECE Deck Treatments

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Norcure® ECE Deck Treatments

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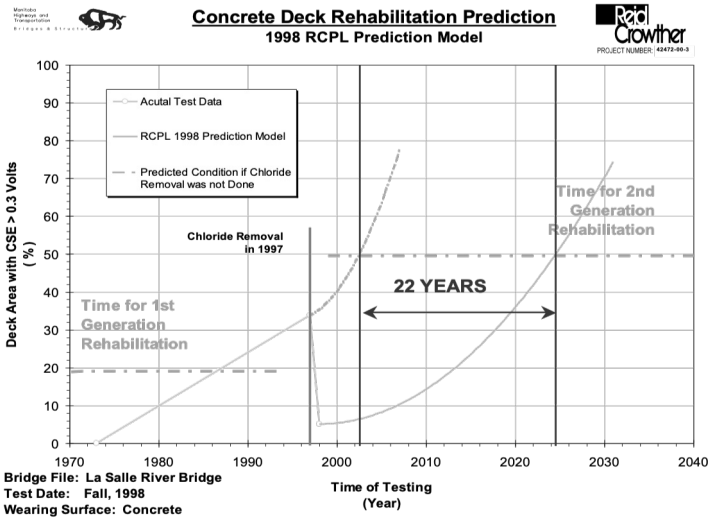
Lifetime Extension



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Burlington Skyway, Burlington, Ontario
Ministry of Transportation Ontario

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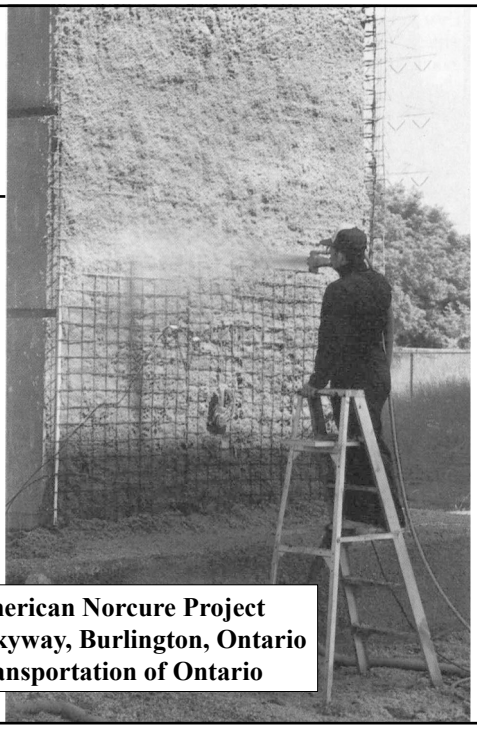

First North American Norcure Project
1989 Burlington Skyway, Burlington, Ontario
Ministry of Transportation of Ontario

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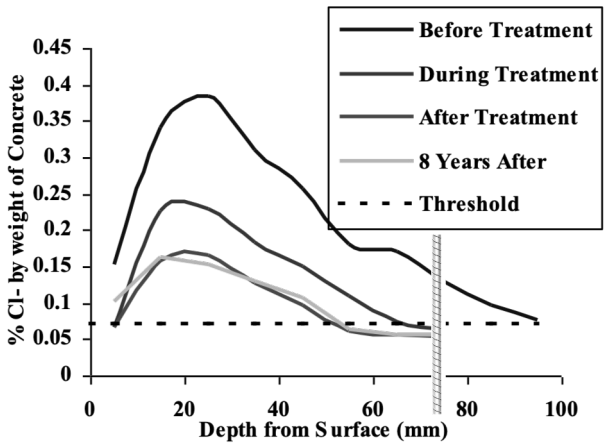
Burlington Skyway Chloride Analysis
Chloride Profile



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Burlington Skyway - Corrosion Potential Measurements

(mV vs Cu-CuSO$_4$)	North Face (Untreated)			West Face (ECE Treated)		
	<200	200 to 350	>350	<200	200 to 350	>350
Pre-Treatment	0	85	15	0	96	4
1 Yr. After	41	59	0	98	2	0
2 Yr. After	41	59	0	100	0	0
3 Yr. After	26	74	0	96	4	0
4 Yr. After	26	70	4	98	2	0
5 Yr. After	19	74	7	96	4	0
6 Yr. After	26	59	15	96	4	0
7 Yr. After	30	63	7	96	4	0
8 Yr. After	11	78	11	96	4	0
9 Yr. After	15	78	7	96	4	0

