

TECHNICAL
TRAINING SERIES

PART OF THE
MOORELEARNING PROGRAM

ASD
004

Nondestructive Evaluation for Structural Repair and Rehabilitation

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Issue date: September 21, 2009
Revised: July 10, 2010

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What is Structural Diagnostics?

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Traditional Design Process

Design

Conceptualize

Schematic Design

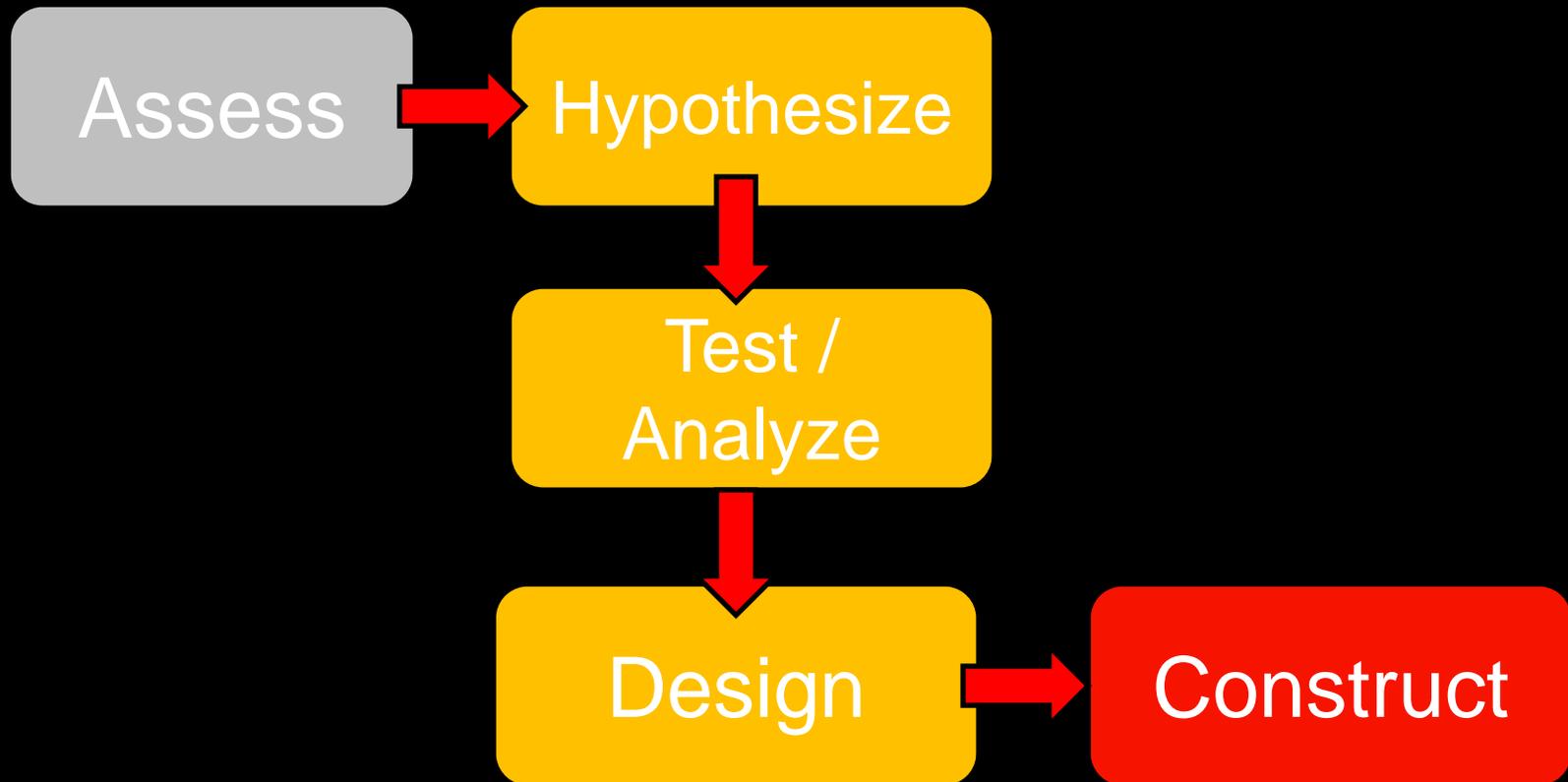
Detailed Design

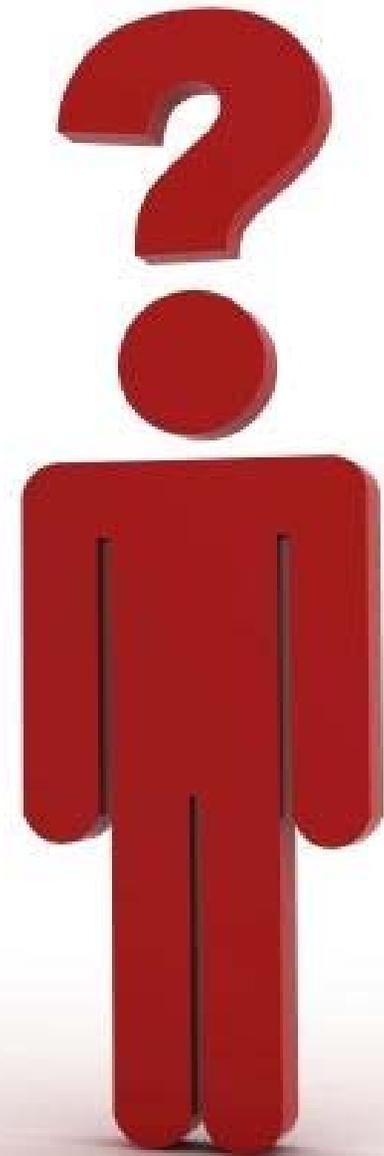
Coordination



Construct

The Diagnostic Process





Introduction to NDE

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Agenda

- Overview of NDE
- Physical phenomena
- NDE techniques
- Case studies

How Do We Characterize Structures?



What is Nondestructive Evaluation?

Methods for assessing the condition of a structure without causing any structurally significant damage.

Destructive vs. Nondestructive



Original Approach
(bad)

NDE Approach
(better)

When is Nondestructive Evaluation Used?

- Quality control of new construction
- Condition assessment of structures
 - Rehab
 - Due diligence
 - Change of use
- Quality control of repairs
- Identify as-built construction

What are Types of NDE for Concrete Structural Evaluation?

Visual

Electromagnetic

Stress
Wave

??

Nuclear

Electrical

Magnetic

What are Common Types of NDE Methods?

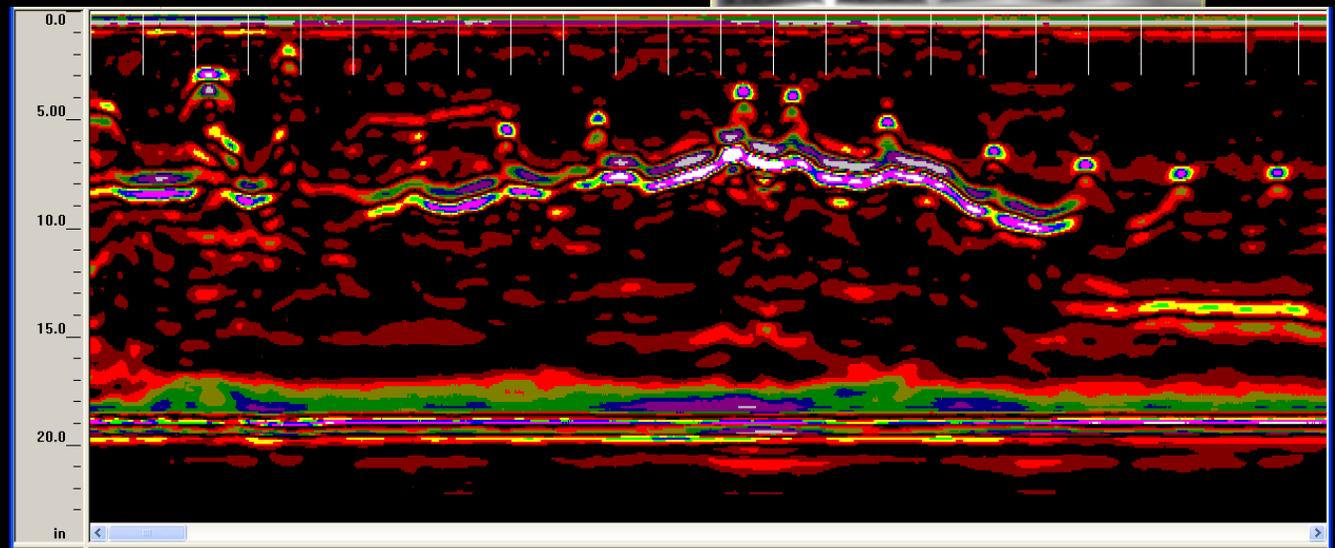
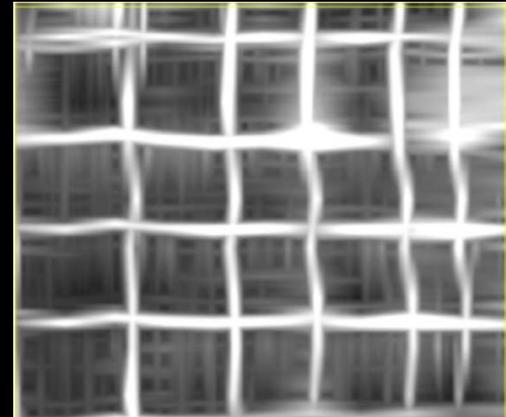
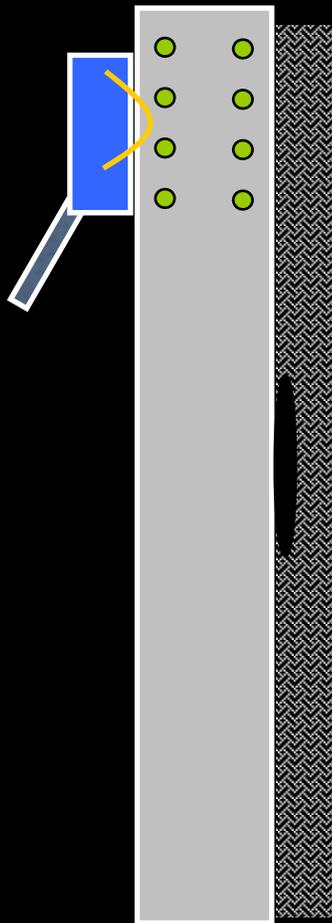
- Short pulse radar
- Stress wave
 - Impact-echo
 - Impulse response
 - Ultrasonic pulse velocity
 - Ultrasonic Echo
- Electric & Magnetic
 - Half-cell potential
- Nuclear
 - Radiography

Short Pulse Radar (SPR)

- Commonly known as GPR
- Reflected electromagnetic waves
- Applications
 - As-built conditions
 - Rebar location
 - Voids beneath slabs
 - CMU grouting
 - Honeycombing
- Limitations
 - Wet soils
 - Cannot detect small discontinuities

