# Bridge Preservation: Evaluation, Repair and Protection

## Webinar Wednesday Series

We Save Structures™

# CONCRETE PRESERVATION ALLIANCE

The Concrete Preservation Alliance is a growing coalition of organizations committed to advancing best practices in the field of concrete preservation and infrastructure renewal.

Working together to promote education and awareness of concrete repair industry standards, new and innovative corrosion prevention technologies and sustainable construction practices.

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- The construction industry is the largest user of resources and raw materials.
- Approx. 40% of solid waste comes from construction and demolition.
- Making new structures last longer and the rehabilitation and reuse of existing structures saves money compared to the cost of premature failure, demolition and rebuilding.
- In addition to economic benefits, repairing and extending the service life of structures reduces the consumption of natural resources, pollution and construction waste.

| | | | | |
|---|---|---|---|---|
| **Inputs** | | | | |
| Volume of concrete to be preserved | 10000 | yd3 | 7645 | m3 |
| | Calculate | | Calculate | |
| **Outputs** | | | | |
| **Emissions** | | | | |
| Concrete CO2 | 2633 | US tons CO2 | 2385 | metric tons CO2 |
| Steel CO2 | 2835 | US tons CO2 | 2569 | metric tons CO2 |
| Total Carbon Dioxide | 5468 | US tons CO2 | 4954 | metric tons CO2 |
| Equivalent to annual CO2 emission of: | 1243 | people | 1239 | people |
| NOx (as NO2) | 9747 | lbs | 4347 | kg |
| SO2 | 2722 | lbs | 1214 | kg |
| **Total Pollutants** | 10947469 | lbs | 4959689 | kg |
| **Waste Generation** | | | | |
| Solid Waste (Rubble) | 20250 | US tons | 18348 | metric tons |
| Energy (heat generation from cement production, cement hydration, and steel production) | 23846 | GJ | 22633 | GJ |
| Equivalent energy to boiling | 30 | Olympic Pools | 28 | Olympic Pools |
| **Natural Resources Required** | | | | |
| Fine aggregate | 5265 | US Tons | 4770 | metric tons |
| Coarse aggregate | 8302 | US Tons | 7523 | metric tons |
| Cement | 4500 | US Tons | 4014 | metric tons |
| Steel | 1620 | US Tons | 1468 | metric tons |
| **Total tons** | 19687 | US Tons | 17775 | metric tons |
| Potable Water | 253012 | gal | 936512 | liters |
| Equivalent to daily water usage for: | 2530 | people | 2341 | people |

https://www.wesavestructures.info/environmental-impact-calculator

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# Dr. Brian Pailes, Ph.D., P.E., NACE Specialist

Brian is the Principal Engineer with Vector Corrosion Services, a professional engineer and certified NACE Cathodic Protection Specialist (CP4).

Brian has extensive experience in the field of nondestructive evaluation (NDE), material testing, structural evaluation and corrosion assessment of reinforced concrete structures.

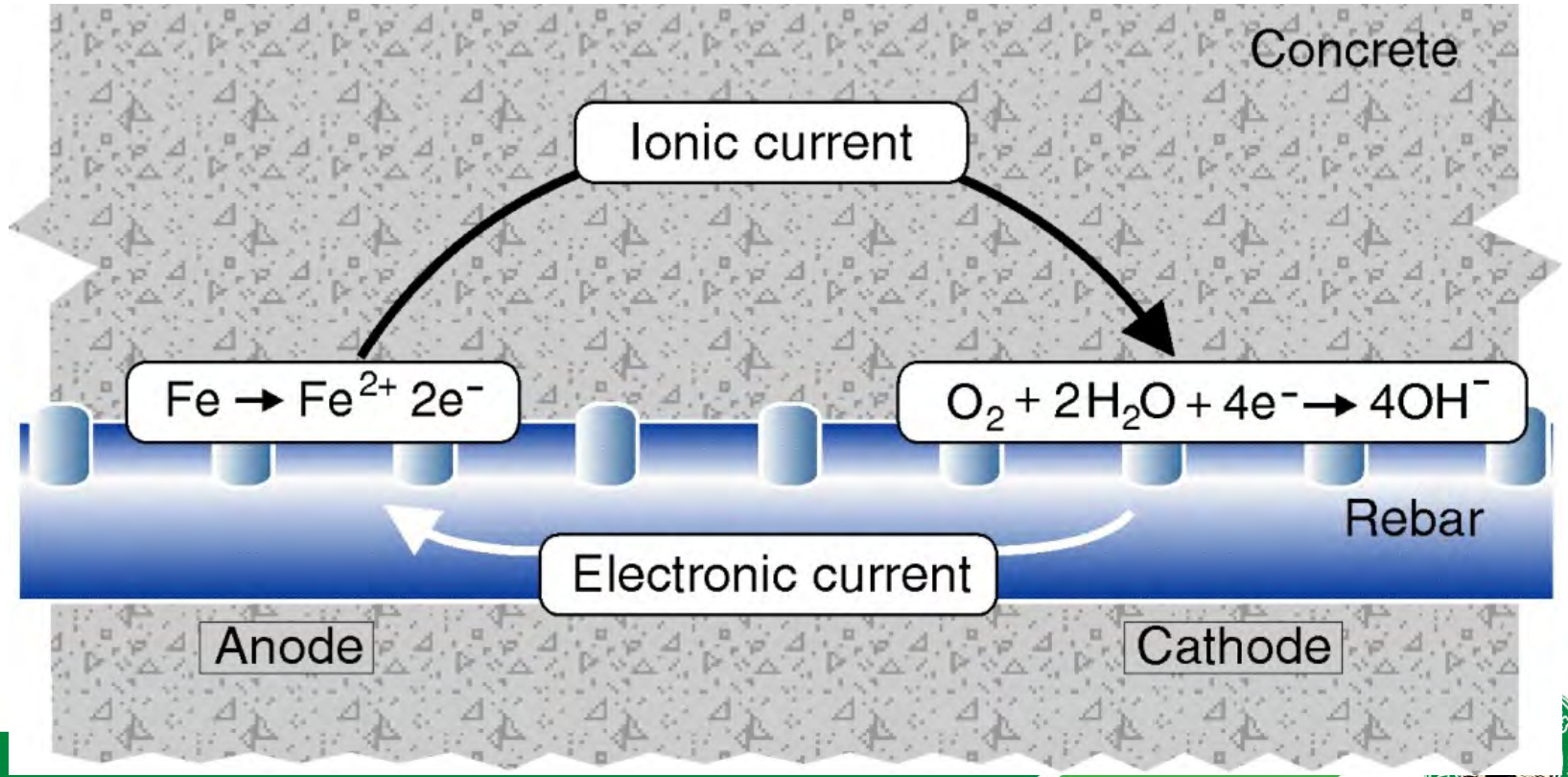
He earned a Ph.D. in Civil Engineering from Rutgers University, an M.S. in Civil Engineering from the University of Virginia and a B.S. in Civil Engineering from Northeastern University. Brian has also obtained a Graduate Certificate in Engineering Geophysics.

# Corrosion Assessments for Concrete Bridge Elements

- Understanding the cause and effect of reinforcing steel corrosion in concrete
- Quantifying the magnitude and extent of corrosion risk.
- Many destructive and non-destructive test methods for assessing corrosion risk.

# What is Corrosion Reaction

- Electrochemical Reaction
- Anode – where rust is formed
- Cathodic – no section loss

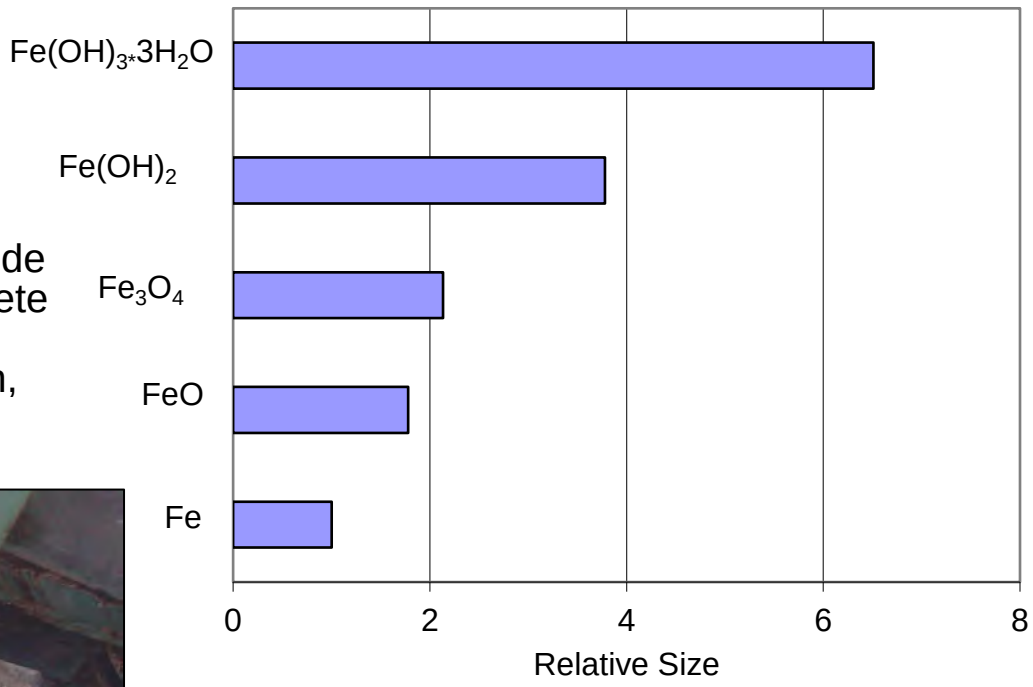


# Concrete Protects Steel

- Concrete is naturally alkaline
  - pH of about 13
- Steel is naturally passive at this alkalinity
- Formation of passive layer
- Passive layer can be destroyed by;
  - Chlorides
  - Carbonation

# Corrosion Induced Damage

- Damage resulting from
- Metal section loss and
- Formation of iron oxide (rust)
- Expansive properties of iron oxide create tensile stresses in concrete
- Leads to cracking, delamination, and eventual spalling




# Corrosion Damage

**Conventional Mild Reinforcing Bar**

In most cases loss of steel section not primary concern
Typically damage to concrete becomes significant and observable prior to severe section loss

