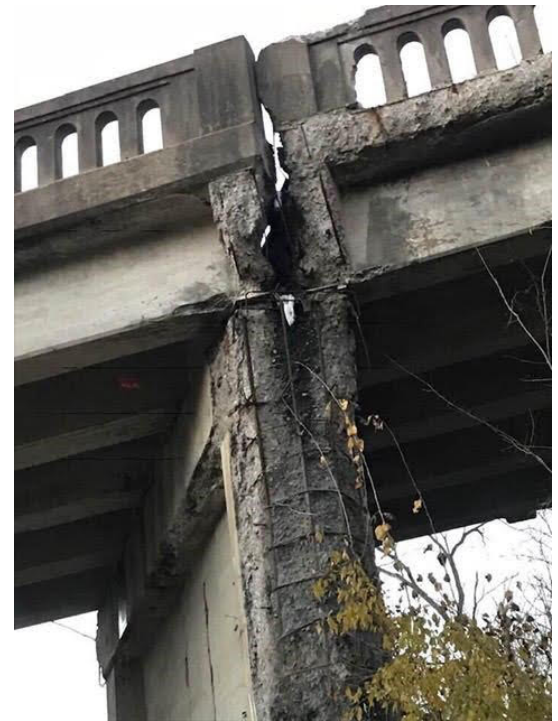


Bridge Preservation

Evaluation and Protection
Systems

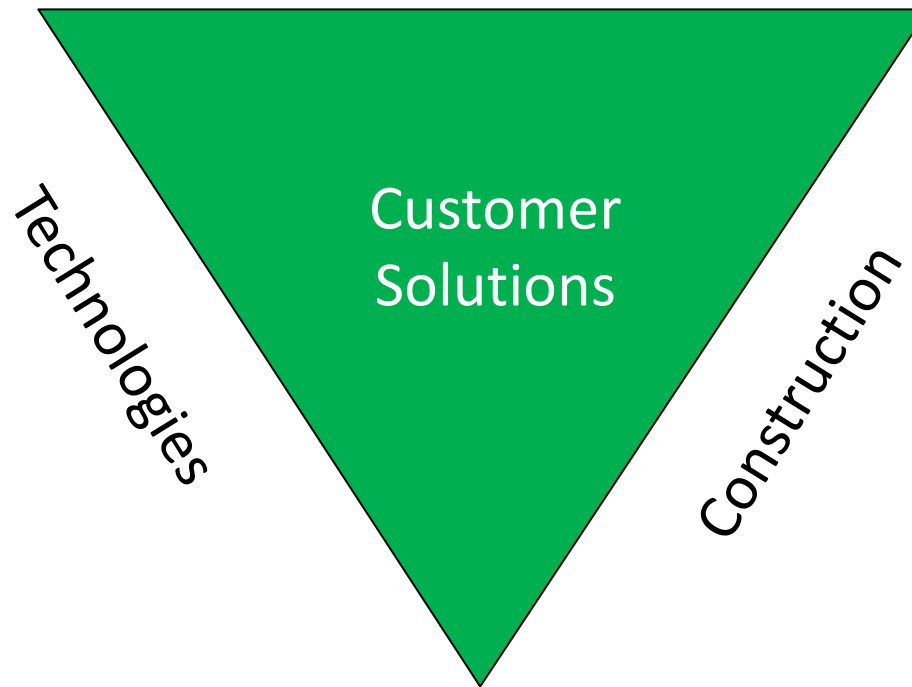
Erik Thorp

Vector Corrosion Technologies



Vector Group

Corrosion Services & NDT



CONCRETE PRESERVATION PROCESS

© 2018 Vector Construction Ltd.

Form A Rev 01 November 01, 2018



Concrete Deterioration

- Freeze thaw
- Abrasion
- Cavitation
- Alkali aggregate reaction
- Shrinkage Cracking
- Impact
- Corrosion







Bridge Corrosion



Halo Effect / Patch Accelerated Corrosion

Evaluation



Visual Inspection



Low / no cover of Reinforcing Steel

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

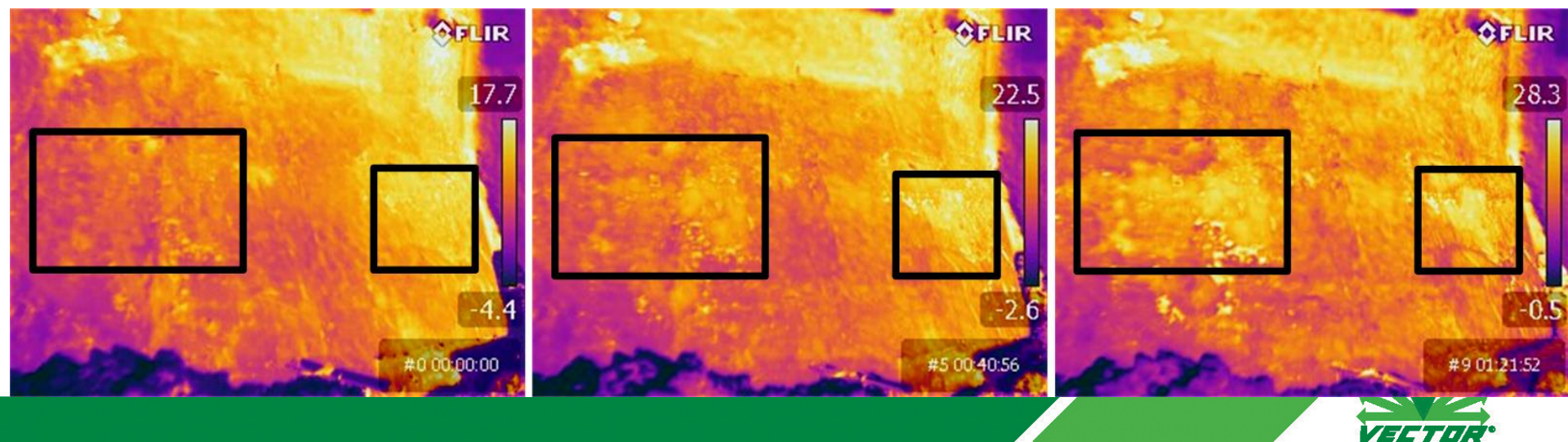
Delamination Survey

- 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



Infrared Thermography

- Locating Delaminations with Infrared camera
 - Ability to test large concrete faces rapidly
 - Limited investigation to near surface



Infrared Thermography

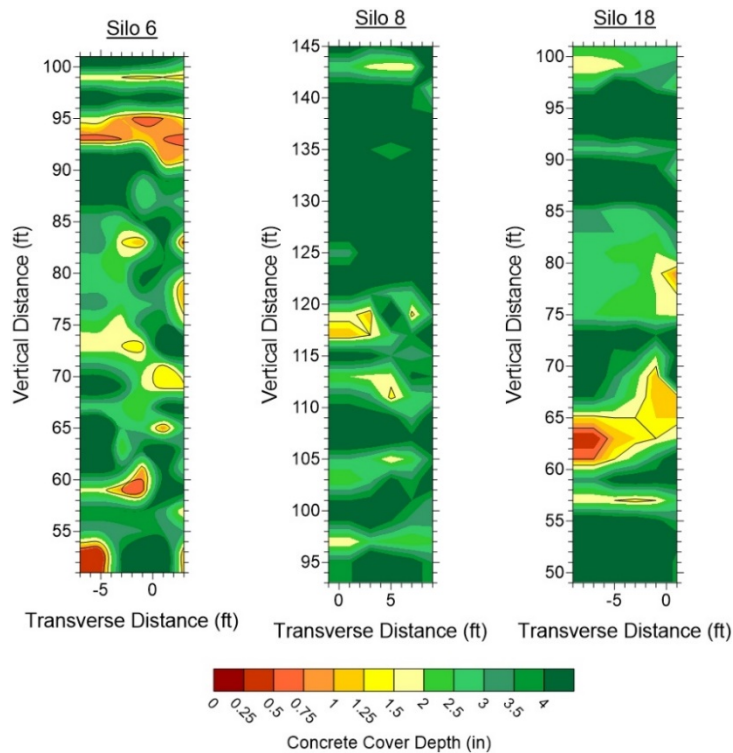


Figure 2: Upstream: Arch Spalling under Spandrel Columns A (left) and B (right)



Figure 3: Upstream: Arch delaminations around pipe bracket and corners

Cover Depth Survey

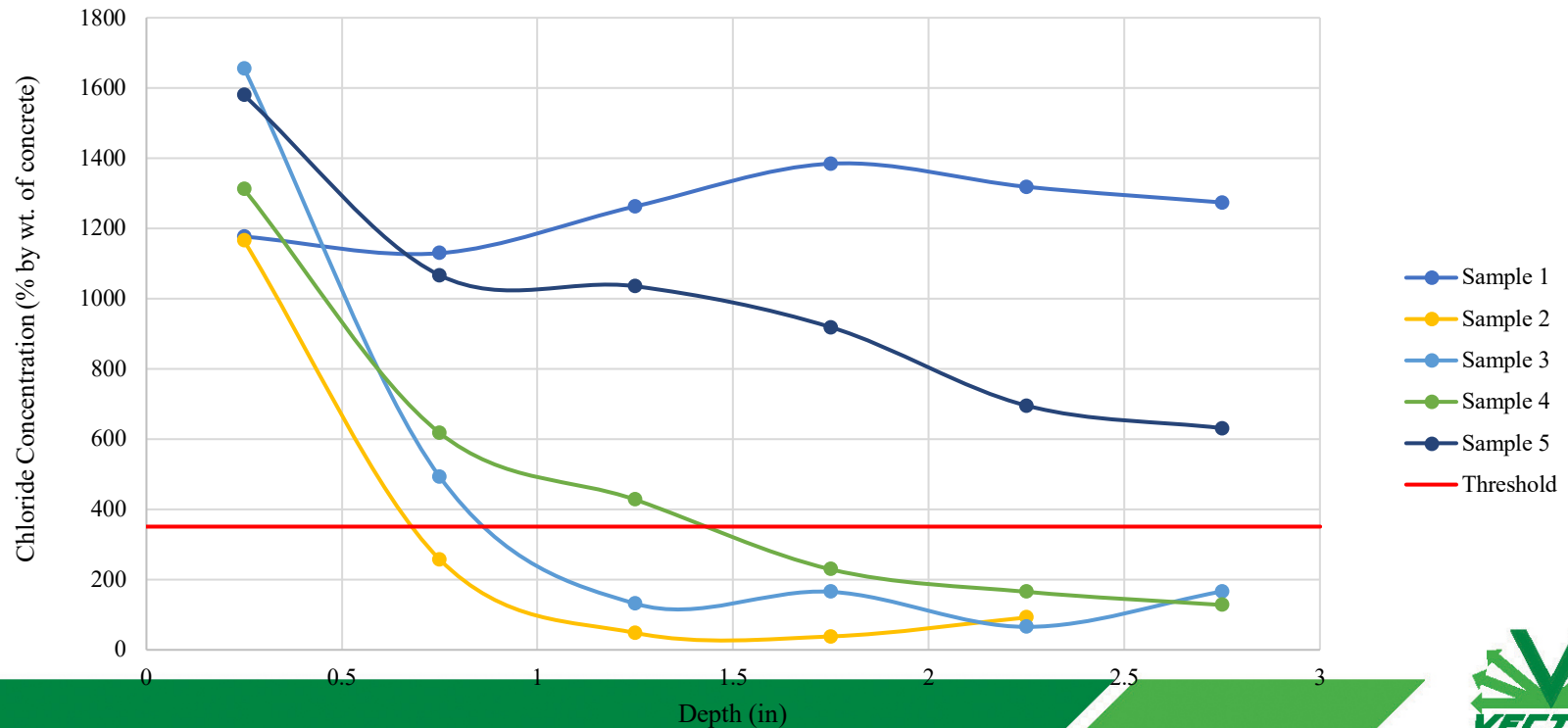


Horizontal Reinforcement Cover Depth							
Silo	1	2	3	4	5	6	Total
Minimum (in)	0.25	1.00	0.25	0.25	0.25	0.00	0.00
Maximum (in)	6.50	6.75	6.50	5.50	7.25	7.60	7.60
Average (in)	3.04	3.85	3.36	1.98	3.96	3.89	3.34
Standard Deviation (in)	1.60	1.19	1.56	1.65	1.57	1.71	1.70

Chloride Profile

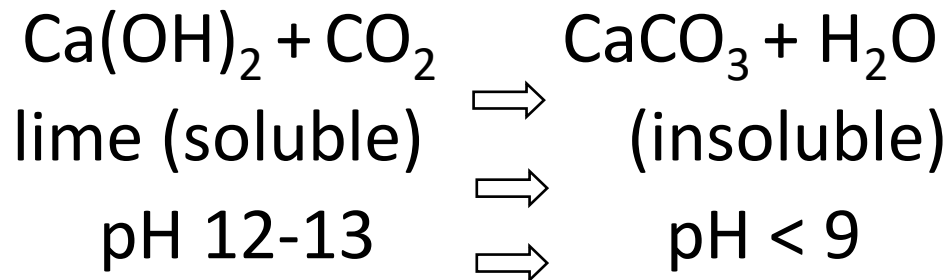


Chloride Concentration with Depth



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)

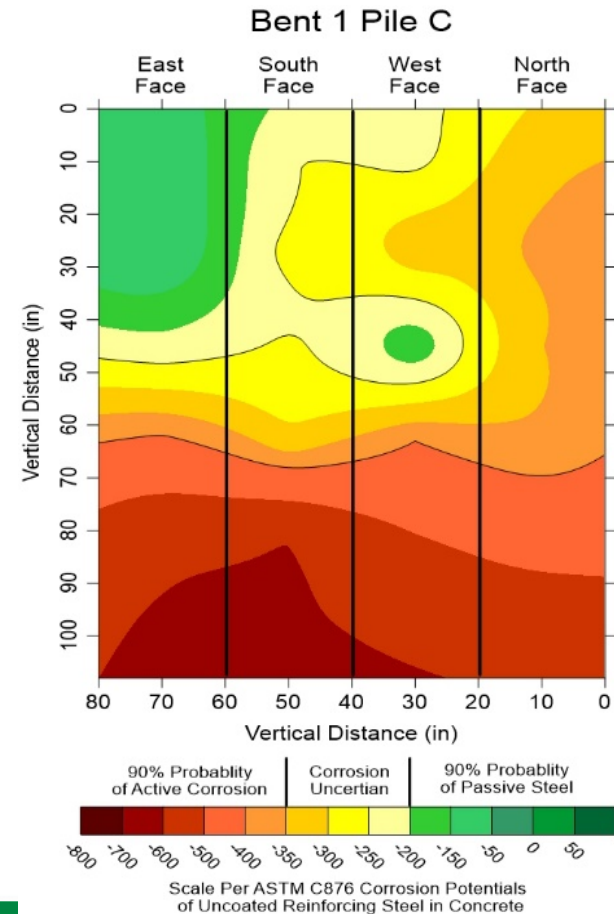


pH Testing



- Mainly to determine depth of carbonation
 - Also 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