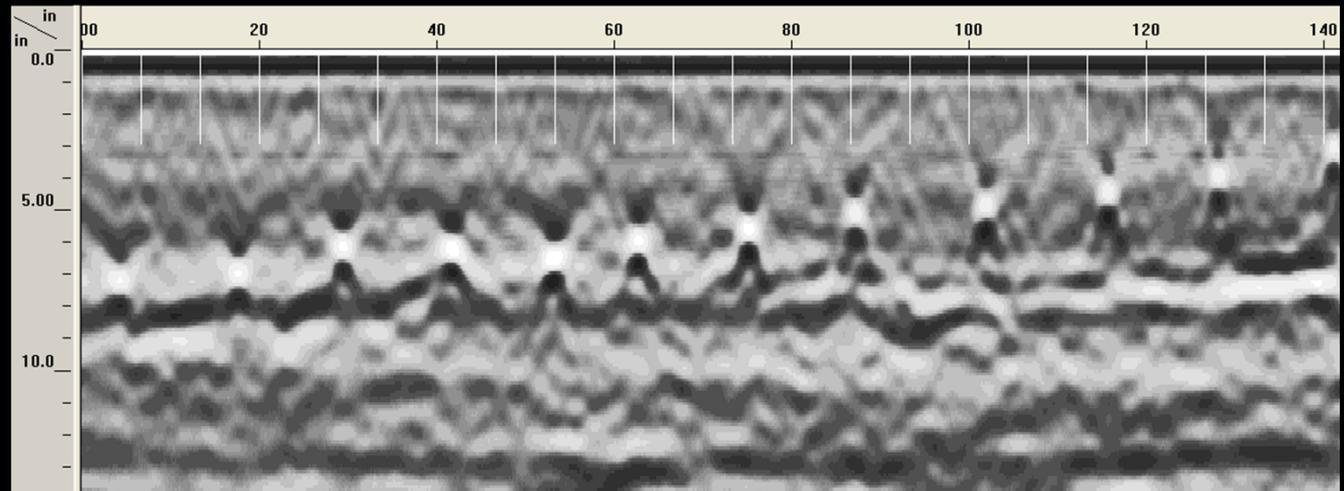


SPR Schematic

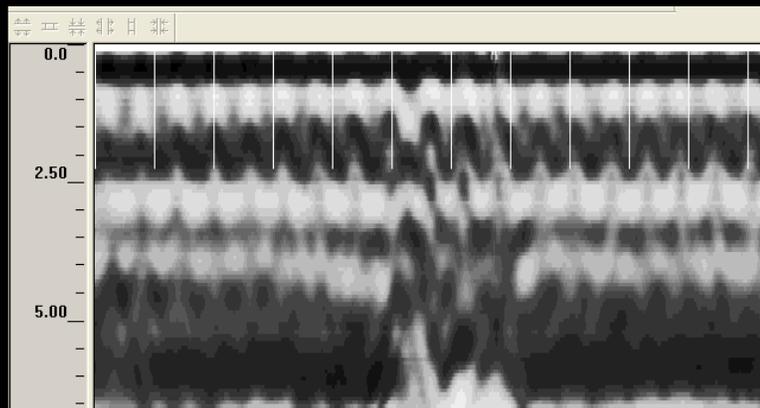


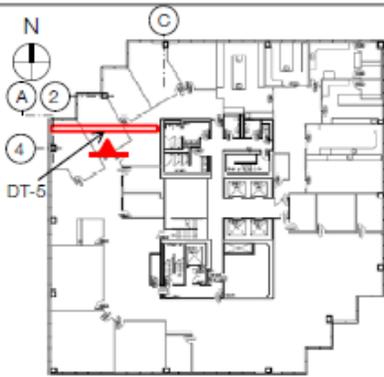
SPR: Common Limitations

PT Slab

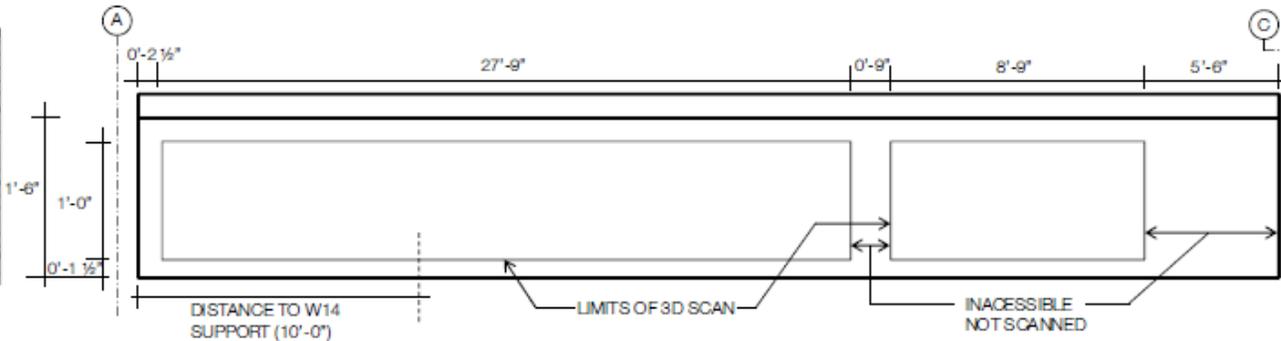


4x4 WWR

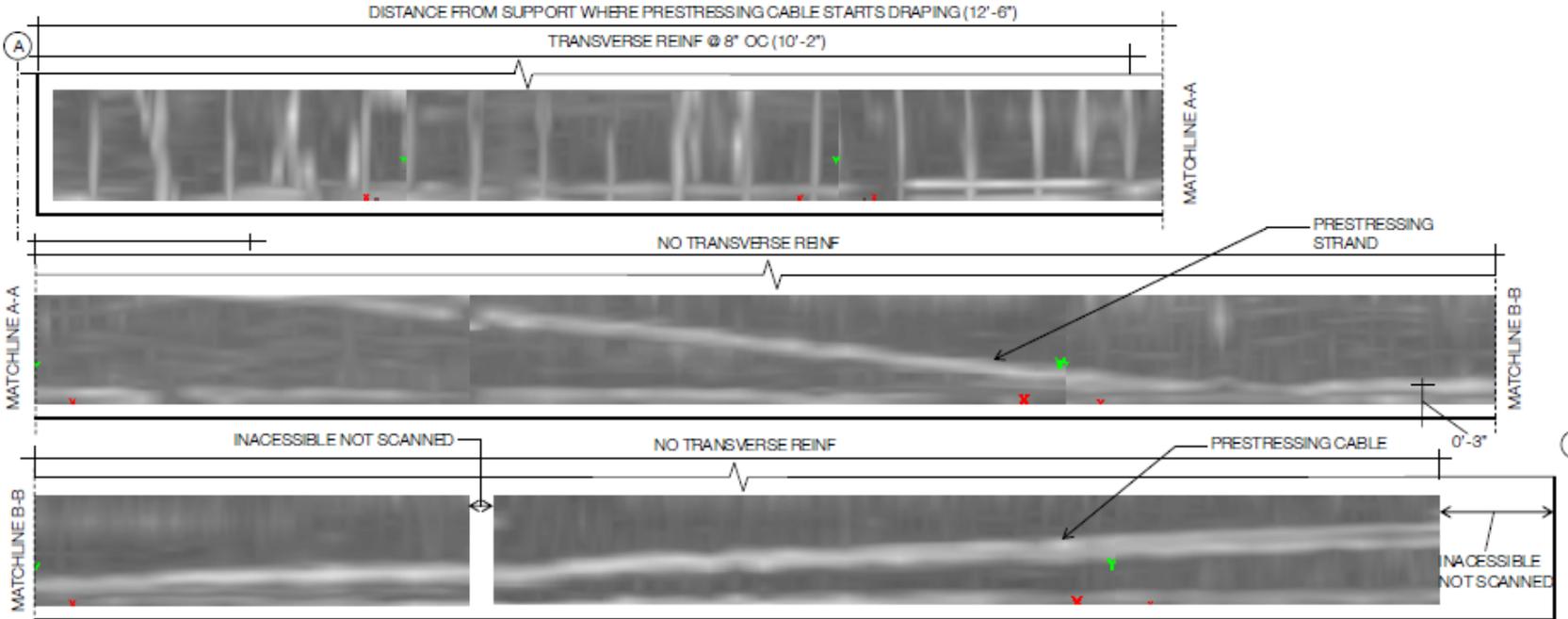




KEY MAP LEVEL P2



ELEVATION: GRID LOCATIONS (NTS)



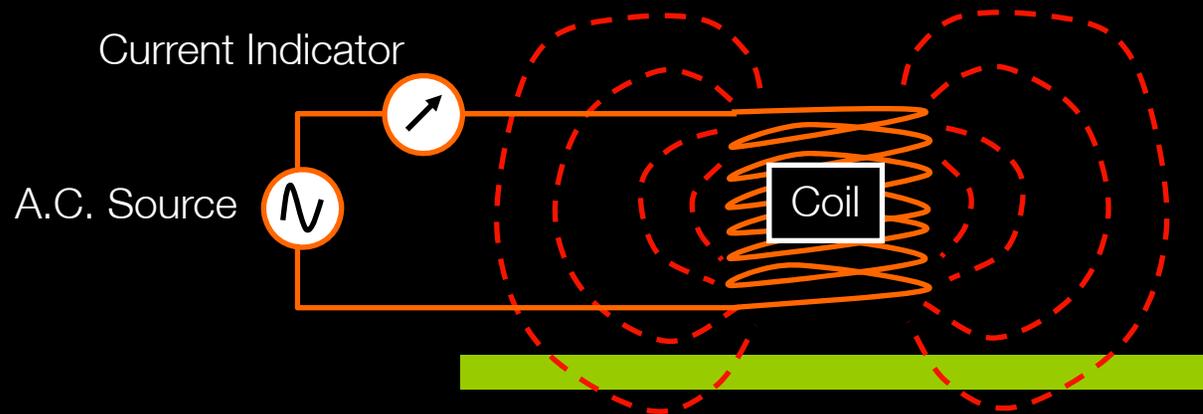
1 LEVEL P2 DOUBLE-TEE STEM DT-5 BETWEEN GRID LINES A & C AND 2 & 4

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 WALTER P. MOORE AND ASSOCIATES, INC.
 13730 MARINE DRIVE, SUITE 100
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Project Name		Client	
No.	Date	Description	Drawn By
	08/04/2010		JR/DB/UP
Proj No.	MOE-10014-00	Eng.	JR/DB/UP

Sheet: EX-D5

Cover Meter Schematic



- Presence of bar causes electrical flow
- Generates a secondary current
- Reinforcement inferred by monitoring current

Stress Wave Methods

- Induce a stress wave (impact)
- Measure response



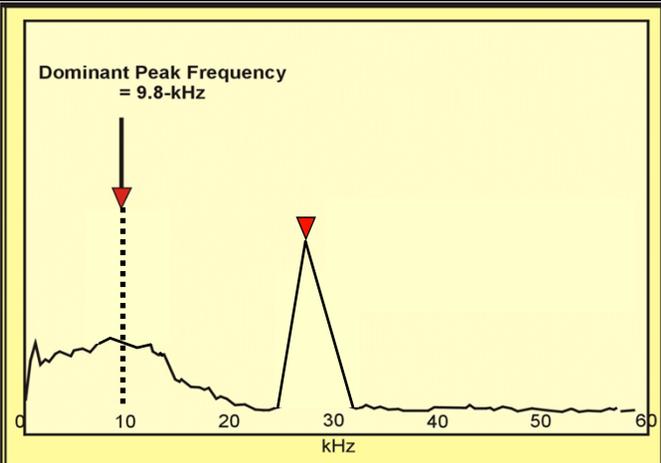
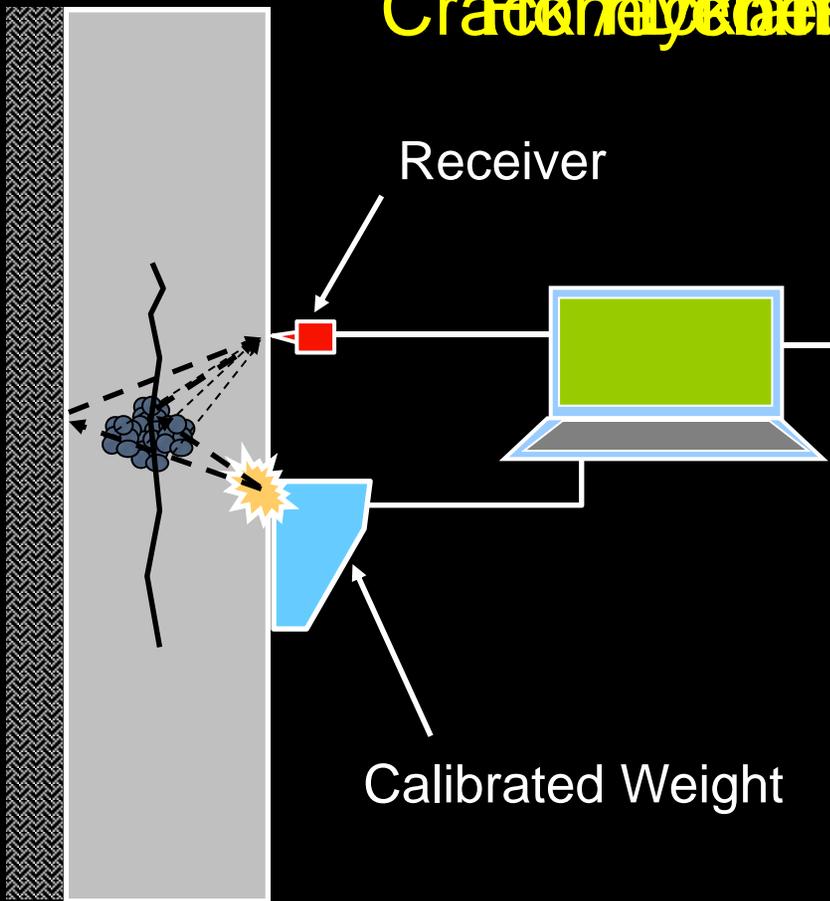
Impact-Echo

- Measure properties of reflected P-wave
- Applications
 - Concrete thickness
 - Crack depths
 - Delaminations
 - Unconsolidated concrete
- Limitations
 - Near surface discontinuities
 - Edge effects



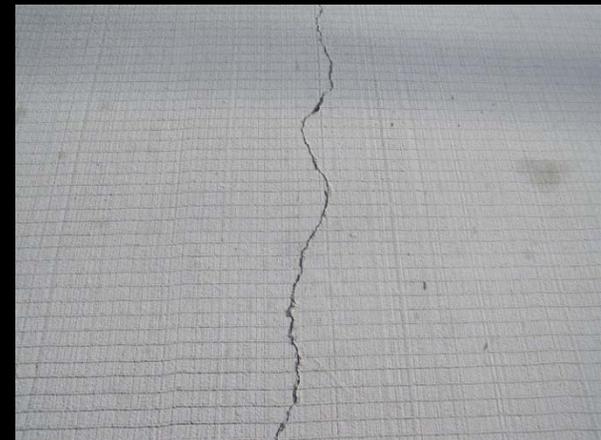
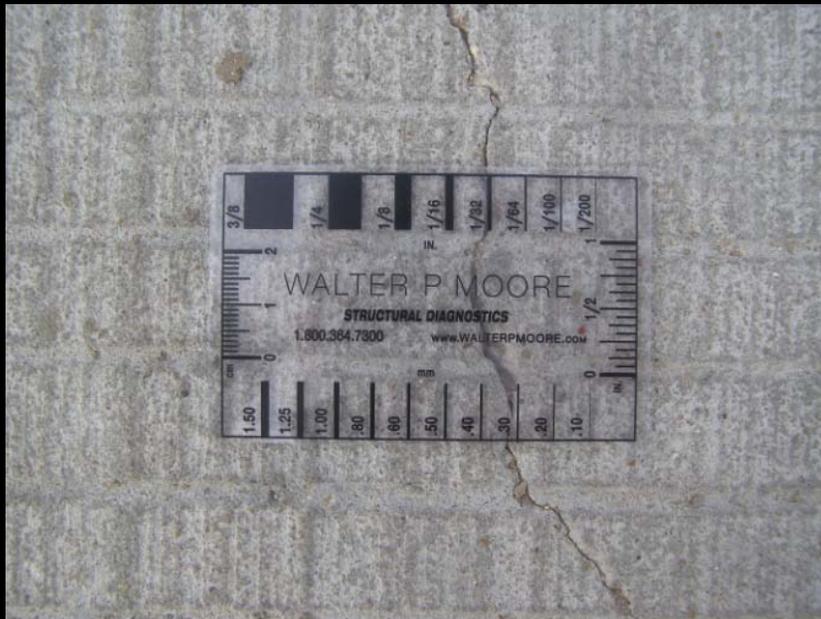
Impact-Echo Schematic

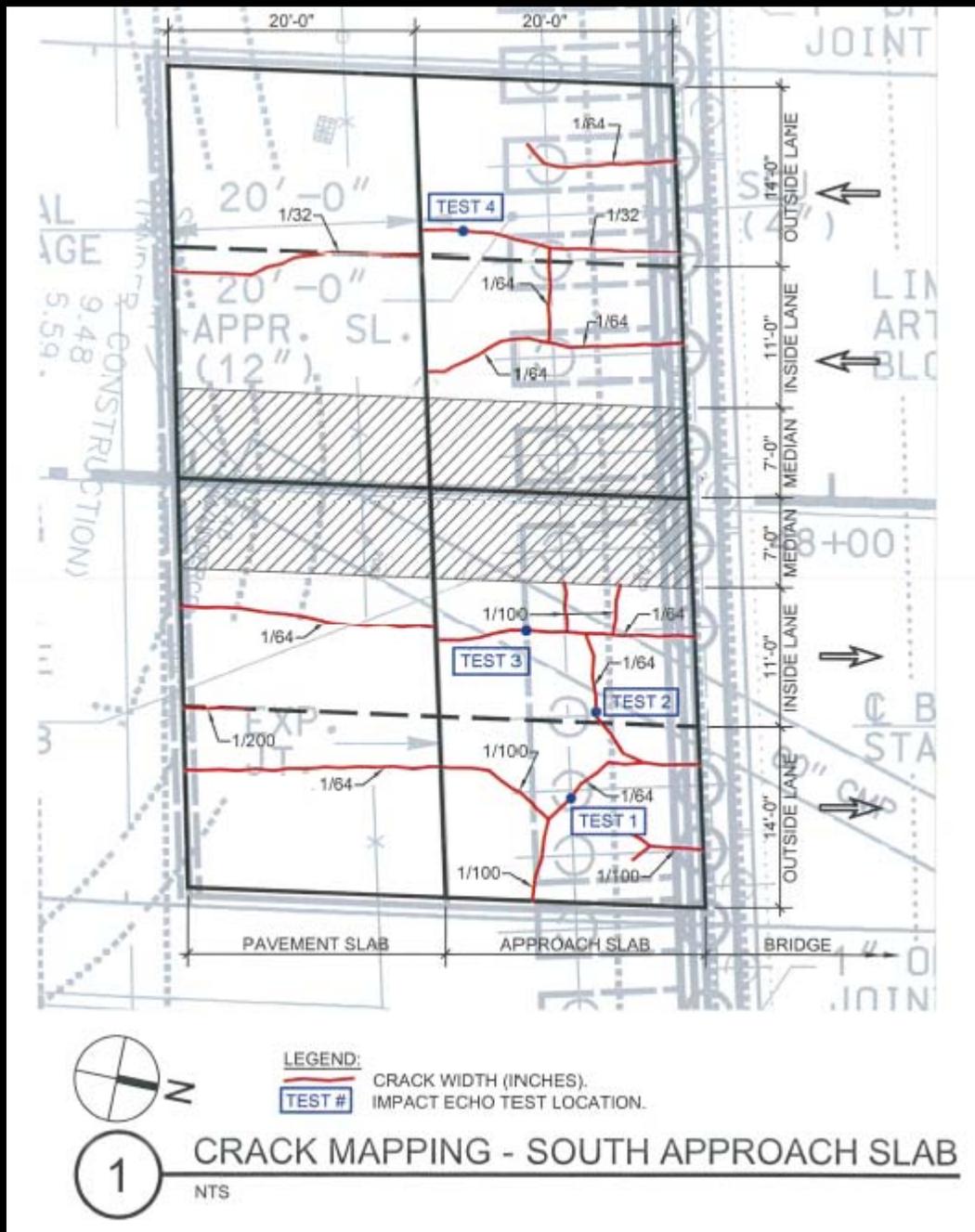
Crack Detection



Cambridge Street Approach Slab Cracking

- Constructed in 2008
- Cracking in 2009

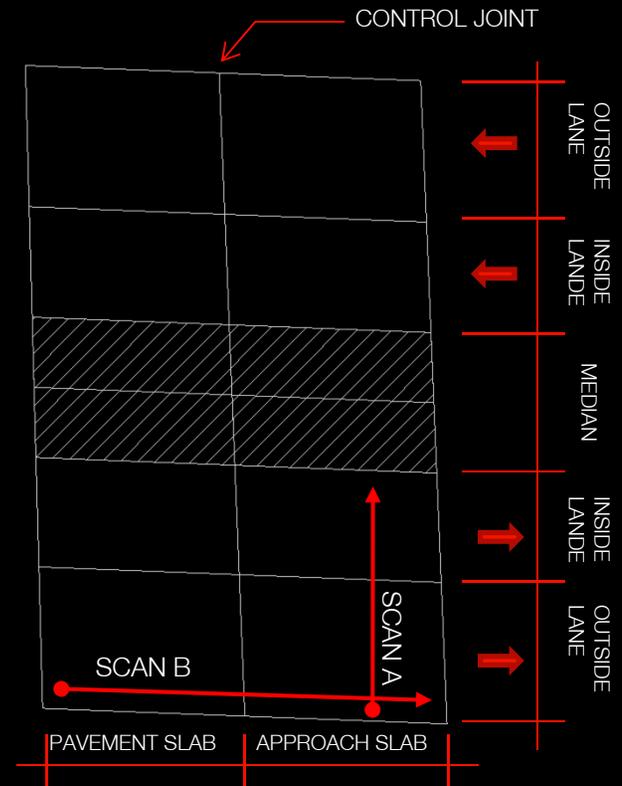
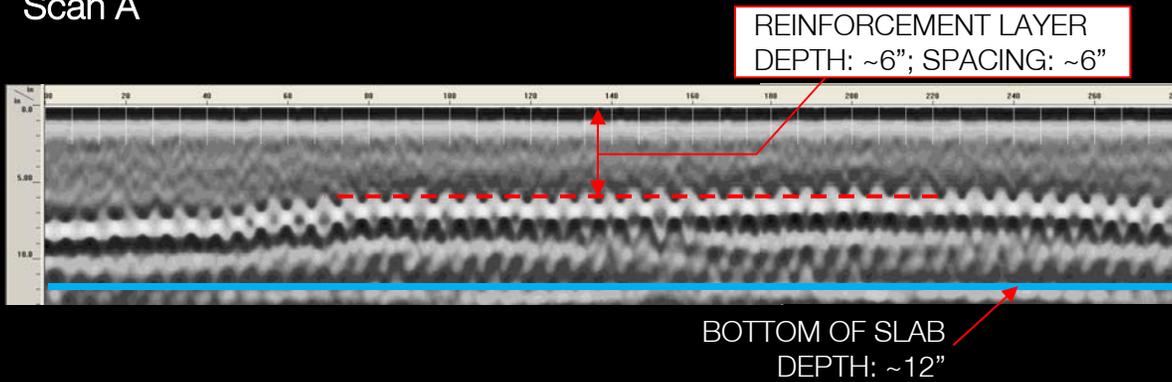