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Norcure® Chloride Extraction

- Less noise, dust and environmental pollution than removal and replacement
- No need for permanent monitoring system after treatment is complete
- Architectural and exposed aggregate finishes can be maintained

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Carbonation

- Reduction of pH in cover concrete which causes loss of passive oxide layer
- 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) ⇨ (insoluble)

pH 12-13 ⇨ pH < 9

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Carbonation-induced Corrosion

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Norcure® Re-alkalization

- Draws highly alkaline electrolyte (sodium or potassium carbonate) to the reinforcing steel
- Restores 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

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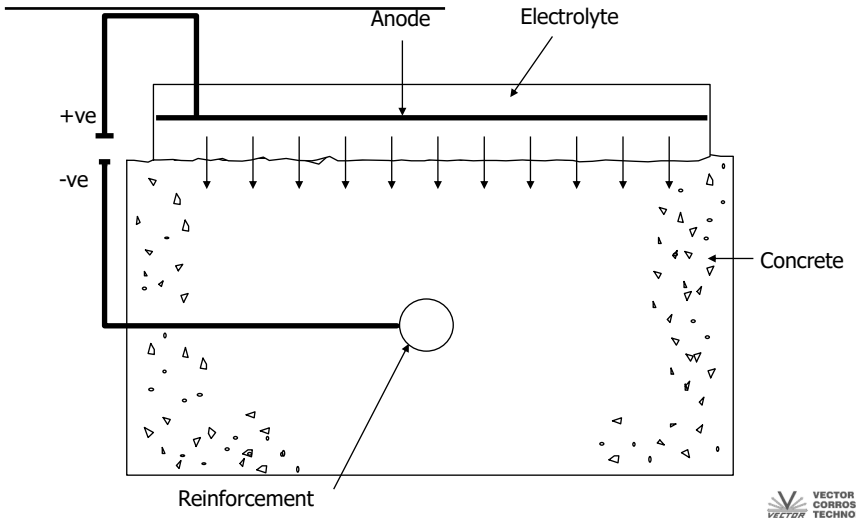
Norcure® Re-alkalization



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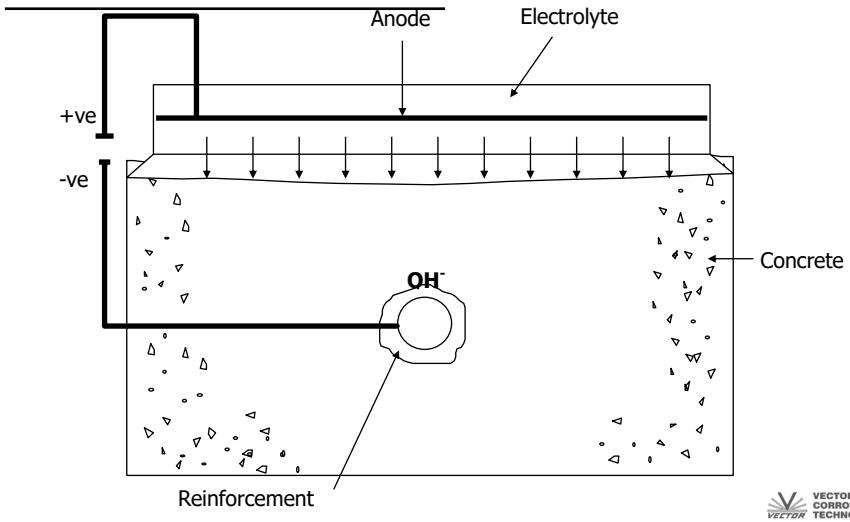
Norcure® Re-alkalization