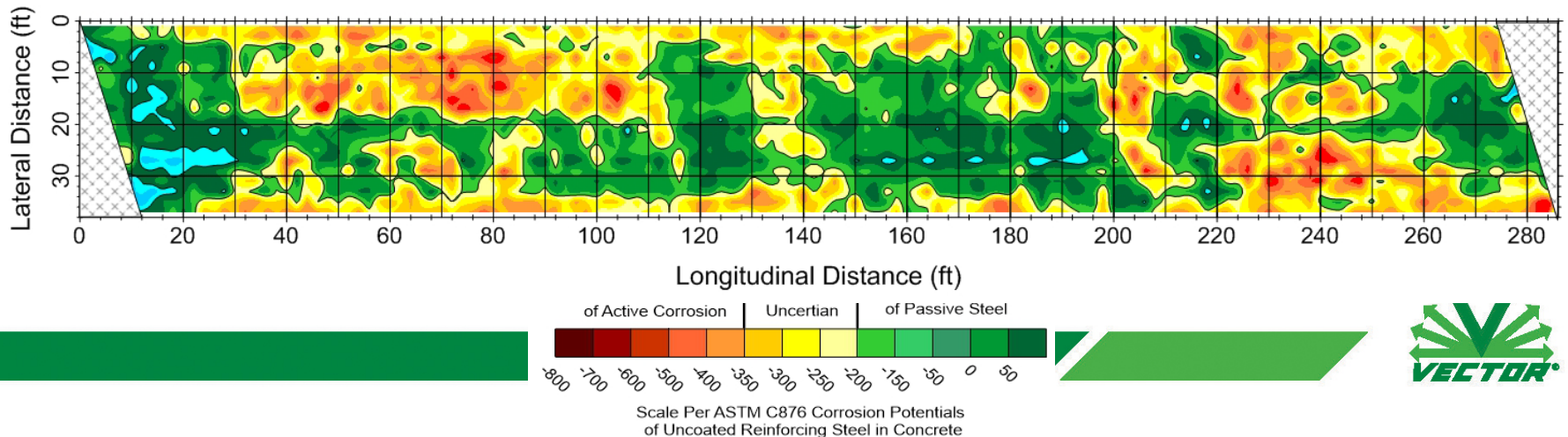
Corrosion Potential Survey



- Measures electrical potential of the reinforcing steel (mV) and the probability of corrosion
- Indication of corrosion activity when no other damage is visible
- Mapping helps to identify corrosion 'hot-spots'



Corrosion Potential – Bridge Deck

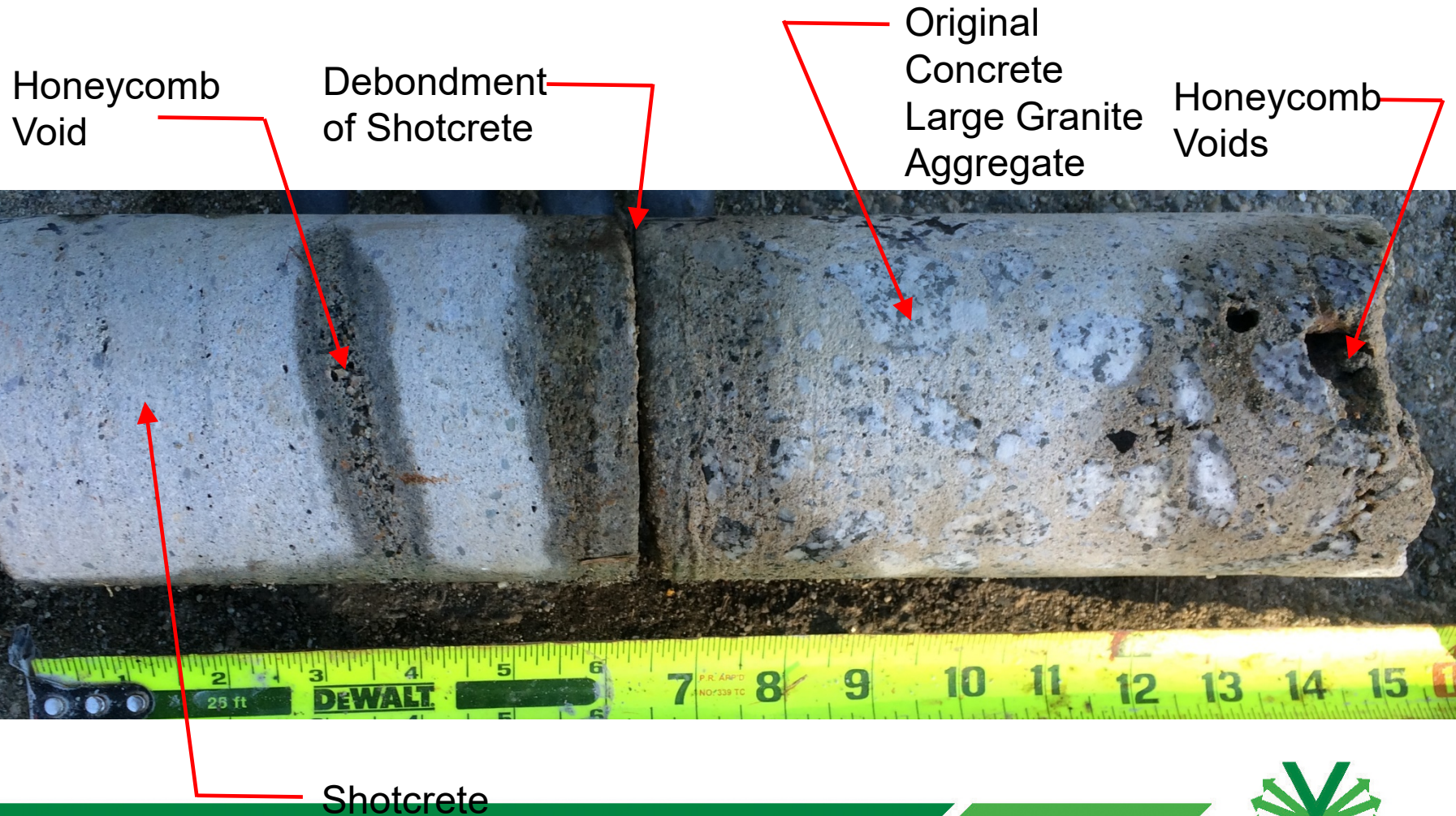


Borescope Inspection

- Visual inspection of voids with minor physical impact
 - Entry through vent tube or small diameter drill hole (Borescope Diam. 4 mm)



Verification Coring



Sonic/Ultrasonic (Mechanical)

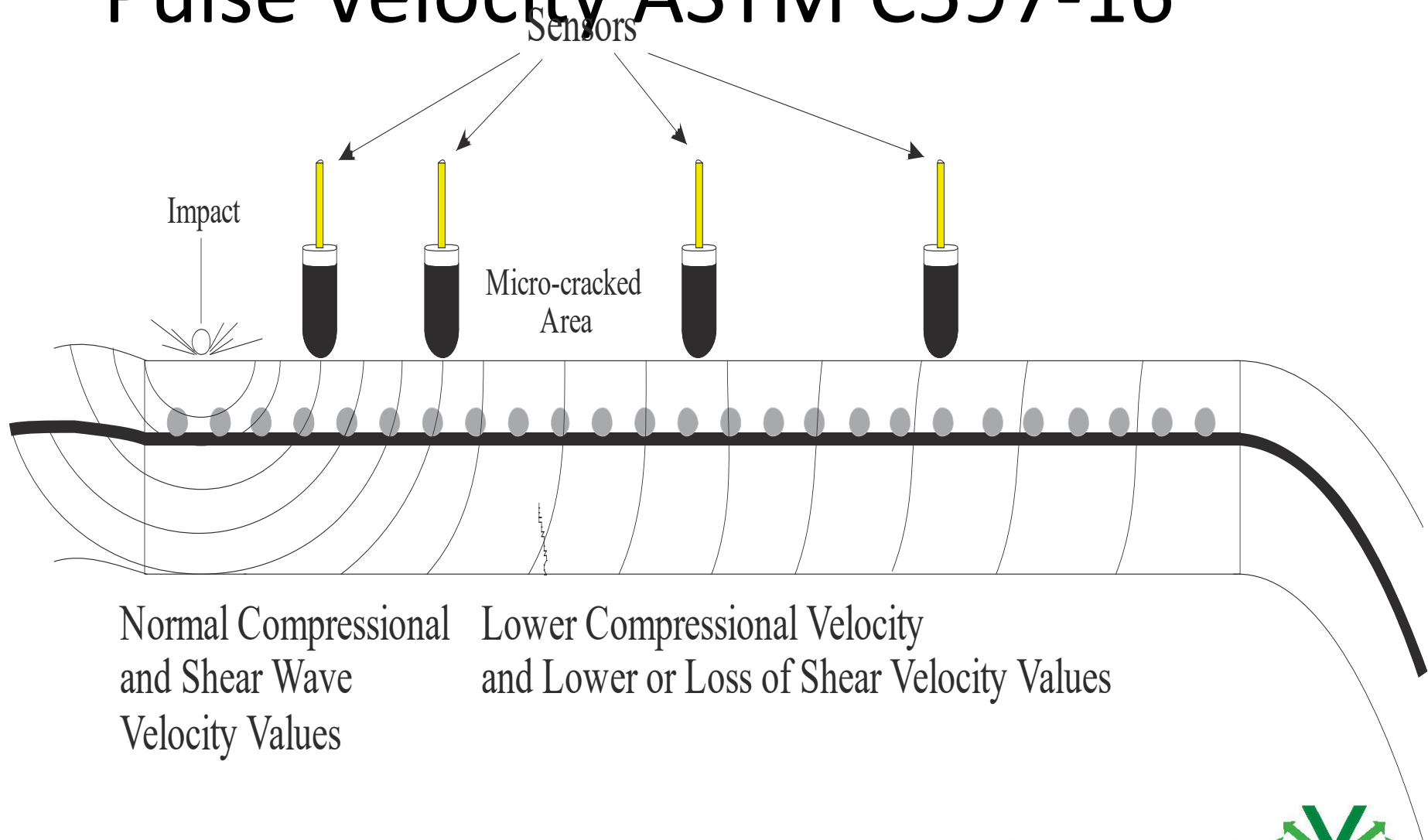
- Pulse Velocity **ASTM C597-16**
- Impact Echo **ASTM C1383-15**