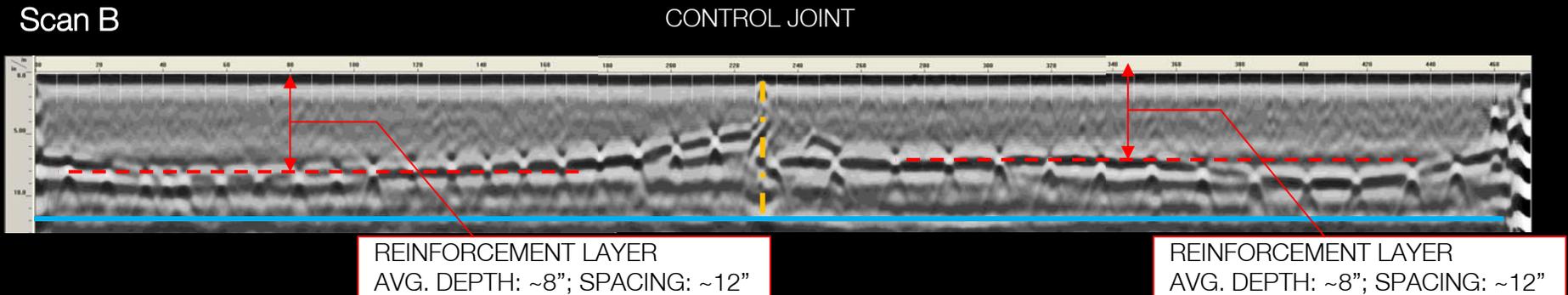
- 12" thick reinforced concrete slab
- Two layers of reinforcement
 - #5 bars @ 12" OC
 - Top and bottom
- *Are there voids beneath the slab causing settlement?*

Approach Slab GPR

Scan A

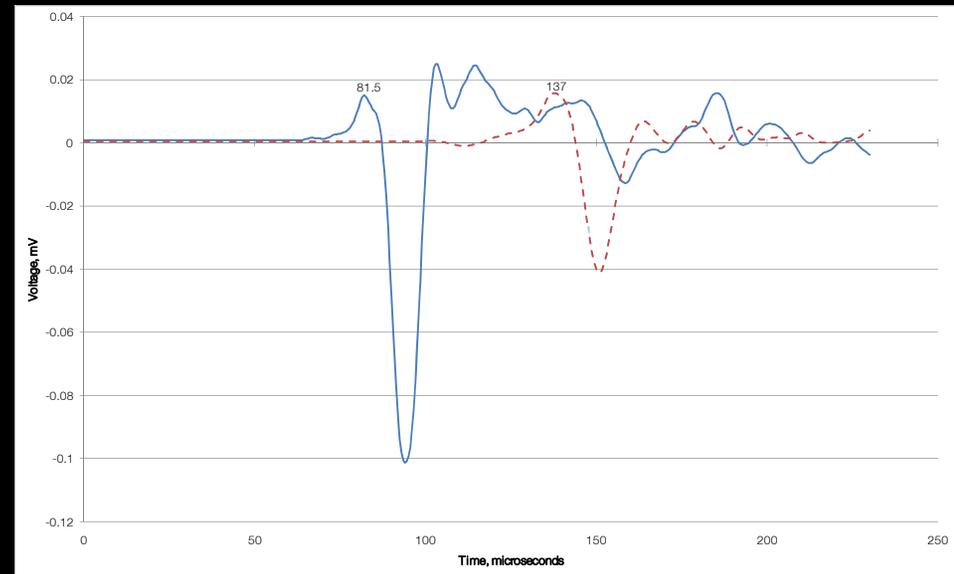
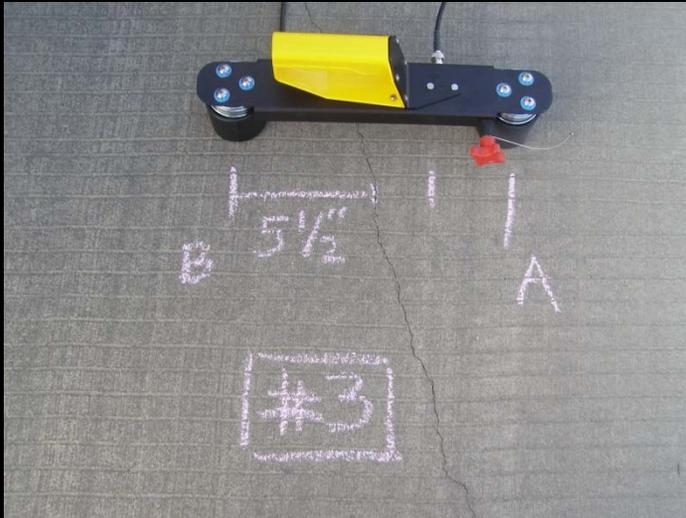


Scan B



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Impact-Echo Surface Crack Depths



	t_1 (μs)	t_2 (μs)	Δt (s)	D (in.)
Test 1	81.5	137	7.53E-05	7.69
Test 2	81	130	6.88E-05	6.79
Test 3	83.5	132.5	6.88E-05	6.79
Test 4	59	99	5.98E-05	5.48
Test 5	41	73.5	5.23E-05	4.29

Validation!



FDA Building 71

- Under Construction – 2012
- Two reinforced concrete structures
- Connected by steel framed breezeway
 - Supported on steel brackets



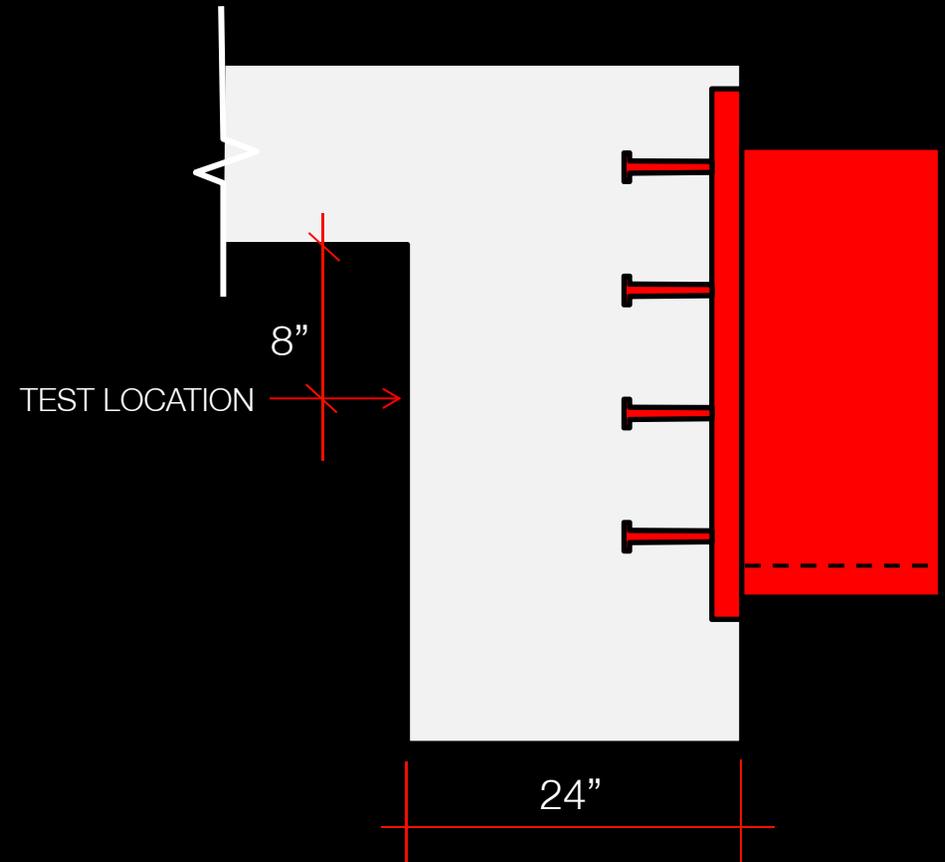
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FDA Building 71

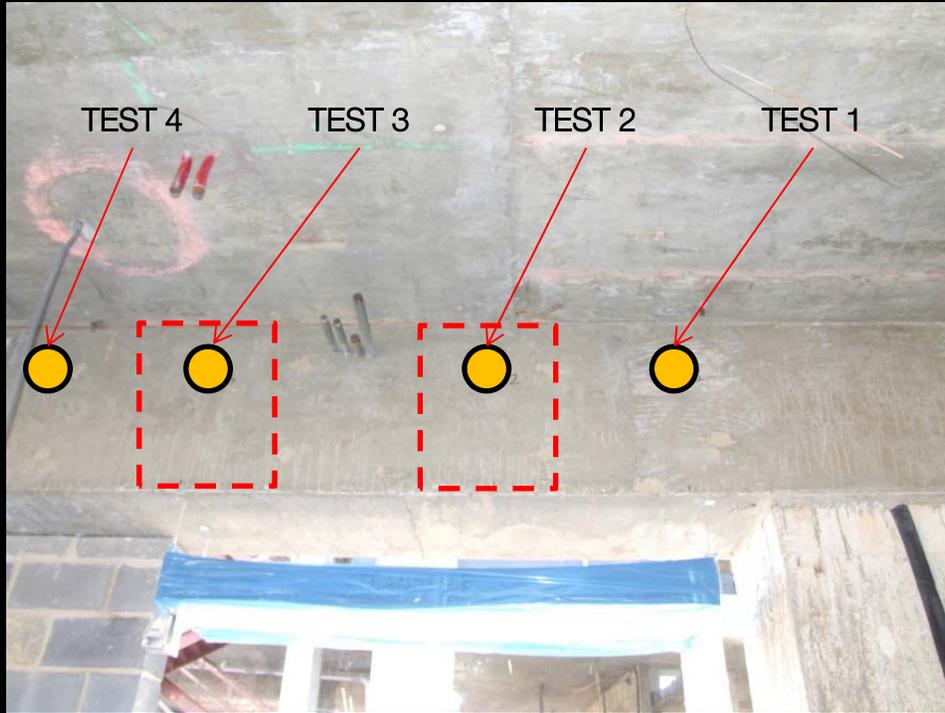
- Welding
- Torch Cutting
- *Has the concrete behind the embed plate experienced heat damage?*

FDA Building 71

- Impact Echo testing

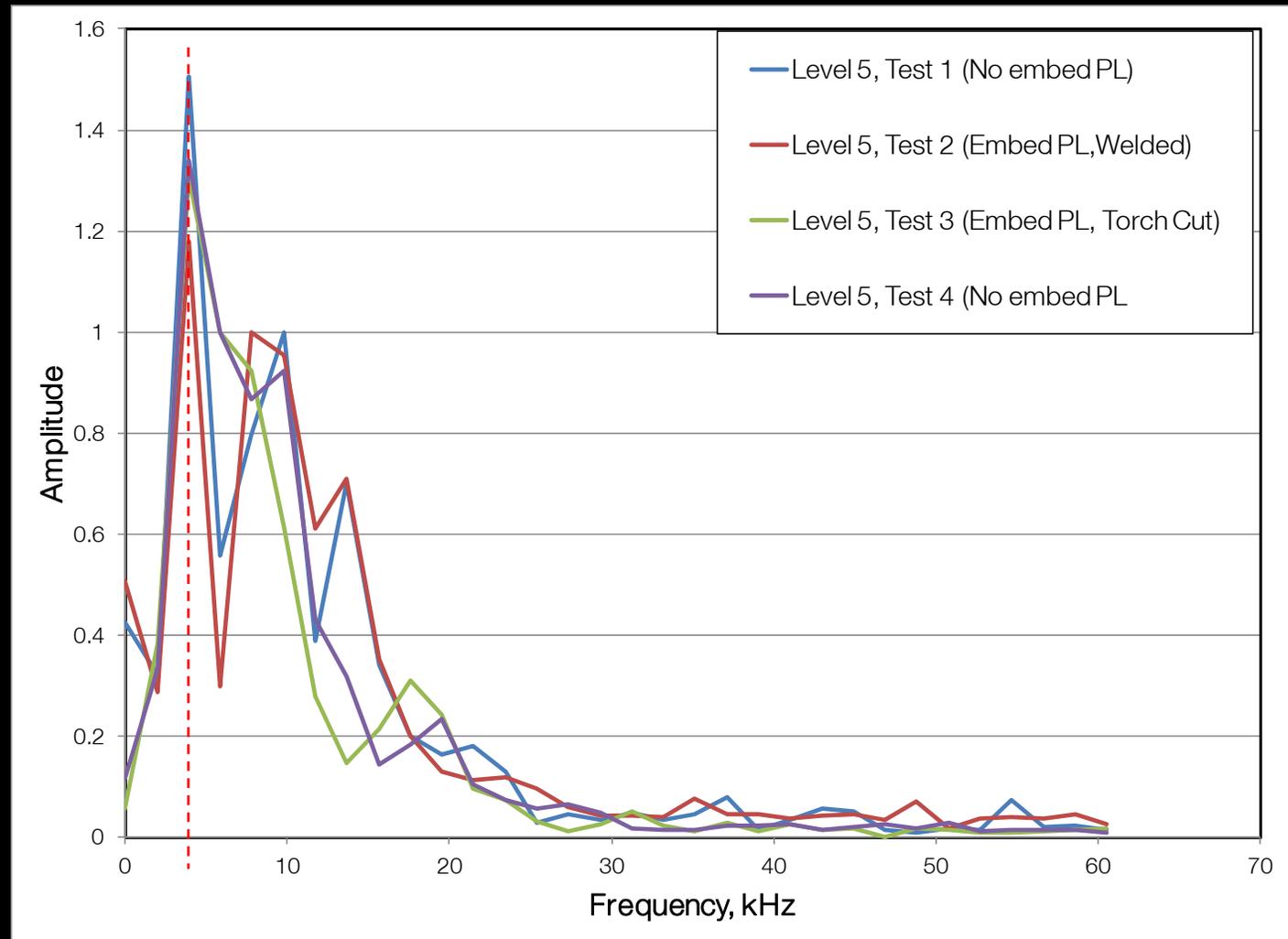


SECTION VIEW OF TYPICAL TEST LOCATION



TYPICAL TEST LOCATIONS

FDA Building 71: Testing Results



TYPICAL FREQUENCY DOMAIN RESPONSE

Impact of Testing

- Cost to perform testing: \$4,500/day + expenses
- Total cost of testing: ~\$17,000

- Approximate cost of repairs:
 - Chip out and replace concrete: \$25,000 per beam
$$\begin{array}{r} \text{x } \underline{\quad 6 \text{ beams}} \\ \$150,000 \end{array}$$

Case Study: Bobby Dodd Stadium



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Case Study: Bobby Dodd Stadium

