



Advanced Methods to Identify Asphalt Pavement Delamination--R06D Sonic Surface Scanner (S³)

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U.S. Department of Transportation
Federal Highway Administration

AMERICAN ASSOCIATION
OF STATE HIGHWAY AND
TRANSPORTATION OFFICIALS

AASHTO

Sonic Surface Scanner – S³

- Slow-rolling (1 mph) scanner for delamination mapping of asphalt pavements and bridge decks
- 6 Displacement transducers on two wheels lined up 6 to 9 inches apart
- Impacts surface every 6 inches for
 - Impact Echo (IE) test
 - Spectral Analyses of Surface Waves (SASW) test



Stress Wave Basics

P-Wave

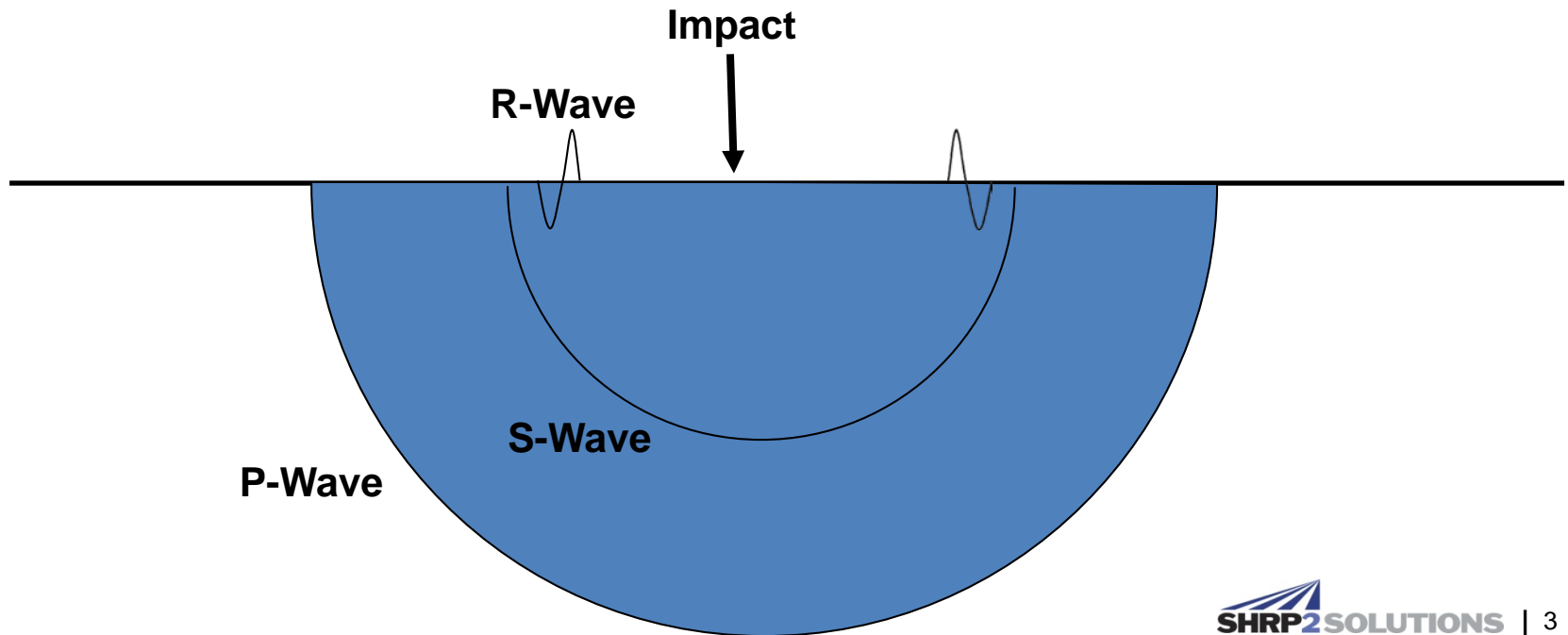
- Also known as the Primary Wave, Compression Wave or Sound Wave

S- Wave

- Also known as the Shear Wave

R-Wave

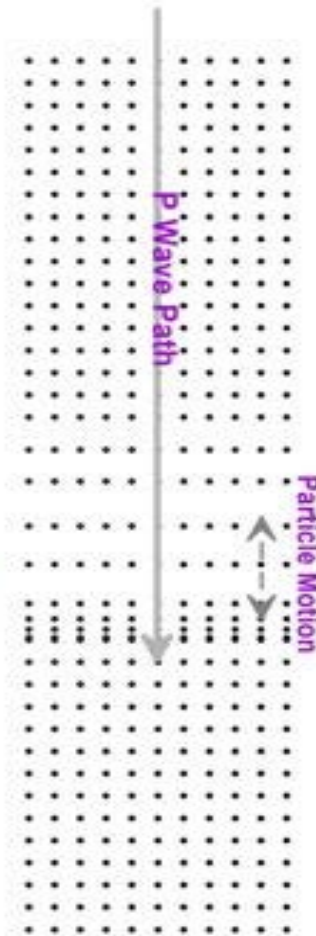
- Also known as the Surface Wave or Rayleigh Wave