**High Strength Strands**

Minor section loss of steel can have significant effect on strength

Steel can have significant section loss without significant concrete damage

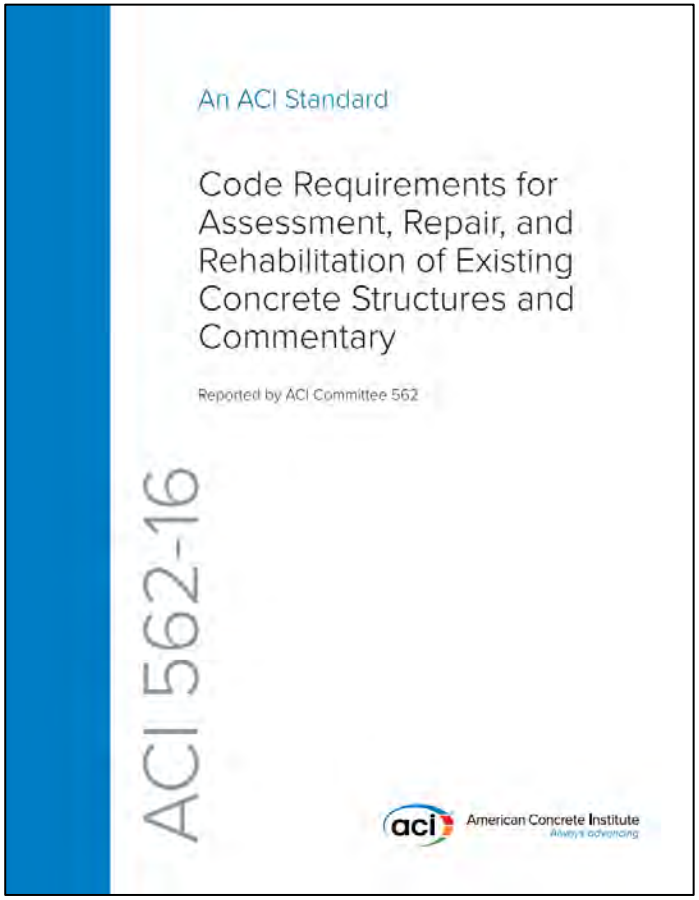
# Concrete Preservation Process

IDENTIFY ISSUES → PERFORM EVALUATION → DETERMINE CAUSE

DEVELOP REPAIR STRATEGY → COMPLETE REPAIR → QUALITY CONTROL

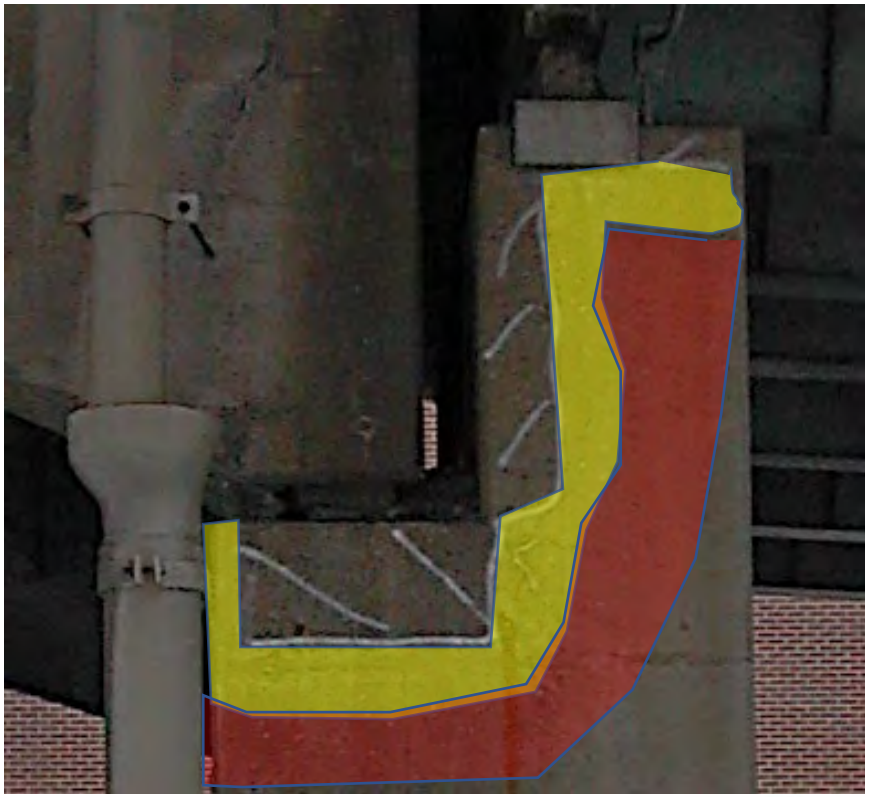
# ACI 562: Concrete Repair Code

- Being adopted in states throughout the US
- Requires that an evaluation take place prior to designing repairs



# Delamination Survey

- Hammer sounding located areas where concrete has debonded
- Is there more going on here?
- Yellow – extent of delamination that cannot be heard through hammer sounding
- Red – extent of activate corrosion that will be a delamination in the near future

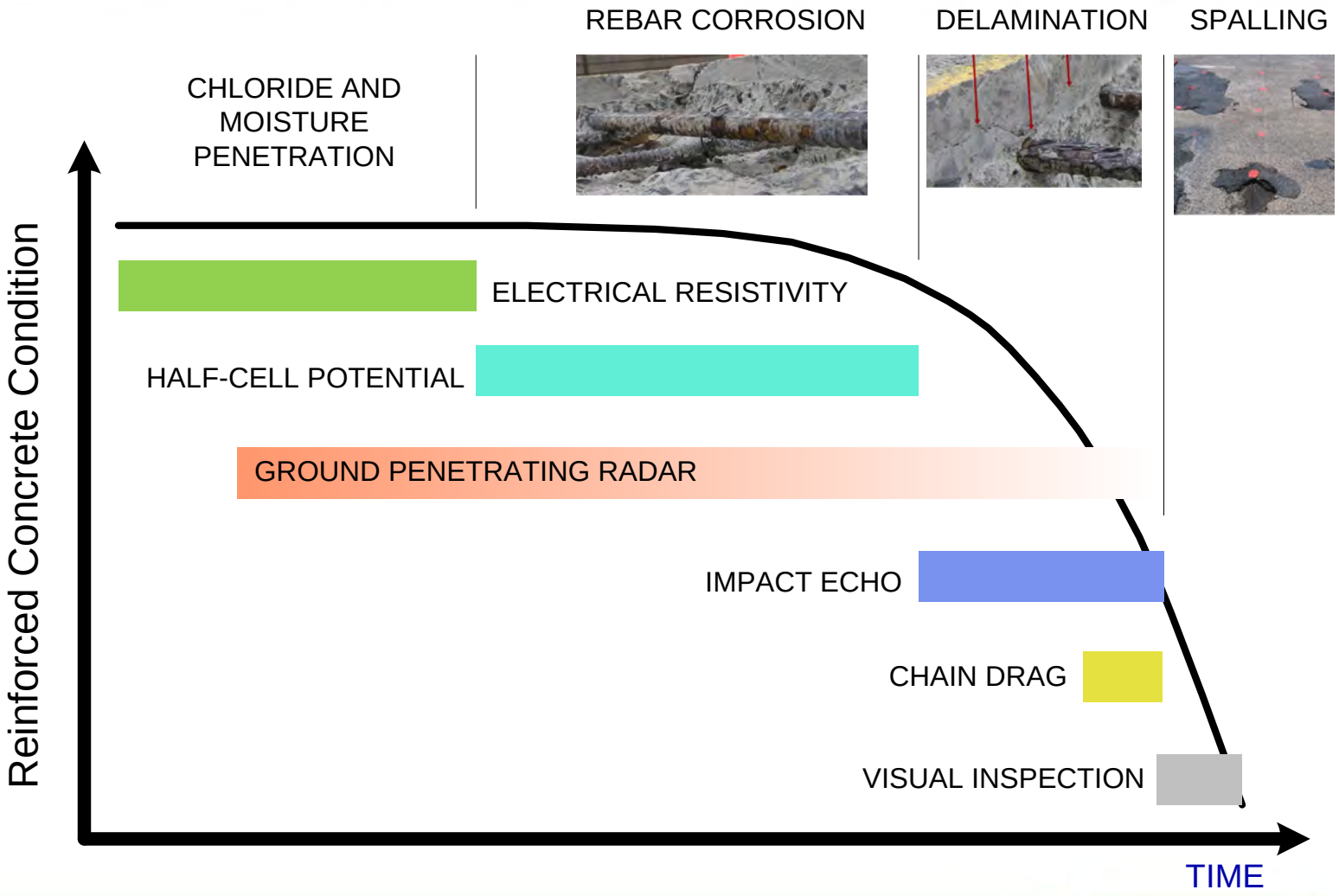


# Why use NDT in Evaluation?

- We need to more accurately determine location and extent of deterioration?
- Sounding and visual inspections are known to underestimate true repair area
- Impacts of underestimating repair quantities?
- Costly change orders
- Increased project duration
- Time from inspection to construction can be long
- Deterioration will have grown from last inspection

NOT JUST FOR DECKS!

# Corrosion Deterioration and NDT



# Visual Inspection

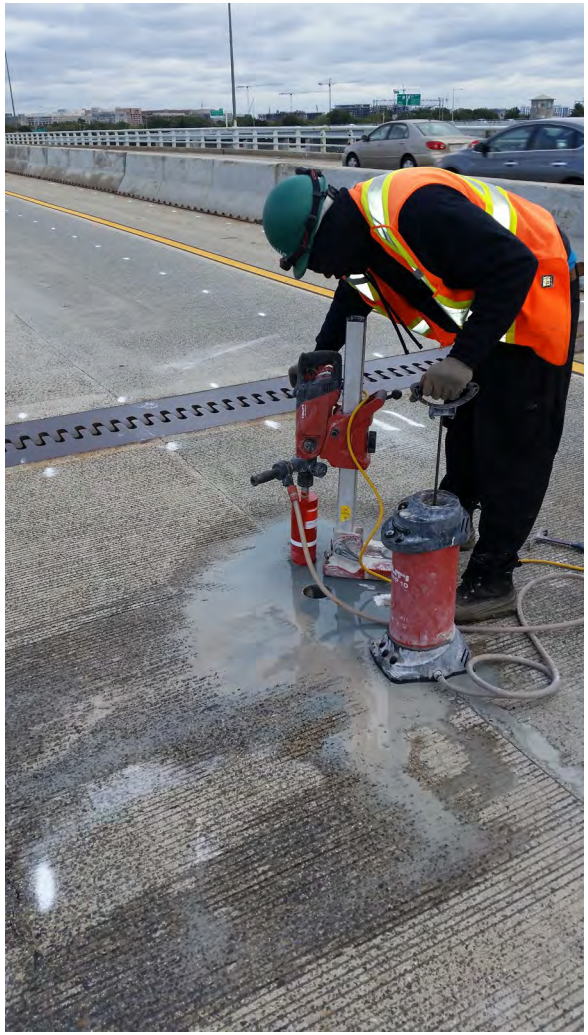
Identify areas of visual deterioration

- Rust Staining
- Cracking
- Spalling
- Exposed Reinforcement
- Water Seepage
- Efflorescence

# Sounding Survey

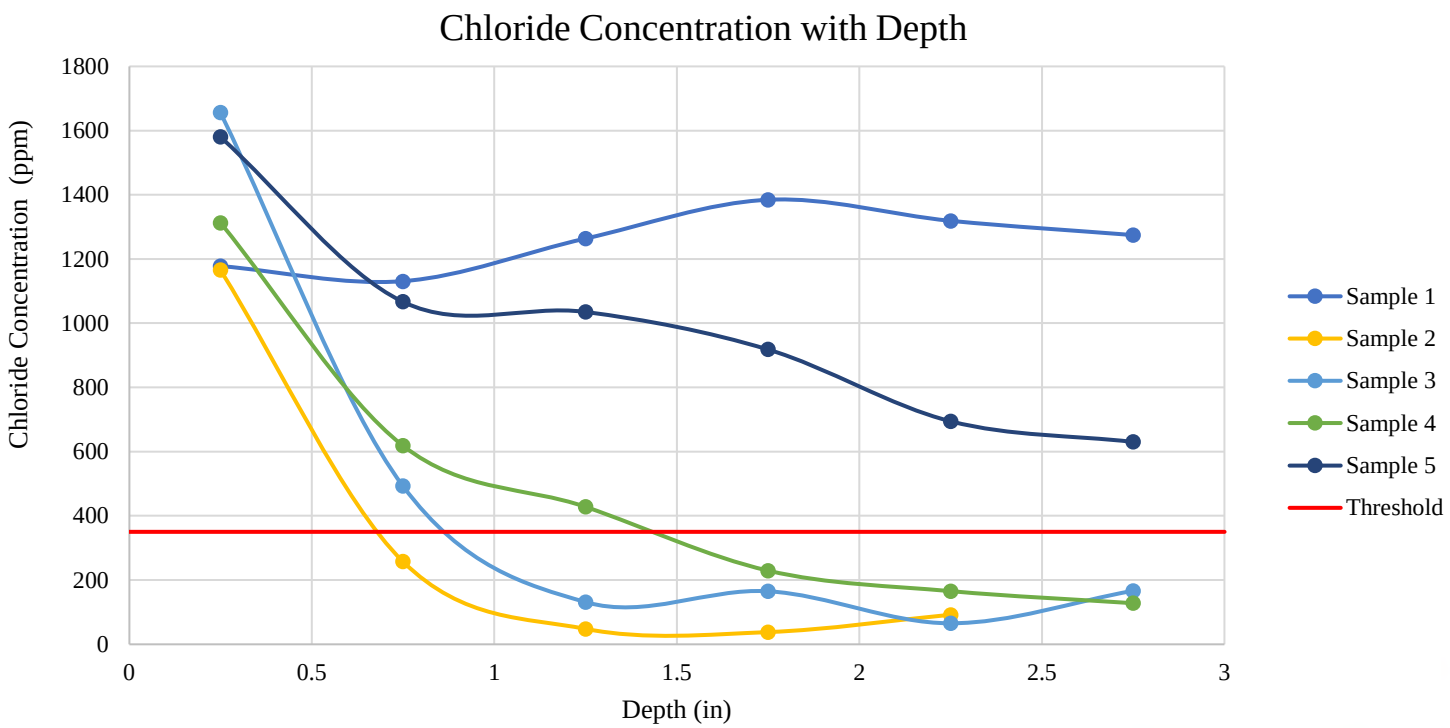
- Hammer sounding or chain drag
- Locates areas of large near surface delaminations
- Incipient delaminations cannot be identified
- False positives are rare
- False negatives are common