- \$75 Million Expansion project
- Design Build Project
- Tight Schedule
- High Profile



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Case Study: Bobby Dodd Stadium

- Testing
 - SPR
 - Impact Echo



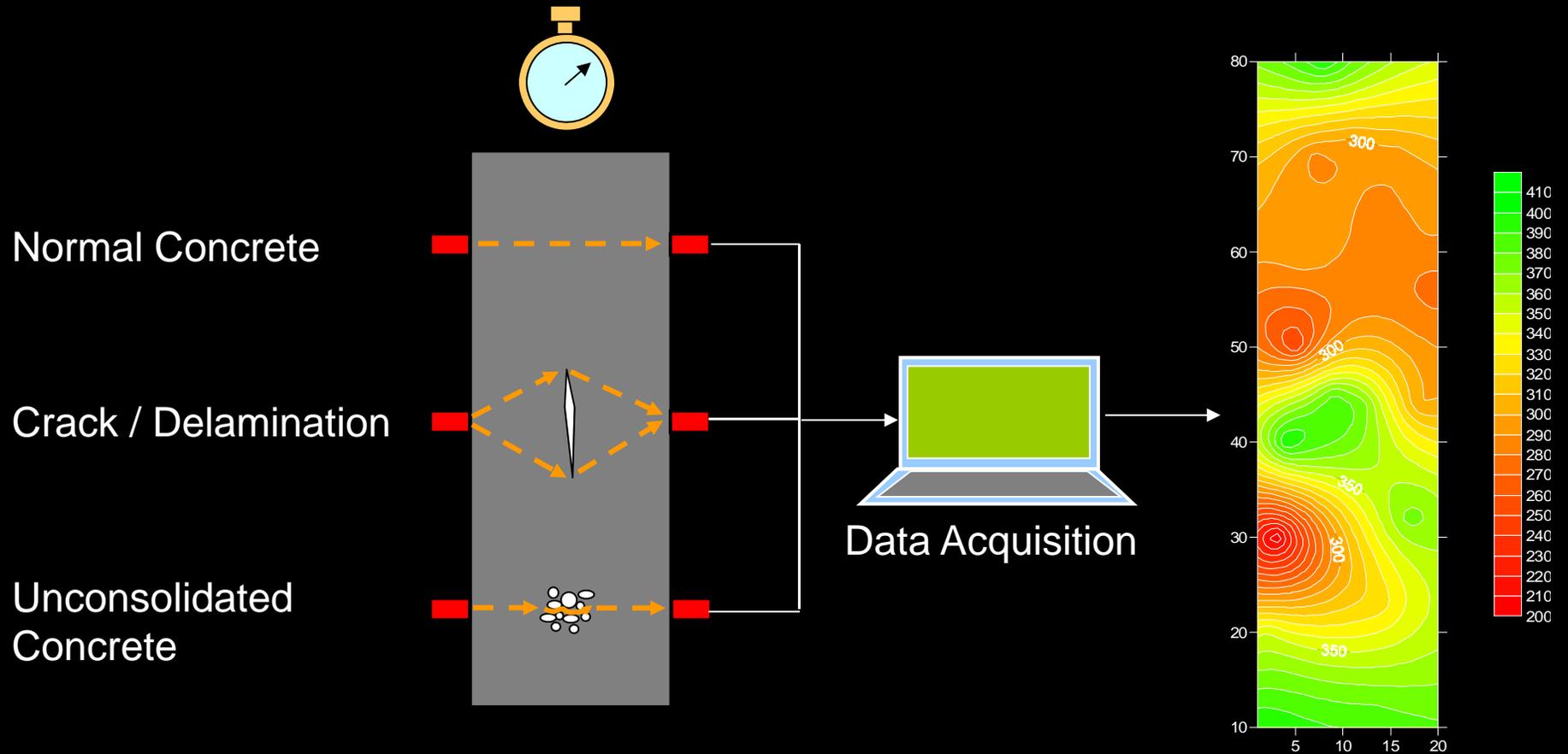
Findings of Field and NDT Study

- SPR of the columns
 - Concrete cover varied between 2” – 6”
 - Tie spacing was large at the embedment plate
 - Headed studs located outside rebar cage
- Impact Echo determined cracks were deep and hence needed to be repaired.

Ultrasonic Pulse Velocity (UPV)

- Wave speed through concrete
- Applications
 - Delaminations
 - Unconsolidated Concrete
 - Concrete material properties
- Limitations
 - Access to both sides (preferred)
 - Qualitative

UPV Schematic



Parking Garage Fire

- Reinforced concrete pan-joint deck
- Ford F-150 @ 2 AM
- Visible spalls and delaminations
- Pink concrete
- *What is the extent of area which requires repair?*



Parking Garage Fire

- Options
 - Visual
 - Cores
 - NDE (!!)

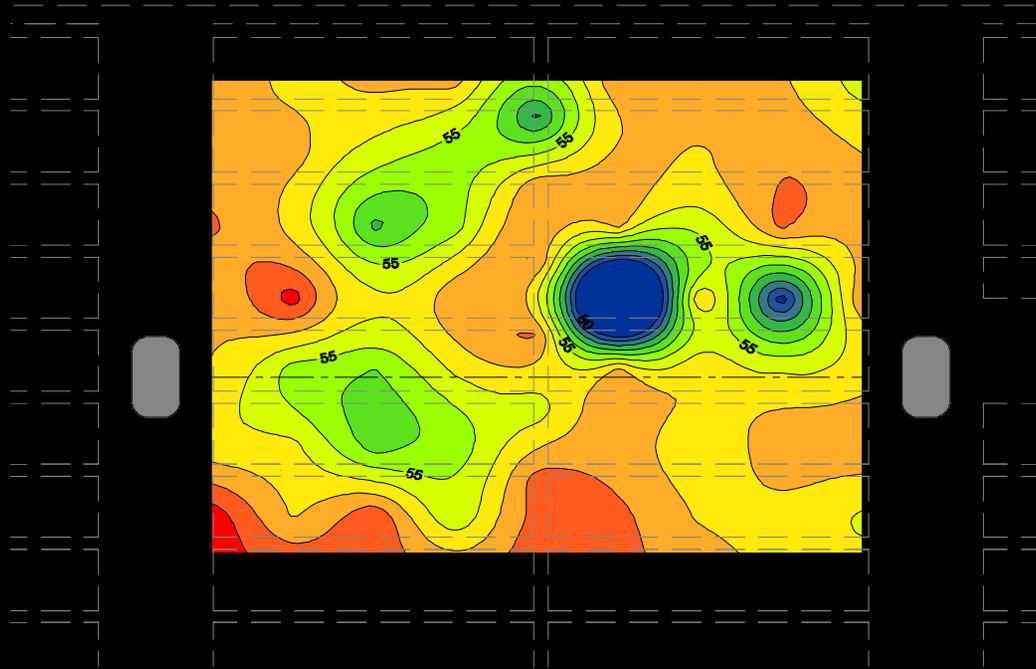


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Parking Garage Fire

9

10

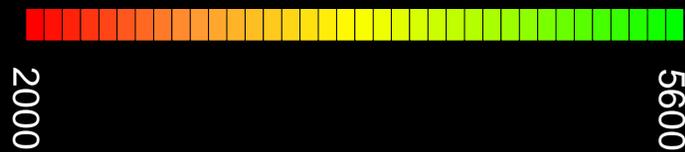
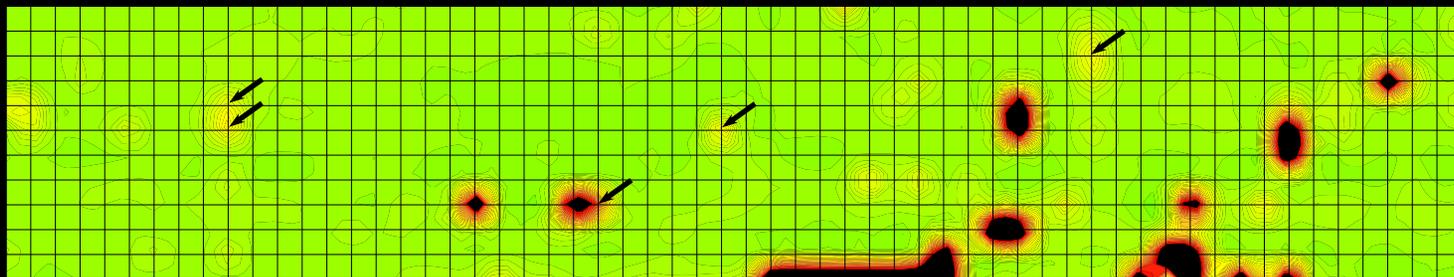
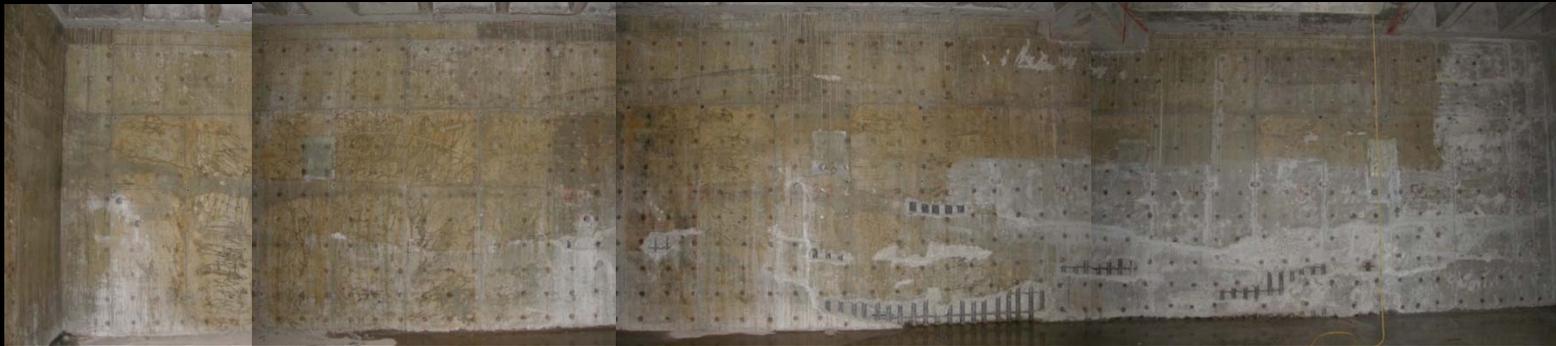


SAMMC Shear Wall

- 36-inch thick shear wall
- Voids observed after form removal
- Visible cold joints
- *Are there other locations with voids that are not visible?*



SAMMC Shear Wall



- Black areas denote locations with visible voids
- Arrows indicate recommended locations for coring

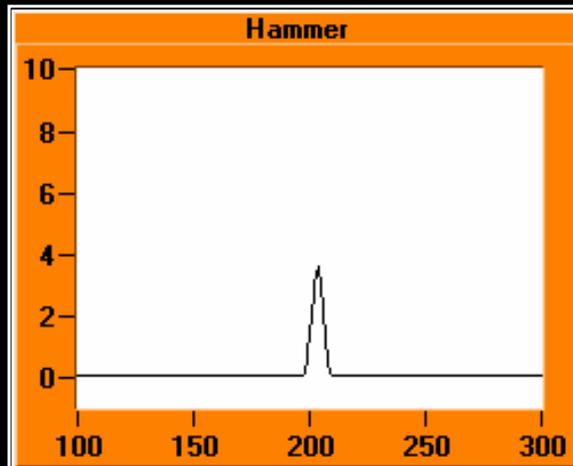
Impulse Response

- Low-strain impact
- Mobility plot
- Applications
 - Stress transfer
 - Delaminations
 - Deep foundation integrity
- Limitations
 - Cannot determine depth of flaws
 - Qualitative
 - Verify with coring

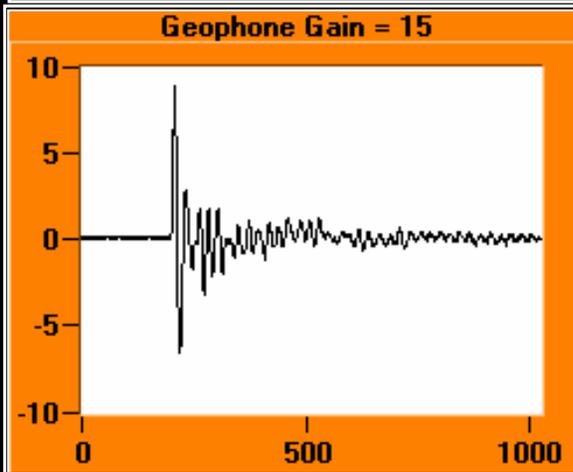


What is a Mobility Plot?

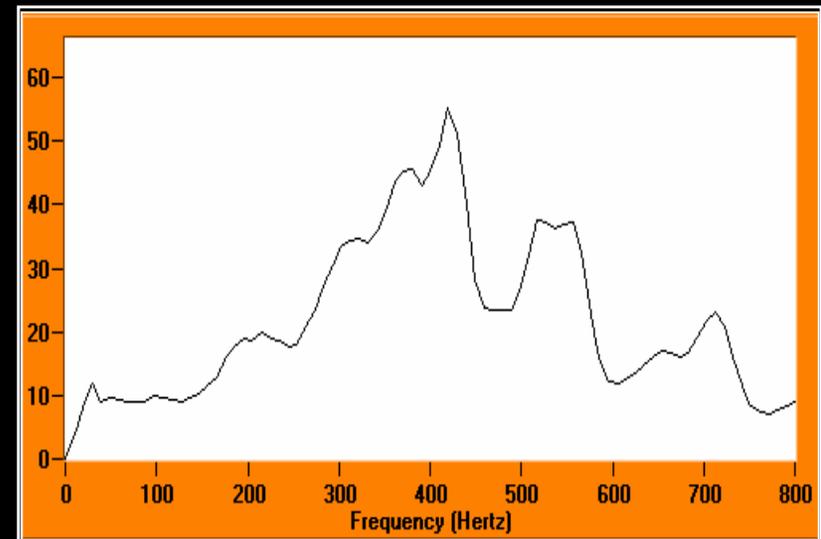
Force



Velocity



÷

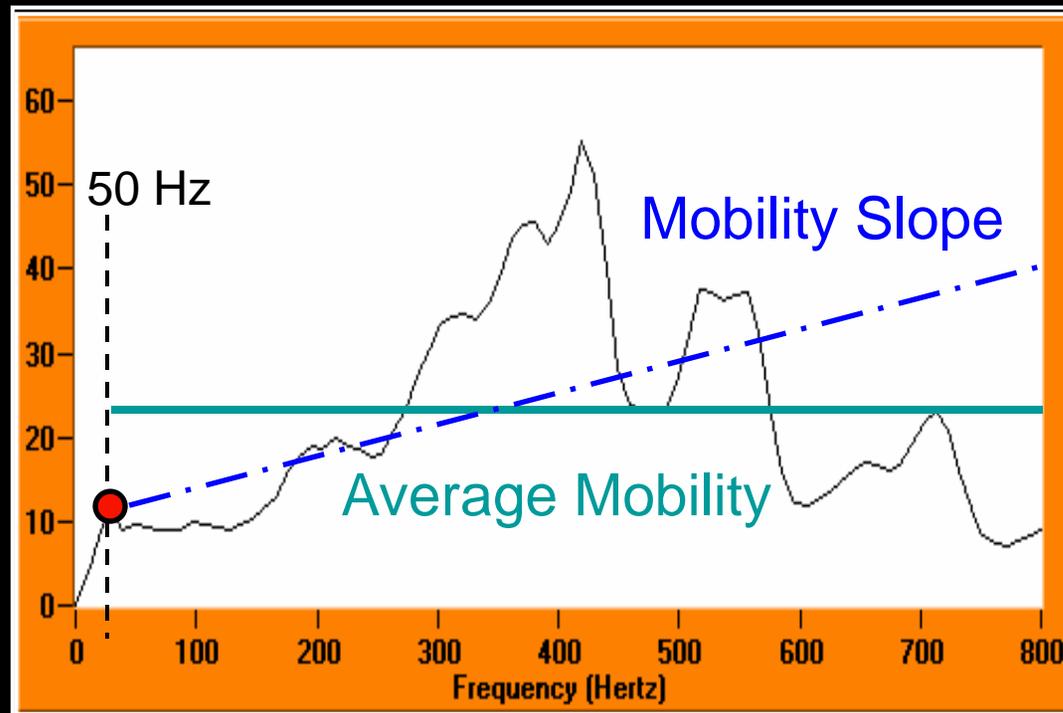


Mobility

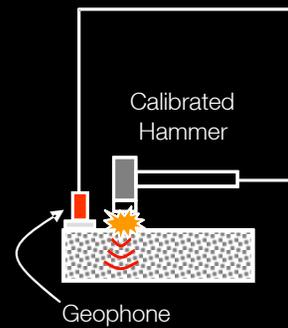
Frequency

What Information is in a Mobility Plot?