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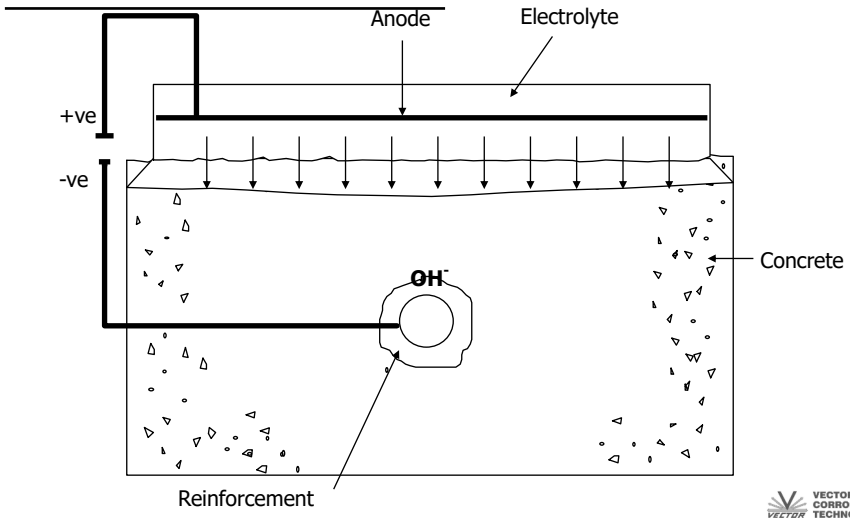
Norcure® Re-alkalization



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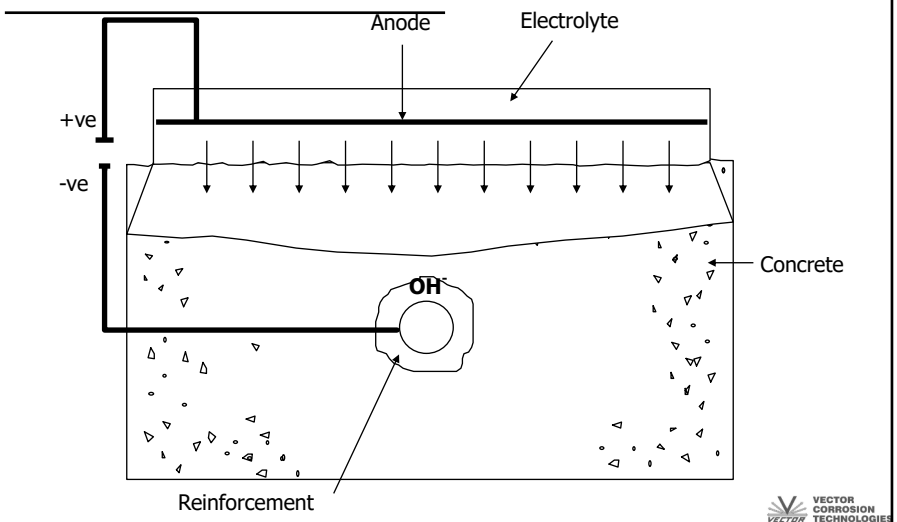

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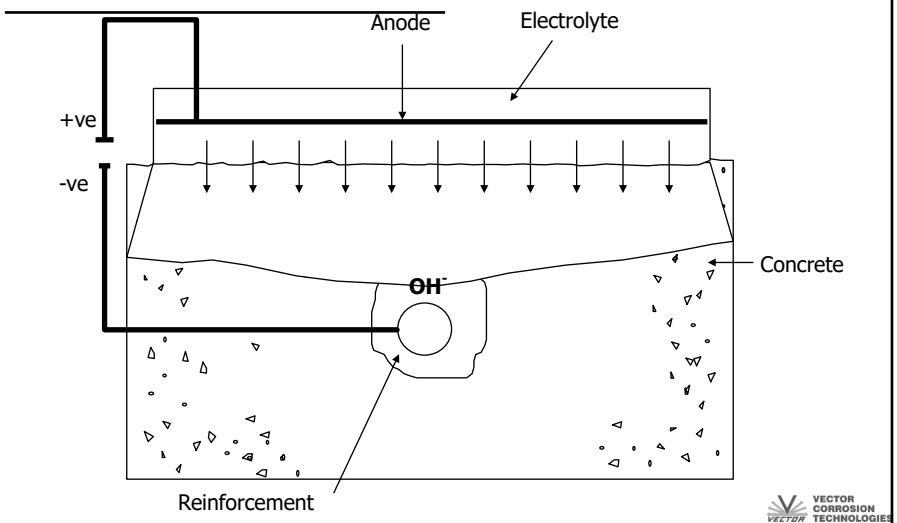
Norcure® Re-alkalization