# Collection of Cores

# Chloride Sampling

- Chloride Threshold - Between 1 to 2 lbs of chloride per cubic yard of concrete
- 350 ppm of chloride in concrete is about 1.5 lbs per cubic yard

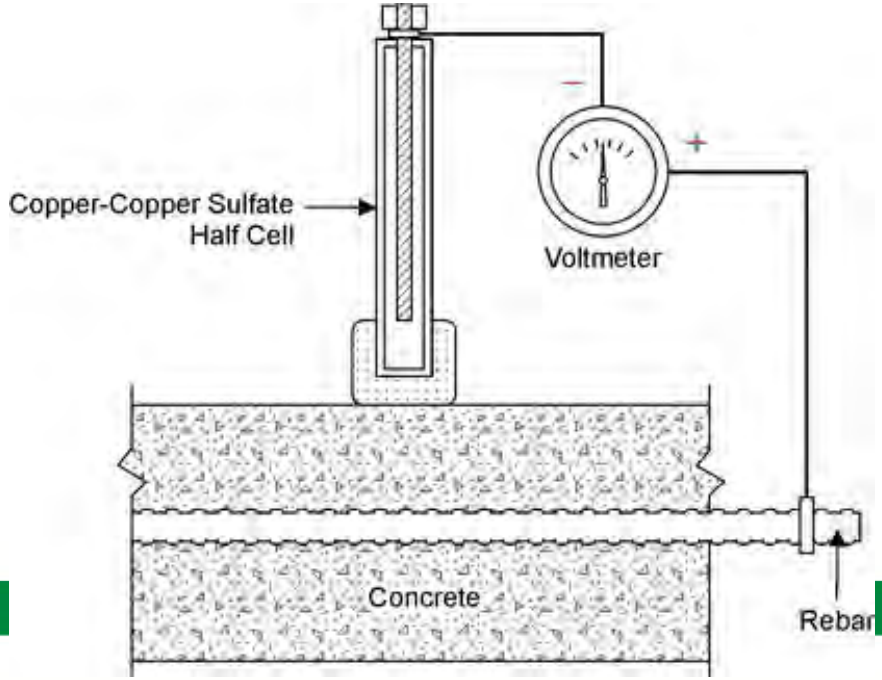


# Carbonation Depth

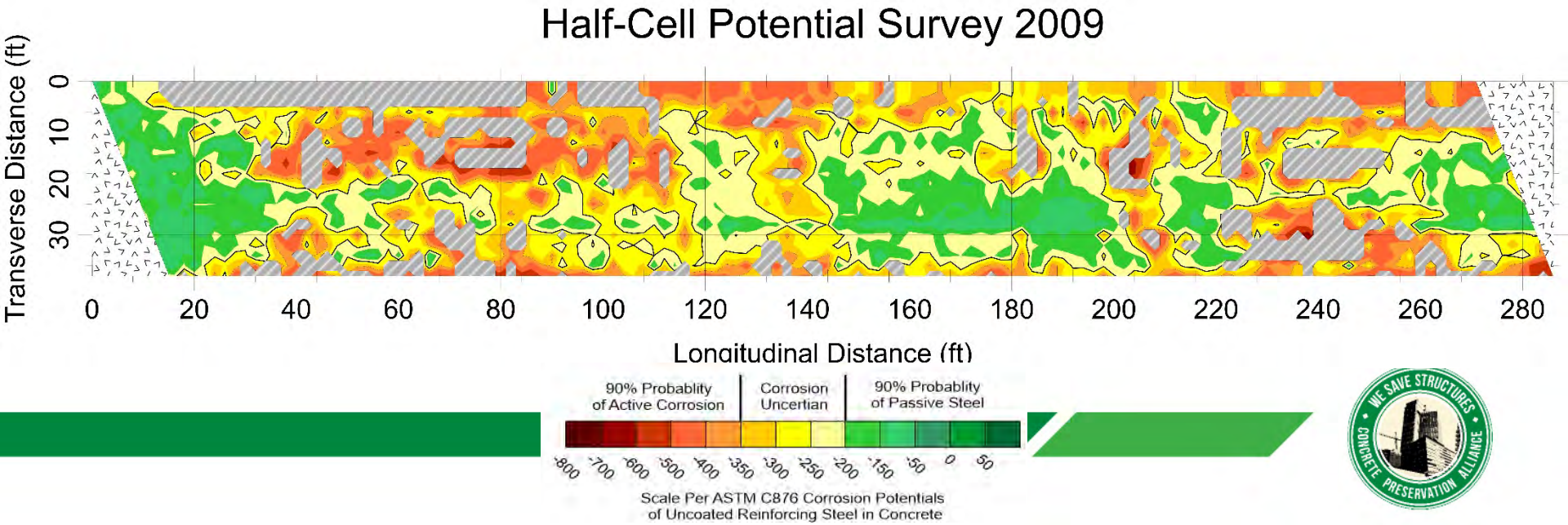
- Carbon dioxide permeates into concrete
- Reduces pH of concrete
- $CO_2$ reacts with free lime, $Ca(OH)_2$, resulting in $CaCO_3$ and $H_2O$
- Reduced pH de-passivates steel
- Often seen when
- Concrete permeability is high
- Industrial sites
- Very old structures – carbonation is a result of time and exposure

# Corrosion Potential Measurements

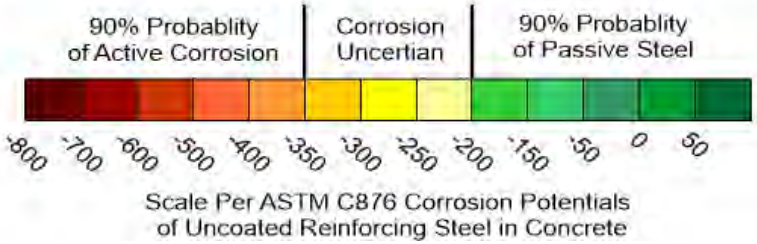
- ASTM C876
- Most people refer to it as the “half-cell” method
- Determines the probability of active corrosion of embedded metals



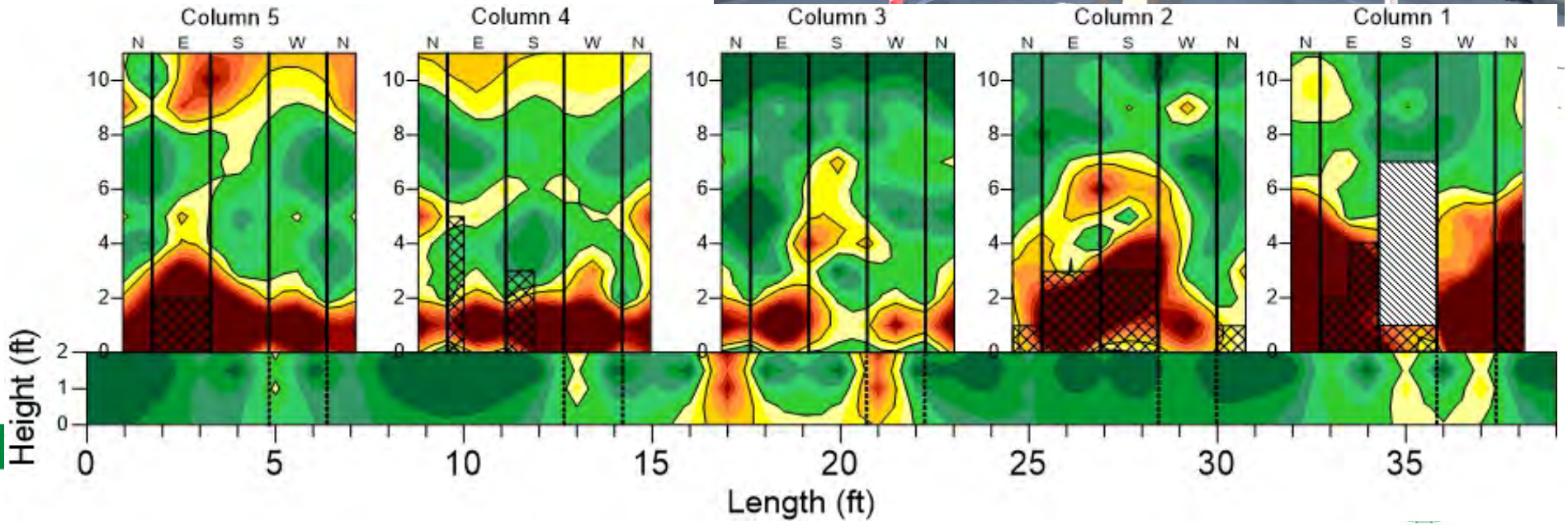

# Corrosion Potential – Bridge Deck



# Corrosion Potential – Substructure

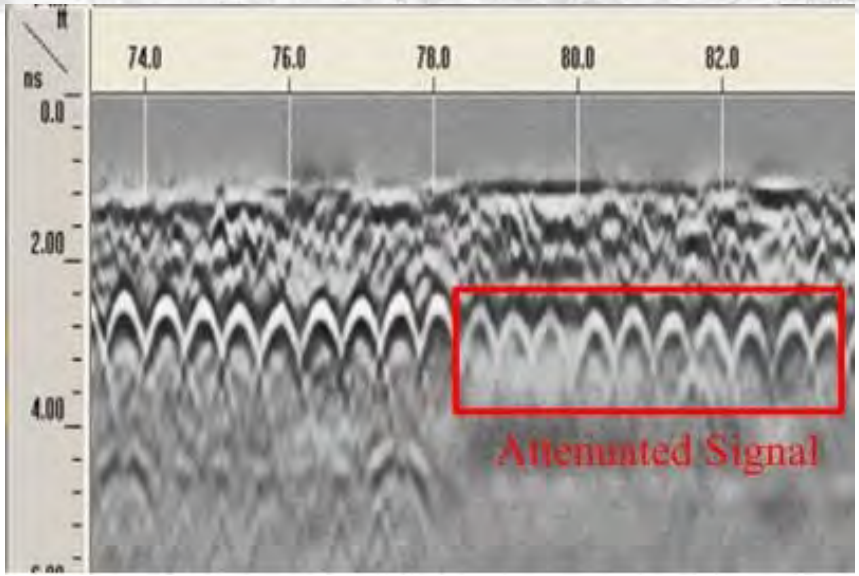




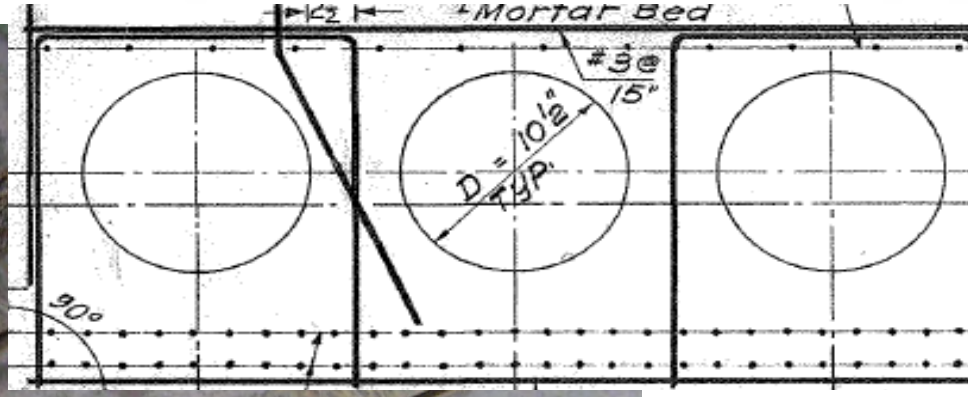


# Ground Penetrating Radar

- Electromagnetic evaluation of concrete
- Reinforcement layout
- Location of embedded metals
- Cover Depth
- Qualitative condition of reinforced concrete
- Chlorides, moisture, and concrete deterioration attenuate GPR signal