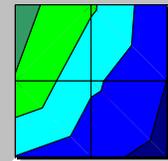
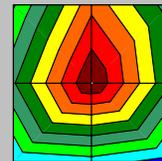
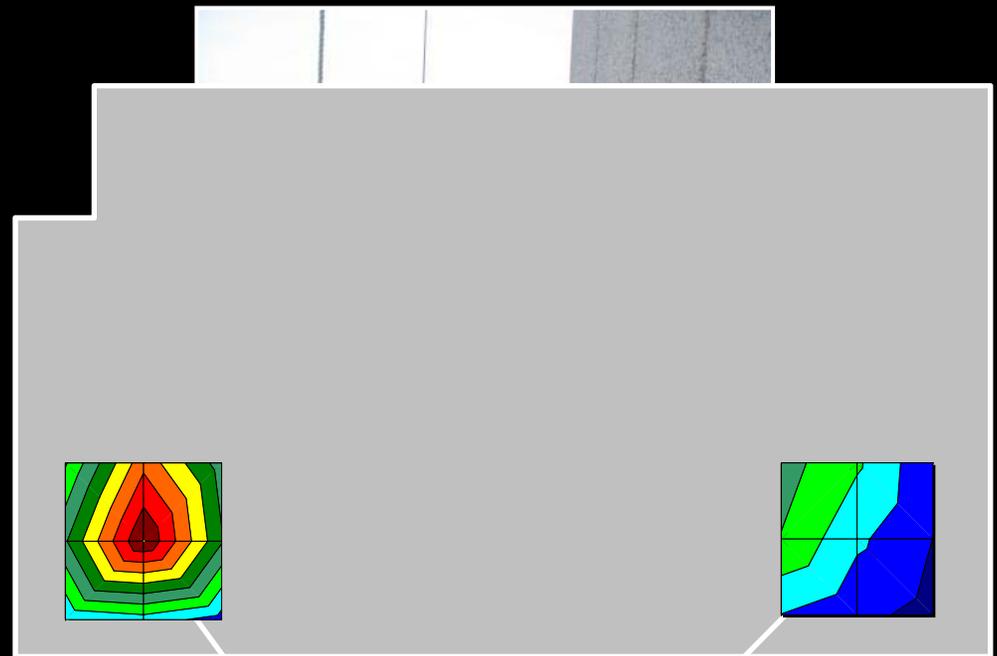
Dynamic Stiffness



Impulse Response Schematic



Case Study: Precast Concrete Panel Connection Failure

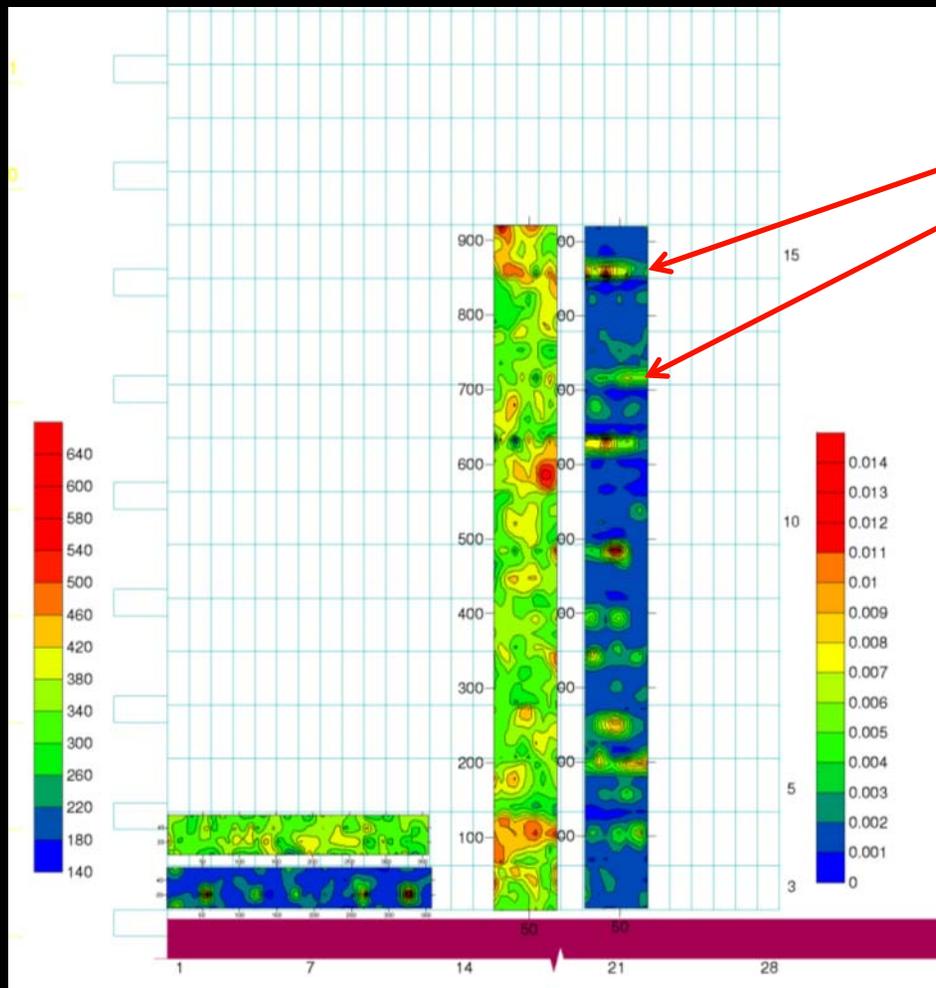


Gravity Connections

1020 Holcombe Marble Panel Assessment



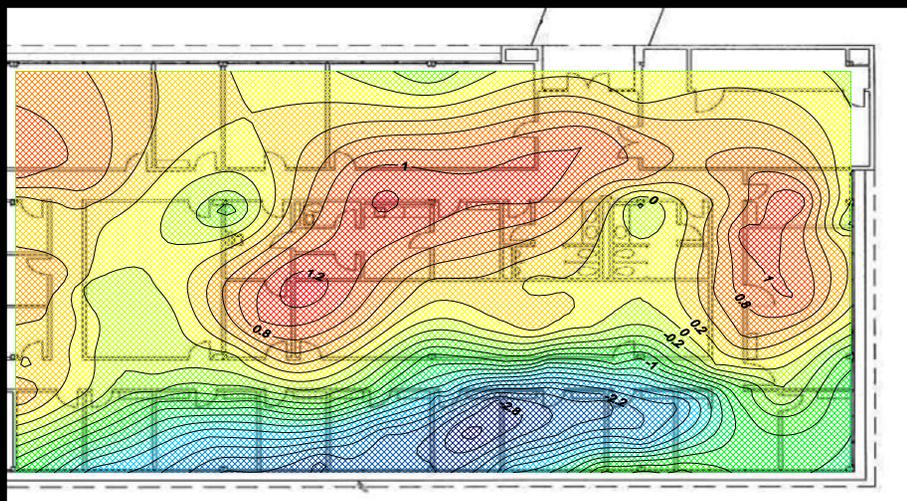
1020 Holcombe: Impulse-Response Results

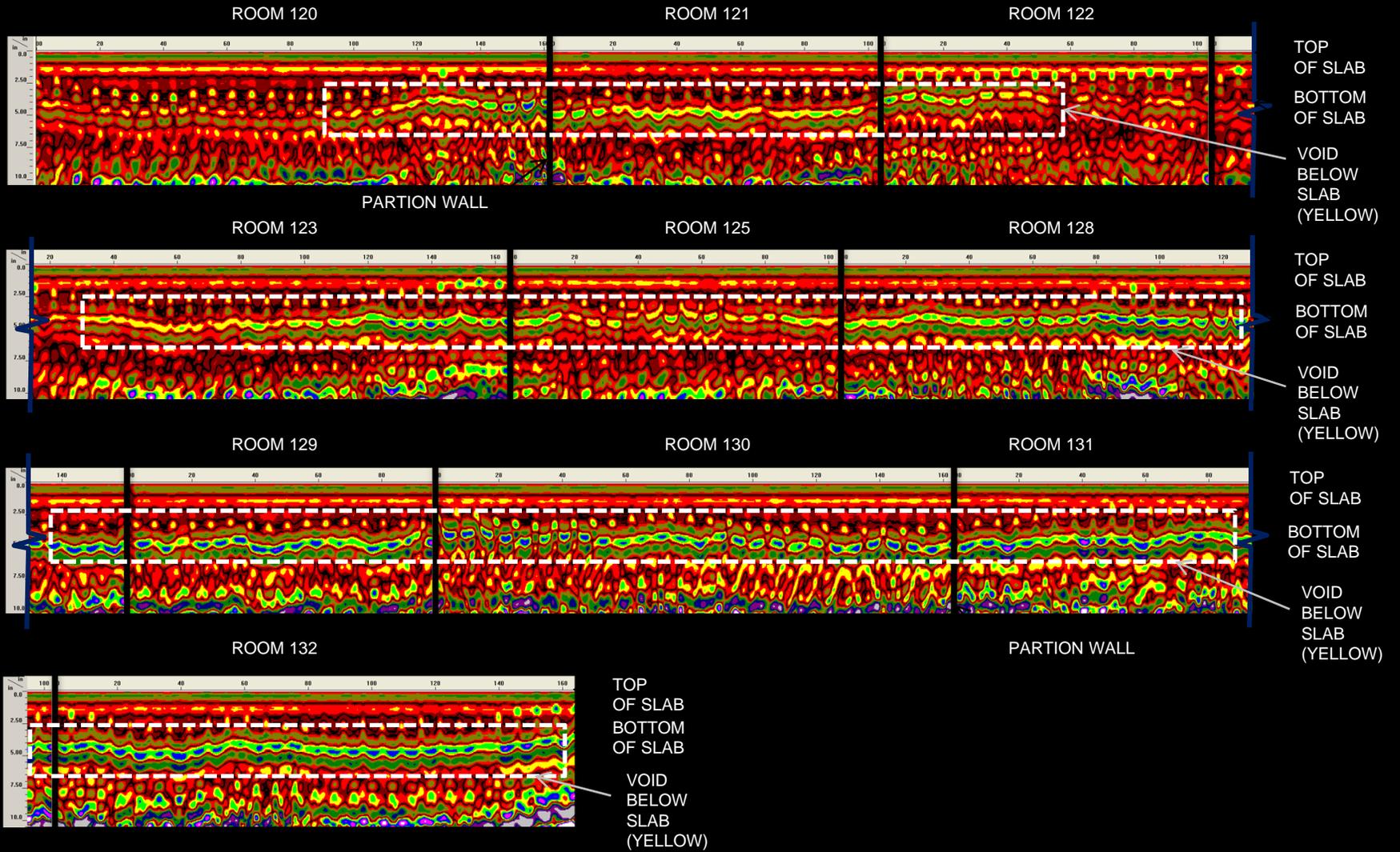


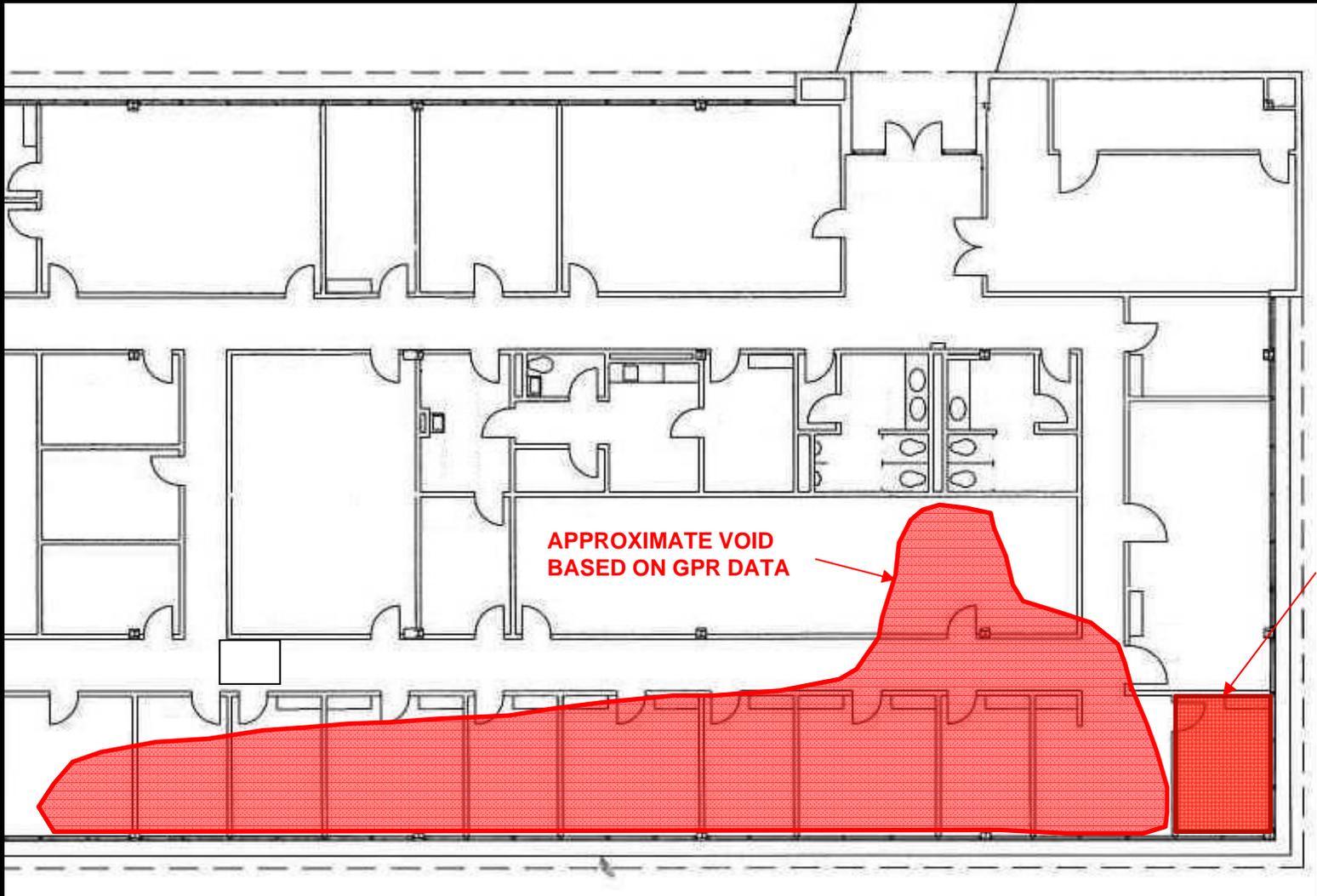
Good Connections

Voids beneath Slab on Grade

- Downward movement reported by owner
- Evidence of possible voids visible
- *What are the extents of the void?*