VECTOR

Pulse Velocity ASTM C597-16

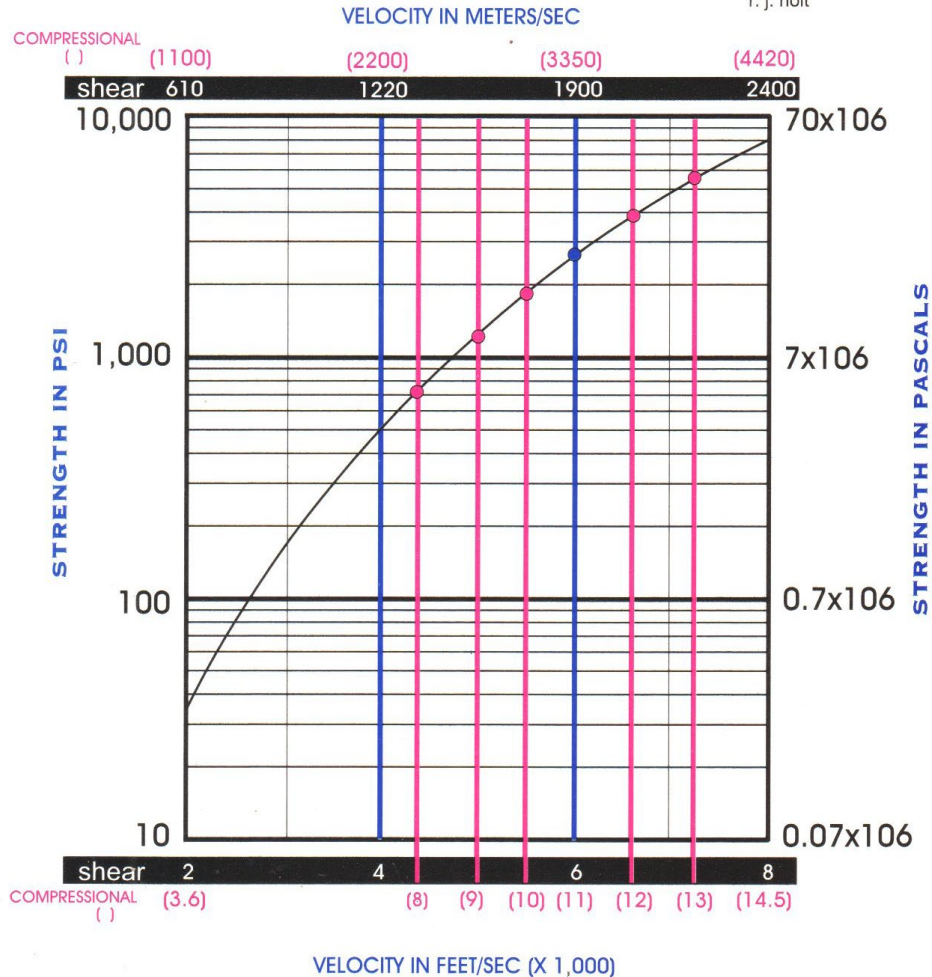




Concrete Strength Vs Velocity

STRENGTH OF CONCRETE VERSUS VELOCITY

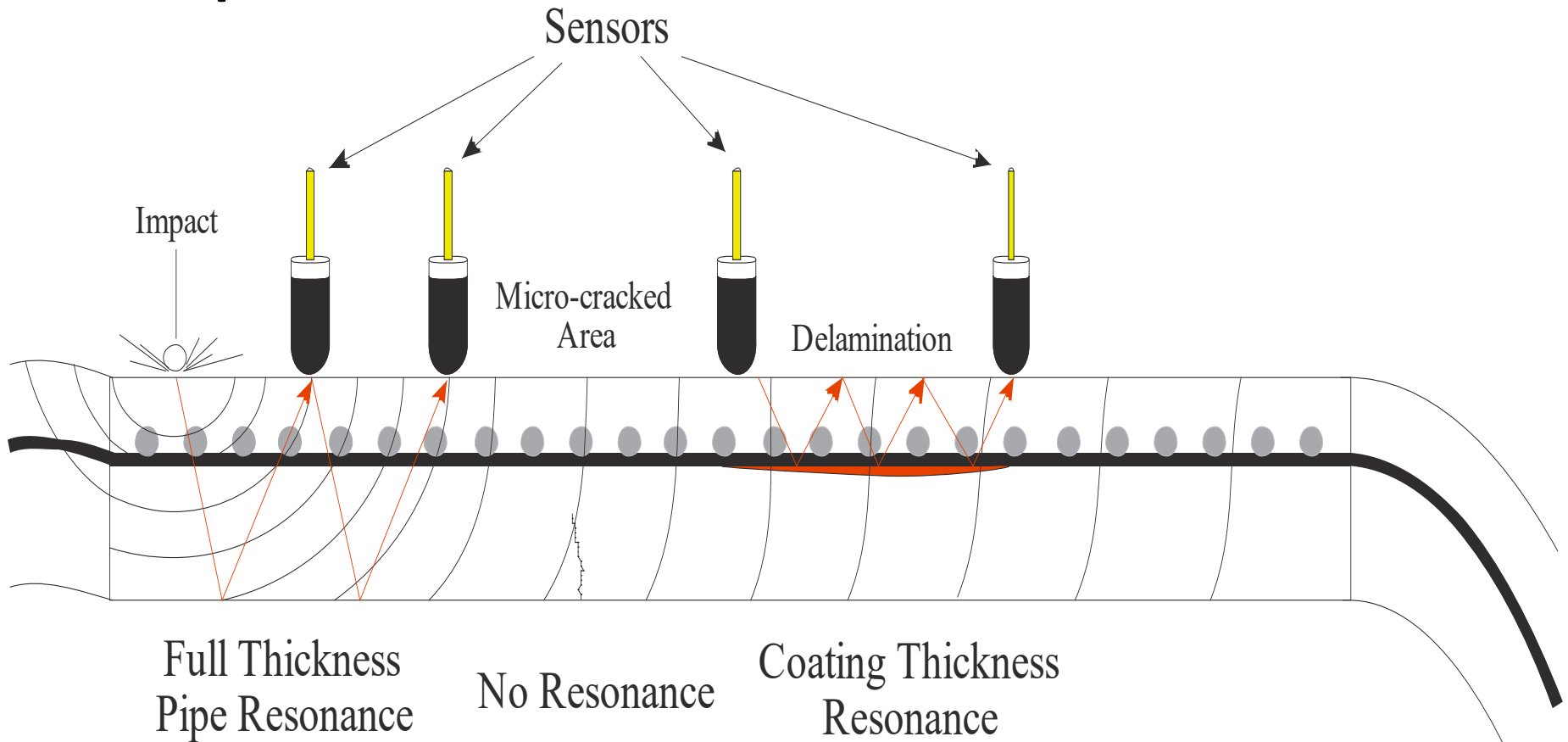
NDT ENGINEERING, INC.
r. j. holt



CURVE IS FOR THE RATIO: $v_{\text{SHEAR}} / v_{\text{COMPRESSIONAL}} = 0.55$
WHICH IS EQUAL TO A POISSON'S RATIO OF 0.28



Impact Echo ASTM C1383-15





Theory

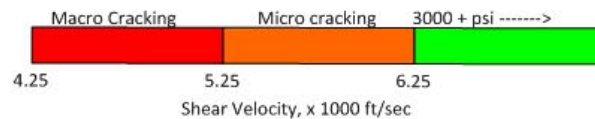
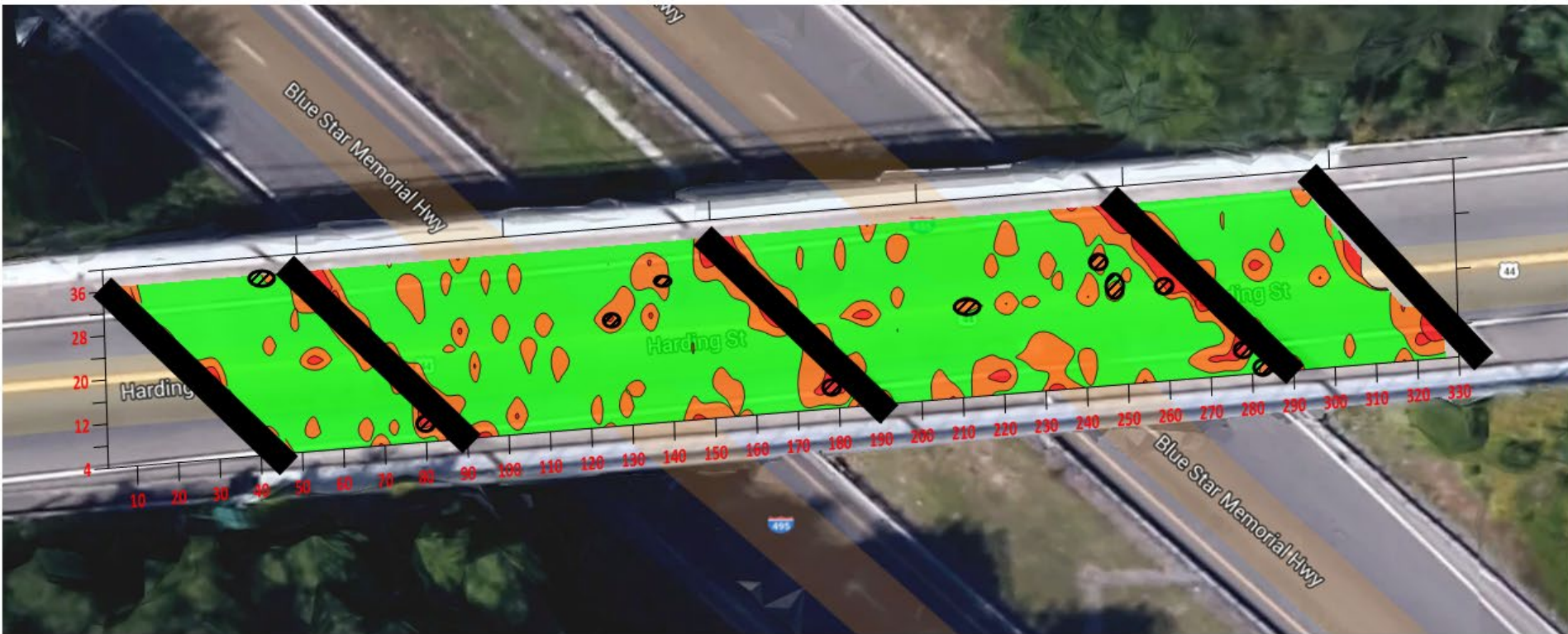
- **Faster Velocity = Stronger Material**
 - Granite is Stronger than Shale
 - Glacial Till is Stronger than Clay
 - Concrete is Stronger than Air
- **Cracking Slows Velocity**
 - Energy Passes Through Air Void (Slower Velocity)
 - Longer Travel Path (Slower Velocity)



Bridge Deck Testing



Bridge Deck Results

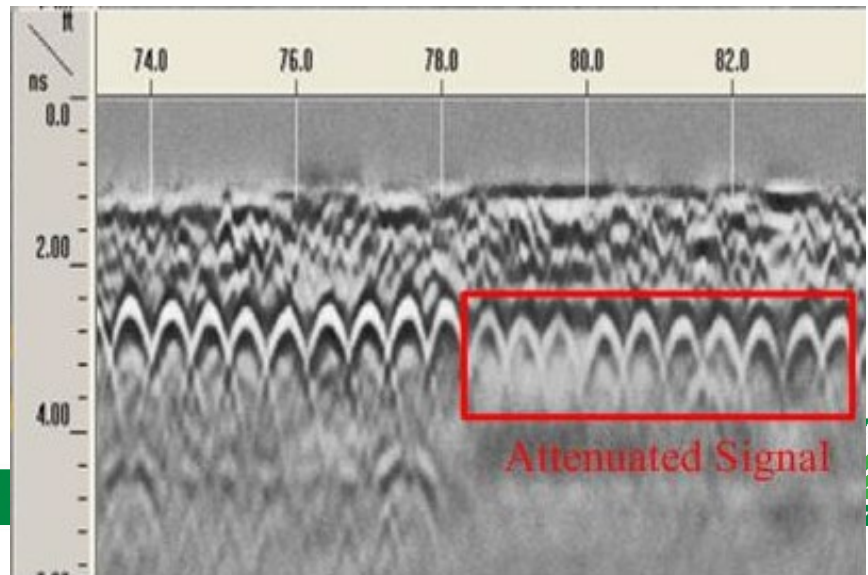


 - DELAMINATION AREA

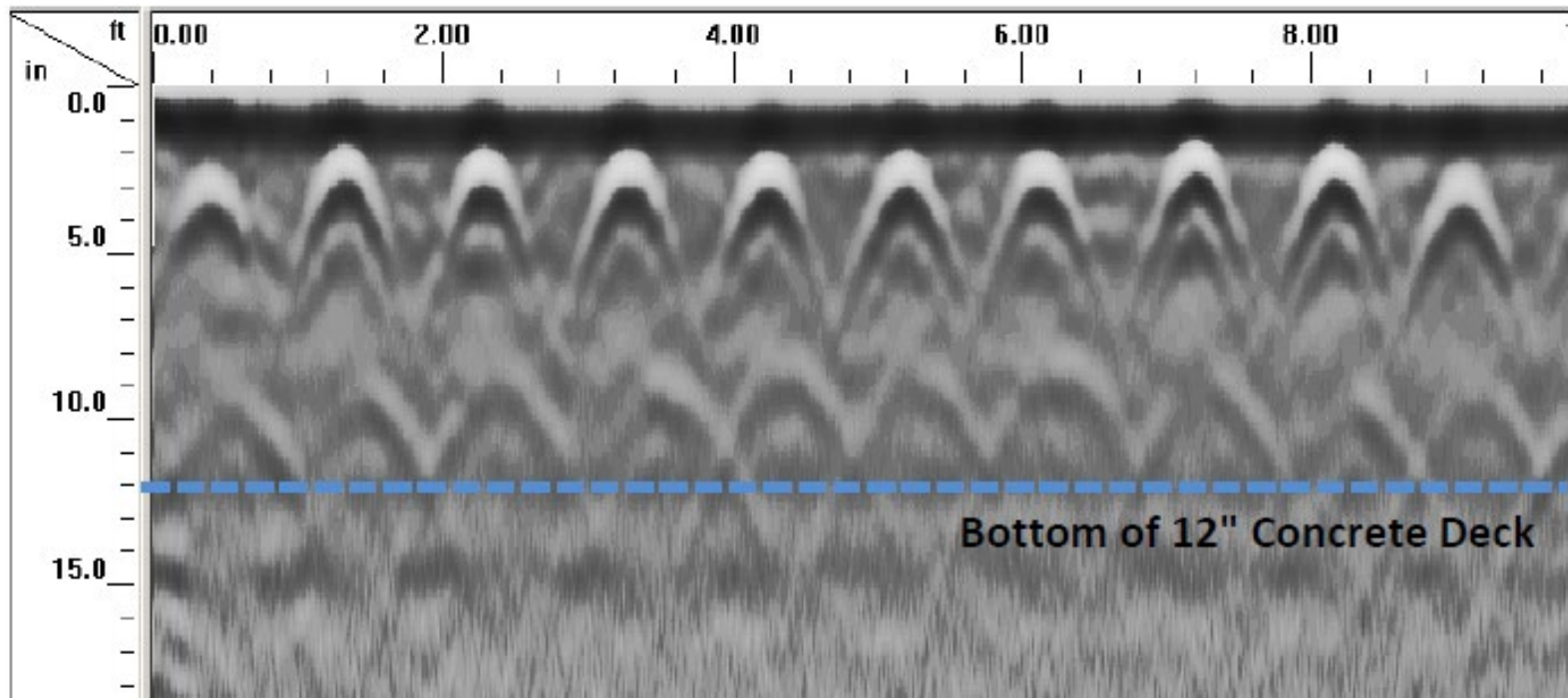
 - EXPANSION JOINT

Ground Penetrating Radar

- Electromagnetic evaluation of concrete
 - Reinforcement layout
 - Location of embedded metals
 - Cover Depth
 - Compare to chloride profile or carbonation depth
 - Qualitative condition of reinforced concrete
 - Chlorides, moisture, and concrete deterioration attenuate GPR signal



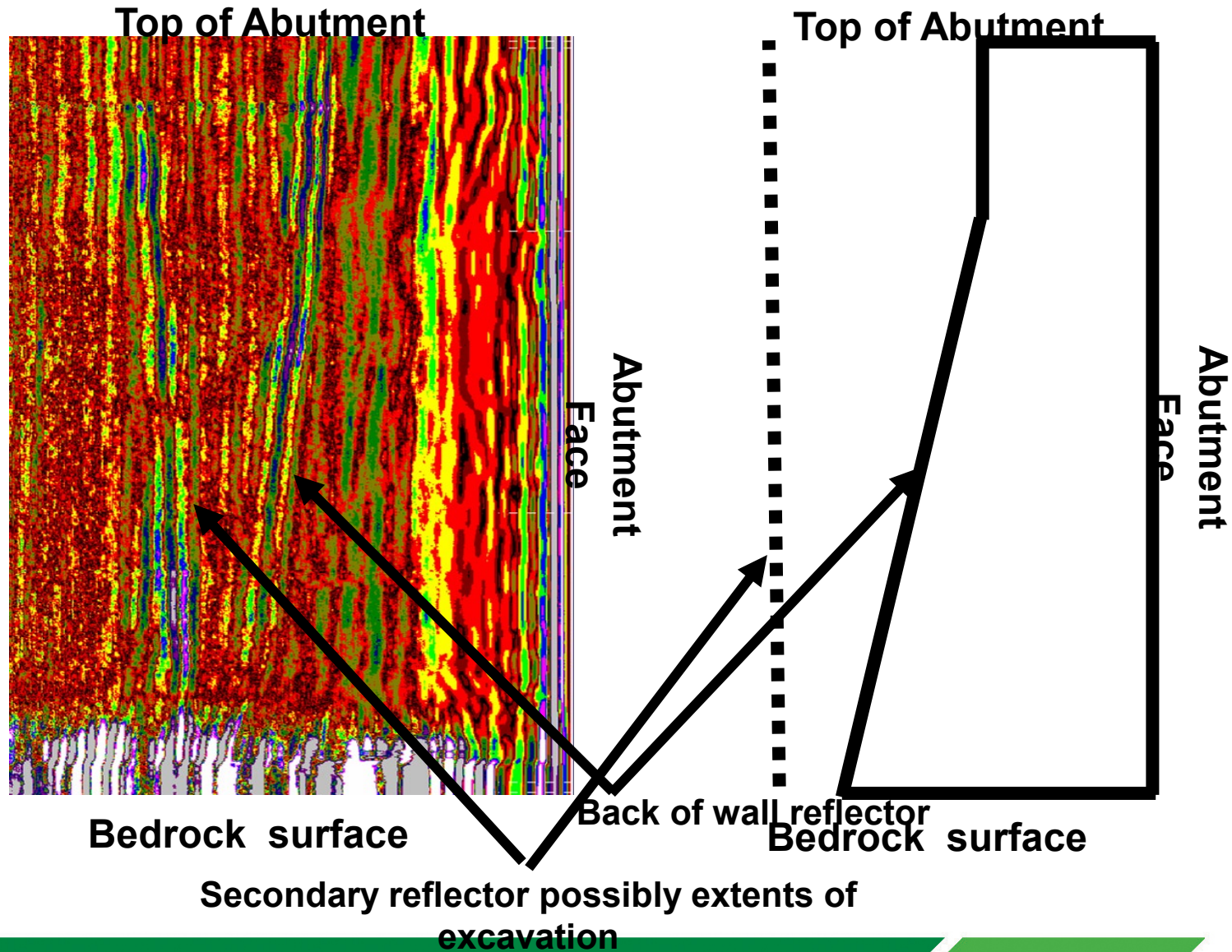
Ground Penetrating Radar (GPR)