# GPR Locating Existing Reinforcement

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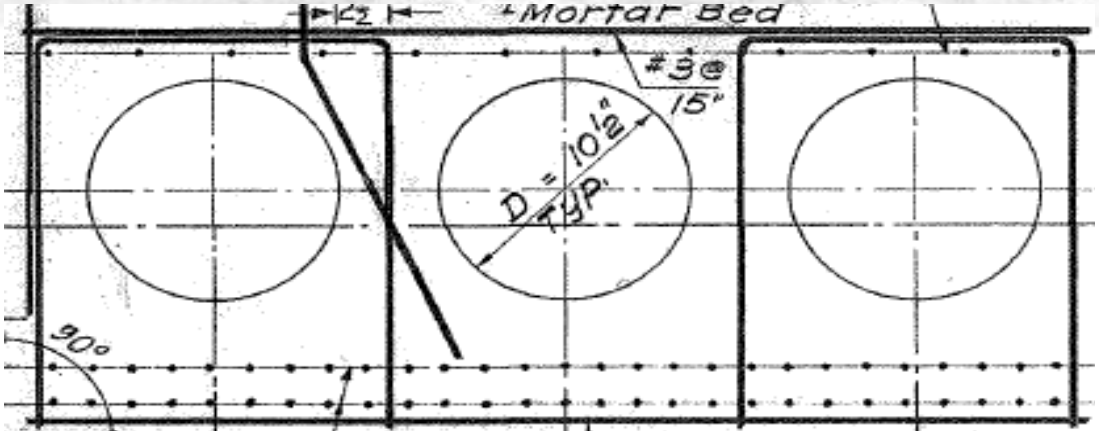
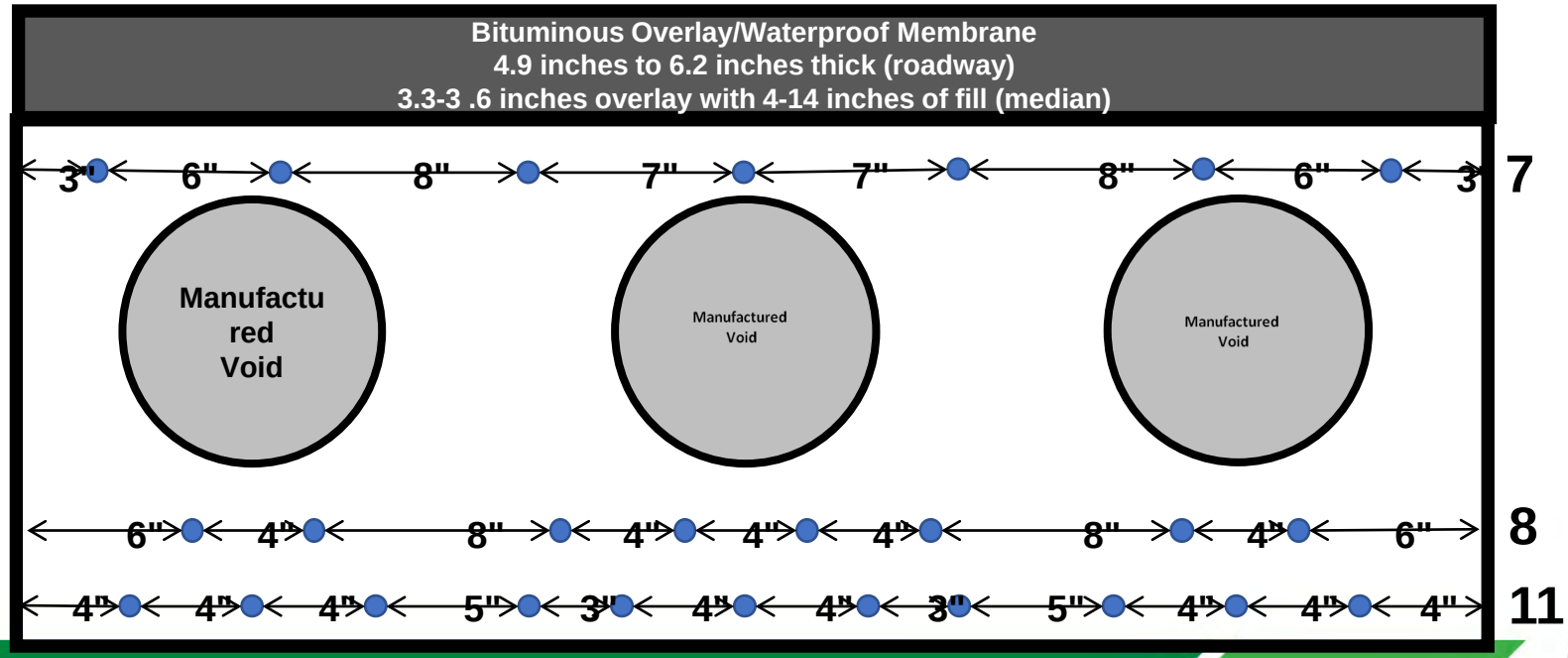



12

27

27




7

8

11

# Cover Depth Survey

- Cover depth is an important factor in the service life of a structure
- Reduced cover depths allow for chlorides and carbonation to reach steel faster


Chloride Diffusion

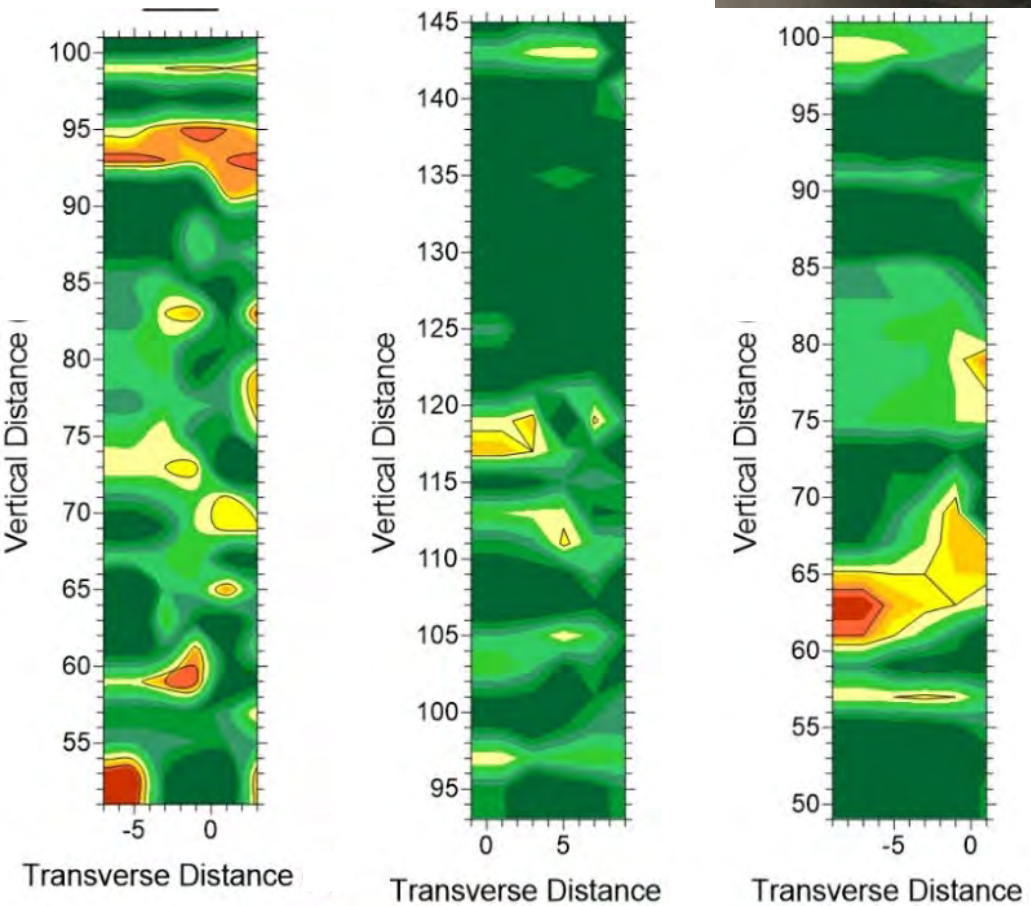
$$C_{(x,t)} = C_o\left(1 - erf\,\frac{x}{2\sqrt{D_c t}}\right)$$

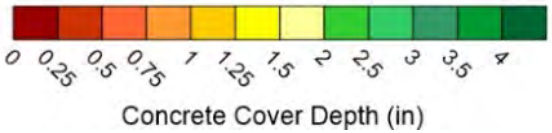
$$t = \frac{1}{D_c}\left[\frac{x}{2 \times inverf\left(1 - \frac{C_{x,t}}{C_o}\right)}\right]^2$$