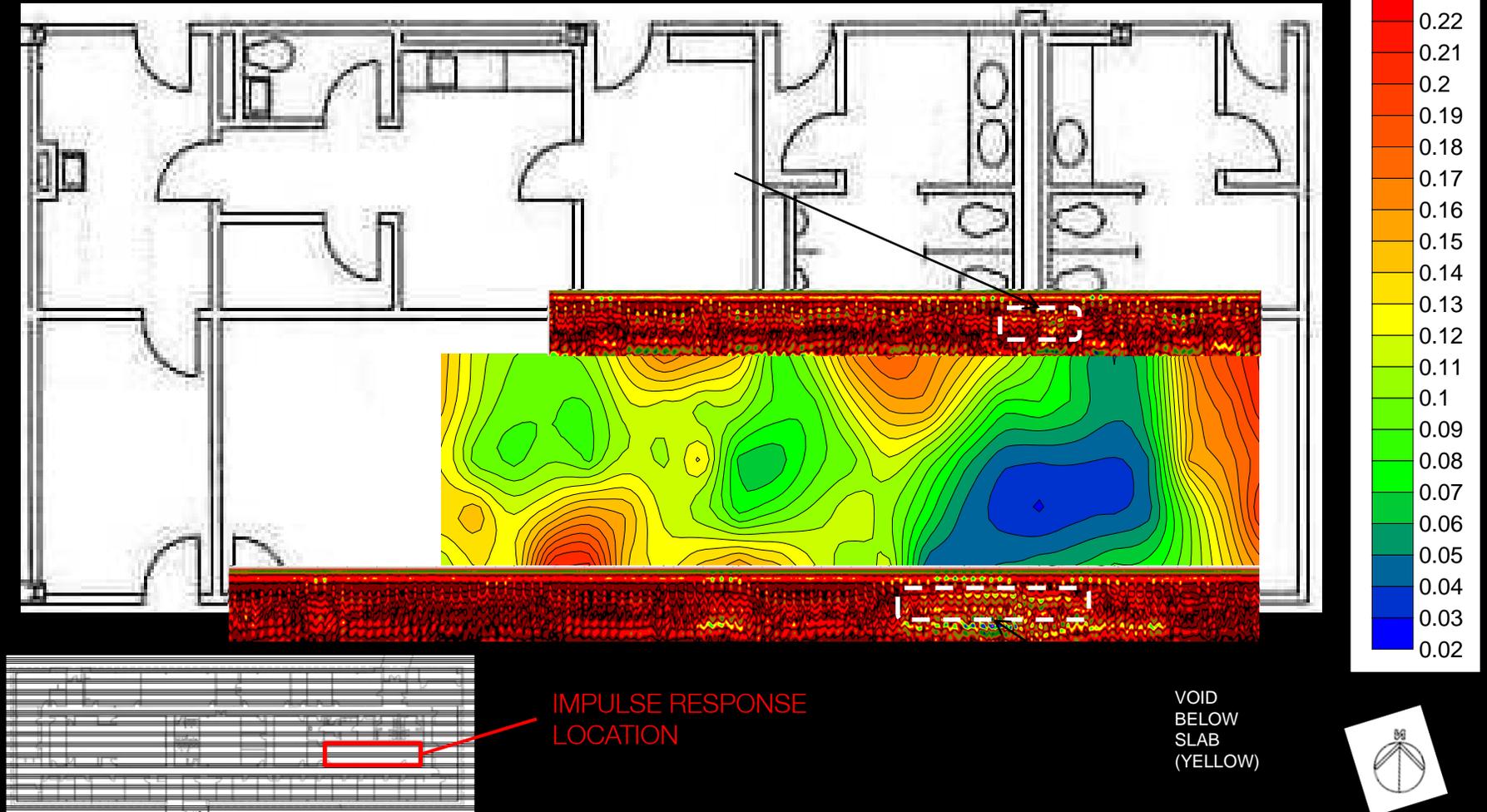




APPROXIMATE VOID
BASED ON GPR DATA

NO
ACCESS
TO THIS
ROOM

Impulse Response + GPR



Straight Beam Ultrasonic Testing (UT)

- Wave speed through metallic substrates
- Applications
 - Section Thickness Verification
 - Detecting Delaminations
 - Detecting Section Loss
 - Detecting Interface depth
- Limitations
 - Requires calibration and knowledge of the substrate medium.
 - Requires contact with the medium being tested
 - Requires parallel surfaces which are generally smooth for quantitative measurements.
 - May require cleaning to removal thick coatings or surface corrosion.

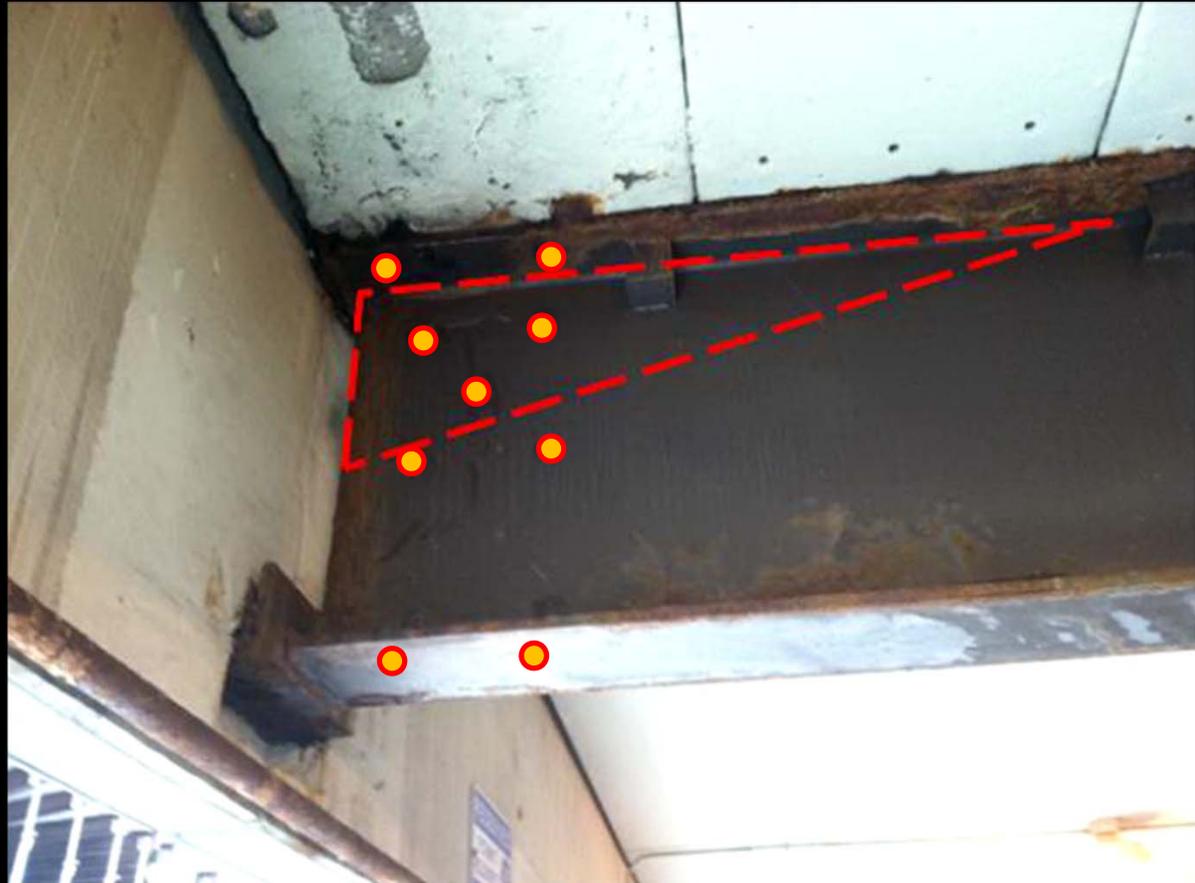
Parking Garage Bumper Wall Failure

- Precast Concrete Bumper Wall panel supported by steel beams fell off of the side of the parking structure.
- *Are there other locations where there is a hidden problem?*



Parking Garage Bumper Wall Failure

- Options
 - Visual
 - NDE



Rebound (Schmidt) Hammer

- Elastic rebound of hammer impact
- Applications
 - Concrete compressive strength
 - Fast, qualitative assessment of overall quality
- Limitations
 - Near-surface properties only
 - Affected by many variables
 - Uniformity of concrete



Building Envelope Testing

Equipment:

Infrared Thermography; Anemometer; Moisture Meters; Spray Nozzle
Infrared Thermometer; Hygrometer; Rilem Tubes; Elcometer
Smoke Tracer; Manometer; Moisture Capacitance Meter

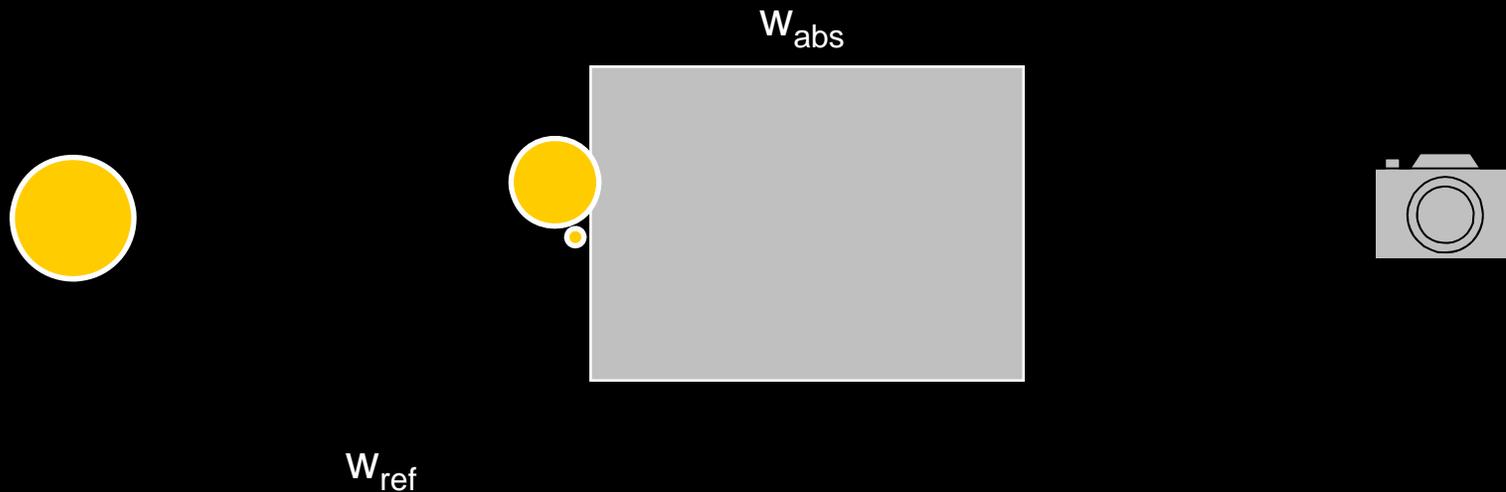
Software:

WUFI; THERM ; eQuest; WPM Hygrothermal Analysis Spreadsheet



Infrared Techniques

- Infrared thermal emissivity
- Noncontact
- Highly absorptive materials
 - Concrete
 - Masonry

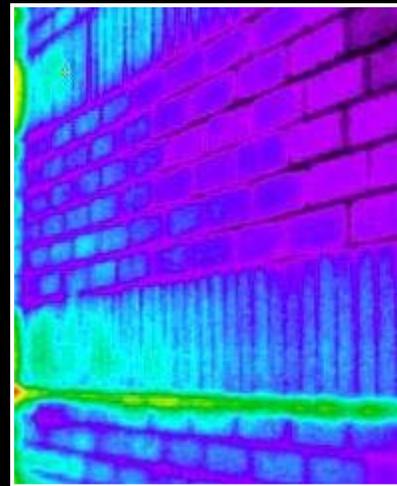


What is Thermography?

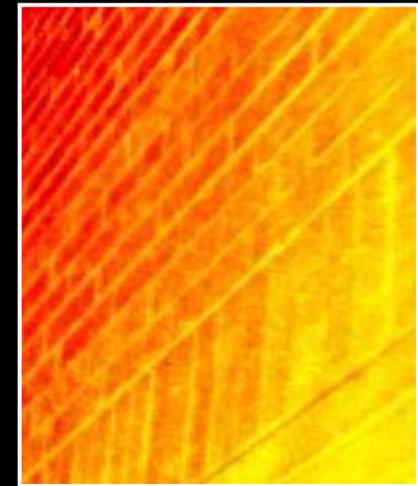
- Infrared thermal emissivity
- Applications
 - Water Intrusion
 - Air leakage
 - Bonding of FRP sheets
 - Location of termite infestation
- Limitations
 - Not effective with reflective materials



Case Study: Moisture Infiltration



Before Coating

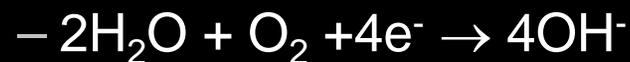


After Coating

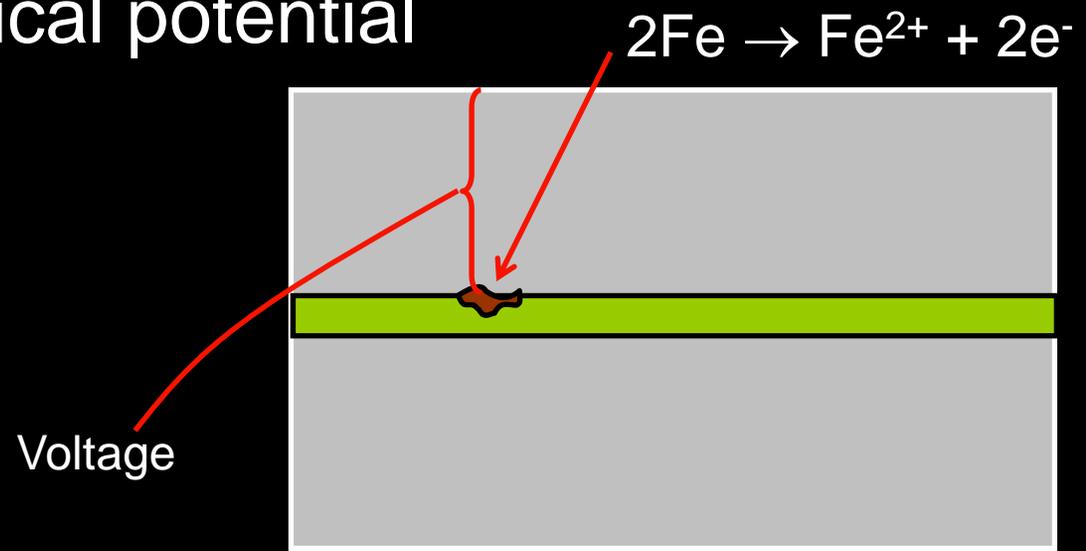
What is Half-Cell Potential?