GPR to Look Behind Abutment



GPR to Look Behind Abutment

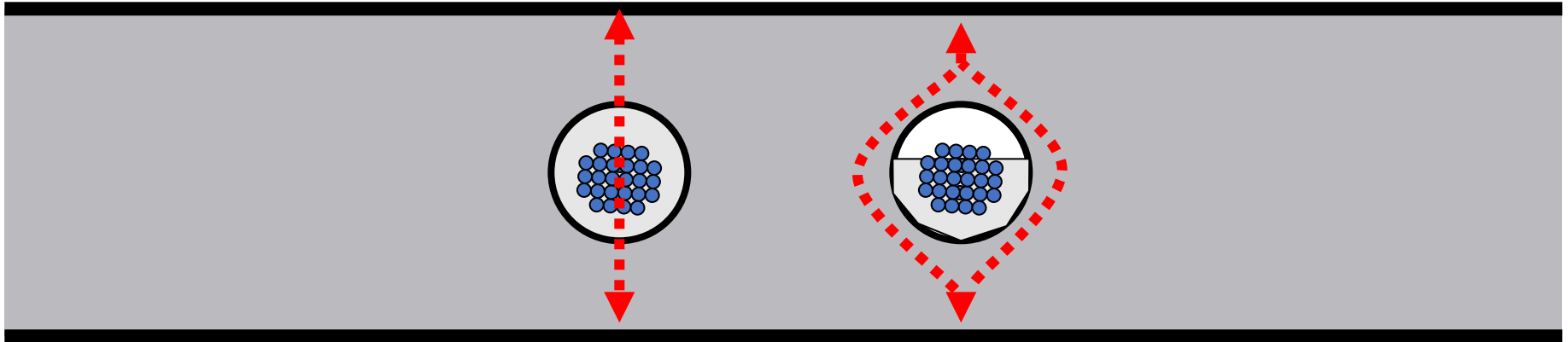


Post Tensioning

- External/Internal
 - Vertical
 - Transverse
 - Deck
- PT Bars



Post Tensioning Theory



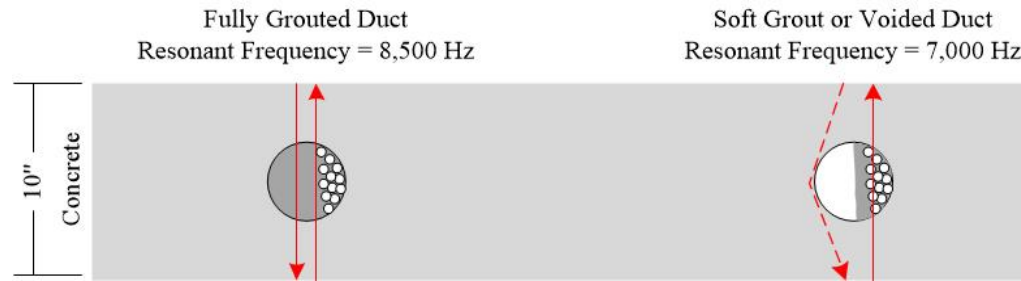
Grouted Duct
wave passes
through grout

Voided Duct
wave passes around
void/tendon duct

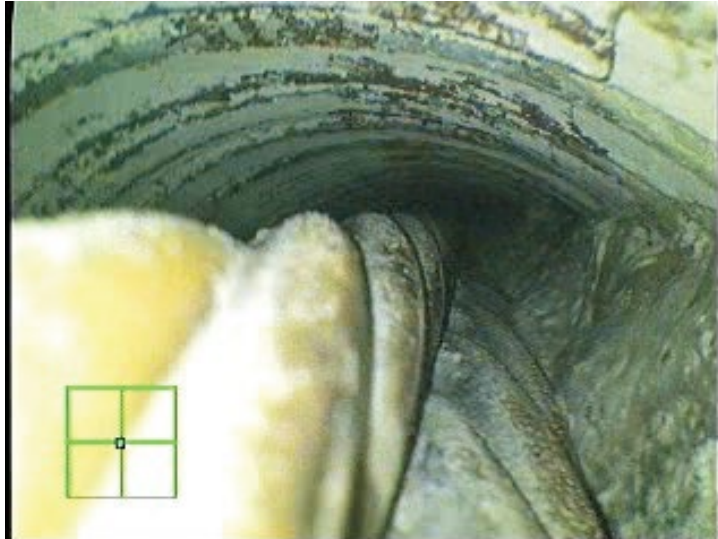
External DT Testing



Impact Echo – PT Overpass



Voided/Corroded Tendons



Problem

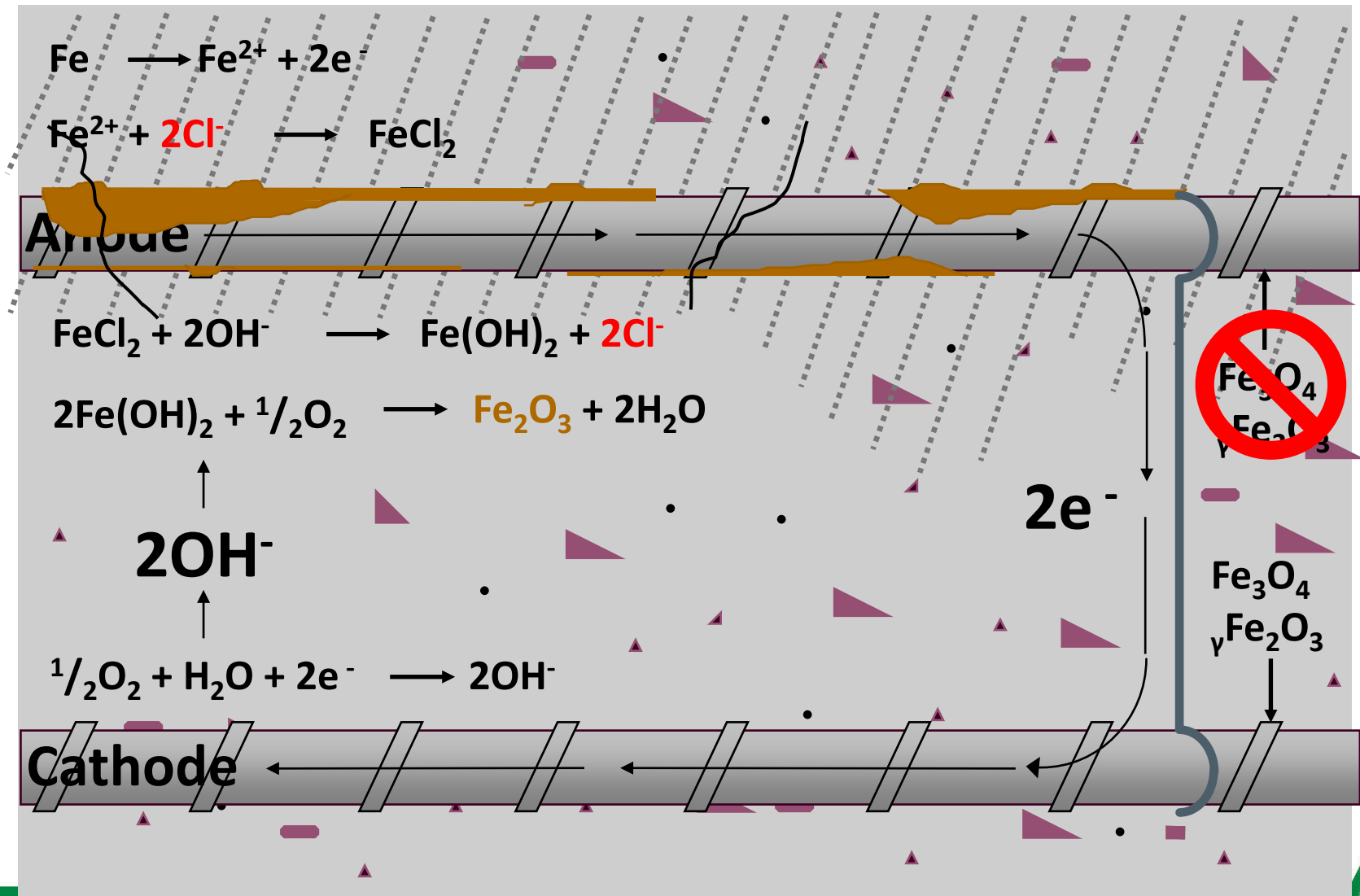
Corrosion Around Patches

Solution

Galvanic Anodes



Corrosion Cell in Concrete







Halo Effect

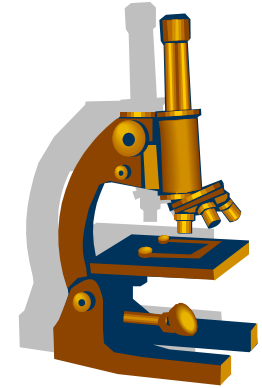


Galvanic Protection Systems

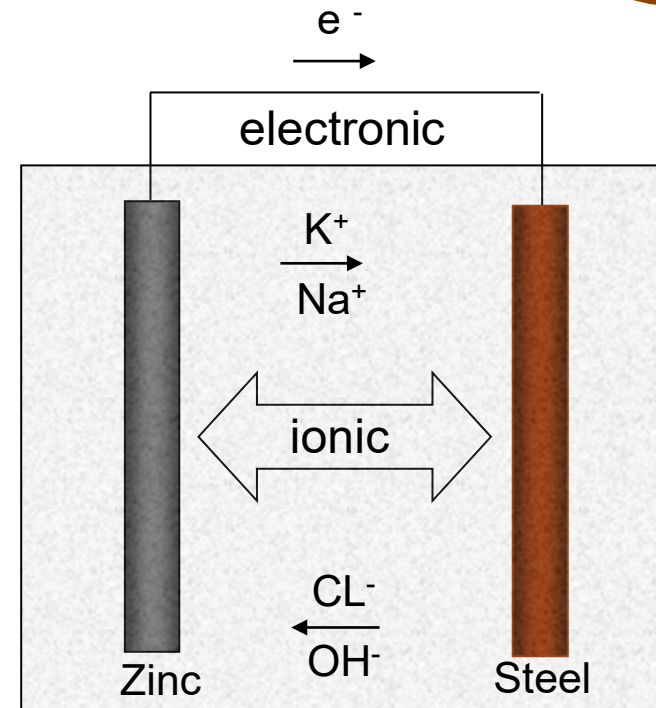
- Two different metals are connected in same electrolyte (concrete)
- More “active” metal = anode
- More “noble” metal = cathode
- Anode corrodes to protect cathode
- Natural reaction
 - no external power required
- Safe for prestressed concrete



Galvanic Protection



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

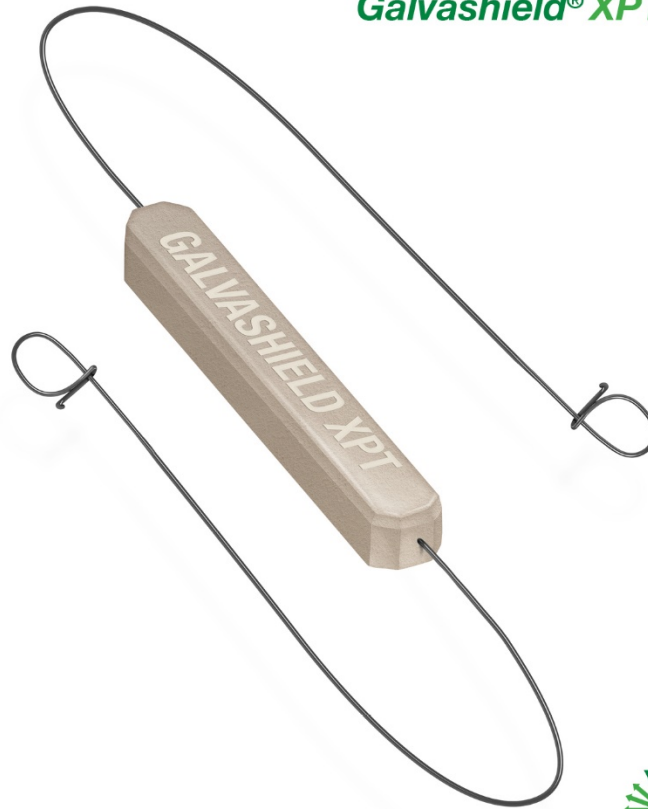


Galvanic anodes naturally operate based on the principle of dissimilar metals corrosion like commonly used batteries. Current flows from the anode (the metal with the most negative potential) to the cathode (steel).