Concrete Carbonation

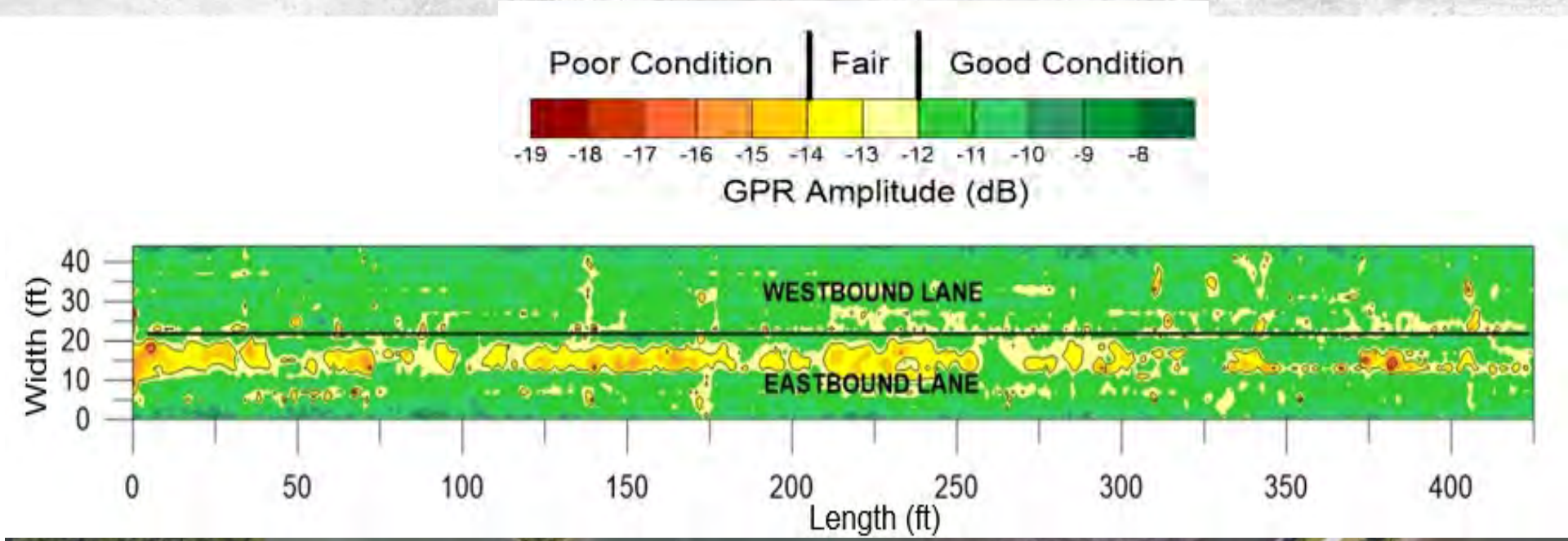
$$t = \left(\frac{d}{A}\right)^2$$

# GPR Cover Survey

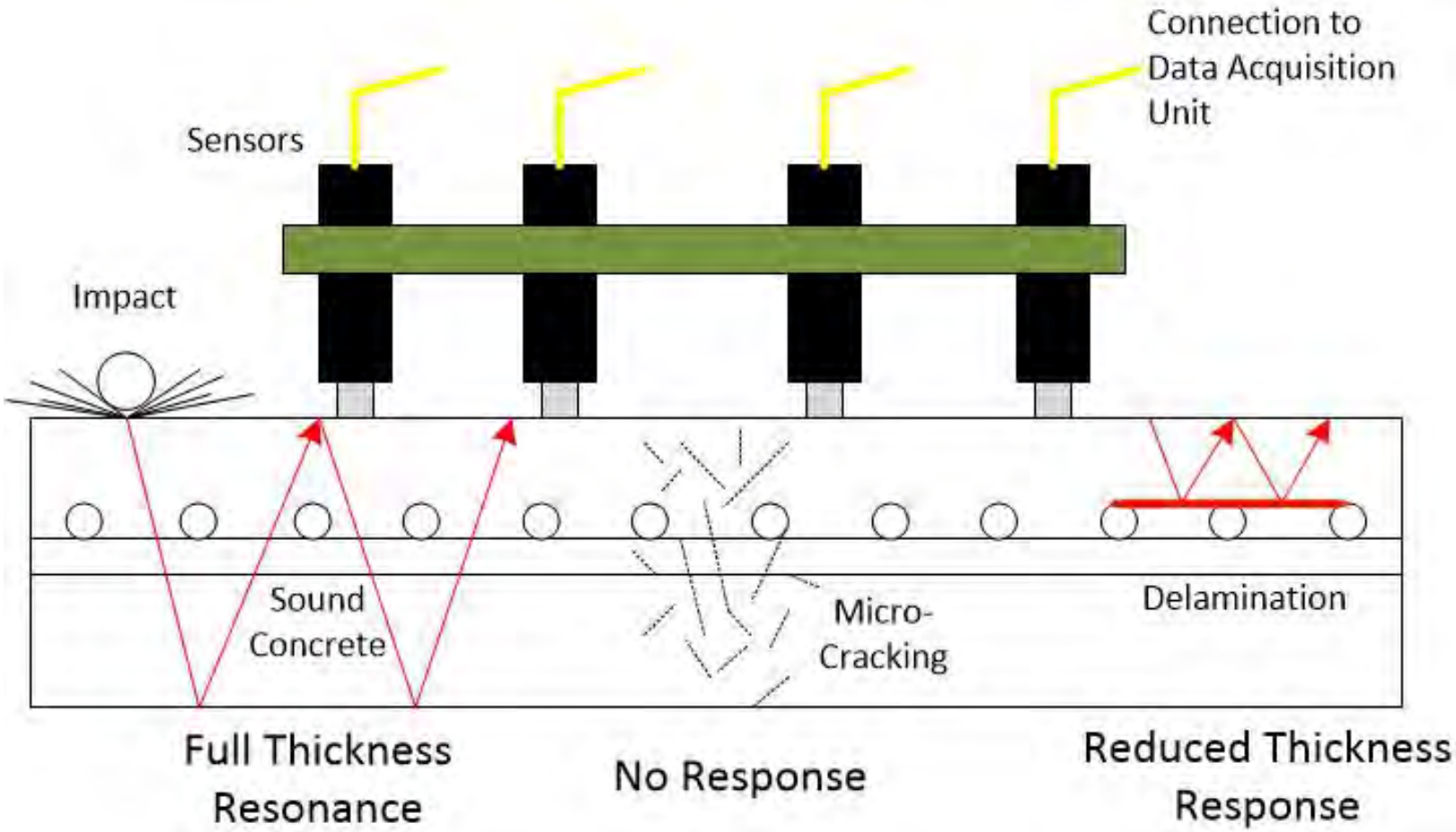


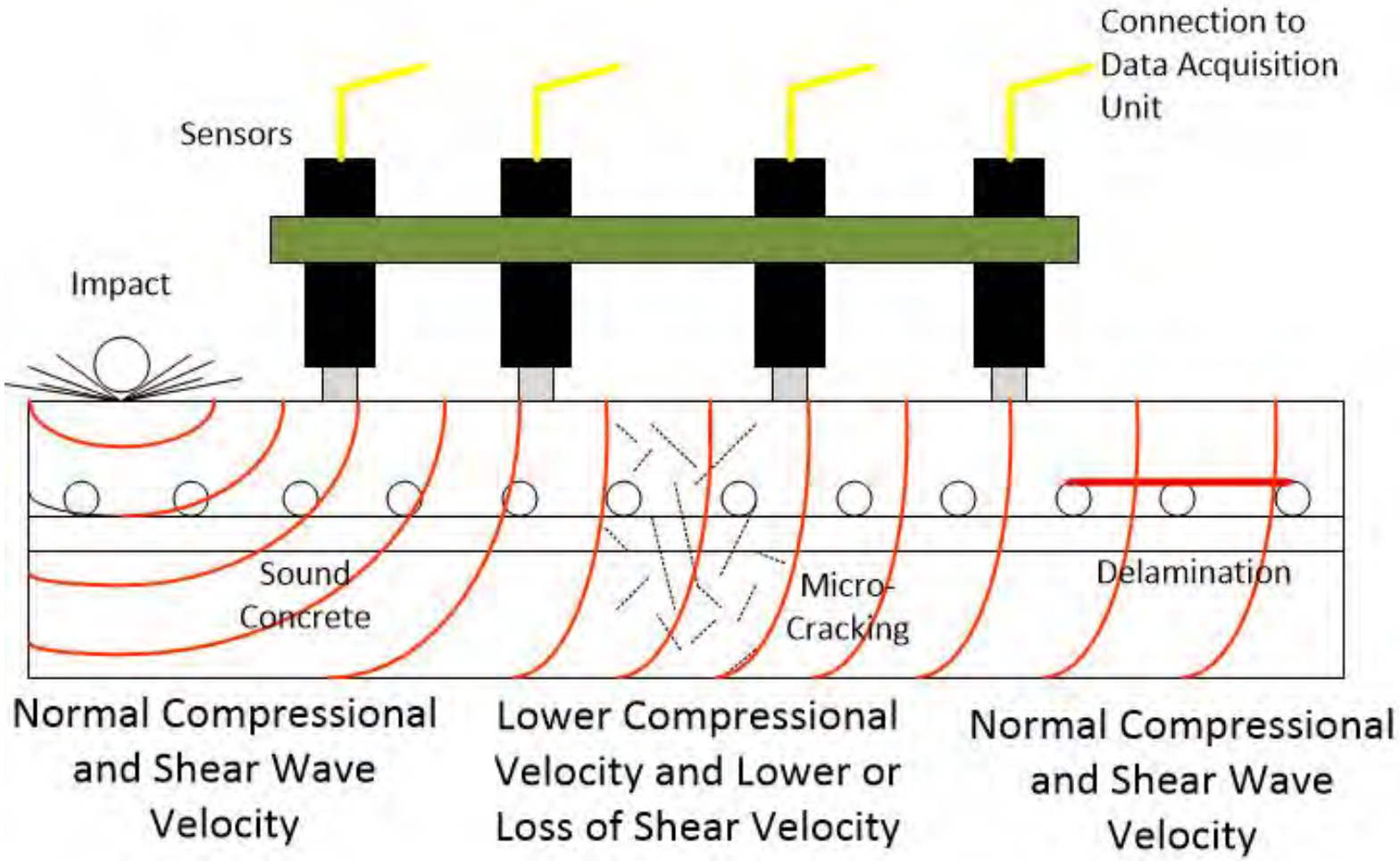
# GPR Amplitude Survey



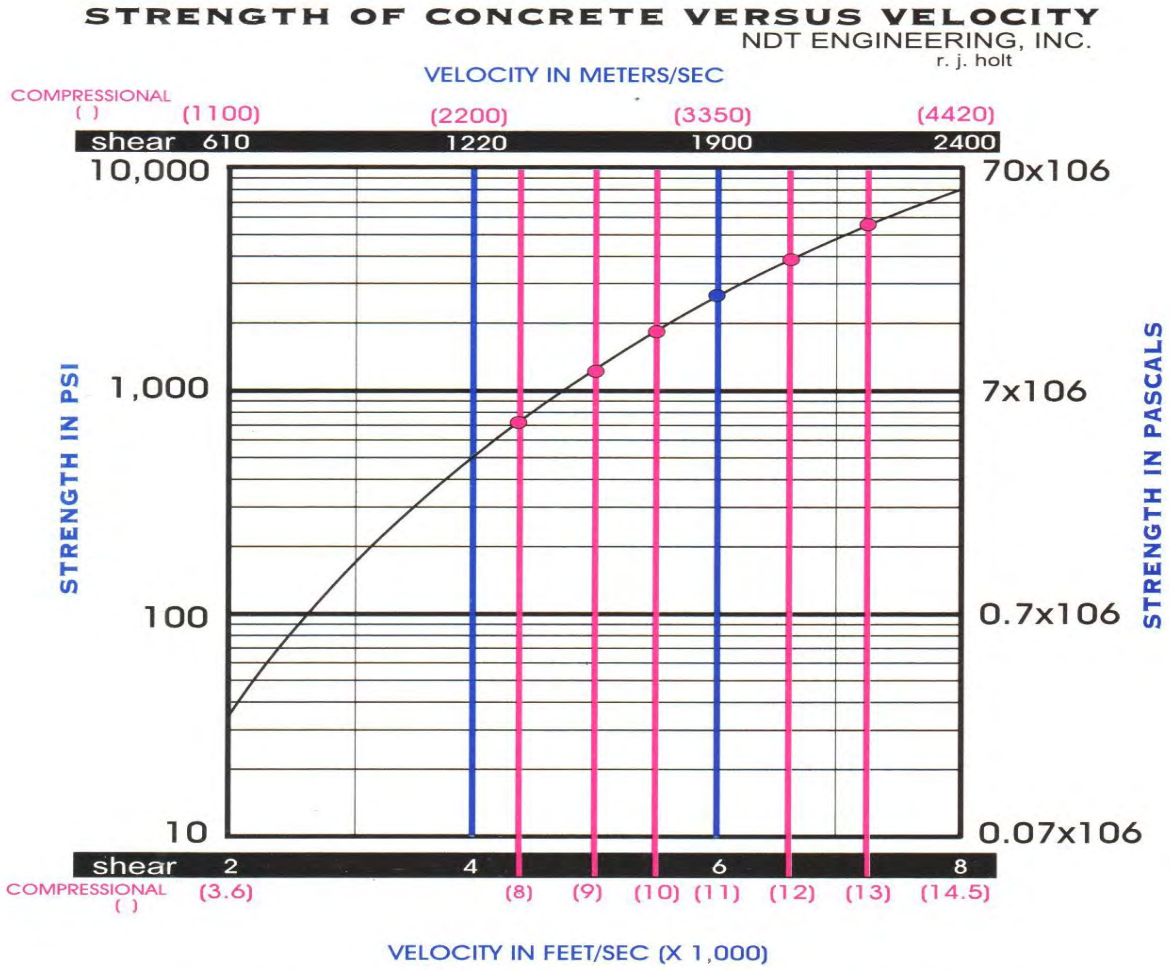

# Acoustic Methods – Impact Echo



# Acoustic Method – Pulse Velocity



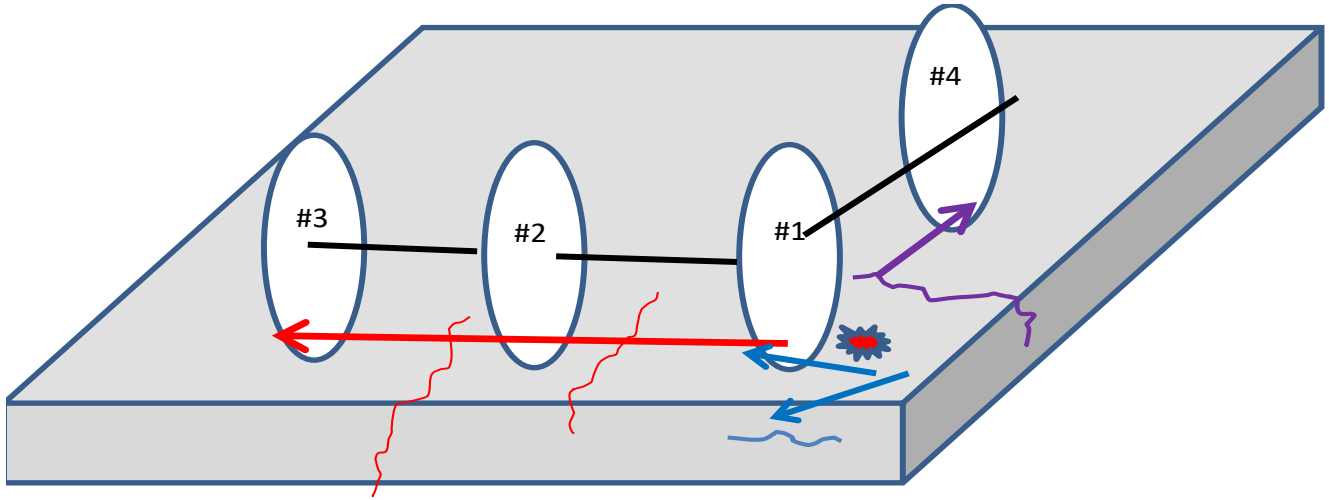
# Relationship between Compressive Strength and Wave Velocity