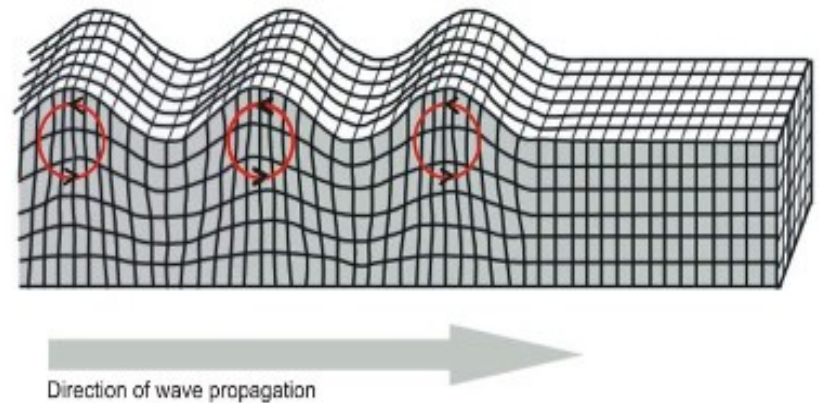
Types of stress waves

P-waves, body waves –
used by Impact Echo (IE) to
measure layer thickness

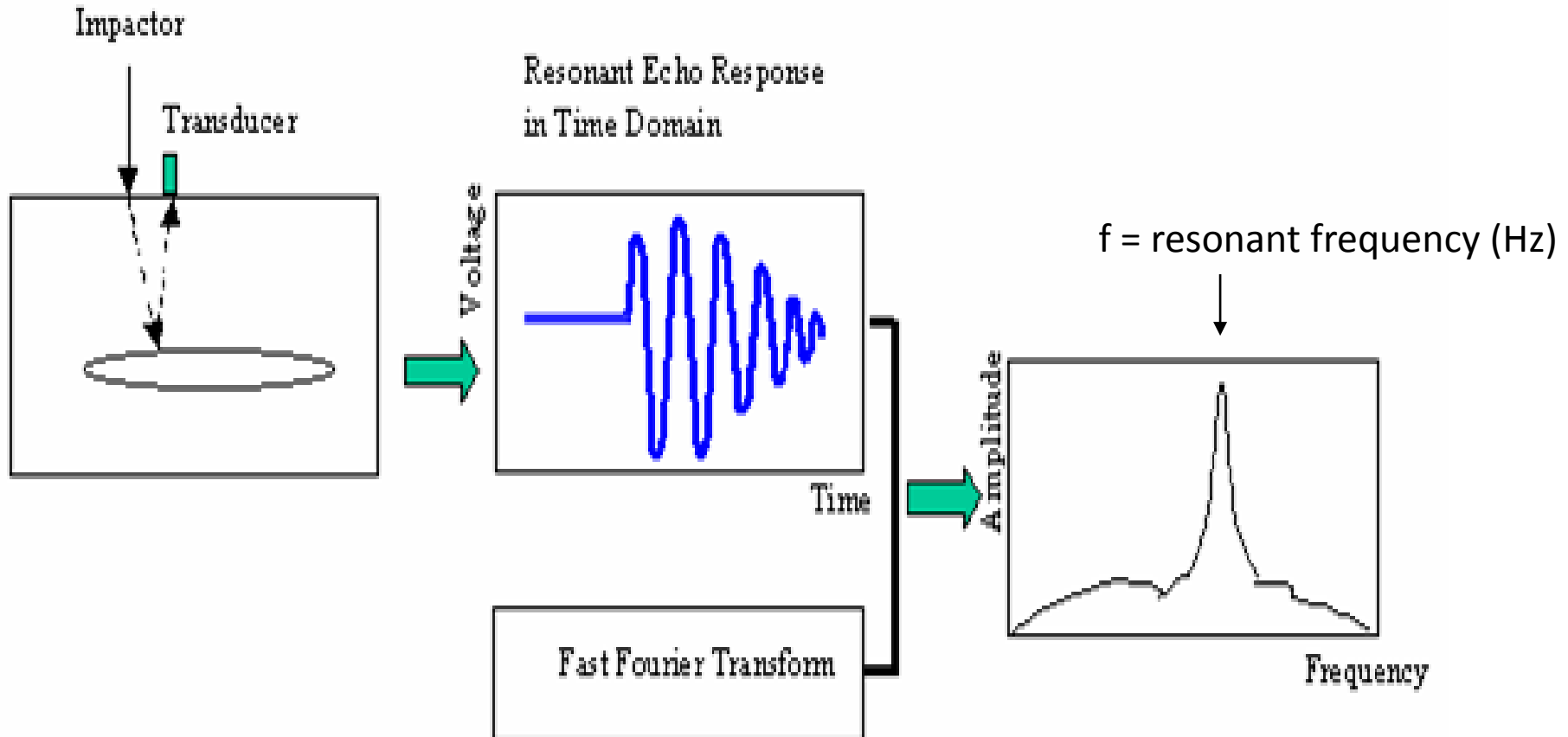
R-waves, surface waves –
used by SASW to measure
material stiffness