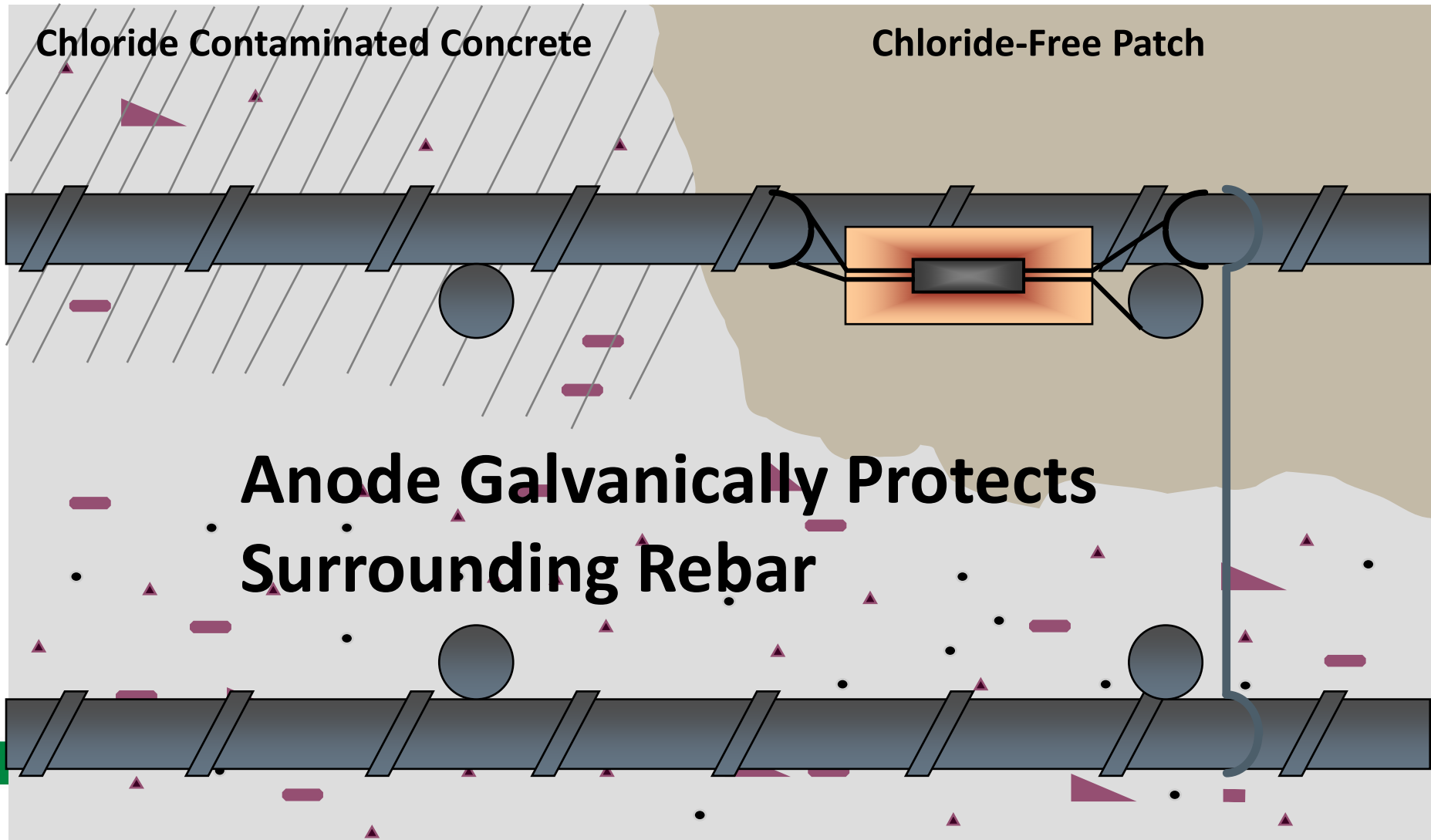


Type 1 Galvanic Anodes

Galvashield® XPT



Installed Galvanic Anode



Checking Rebar Continuity



Anode Installation



Installing anodes around the perimeter of the repair.

Check Continuity Between Anode and Rebar









Type 1A Embedded Galvanic Anodes

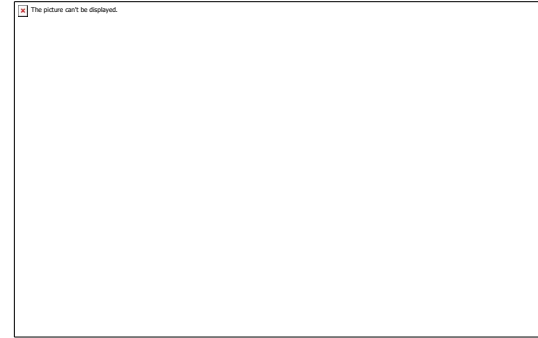
Bridge Widening Port Mann Bridge, Vancouver, British Columbia



Embedded Galvanic Anodes

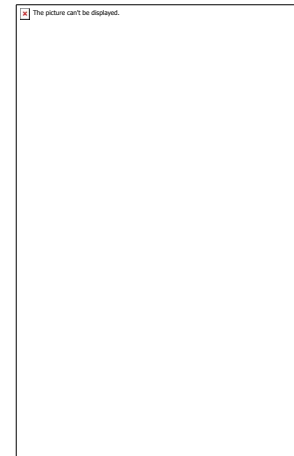
Type 1 Anodes

- Concrete Repairs
- Joint Repairs
- Bridge Widening



Type 2 Anodes

- Installed in Sound Concrete
- Proactive, targeted protection of active corrosion



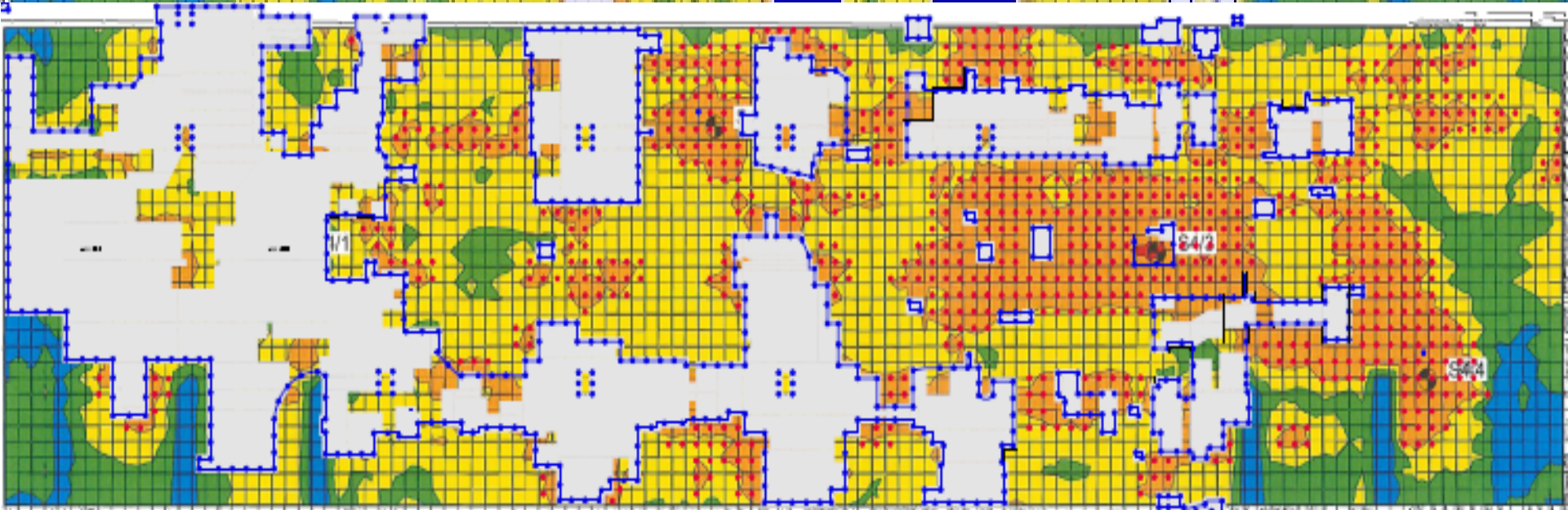
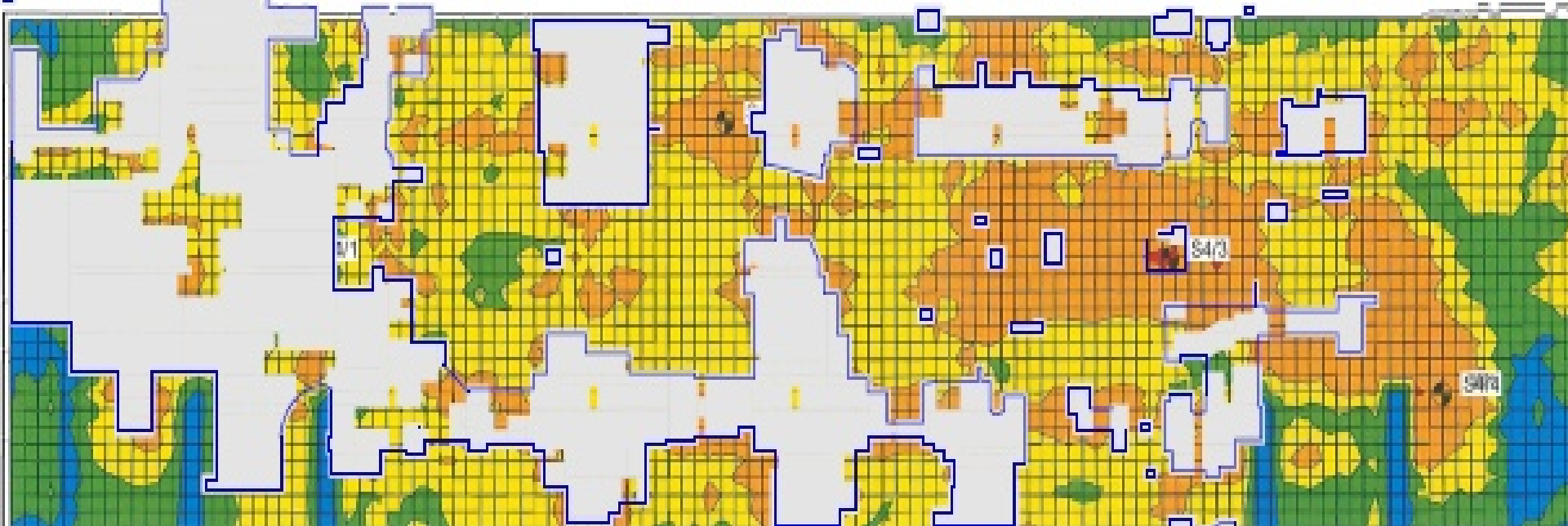
Source: Installation of Embedded Galvanic Anodes (ACI RAP Bulletin 8, 2010)





Corrosion Potential Mapping Overlaid with Delamination Survey





CITY OF
Lincoln
COUNCIL



Design Questions

Which anode?

Spacing?

Where?



Zinc Content

60 grams

100 grams

160 grams



Where?



Installing anodes around the perimeter of the repair.





Where?

Typically

Perimeter of Patch



Anode Spacing

Based upon steel layout

Steel Density Ratio
(Surface Area)

Consider all steel within influence of anode



Steel Density Ratio

$$\frac{\text{Surface Area of Steel}}{\text{Surface Area of Concrete 1 sq.ft (144 sq.in.)}} = \frac{3.14 \times L \times D \times N}{144}$$

Surface Area of Concrete 1 sq.ft (144 sq.in.)

L = Length of bars

D = Diameter of bars

N = Number of bars



Abutment

*#5's at 18" on center
Horizontal and Vertical*



Abutment

*#5's at 18" on center
Horizontal and Vertical*



3.14 x (5/8)" x 12" x 2 bars = 47 sq.in.

.

Abutment

*#5's at 18" on center
Horizontal and Vertical*



$3.14 \times (5/8)'' \times 12'' \times 2 \text{ bars} = 47 \text{ sq.in.}$

.

$\text{Area} = 12'' \times 12'' = 144 \text{ sq.in.}$

Abutment

*#5's at 18" on center
Horizontal and Vertical*



$3.14 \times (5/8)'' \times 12'' \times 2 \text{ bars} = 47 \text{ sq.in.}$

.

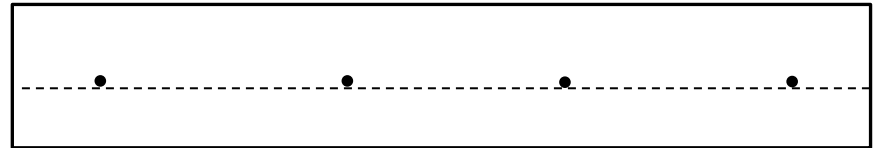
$\text{Area} = 12'' \times 12'' = 144 \text{ sq.in.}$

$47 \text{ sq.in.} / 144 \text{ sq.in.} = .33$



Abutment

*#5's at 18" on center
Horizontal and Vertical*



$3.14 \times (5/8)'' \times 12'' \times 2 \text{ bars} = 47 \text{ sq.in.}$

.

$\text{Area} = 12'' \times 12'' = 144 \text{ sq.in.}$

$47 \text{ sq.in.} / 144 \text{ sq.in.} = .33$

Steel Density Ratio = .33

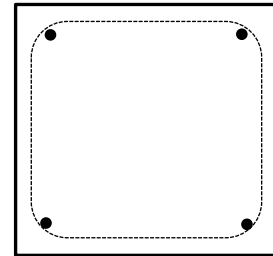


Column

12" square column

4 x #9's

#4 ties at 12" on center

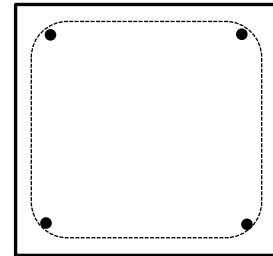


Column

12" square column

4 x #9's

#4 ties at 12" on center



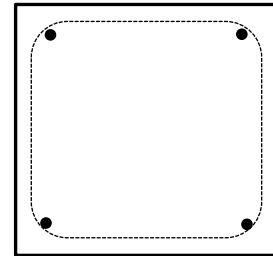
3.14 x (9/8)" x 12" x 4 bars = 170 sq.in.