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

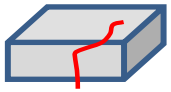
# Acoustic Testing


# Acoustic Testing



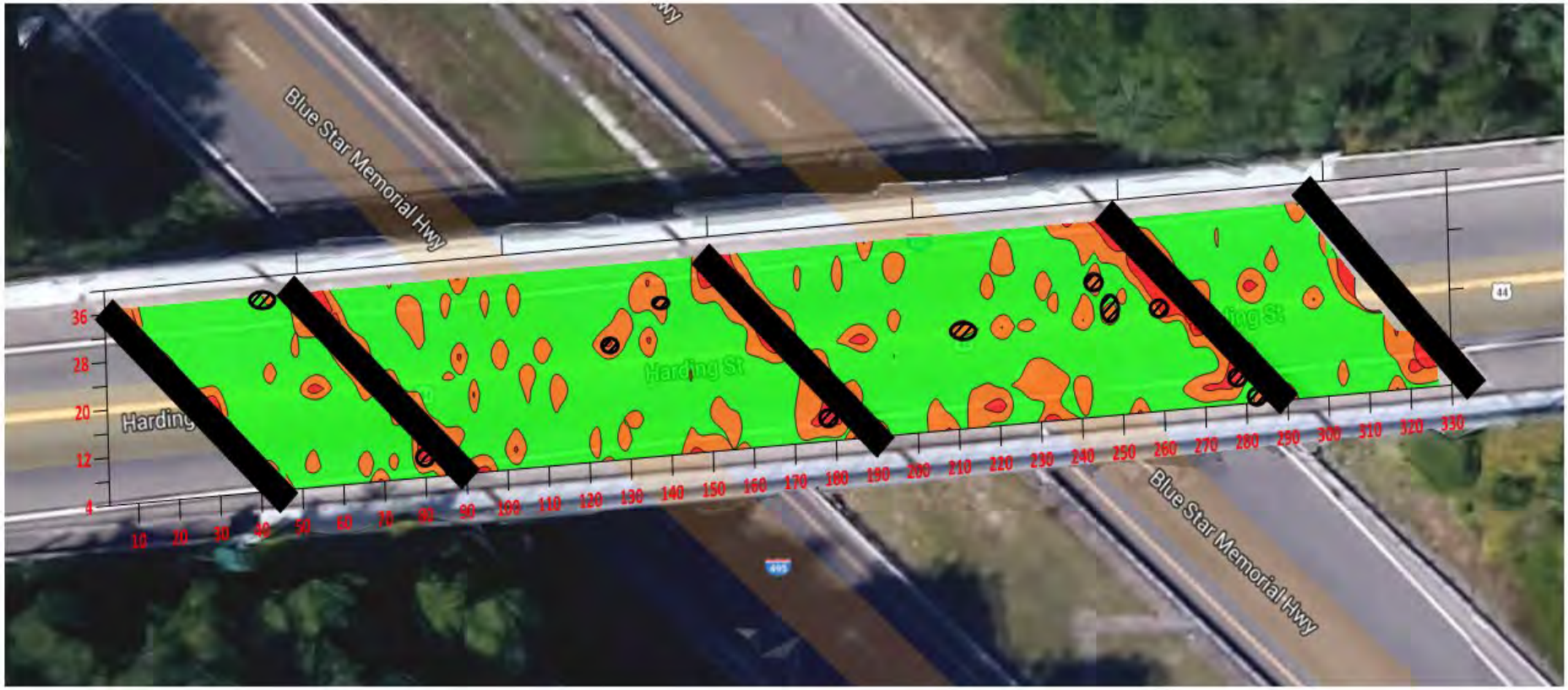

1)  Deck delaminations impact echo measurements at sensor #1

2)  Longitudinal partial deck cracking measurements at sensor #2

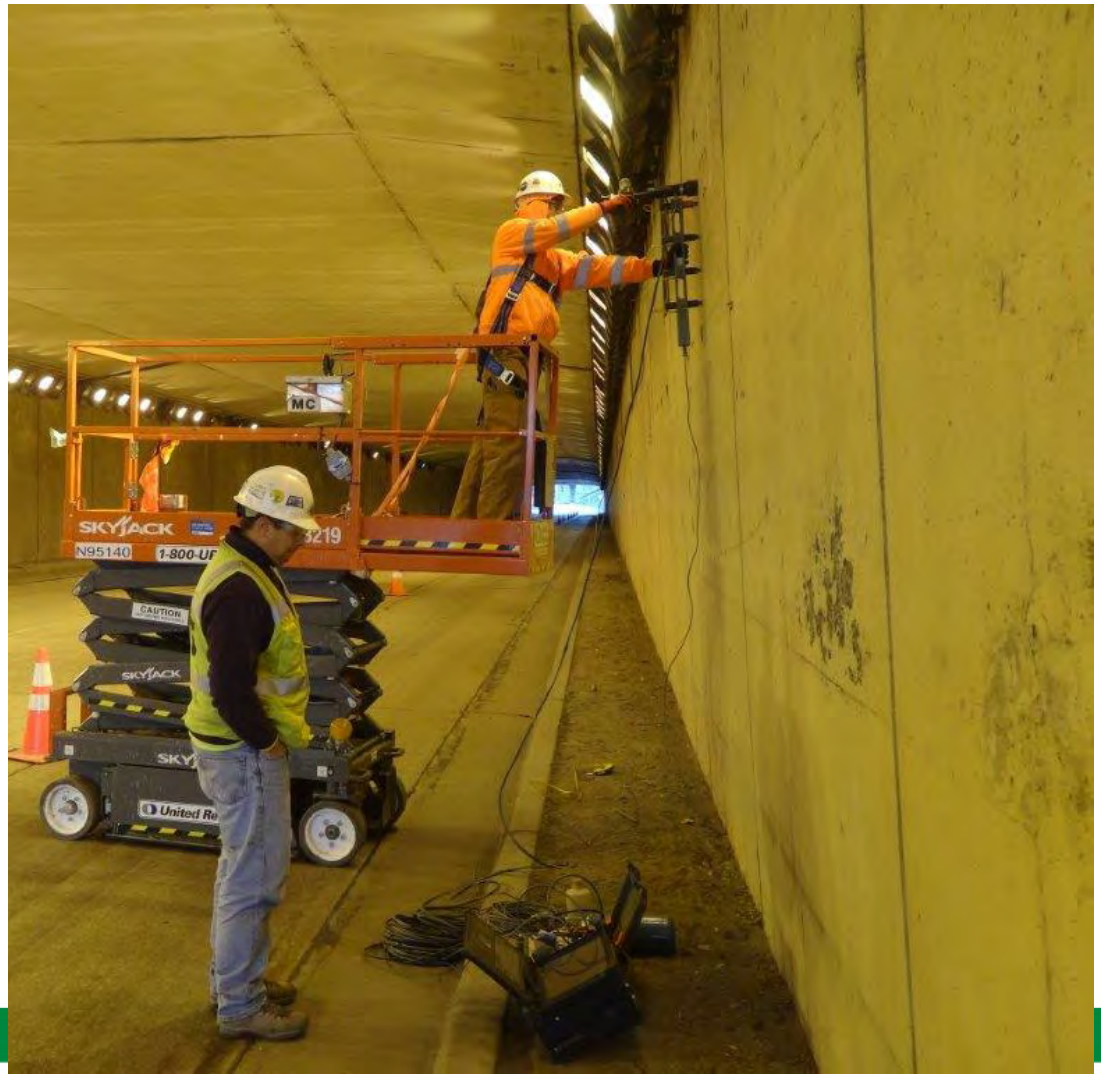
3)  Longitudinal full deck cracking measurements at sensor #3

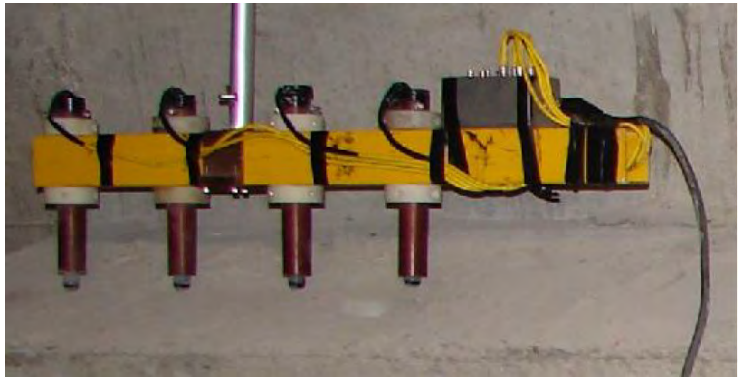
4)  Transverse deck cracking measurements at sensor #4