Rayleigh wave



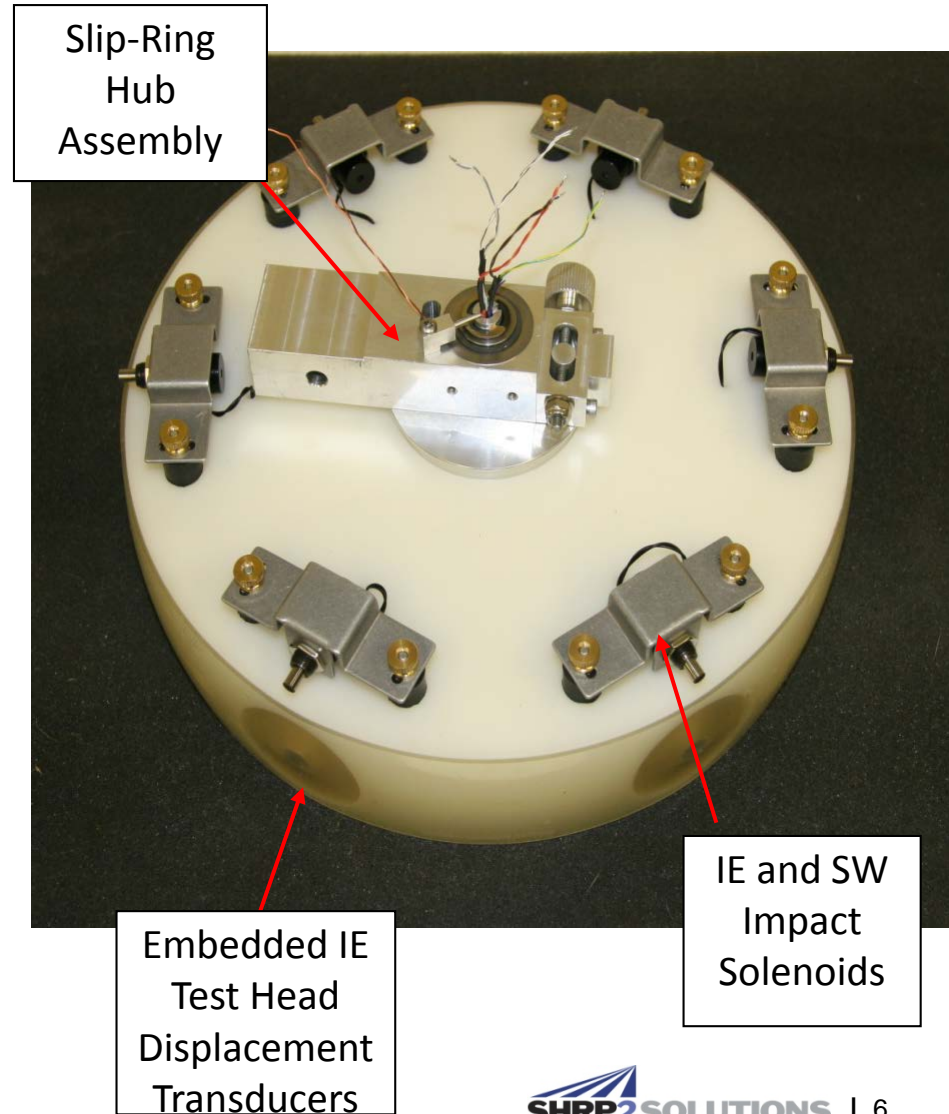
Impact Echo Test



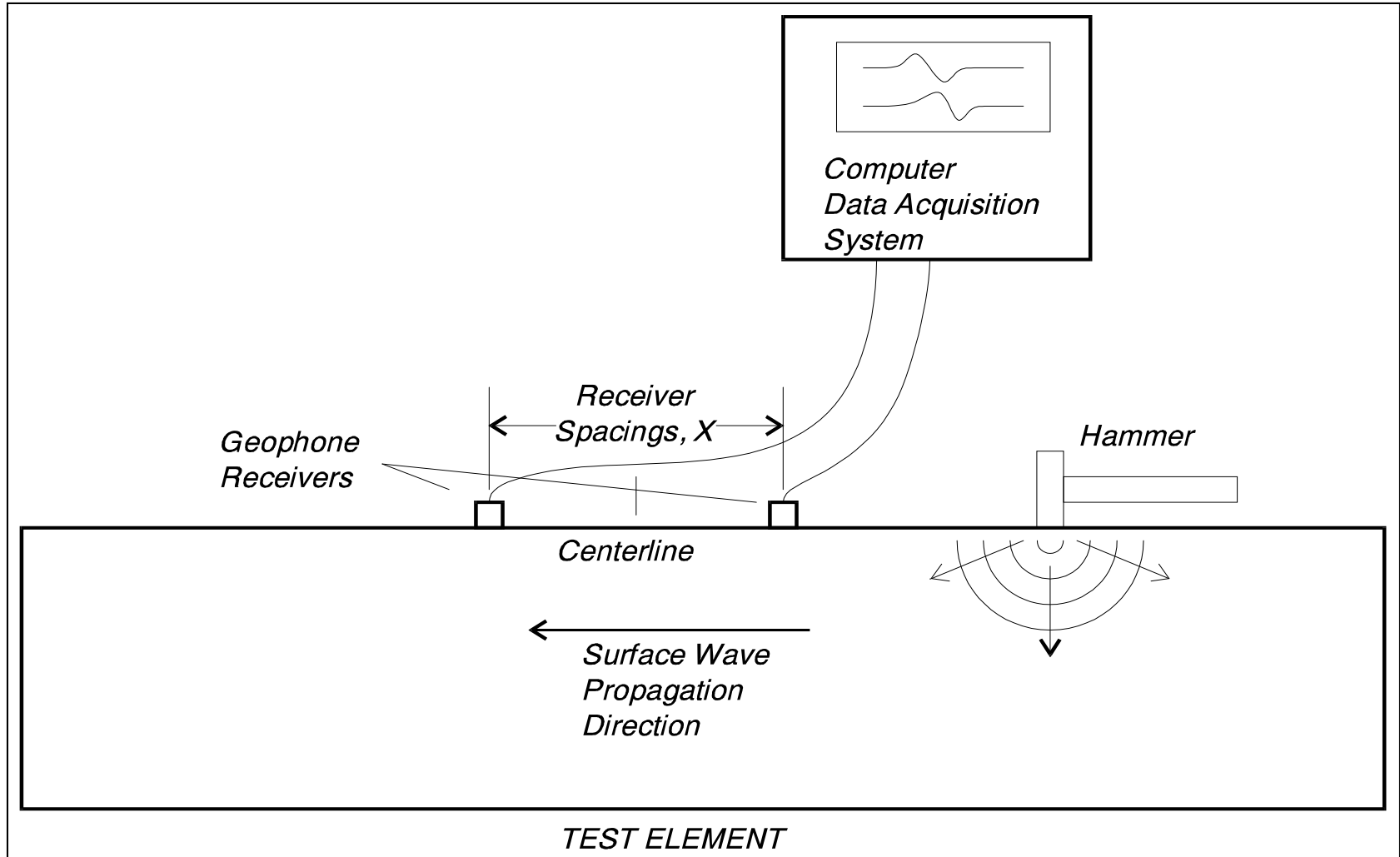
$$\text{Thickness} = V_p / (2 * f)$$

Scanning Impact Echo Testing

- Diameter = 11.5 inches
- 6 Displacement Transducers
- 6 Impactors
- Impacts spaced @ 6 inch intervals
- Transducers spring mounted with rubber isolators
- Sensors captured with a thin urethane tire for coupling and as a dust cover.



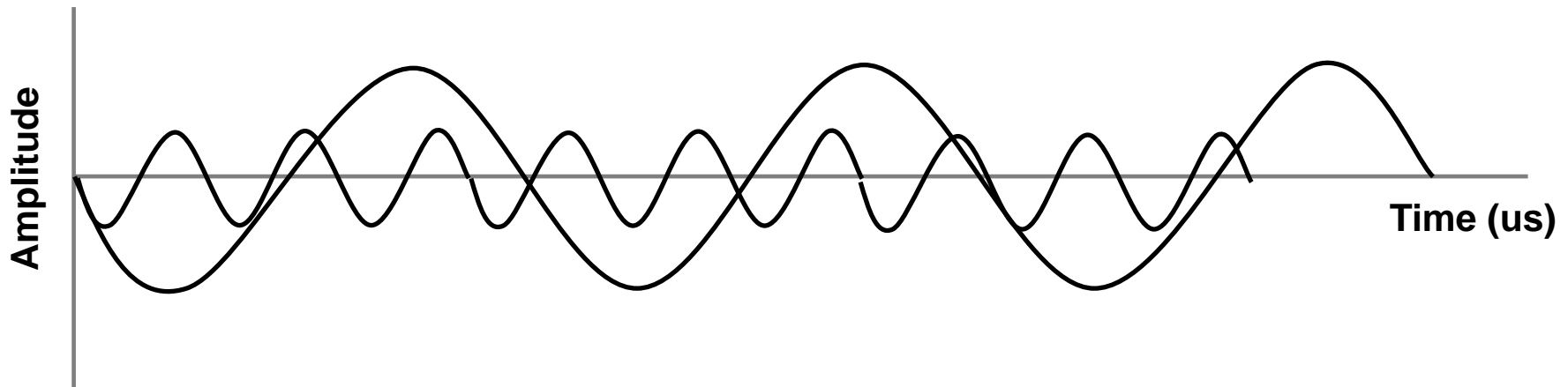
Spectral Analysis of Surface Waves Method (SASW – Stokoe and Nazarian)