Column

12" square column

4 x #9's

#4 ties at 12" on center



$3.14 \times (9/8)" \times 12" \times 4 \text{ bars} = 170 \text{ sq.in.}$

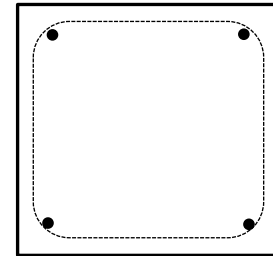
$3.14 \times (4/8)" \times 8" \times 4 \text{ sides} = 50 \text{ sq.in.}$

Column

12" square column

4 x #9's

#4 ties at 12" on center



$3.14 \times (9/8)" \times 12" \times 4 \text{ bars} = 170 \text{ sq.in.}$

$3.14 \times (4/8)" \times 8" \times 4 \text{ sides} = 50 \text{ sq.in.}$

$\text{Area} = 12" \times 12" \times 4 \text{ sides} = 576 \text{ sq.in.}$

Anode Spacing

Abutment

SDR = .33

20" spacing

Column

SDR = .38

20" spacing

Beam

SDR = .53

20" spacing

Corrosion Control		160 Gram Anode
Surface Area Ratio		Spacing
		(inches)
0	0.3	24
0.31	0.6	20
0.61	0.9	16
0.91	1.2	14
1.21	1.5	10
1.51	1.8	8
1.81	2.1	6

Common Issues



Clean Steel





Remove Epoxy Coating



Use Ties for Continuity



High Resistivity Repair Mortars

Polymer Modified (latex)

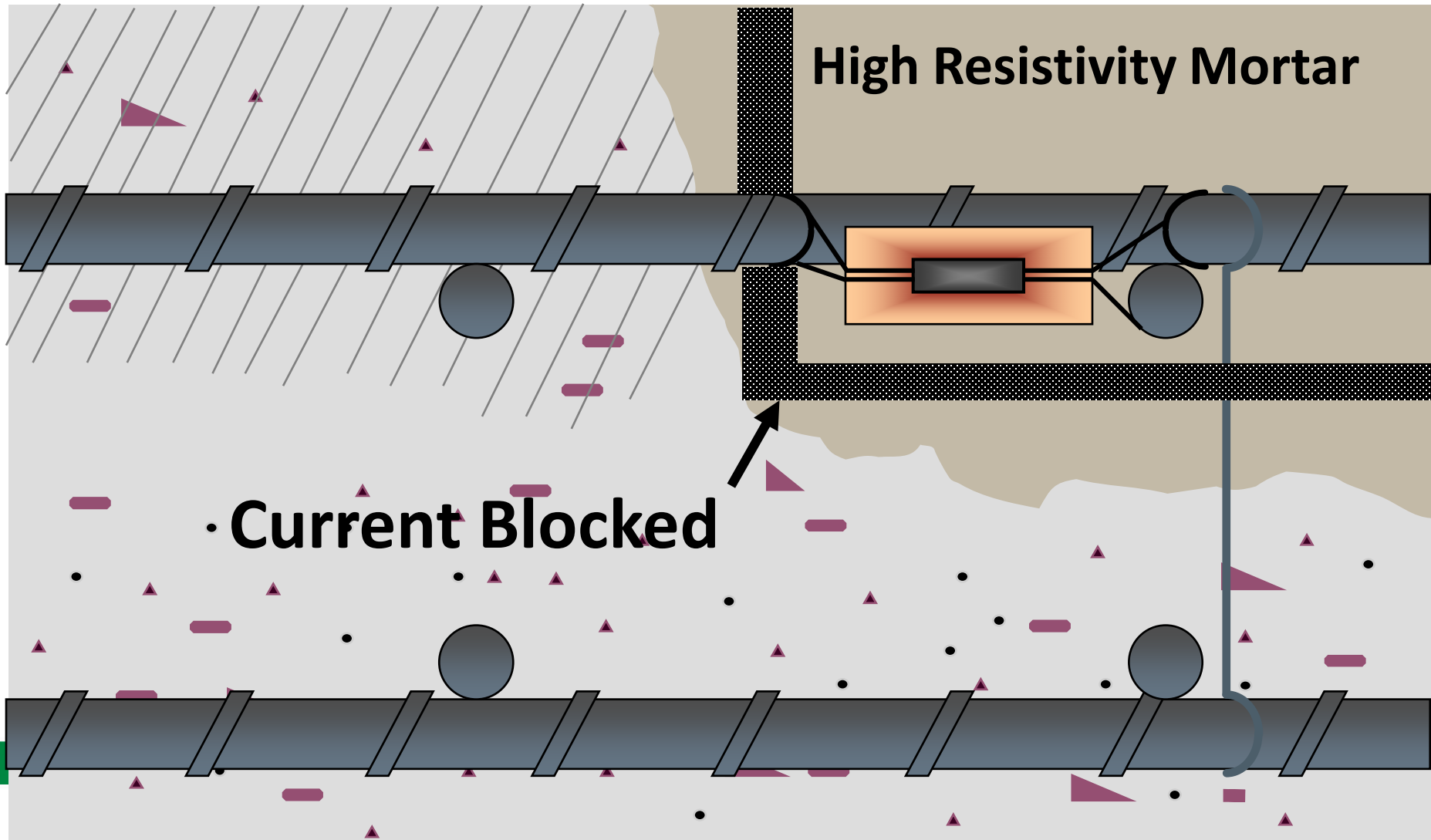
Silica Fume

High Levels of Fly Ash

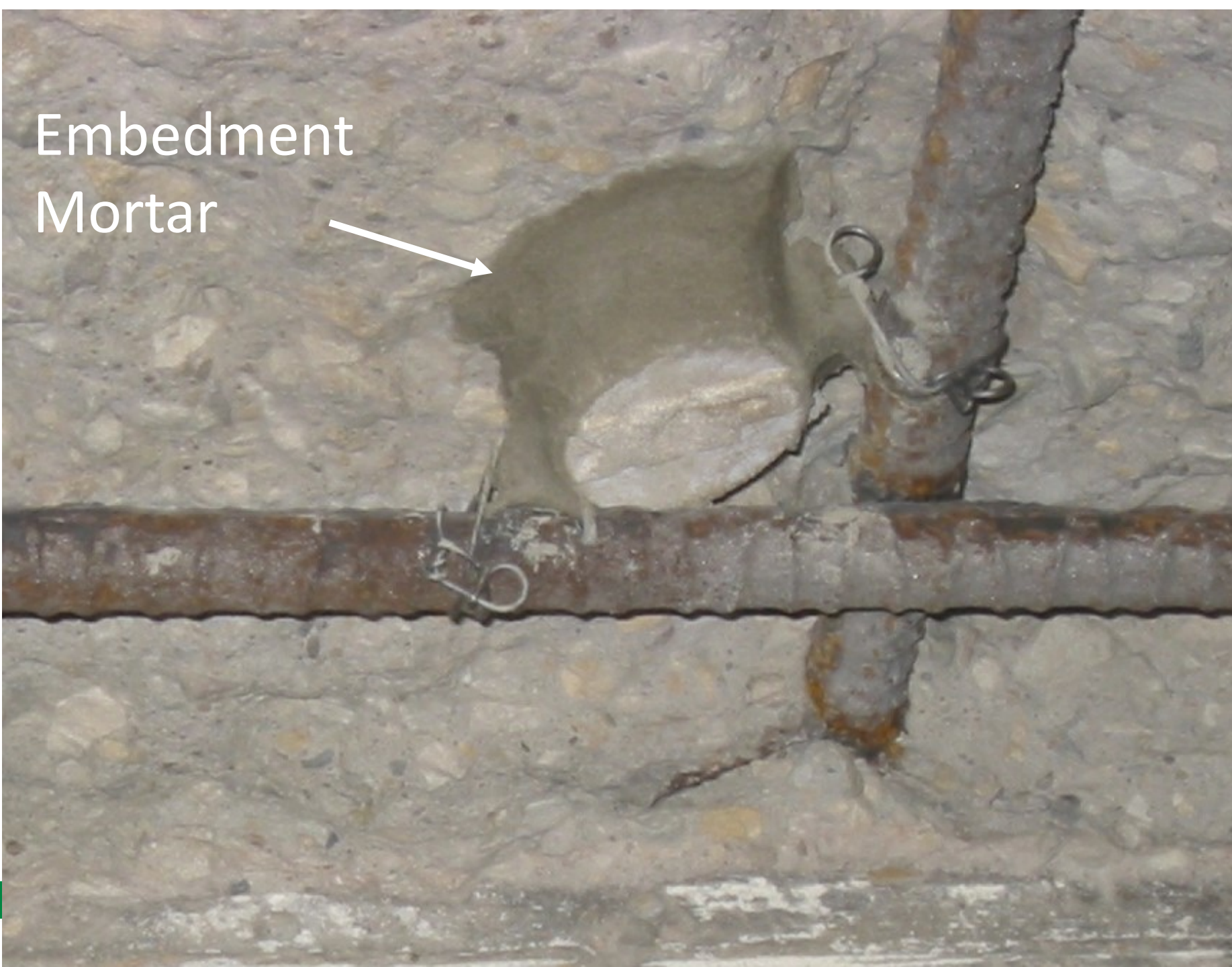
Resistivity > 50,000 ohm-cm



High Resistivity Repair Mortar



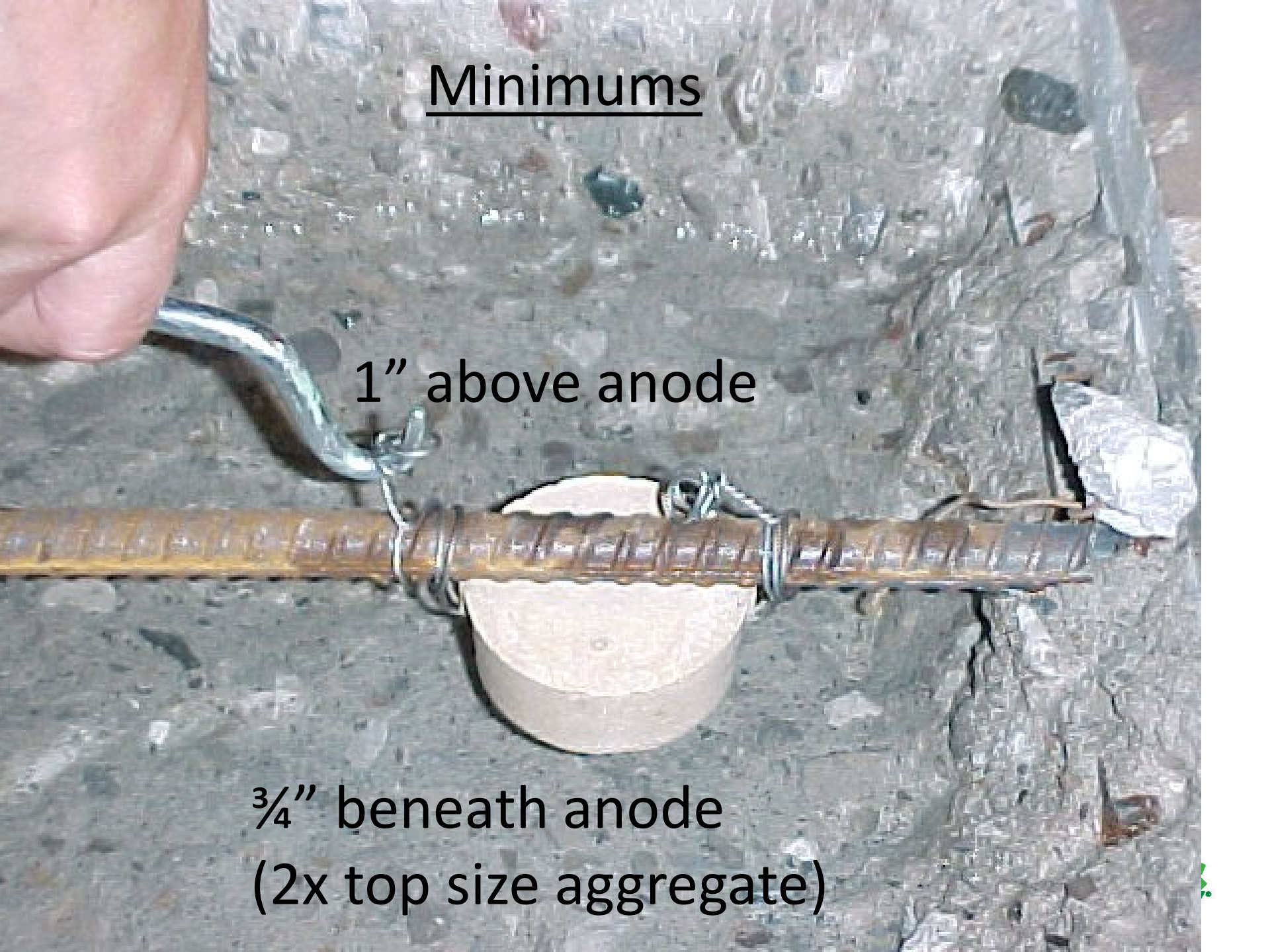
Embedment
Mortar



Minimums

1" above anode

$\frac{3}{4}$ " beneath anode
(2x top size aggregate)



Embedment Mortar

Resistivity < 50,000 ohm-cm

Low or No:

Polymer Modification (latex)

Silica Fume

High Levels of Fly Ash



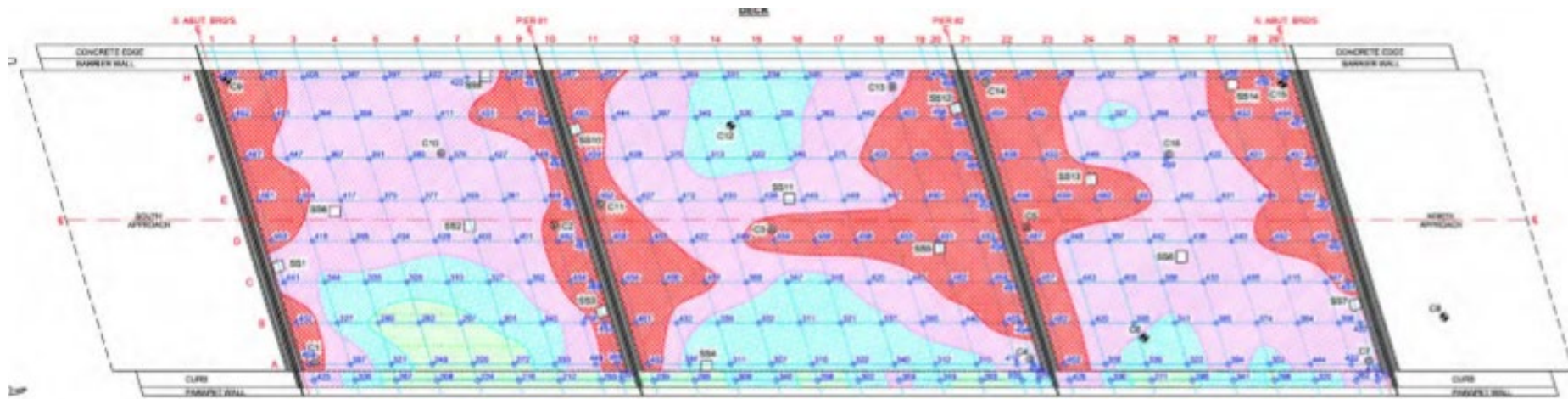
Point Anodes vs. Distributed Anodes







Corrosion Potential Map – Hwy 140 CNR Underpass





Hwy 140 CNR Underpass Repairs





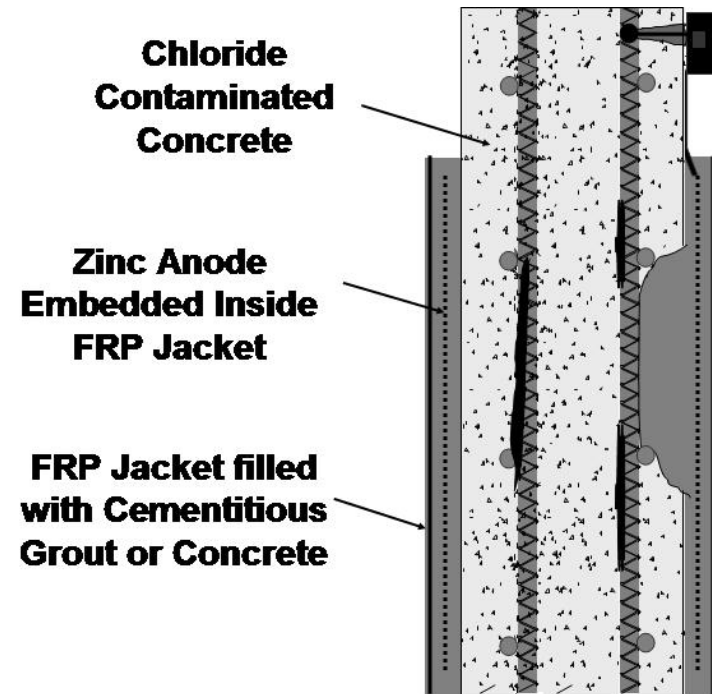




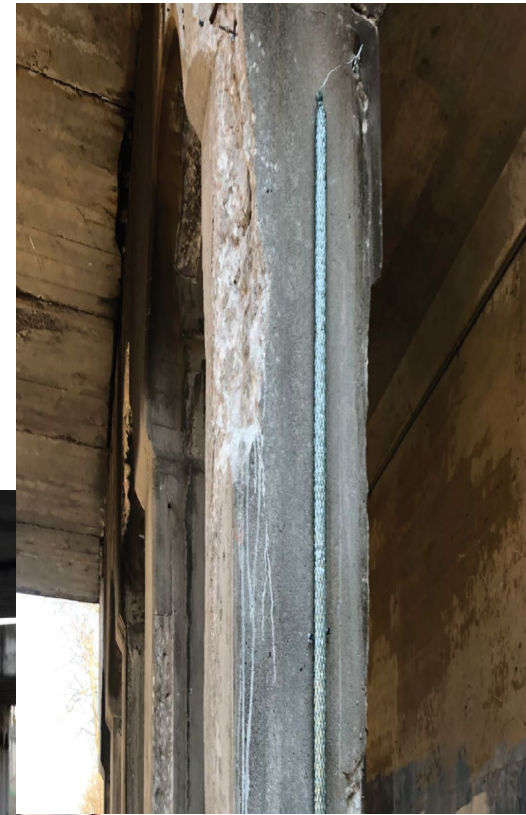


Galvanic Encasements

- What is a galvanic encasement?
 - Overbuild system for one step repair and protection
 - Can include supplemental reinforcing for strengthening
- Embedded galvanic anodes provided within encasement area
 - Annular space filled with mortar or concrete