# Acoustic Deck Testing

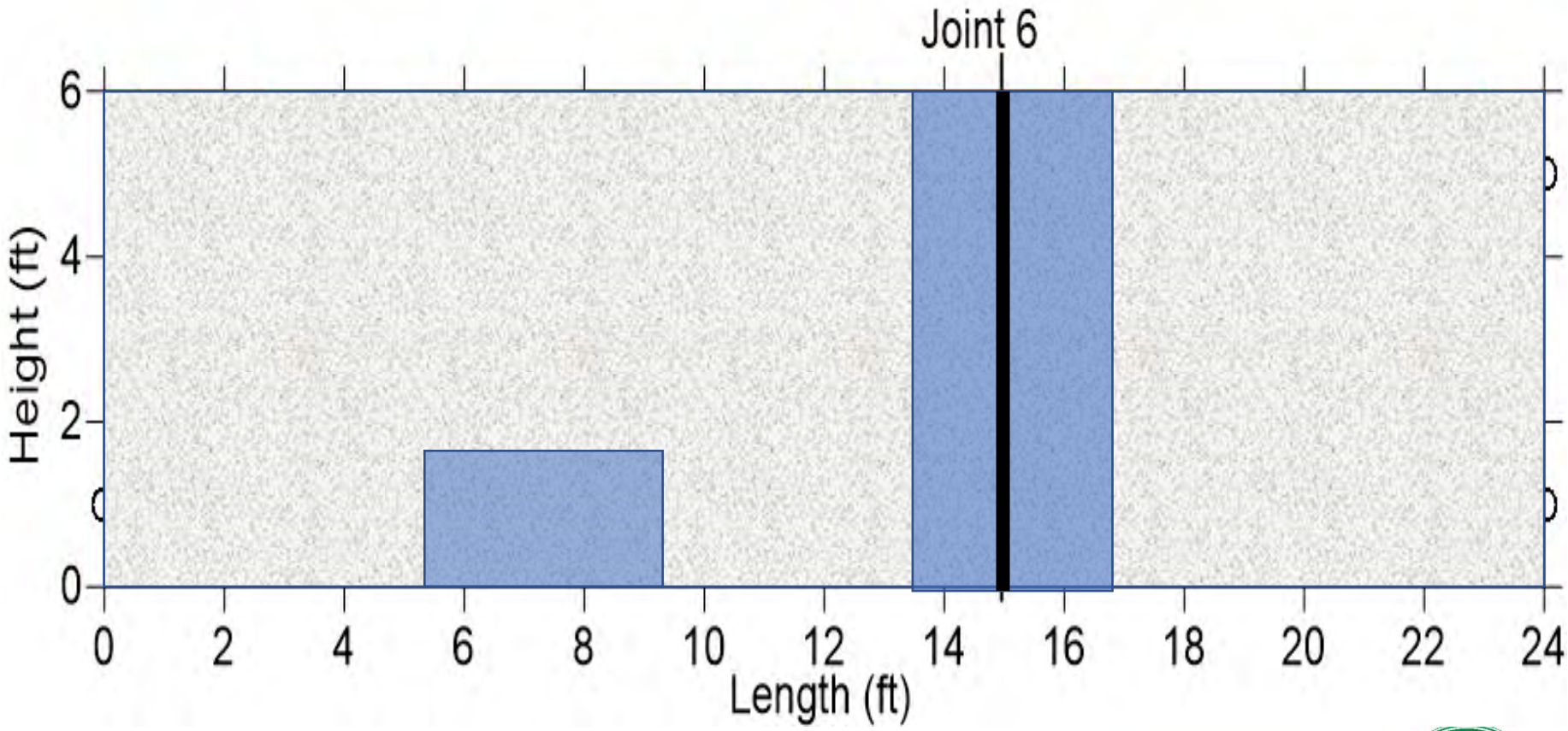


# Acoustic Substructure Testing

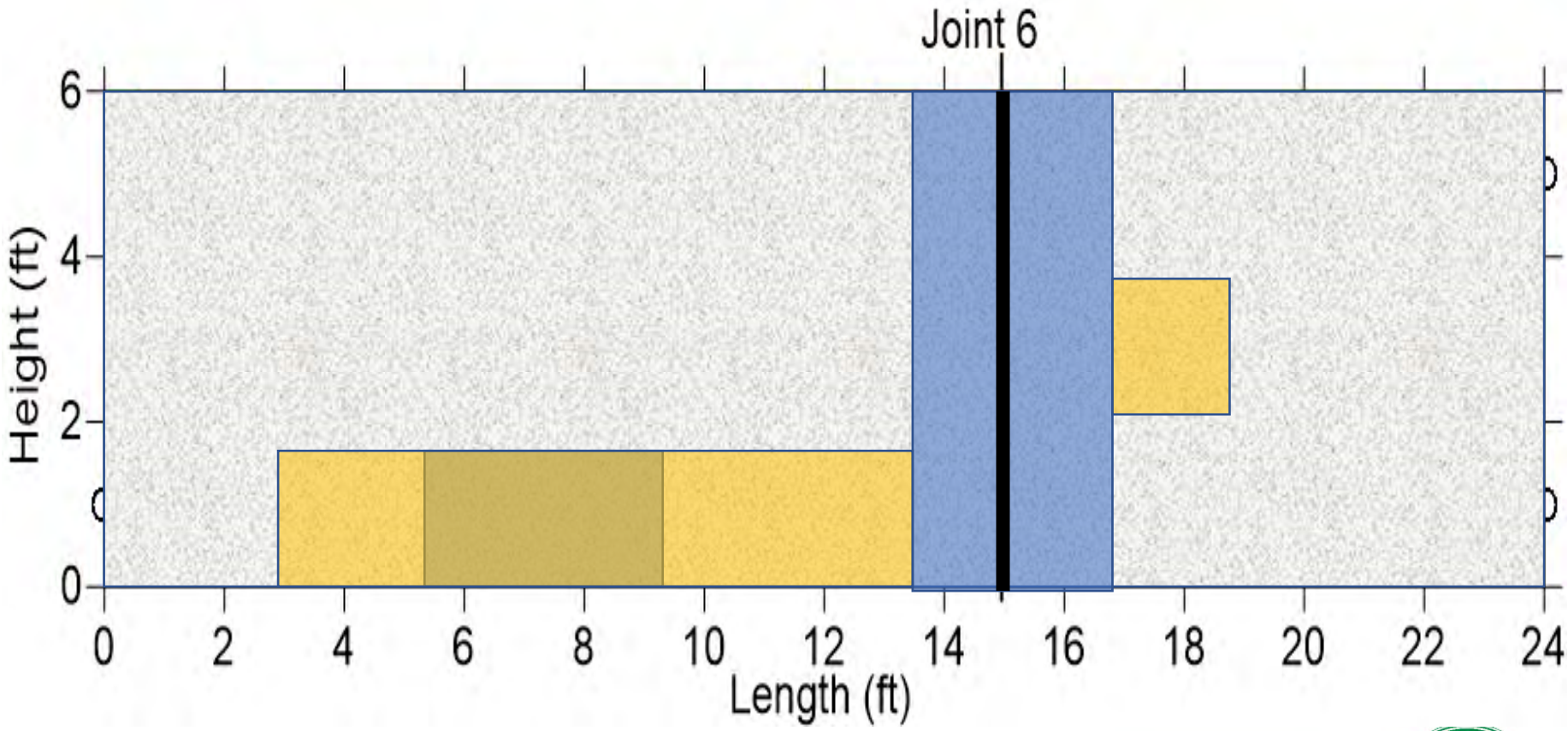


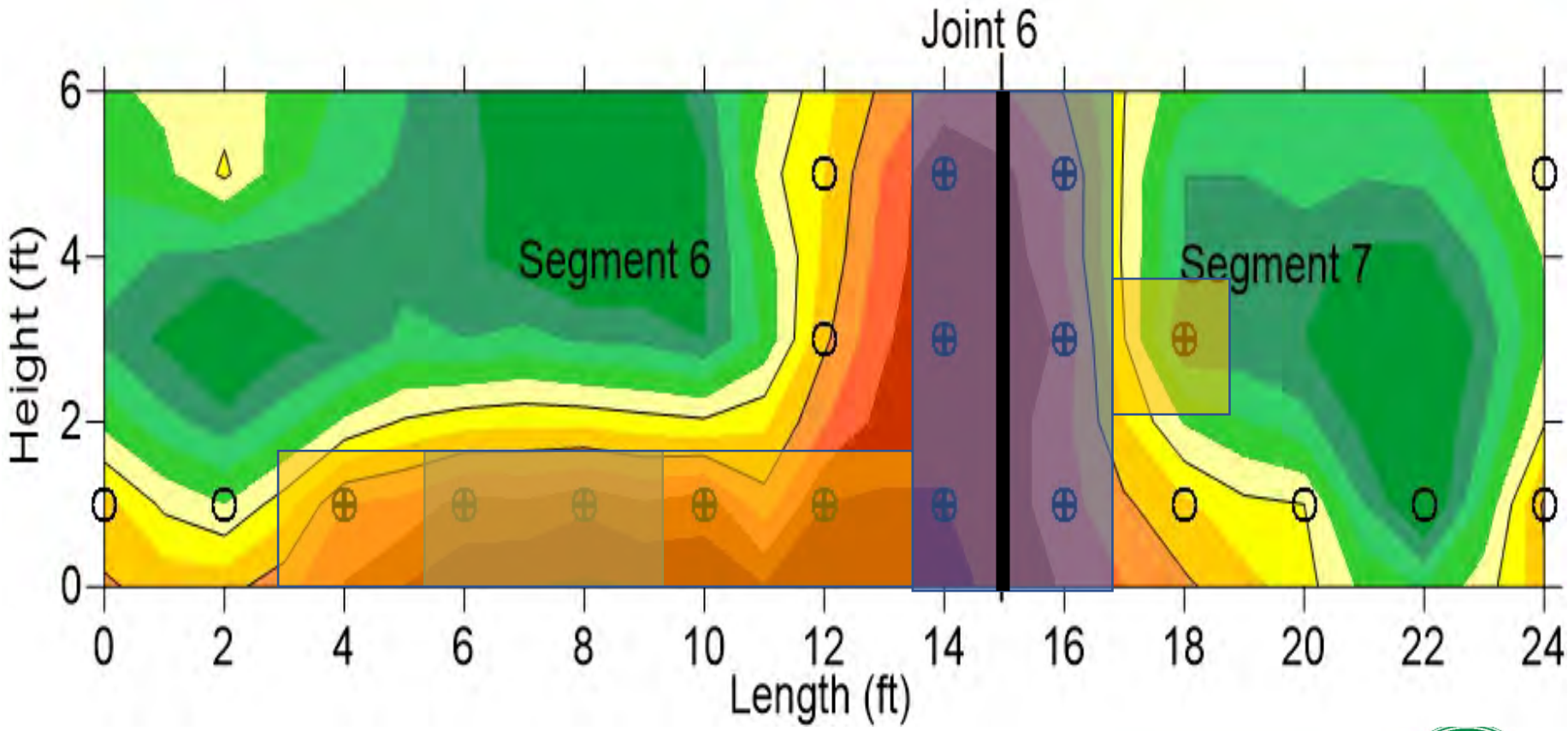
# Delaminations Found by Sounding



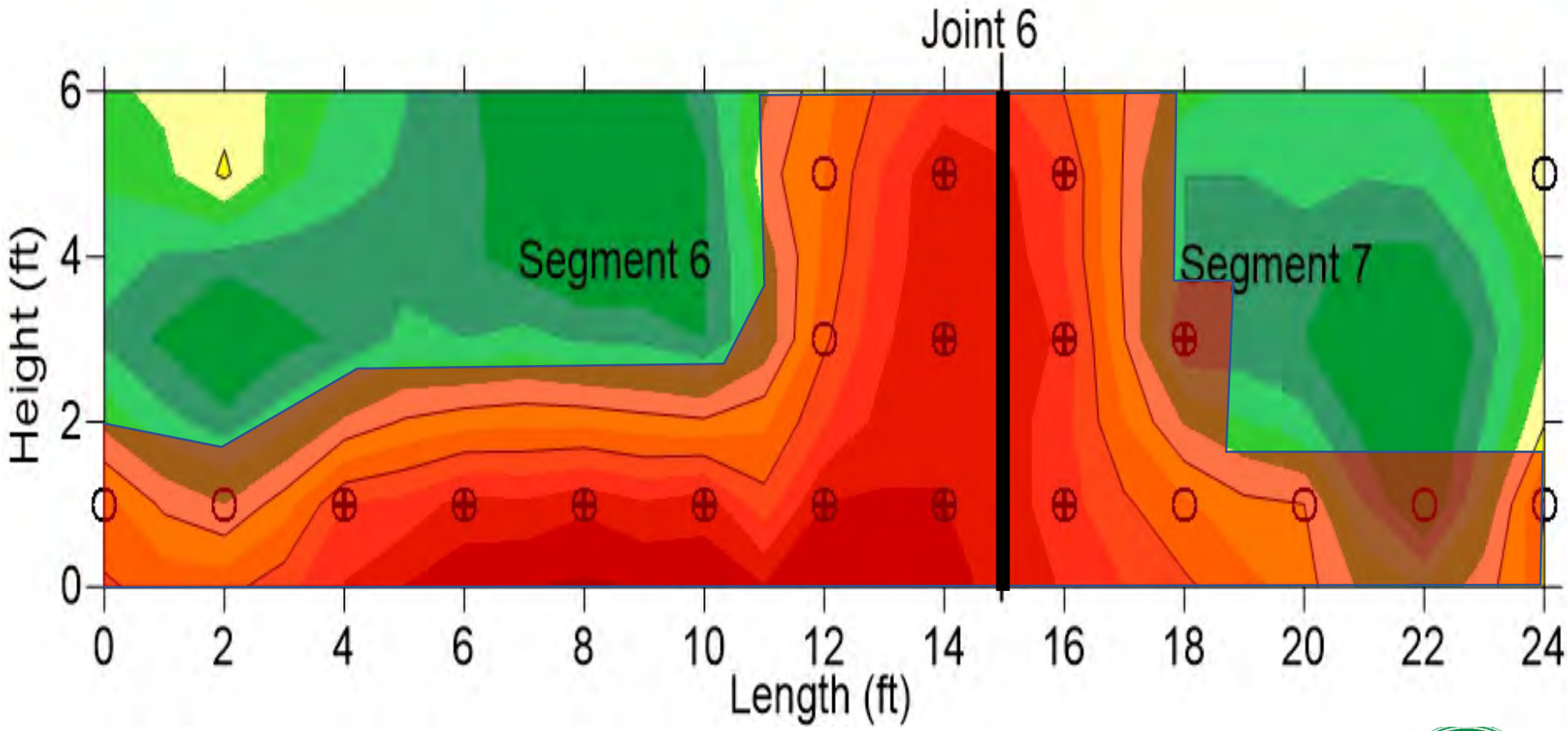
# Delaminations Found by Impact Echo



# Acoustic In-Situ Compressive Strength



# Repair Area


Joint 6
Segment 6
Segment 7
Height (ft)
Length (ft)
0
2
4
6
8
10
12
14
16
18
20
22
24