Spectral Analysis of Surface Waves

KEY ELEMENTS TO SASW Test Method

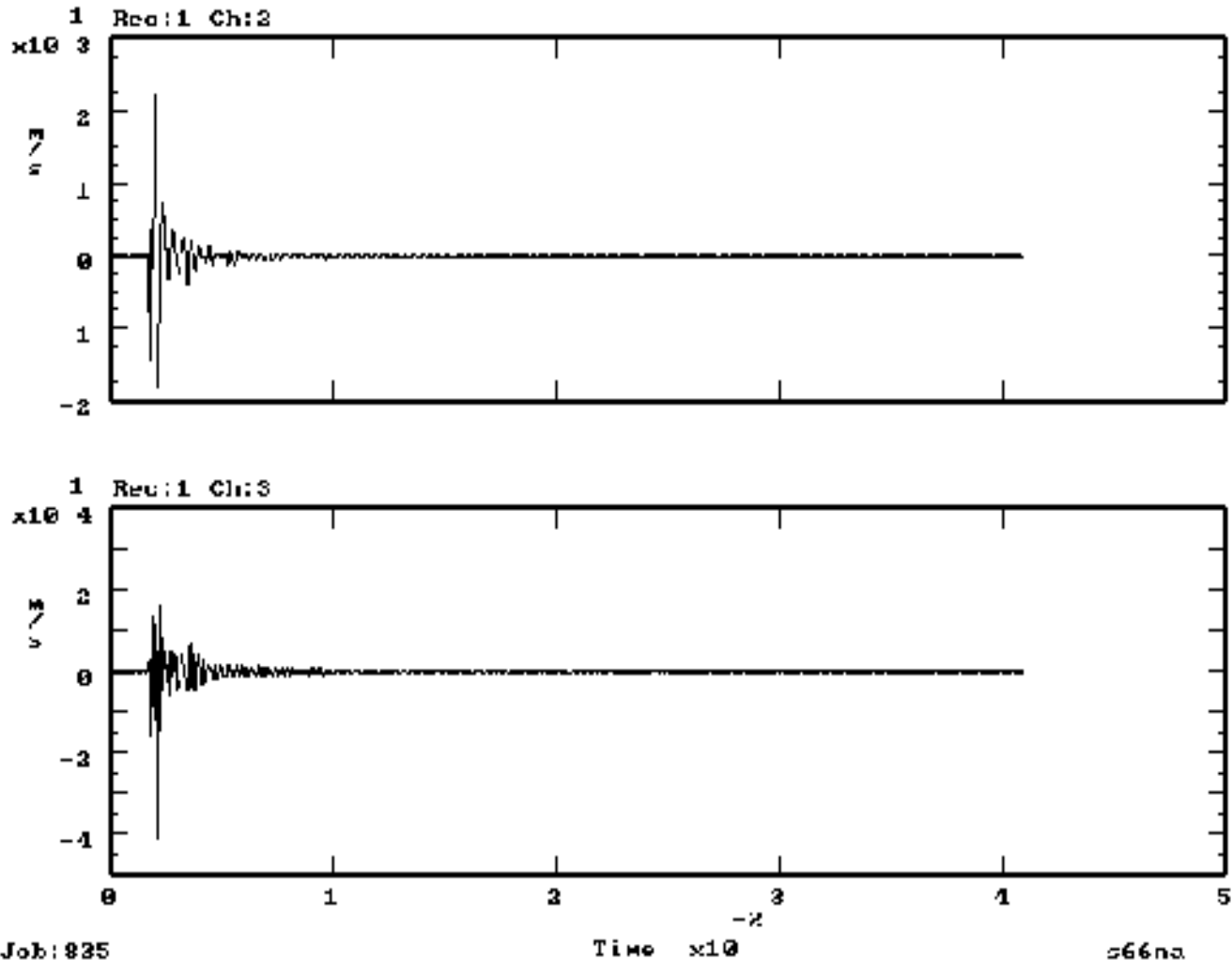
- Surface Wave is “Dispersive” – meaning the different frequencies within the surface wave can travel at different velocities.
- Short wavelength waves (high frequencies) sample shallow, longer wavelengths (lower frequencies) sample deeper.



This allows the measurement of the velocity profile versus depth into the pavement.

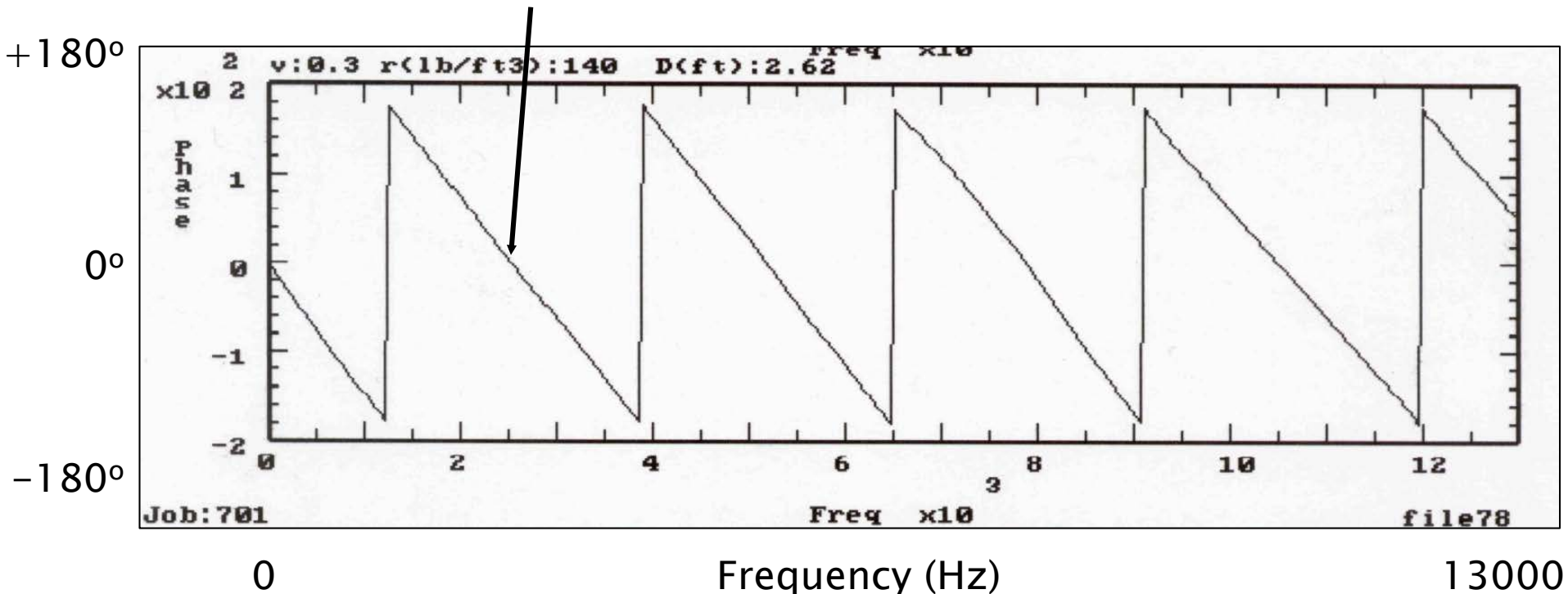
Based on $\text{Velocity} = \text{Frequency} \times \text{Wavelength}$