Galvanic Encasement of Columns



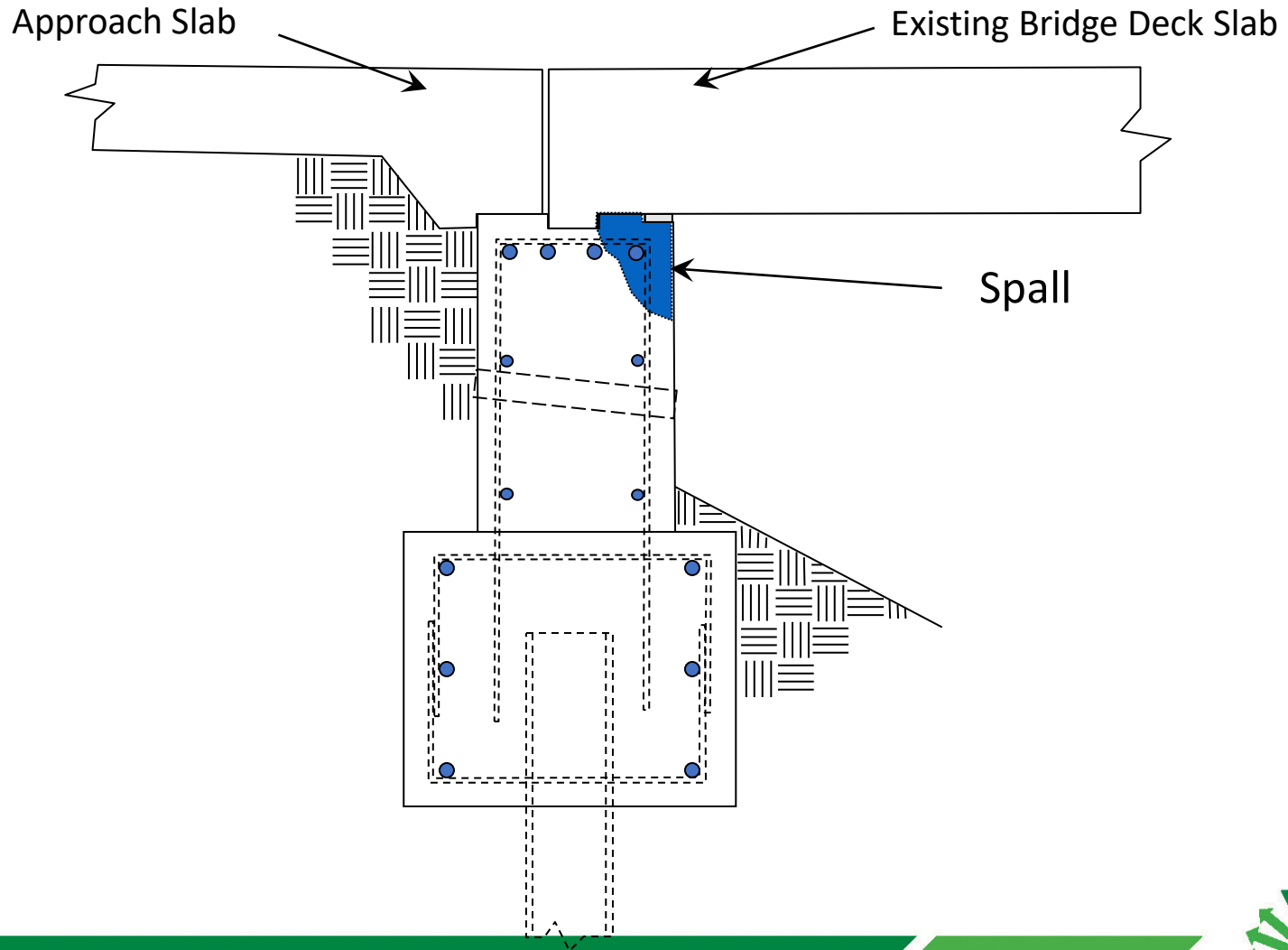
Galvanic Encasement of Beams



Galvanic Encasement of Abutments



Typical Slab Bridge Abutment

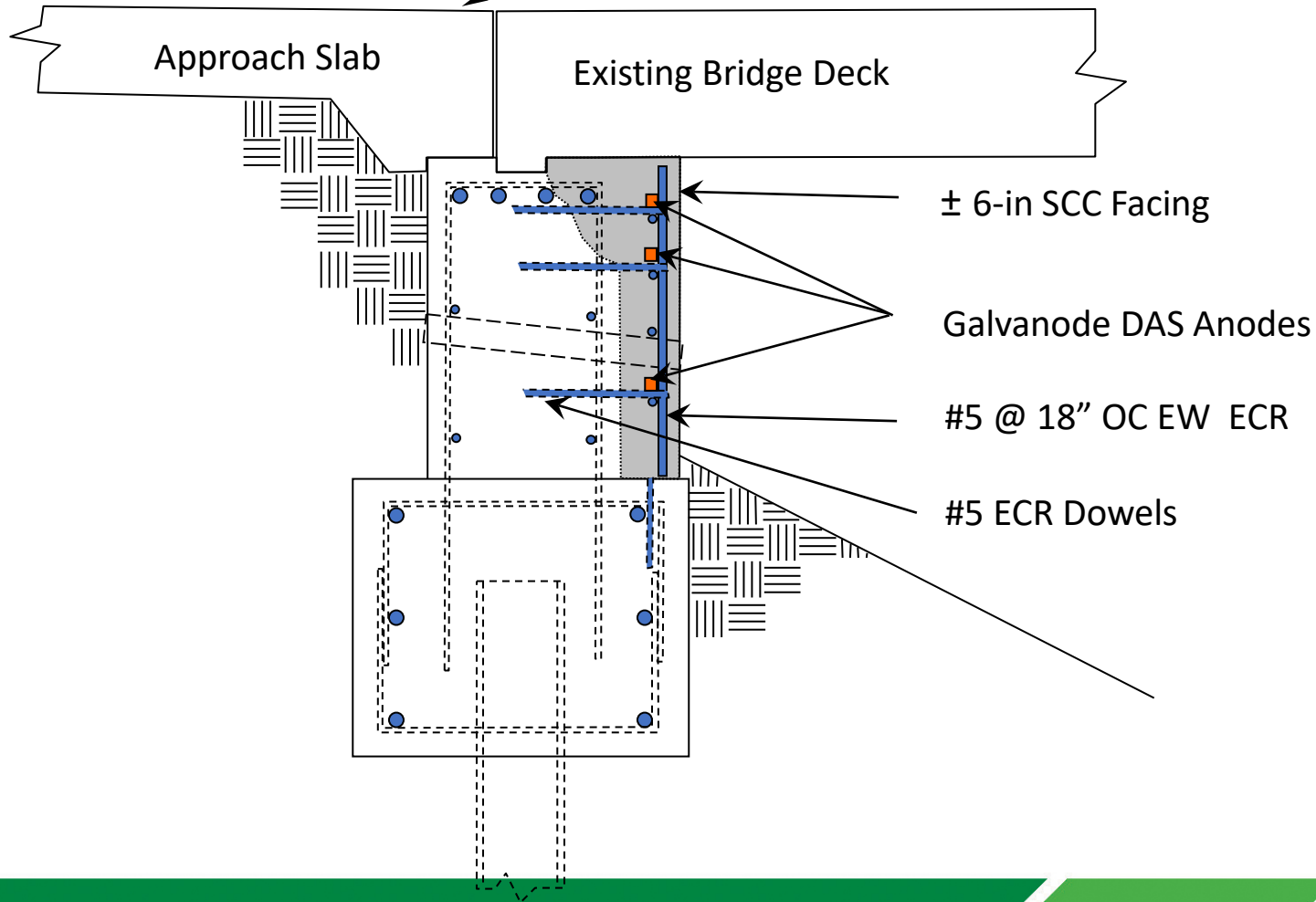


Abutment Conditions



Abutment Repair Detail

Replace Joint Seal

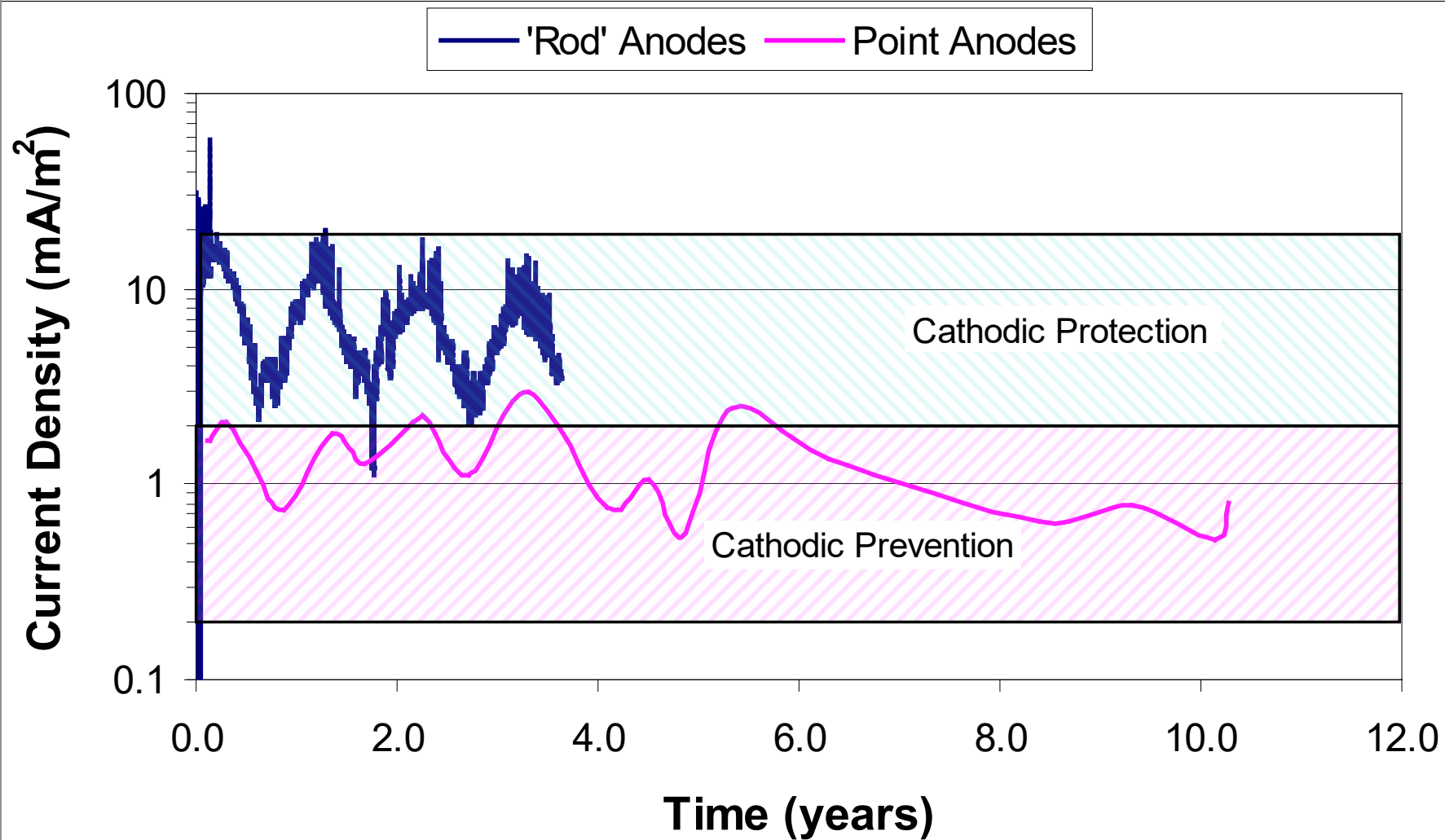






Completed repair

Galvanic anodes











PT Impregnation for Post-Tension Grouting Problems



**VECTOR
CORROSION
TECHNOLOGIES**

Background

- Grout Issues which can lead to Tendon Corrosion:
 1. Bleed water voids
 2. Voids due to grouting problems
 3. Segregated grout
 4. Chloride contaminated grout
 5. Soft grout