- Electrochemical reaction

- Galvanic corrosion



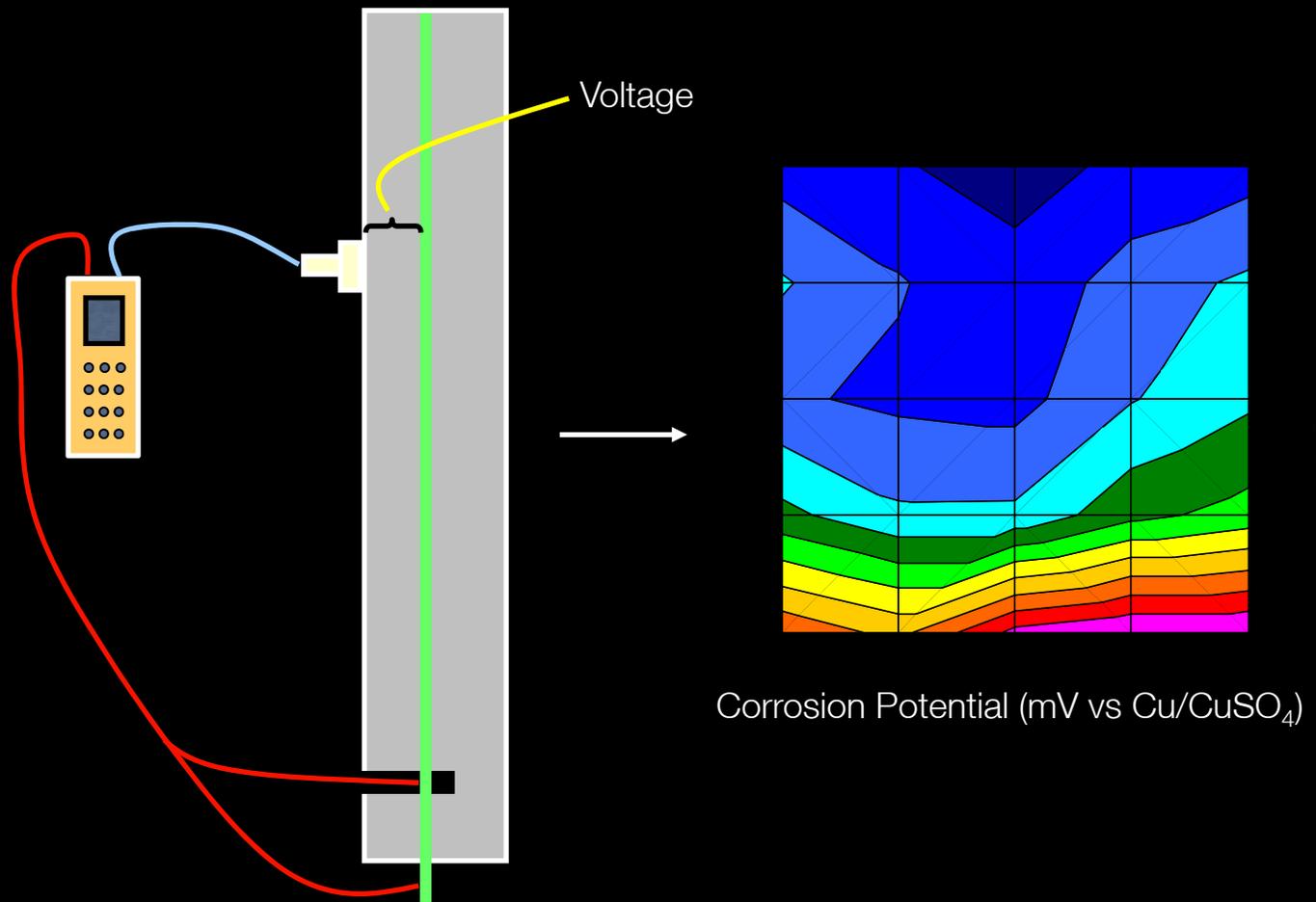
- Measure electrical potential



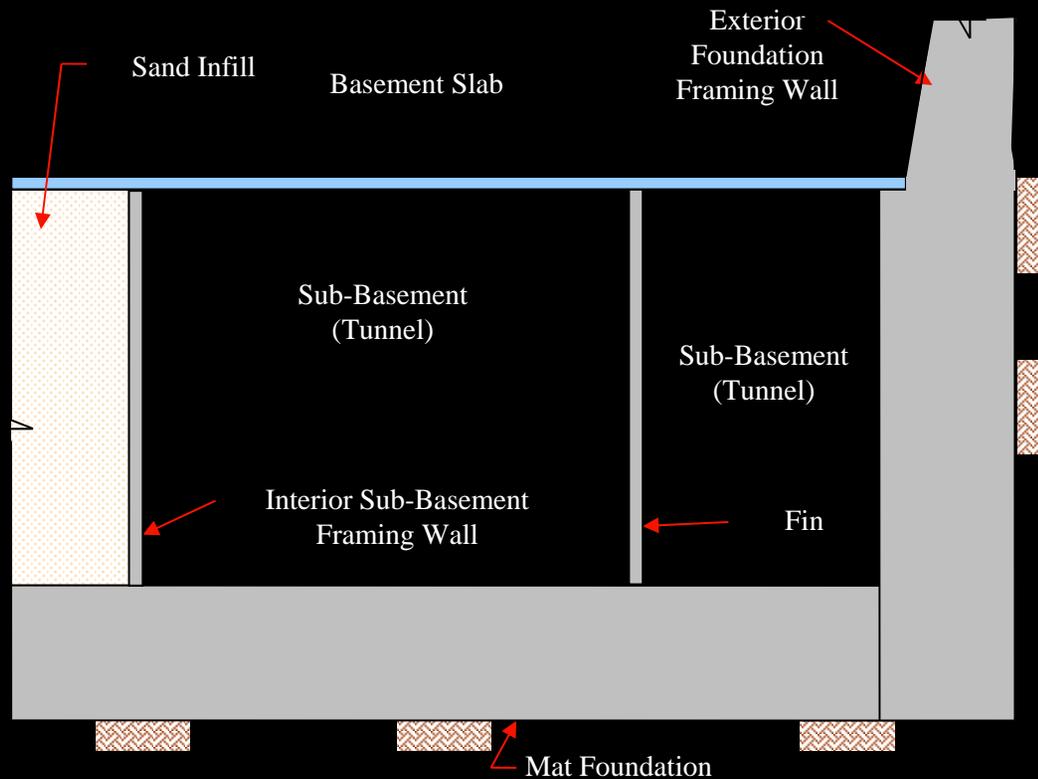
Half-Cell Potential & Corrosion Rate

- Linear Polarization Technique
- Measures corrosion activity
- Applications
 - Corrosion prediction
- Limitations
 - Cathodic protection
 - Requires connection to rebar
 - Depth of cover less than 4 inches
 - Saturated concrete*

Half-cell Potential Schematic



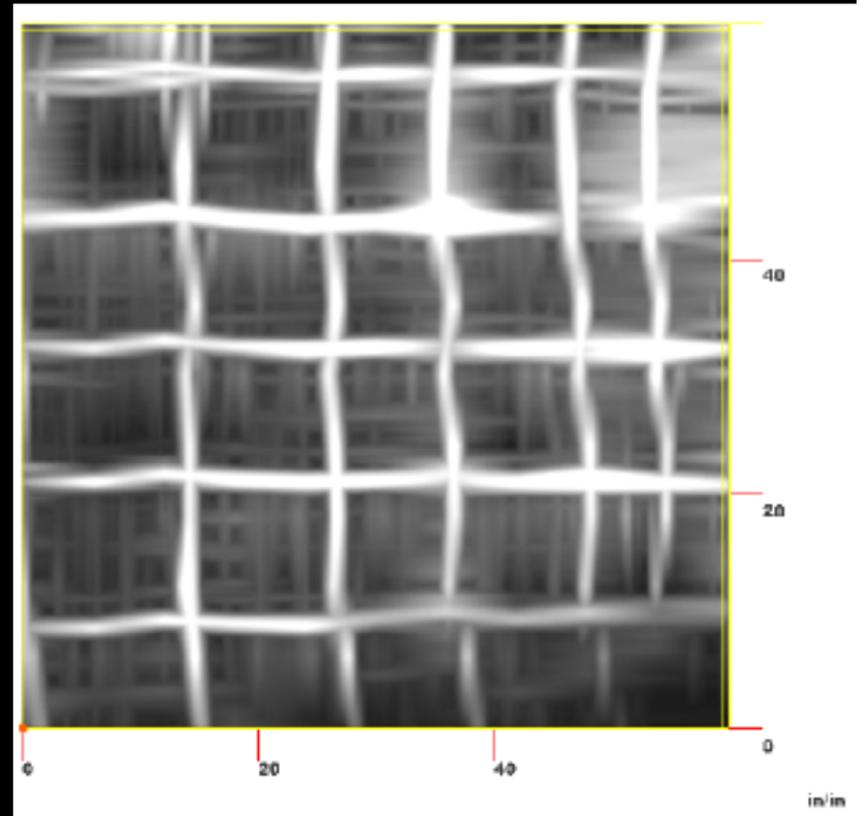
LCRA: TC Ferguson Turbine Building



LCRA: SPR

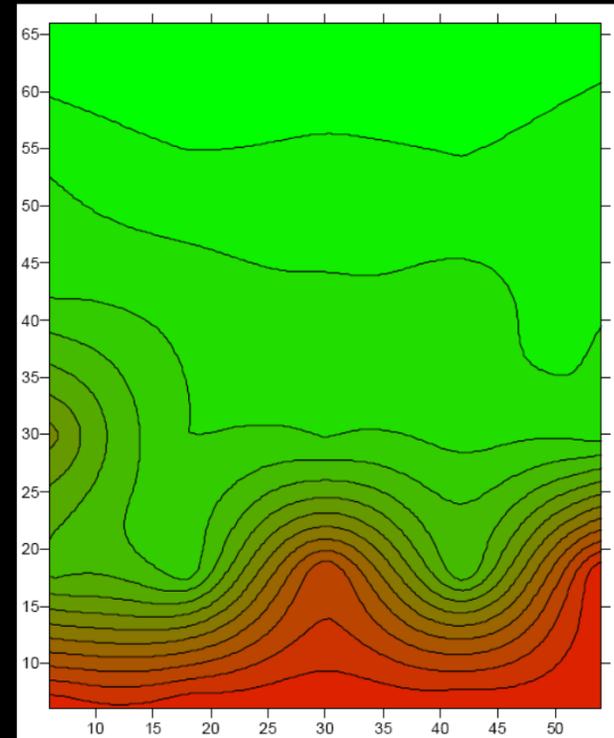


SPR used to position sample locations



LCRA: Sub-basement Level

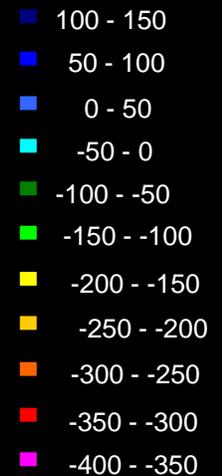
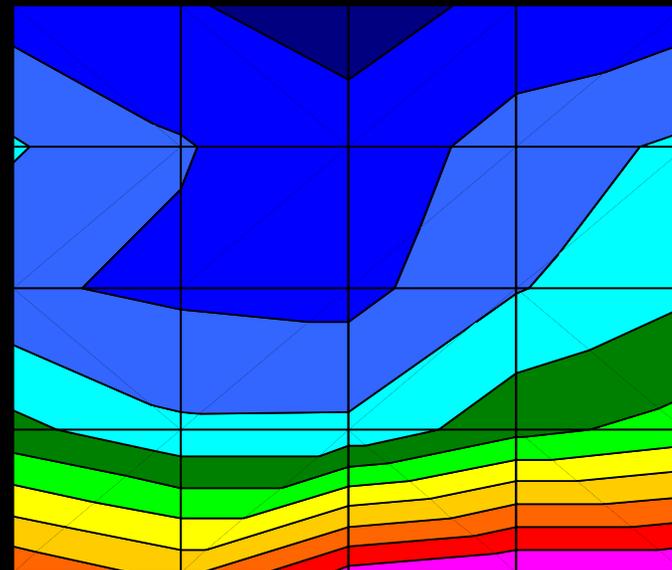
Fin F56 – Ultrasonic Pulse Velocity (UPV)



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LCRA: Sub-basement Level

Fin F56 – Corrosion Testing



Half-cell Potential vs. $\text{Cu/CuSO}_4^{(1)}$	Probability of Corrosion
More positive than -200 mV	Less than 10%
Between -200 and -350 mV	Uncertain
More negative than -350 mV	More than 90%

Corrosion Potential
(mV vs. Cu/CuSO_4)

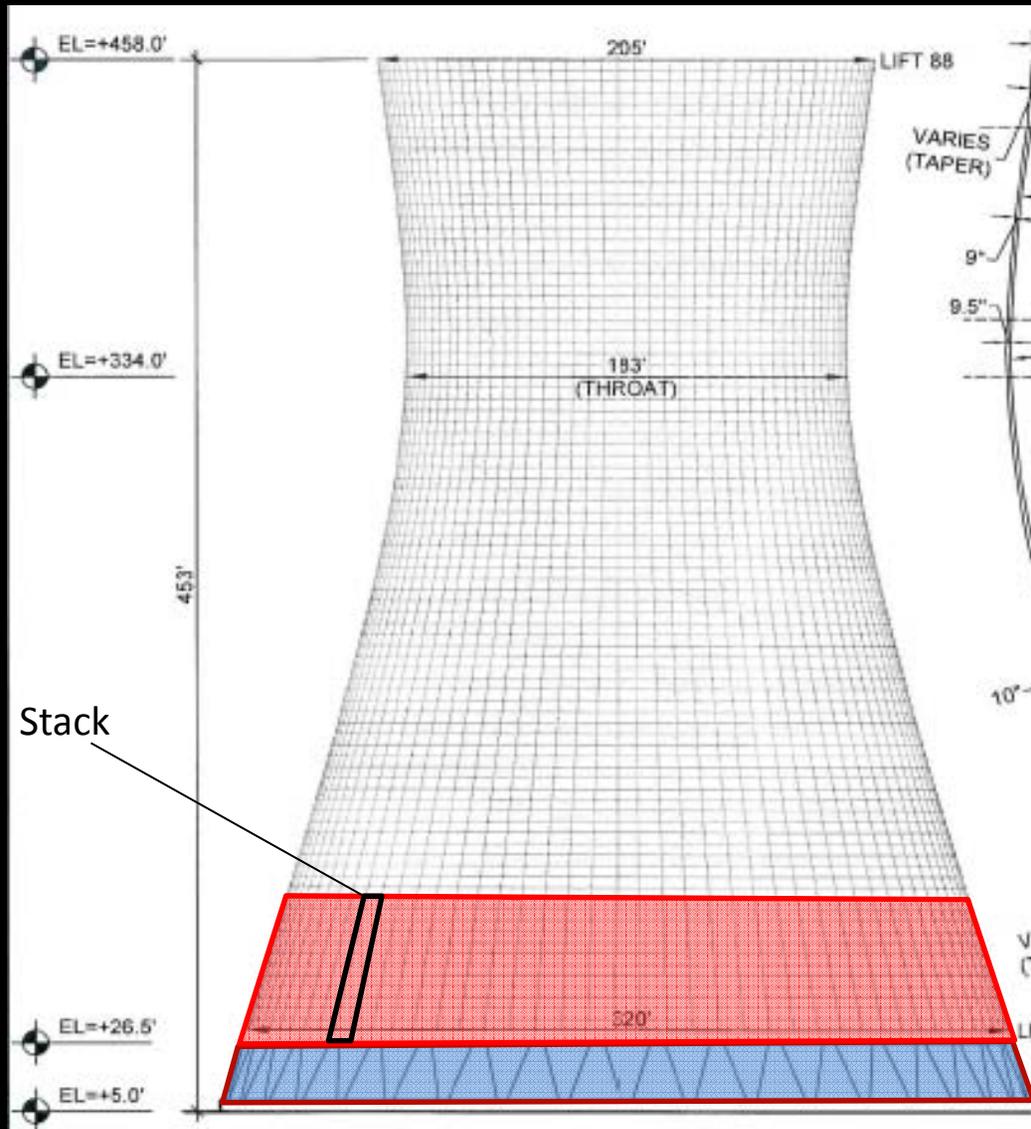
Evaluation of Cathodic Protection System

- 2 Hyperbolic Natural-Draft Cooling Towers
 - Reinforced Concrete Shells
 - 453 feet tall
 - 320 feet diameter at base
- Cathodic Protection (CP)
 - Life Jackets on columns
 - Zinc mesh over lifts 1-12



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Tower Elevation



Lifts 1-12

Columns

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Passive CP System

- Zinc Mesh

- Electrically connected to reinforcement
- Guniting shotcrete overlay
- *Is the CP system working?*
- *Is the overlay sound?*

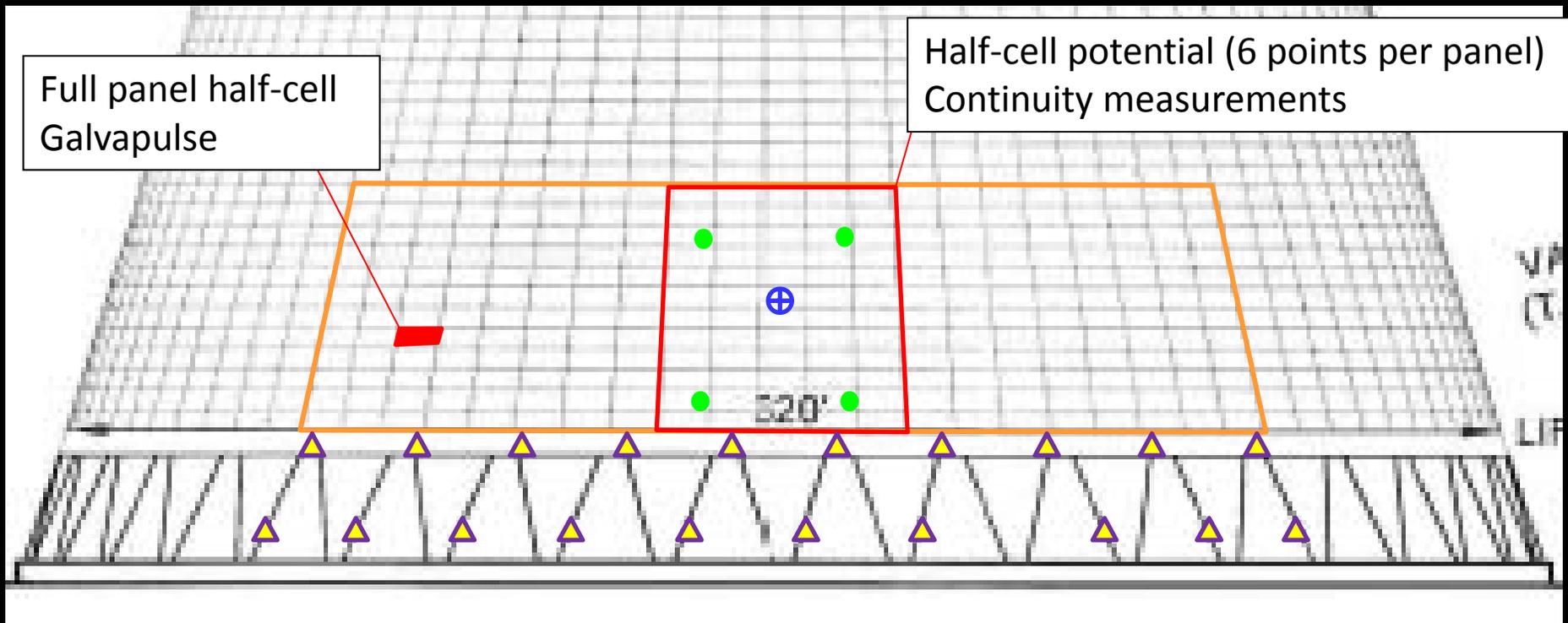


Nondestructive Evaluation

- Half-Cell Potential
- Corrosion Rate
- Impulse Response
- Bond Testing

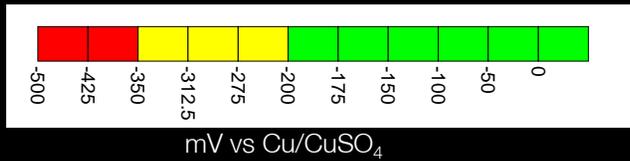
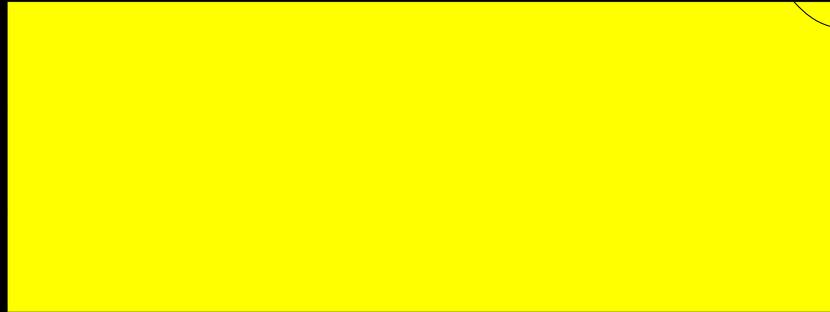
NDE Quadrant Summary