Typical Time Domain Records for Two SASW Receivers



SASW Phase Plot from Sound Concrete

2628 Hz at -360°

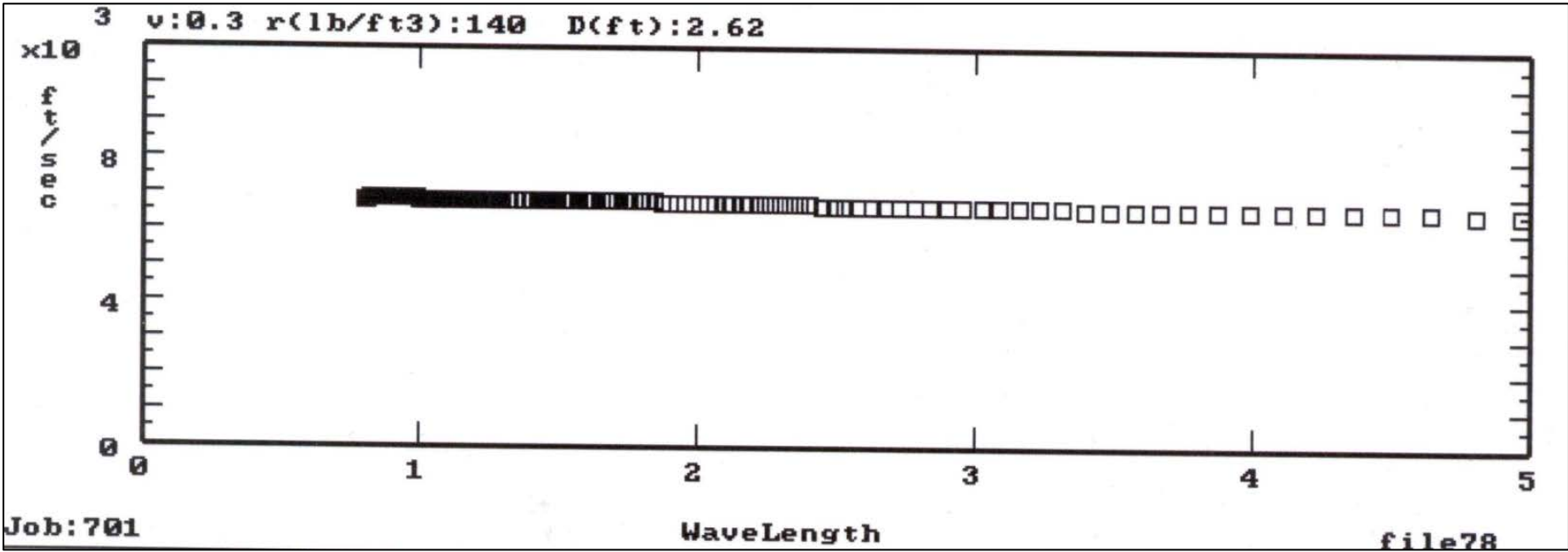


1 wavelength (-360° phase) = 2.62 ft (SASW Transducer Spacing),

Vel=frequency x wavelength = 2628Hz x 2.62 ft =6900 ft/s

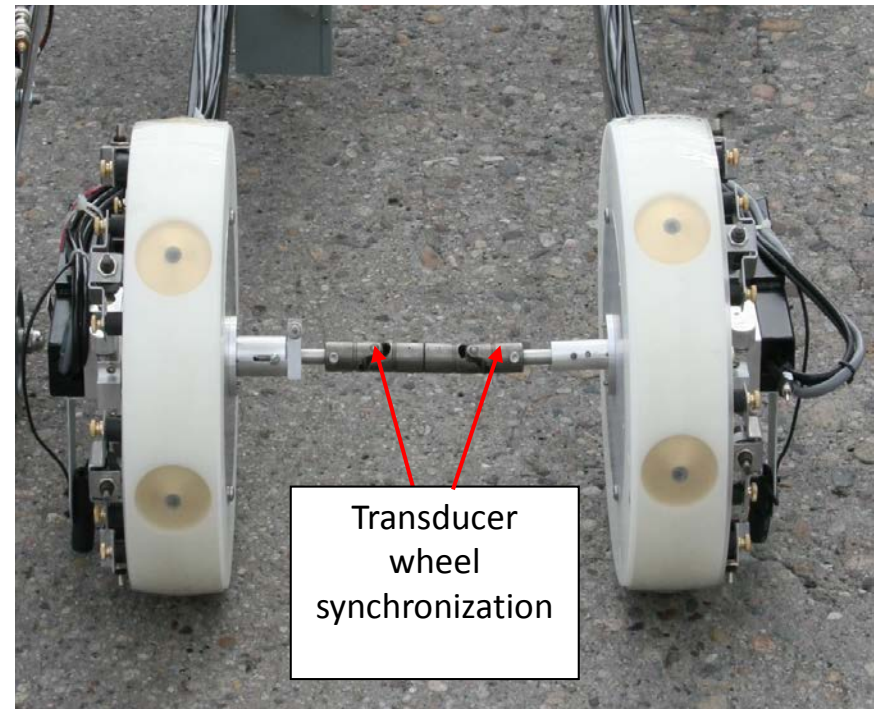
Surface Wave Velocity vs. Wavelength Sound Concrete

V = 6900 ft/sec Surface Wave Velocity for Sound Concrete



Scanning Spectral Analysis of Surface Waves

- 2 identical sensor wheels
- One set of impactors fire
- Spacing typically 6 or 9 inches for (SASW+IE)
- Spacing typically 12 or 24 inches for IE only
- Set wheels 30 degrees out of phase to perform IE testing on both wheels (alternating)