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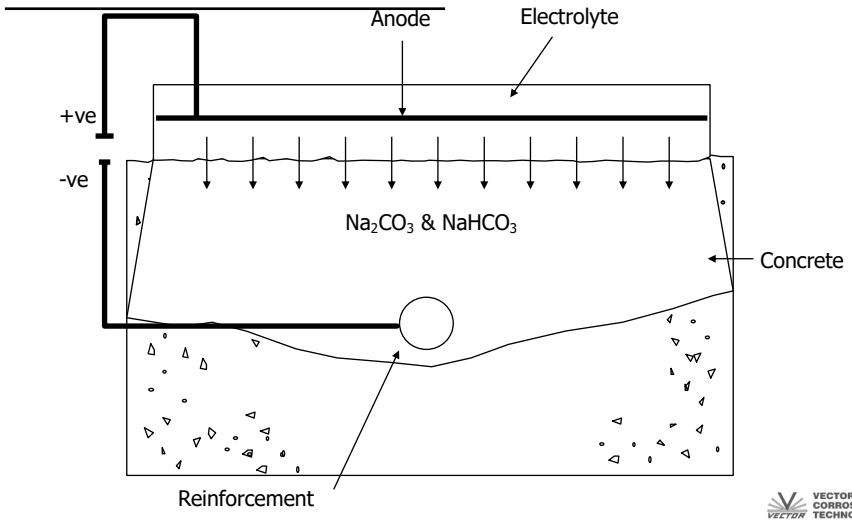
Norcure® Re-alkalization



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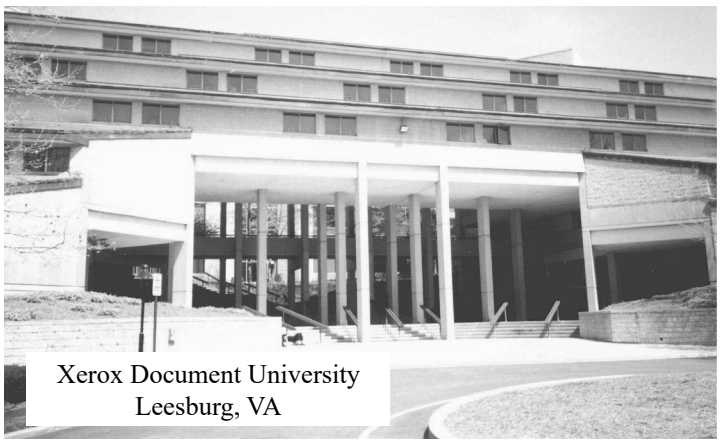
Norcure® Re-alkalization



Xerox Document University
Leesburg, VA

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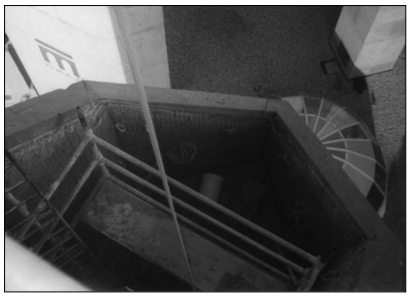
Norcure® Re-alkalization



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Edmonton, Alberta

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Reagan National Airport

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Phenolphthalein Testing

Before

After Re-alkalization

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Norcure® Re-alkalization

- Addresses the cause of the corrosion problem
- Less noise, dust, and environmental pollution than removal and replacement
- No need for permanent monitoring after treatment is complete
- Architectural and exposed aggregate finished can be maintained

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Vector Corrosion Technologies

Level of Protection	Description	Vector Galvashield XP	Vector Galvashield CC	Vector Ebonex	Norcure Treatments
Corrosion Prevention	Preventing new corrosion activity from initiating	●	●		
Corrosion Control	Significantly reducing or stopping on-going corrosion activity		●		●
Cathodic Protection	Highest level of protection intended to stop corrosion activity			●	●

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Electrochemical Corrosion Mitigation Techniques Comparison

System Consideration	ICCP Cathodic Protection	ECE	Embedded Galvanic Anodes
Area of Protection	LARGE	LARGE	LOCALIZED
Duration of Protection	INDEFINITE (if maintained)	20-30+ YEARS (with protection)	10-20 YEARS
Fixes Cause	NO	YES	NO
Skill to Install	HIGH	HIGH	LOW TO MODERATE
Initial Cost	HIGH	HIGH	LOW TO MODERATE
Maint. Required	YES	NO	NO

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Thank You

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Questions

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But don't let it bite!
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