- ▲ Potential Readings Test
- ⊕ Bond Test
- Impulse-Response

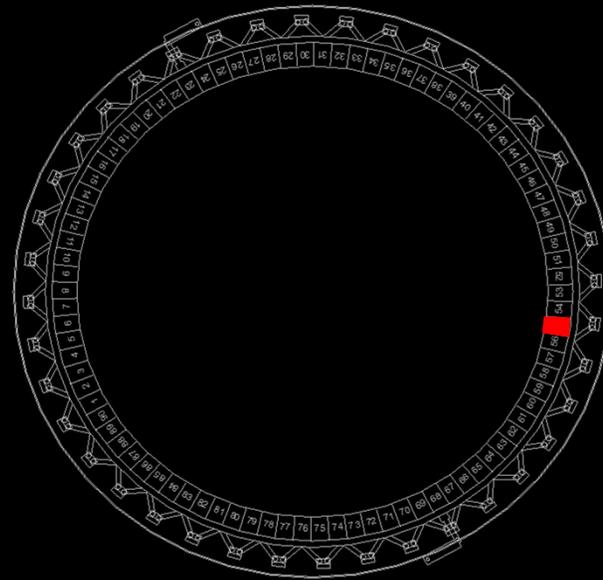
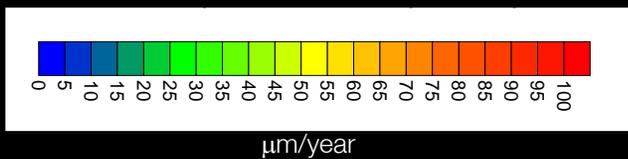
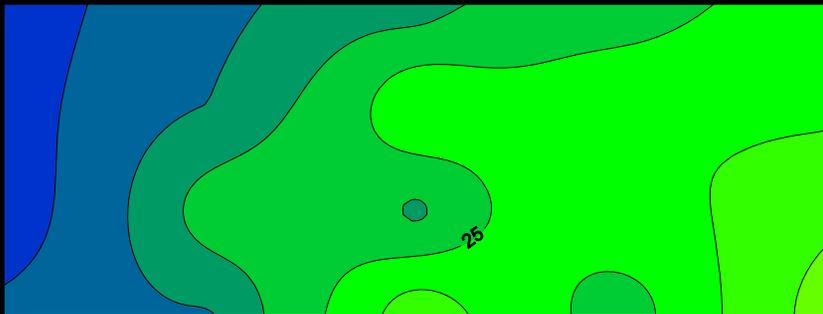


Unit 1 Stack 55 Opening

Half Cell Potential

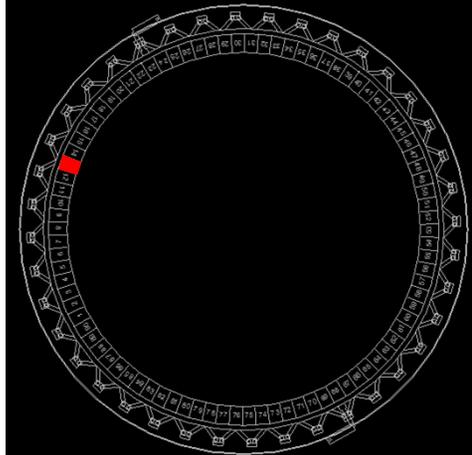
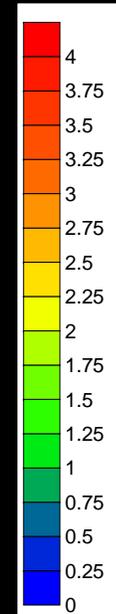
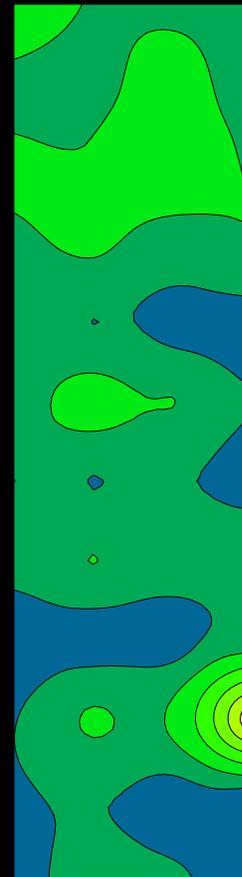


Corrosion Rate



Impulse-response testing

- Grids over 60' of stack
- Low voids index values



Supplemental testing

- Pull-off testing
 - Bond strength 25 psi – 150 psi
- Chloride Testing
 - High chlorides (~2,000 ppm)

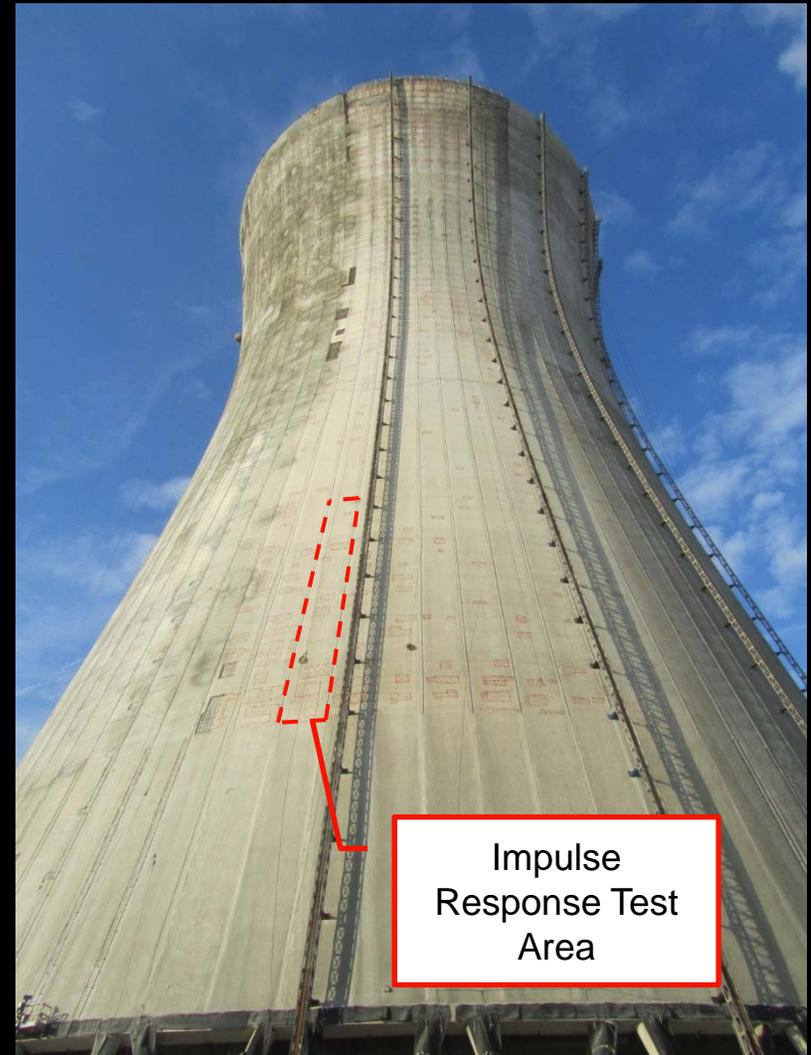


Conclusions

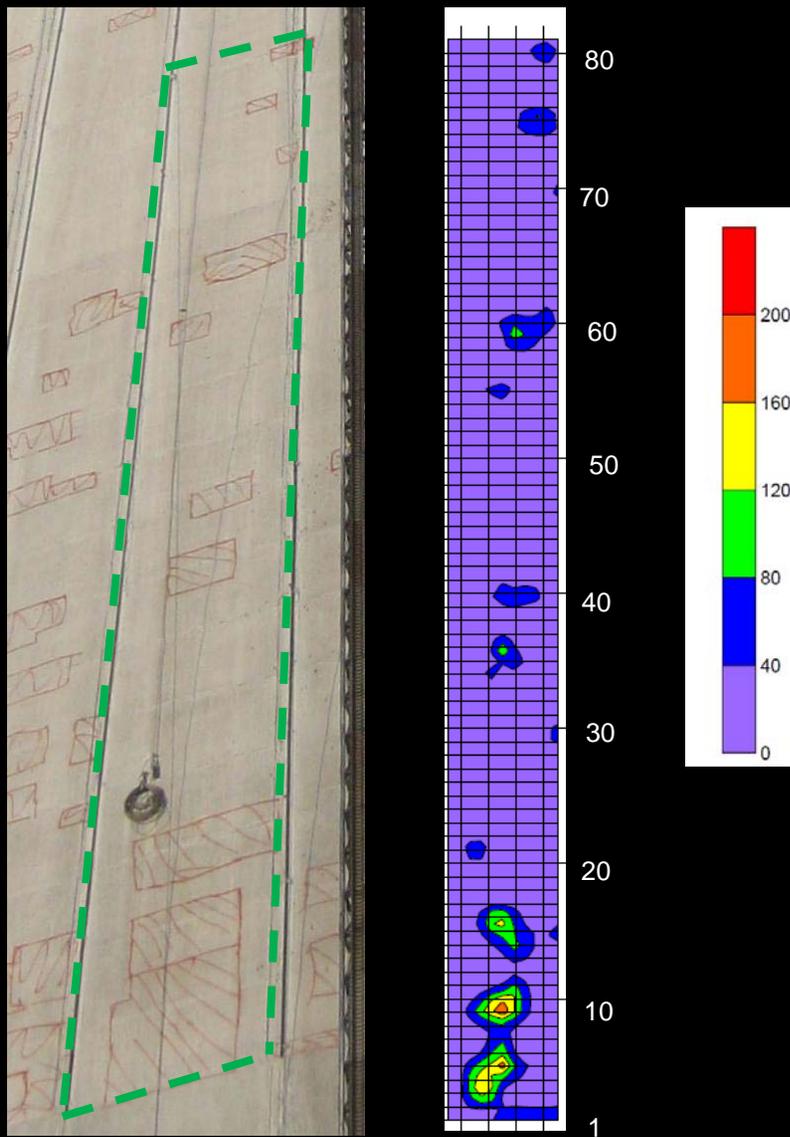
- CP system is performing adequately
 - Low values for active corrosion
 - Half-cell potentials indicate uncertainty
- Overlay cracking but not debonding
- *Replacement not necessary*
 - *Save \$11,000,000*

JEA: Construction Quality Control

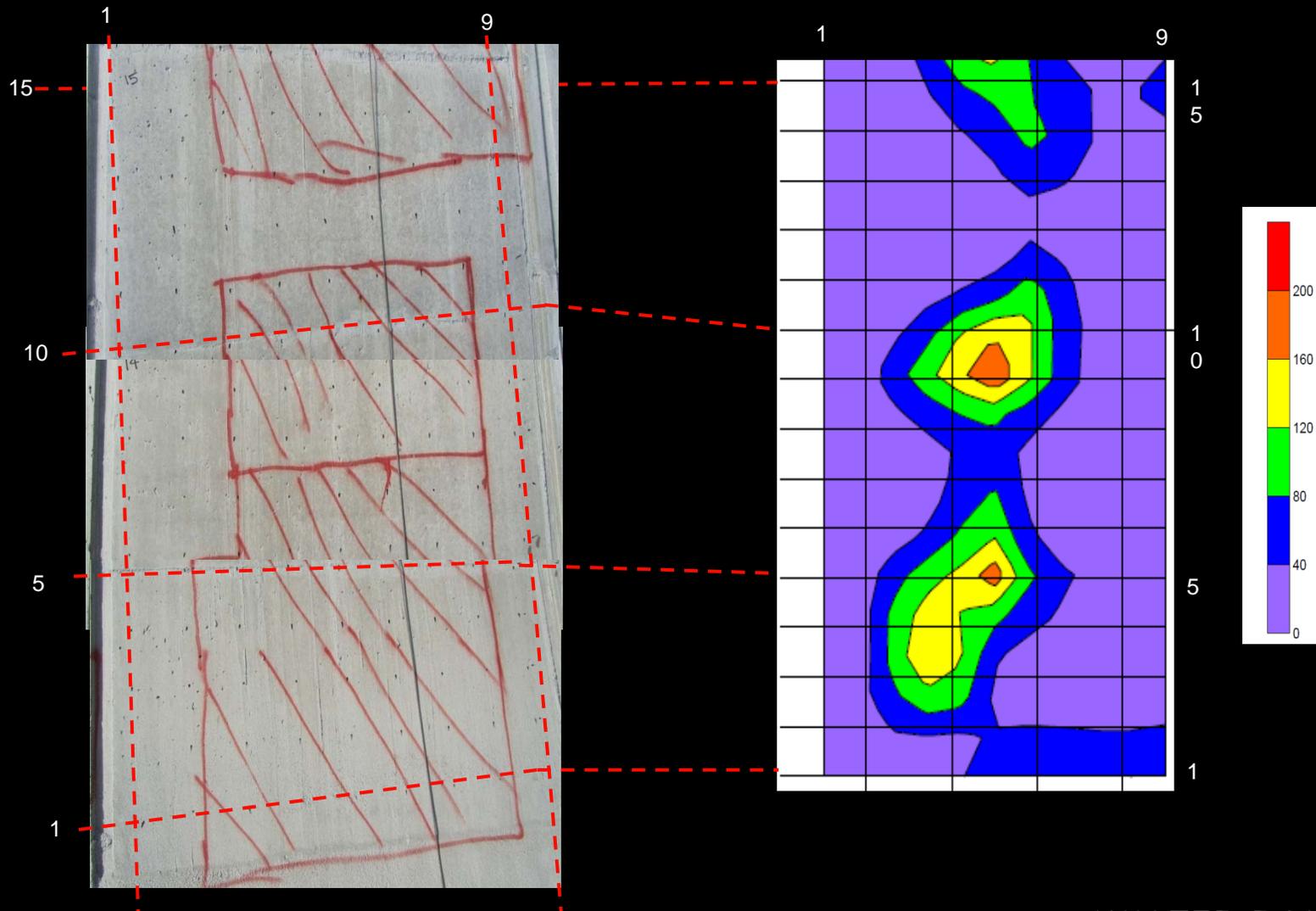
- Confirm contractor is correctly identifying delaminations
 - Unit Pricing
 - Cost controls



JEA: Impulse-Response



JEA: Impulse-Response



Summary

- Techniques to assess in-situ state
 - Obscured conditions
 - Rapid characterization
 - Minimal impact
- Differing techniques for differing problems
 - **Very powerful when used in combination**

A final thought....

Better information

A final thought....

Better information = Better Decisions

Better Solutions

Thank You

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