Sonic Surface Scanner – Layout



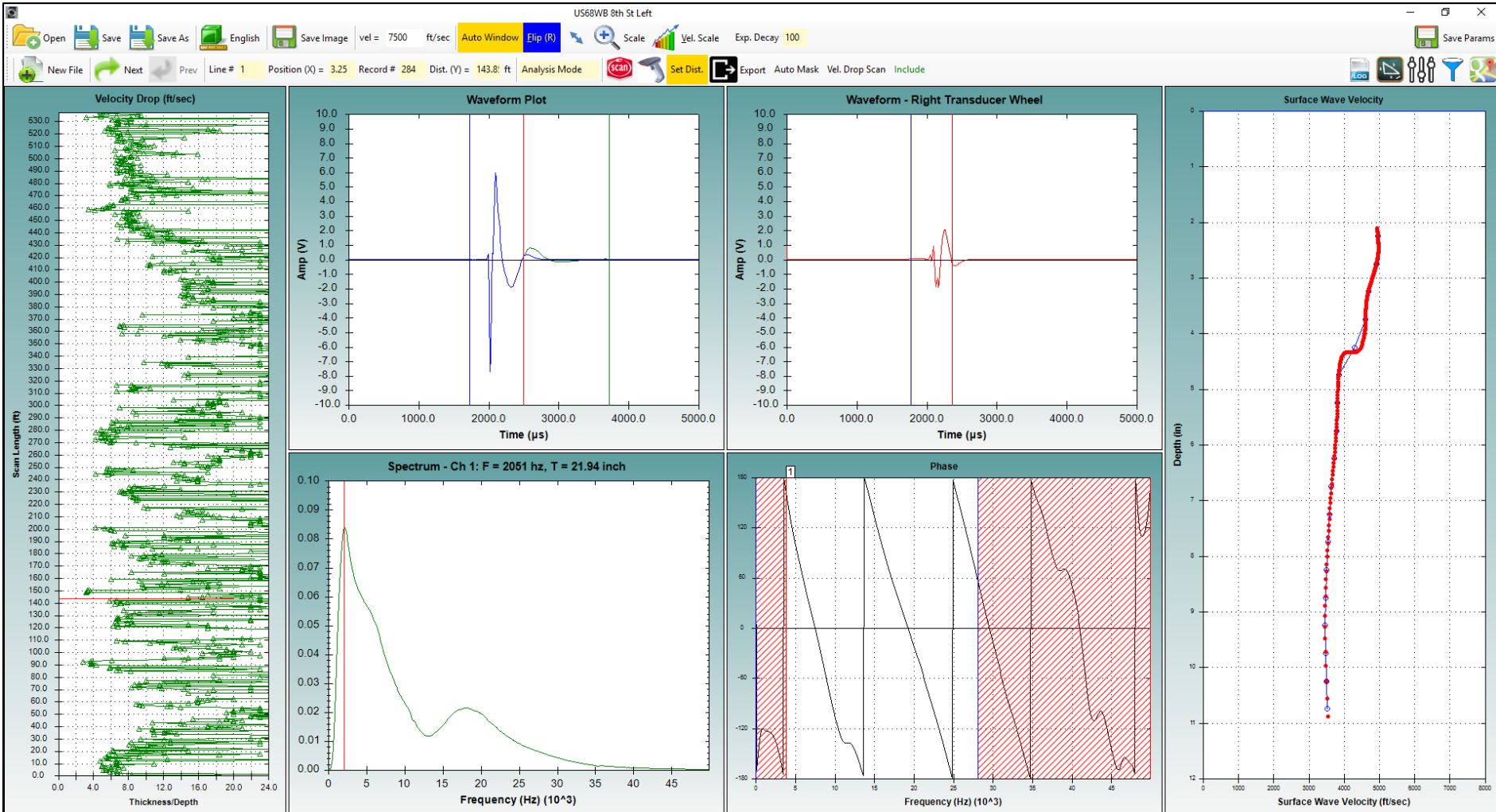
Sonic Surface Scanner – Layout



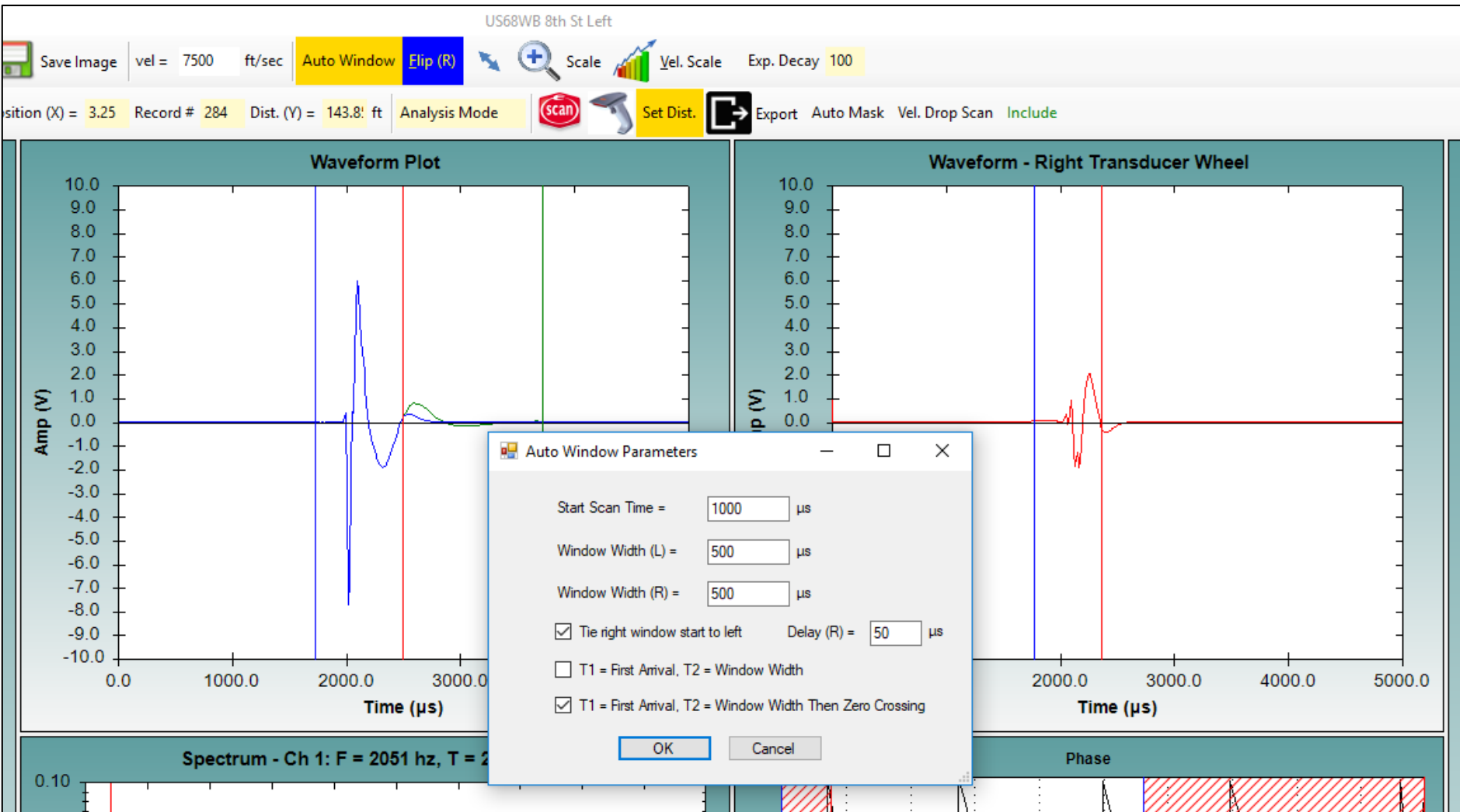
Sonic Surface Scanner – Testing



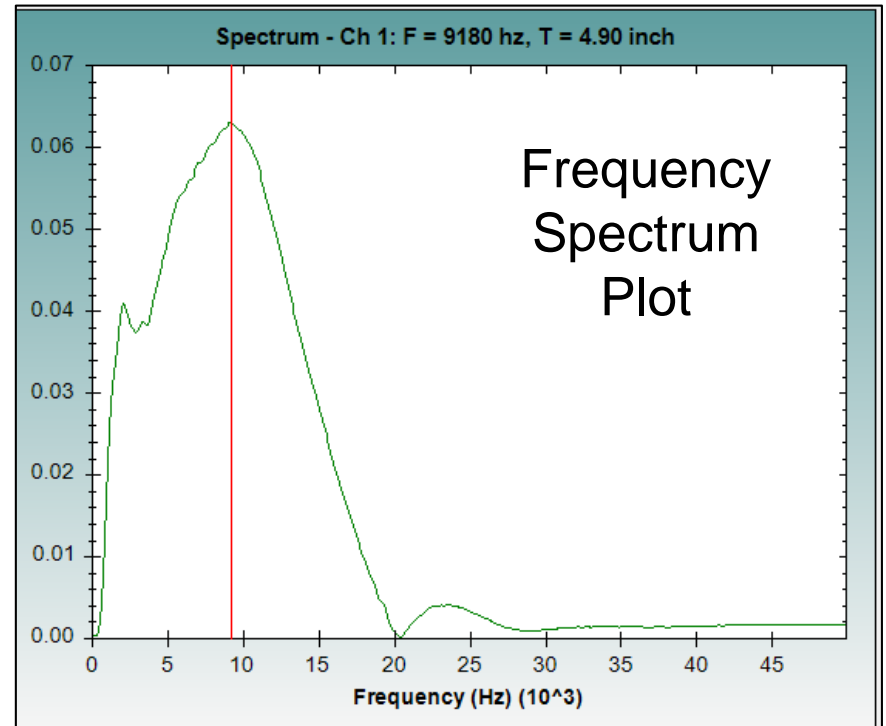
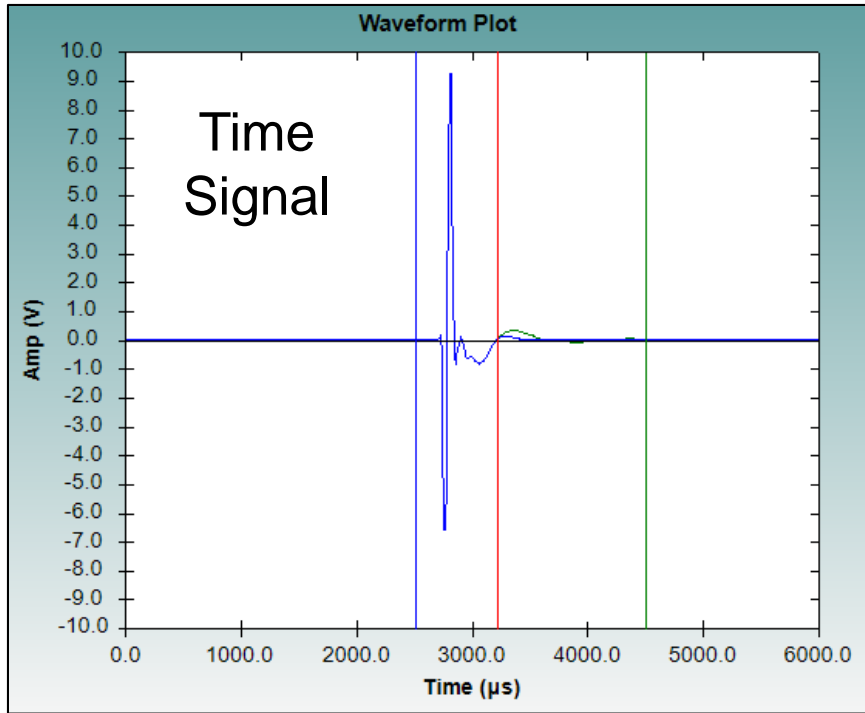
Standard S³ Data Analysis View