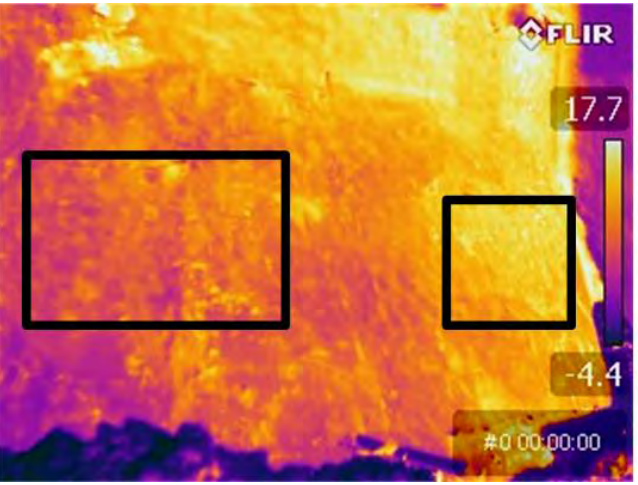
# Infrared Thermography

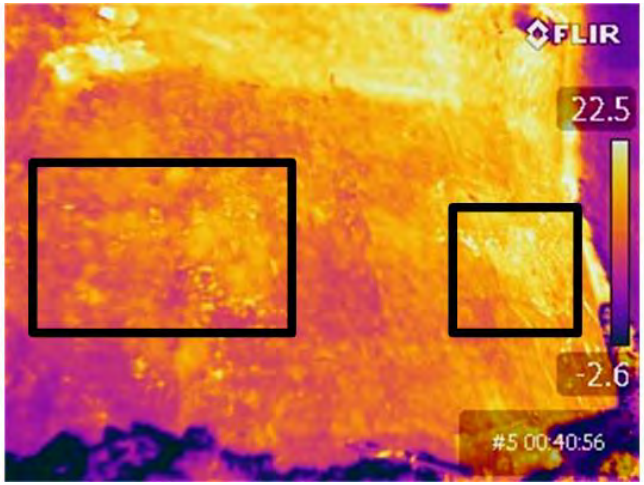
- Delaminations have different thermal properties than sound concrete

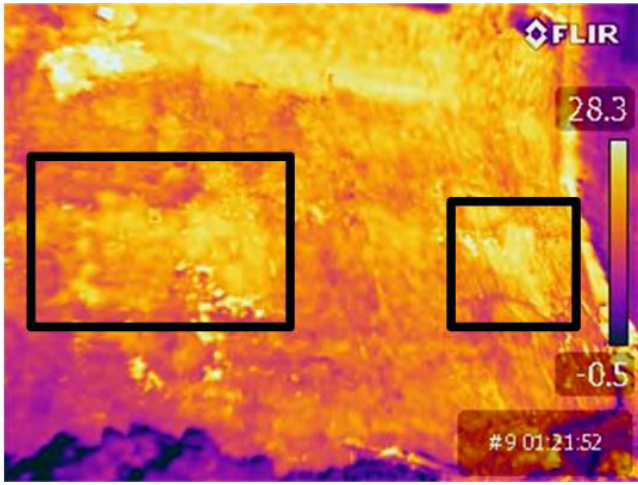
- Result of air-gap caused from the separation of the concrete
- In the morning sun, delaminations heat up faster than sound concrete section

- During evening cooling, delaminations cool down faster than sound concrete section

- Allows for very quick assessment of large areas
- Results are similar to chain drag and hammer sounding



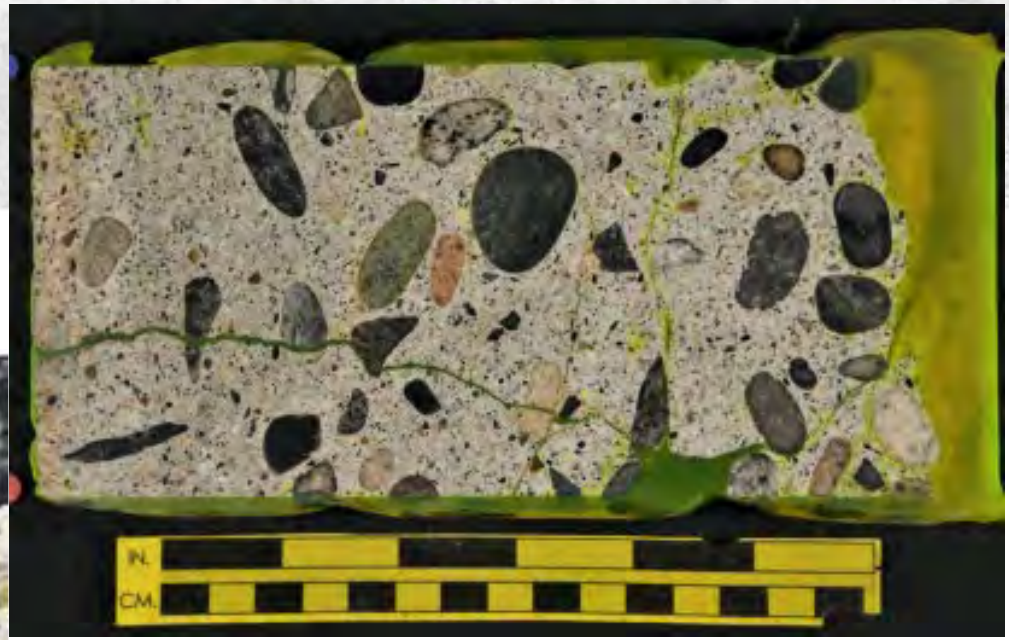
# IR of Arch Bridge

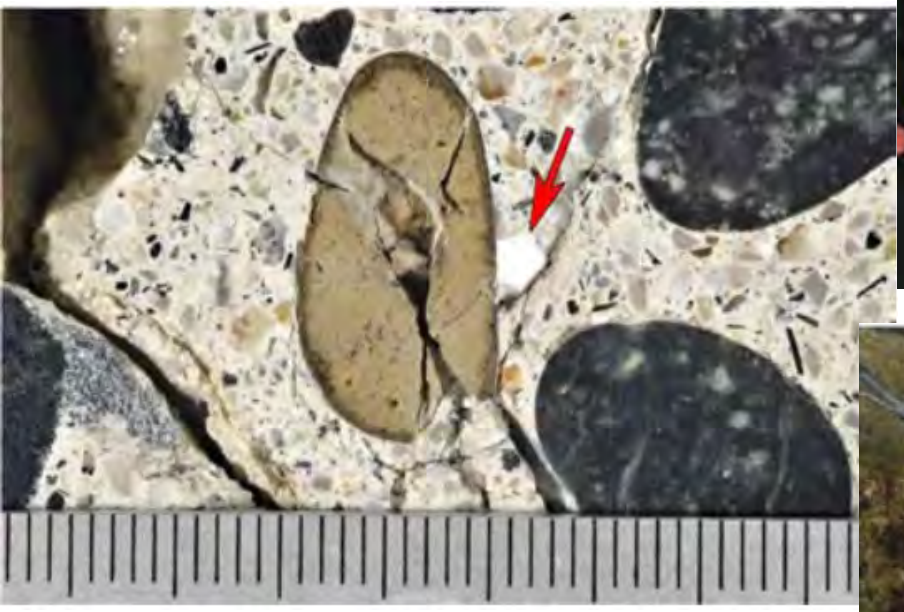
- Hammer sounding survey done several years prior
- Wanted to know growth of deterioration from last survey
- IR provided a quick method to resurvey the concrete

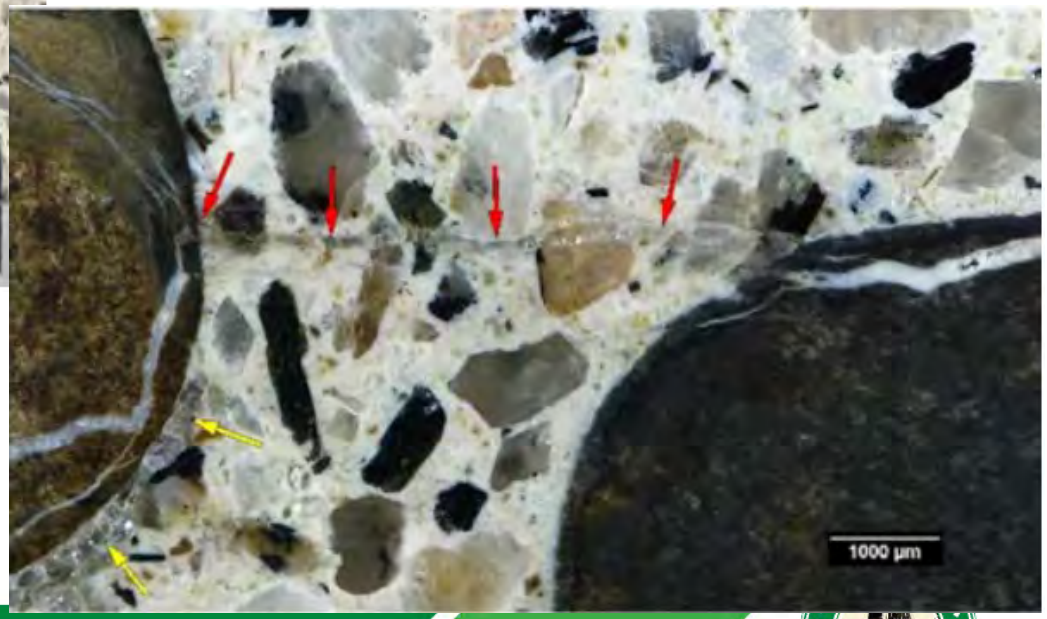

Figure 2: Upstream: Arch Spalling under Spandrel Columns A (left) and B (right)


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

# Petrography





# QUESTIONS?

# Contact Dr. Pailes

Dr. Brian Pailes
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# PROFESSIONAL DEVELOPMENT HOURS

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  - Via E-mail
  - QR code here

# WEBINAR RECORDING & FUTURE EVENTS

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**Sep 9, 2020 | Corrosion Protection and Bridge Concrete Repairs**

George Sergi, PhD

Vector Corrosion Technologies

**Description:** Electrochemical corrosion mitigation techniques were first applied to bridges in the early 1970s to mitigate or arrest corrosion of the reinforcing steel. The field has innovated and the technology has evolved since those early days. The first discrete galvanic anodes were installed in concrete repairs on the substructure of the Leicester Bridge in the UK in 1999. The performance of these anodes has been monitored for 20+ years. This webinar will discuss the development and long-term performance of discrete galvanic anodes on bridge structures in addition to the typical applications such as concrete repairs, joint repairs and bridge widenings.

**Click Here to Register - 7:00 AM EDT / 1:00 PM CEST**

**Click Here to Register - 2:00 PM EDT**

**Oct 14, 2020 | Repair and Protection of Severely Corroded Bridge Substructures with Galvanic**

Chris Ball

Vector Corrosion Technologies

**Description:** Accelerated bridge construction has gained prominence in recent years as a economical way to breathe new life into bridge structures long past their expected service life. The challenge is what to do with substructure elements that are often in as bad shape as the superstructure being replaced. An effective substructure preservation strategy is needed to ensure the expected service of the new substructure matches the expected service life of the existing substructure elements such as the abutments, beams and piers. This webinar will discuss the use of galvanic encasements as an elegant solution to service life extension for substructures and their proven track record.

**Click Here to Register - 7:00 AM EDT / 1:00 PM CEST**

**Click Here to Register - 2:00 PM EDT**

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