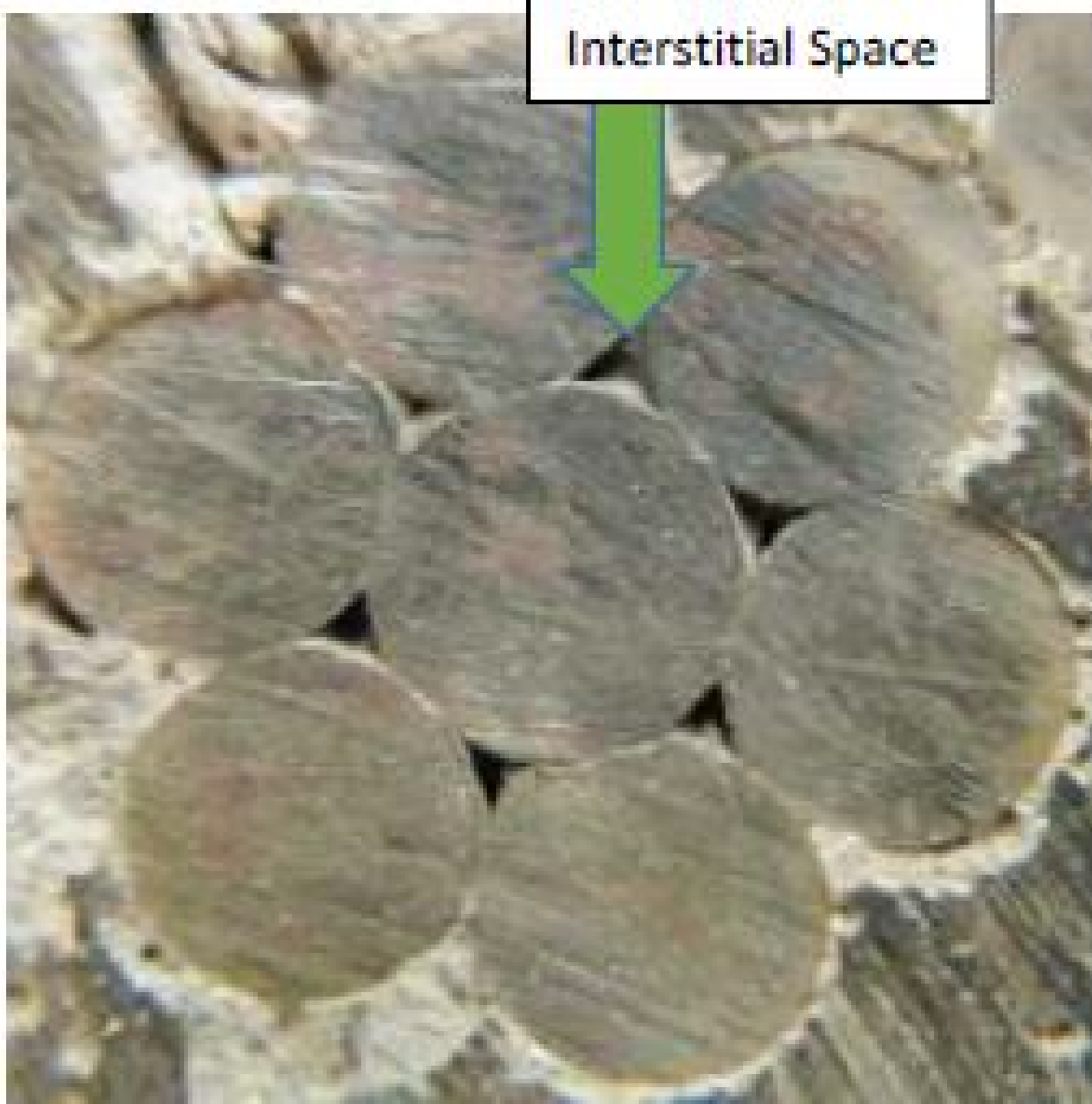


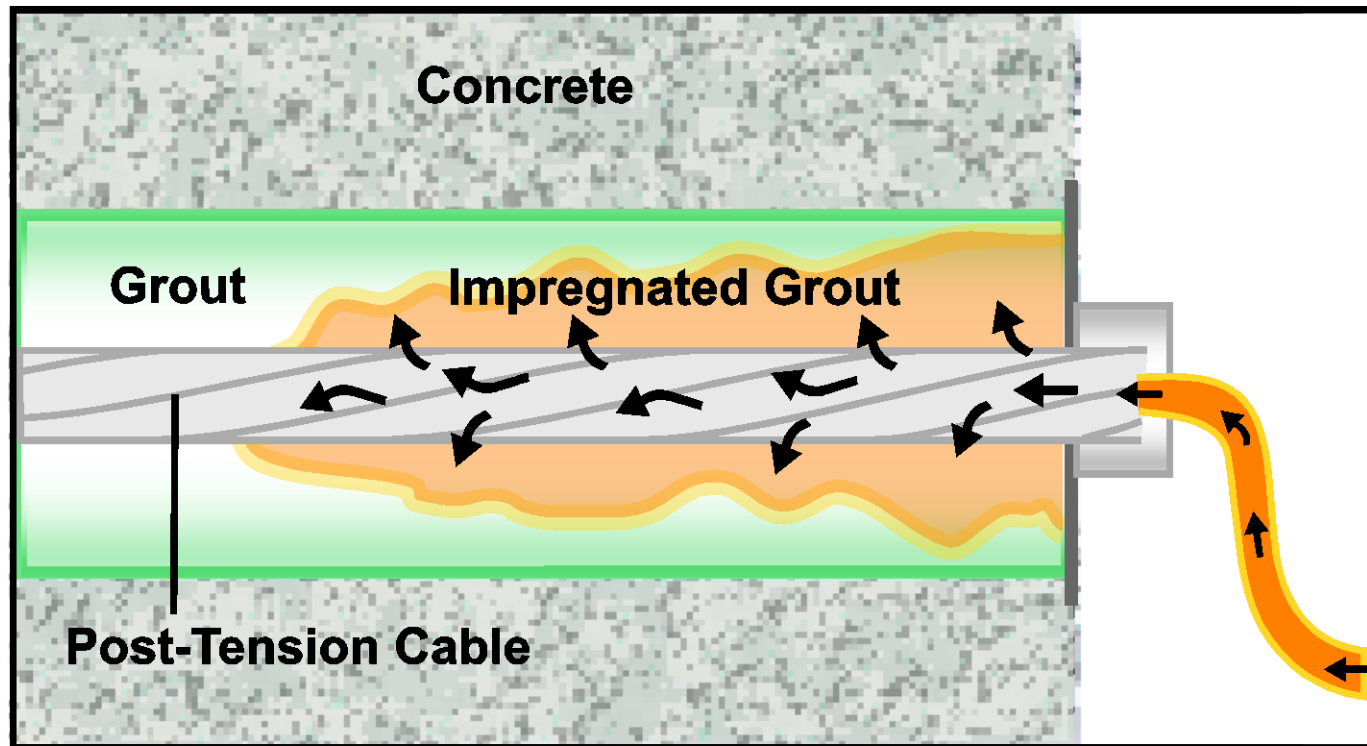
Problem: Corrosion or Grout related issues
Example: Bleed water issues within duct





Interstitial Space





Impregnation of Strands in Prestressed Concrete



FDOT Jacksonville Bridge





Removal of Anchorage Caps and Grout









Chipping grout to expose strands and observe the level of saturation





Post-Tech CI material clearly visible in the strands as well as the surrounding grout

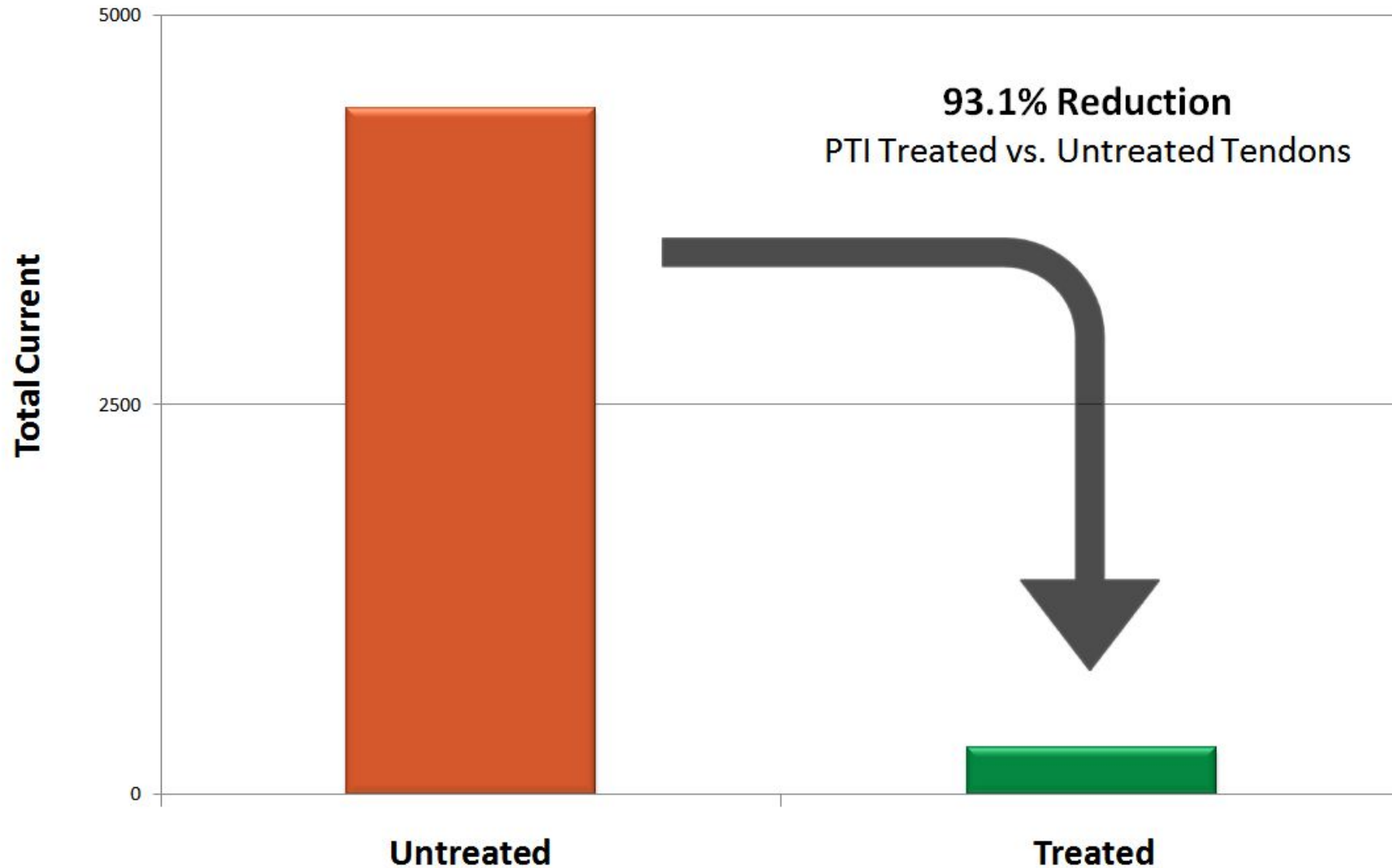




Untreated and Treated Strand Samples

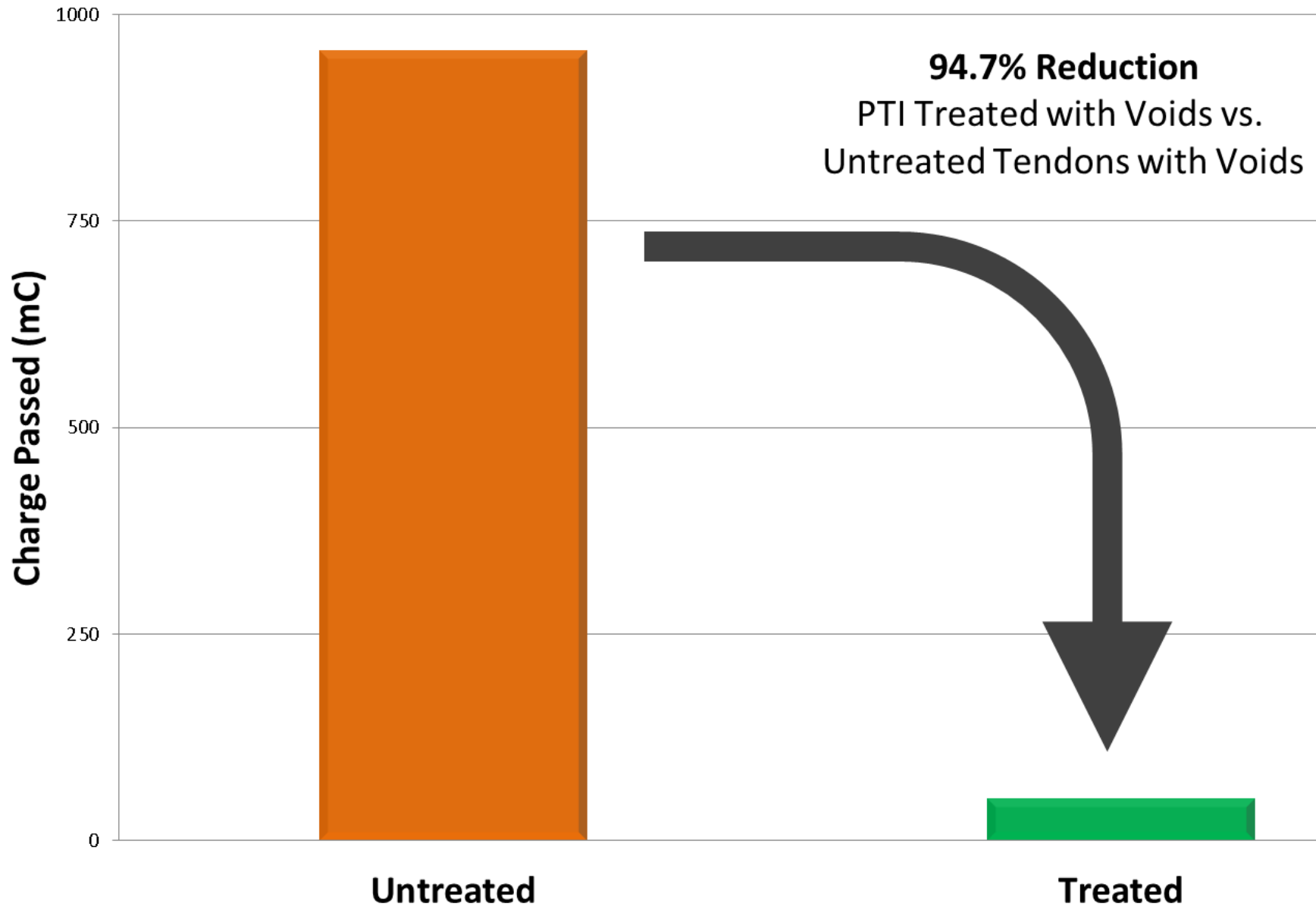
Potentiostatic Testing

Tendons in Chloride-Contaminated Grout (2% Cl⁻)



Verification of Corrosion Protection of Tendons with Voids

Potentiostatic Testing Tendons in Uncontaminated Grout with 4.5% Void



Questions



**VECTOR
CORROSION
TECHNOLOGIES**