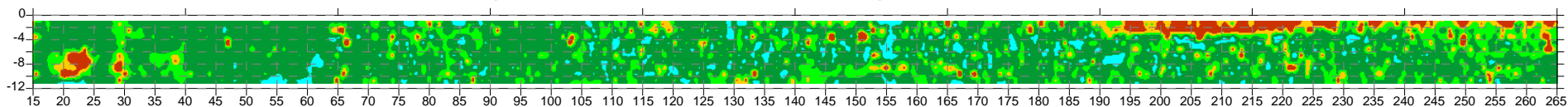
Automated Time Windowing Options



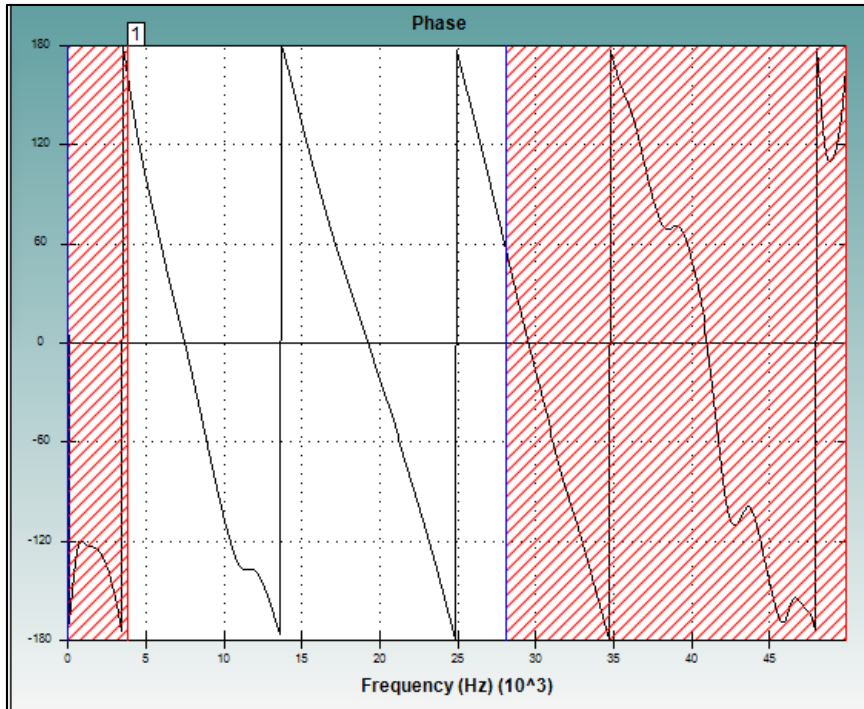
Automated IE Analysis



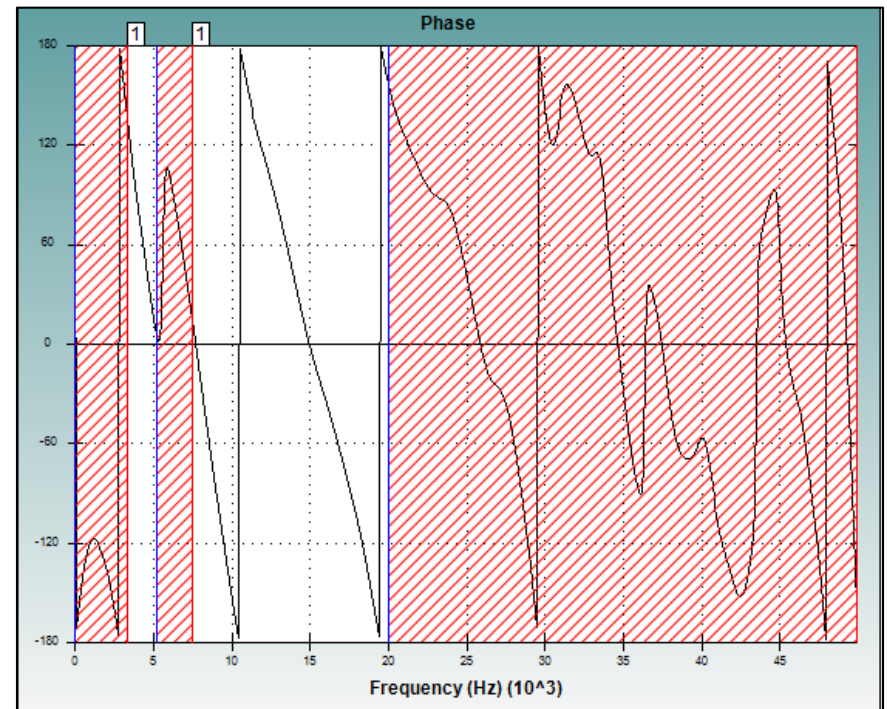
IE NCAT Results Image (Fall 2016 Testing)



Automated SASW Phase Masking



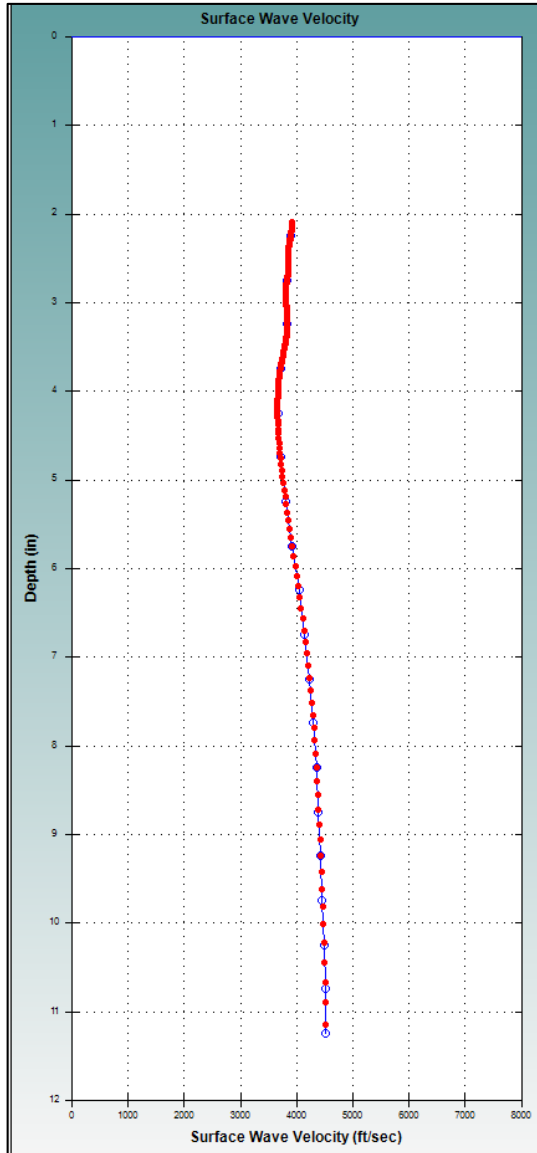
Automated Phase Analysis Works Well



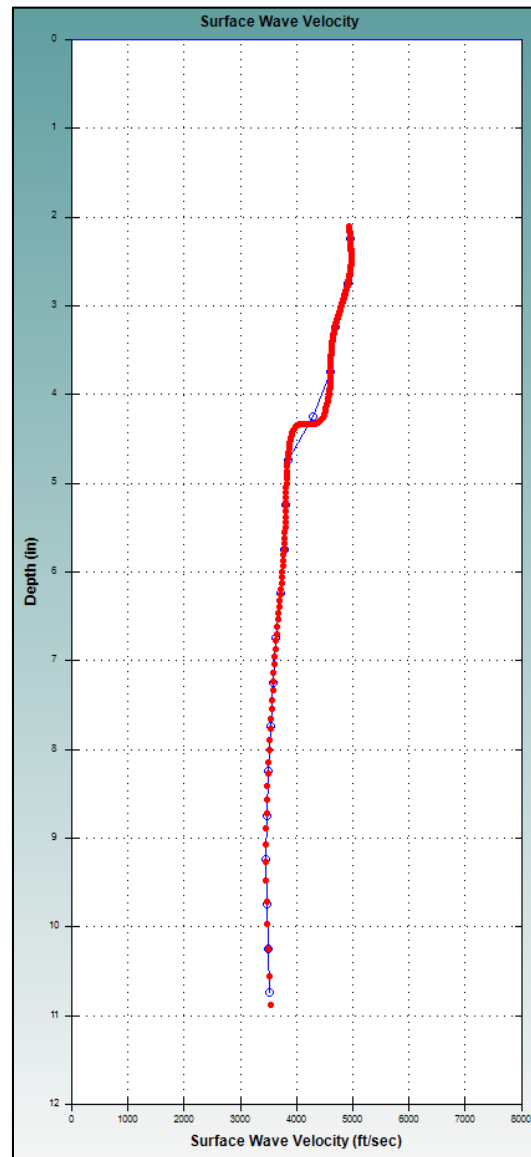
Additional Phase Mask added manually

Dispersion Curve Interval Averaging

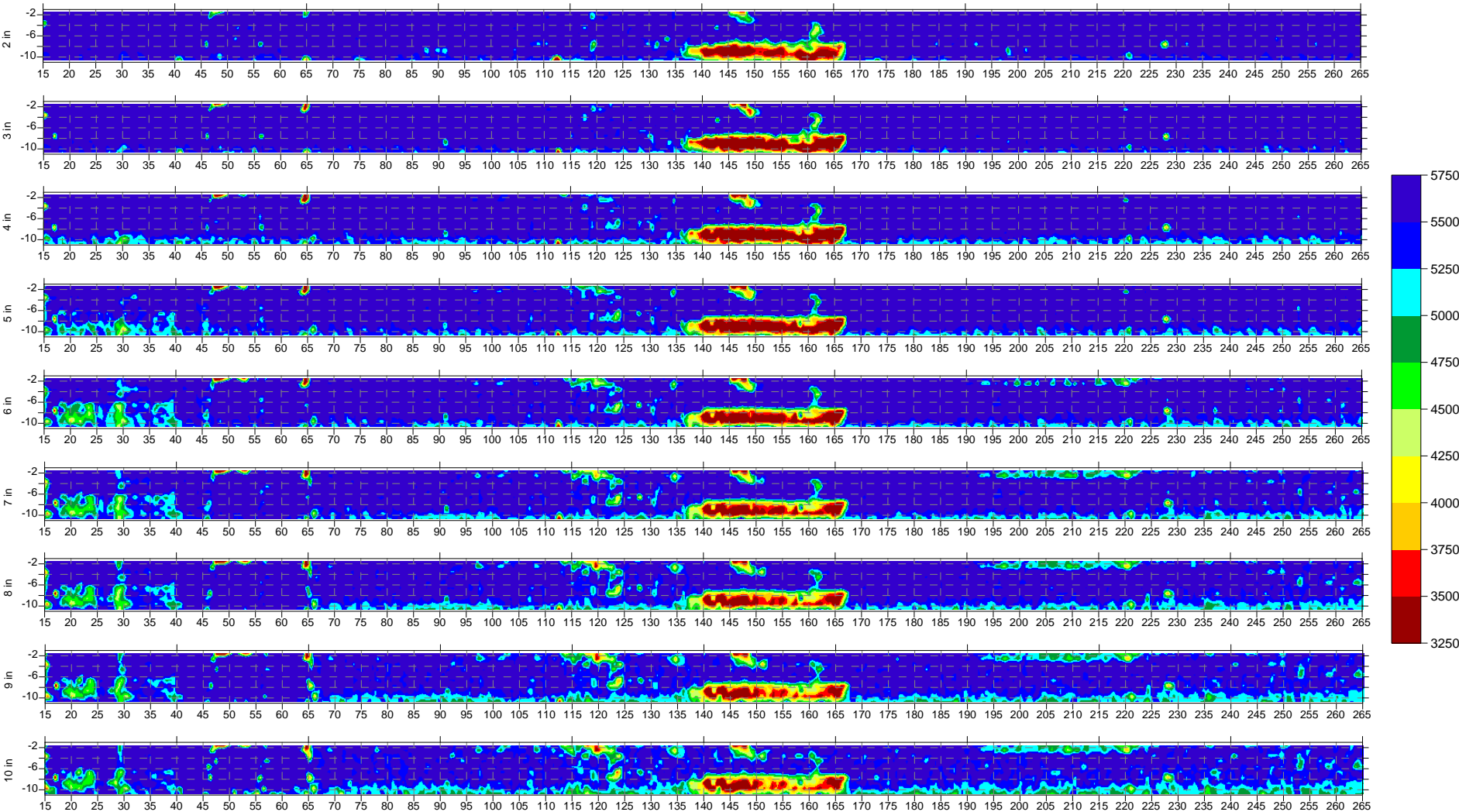
Good
Condition
Velocity vs
Depth



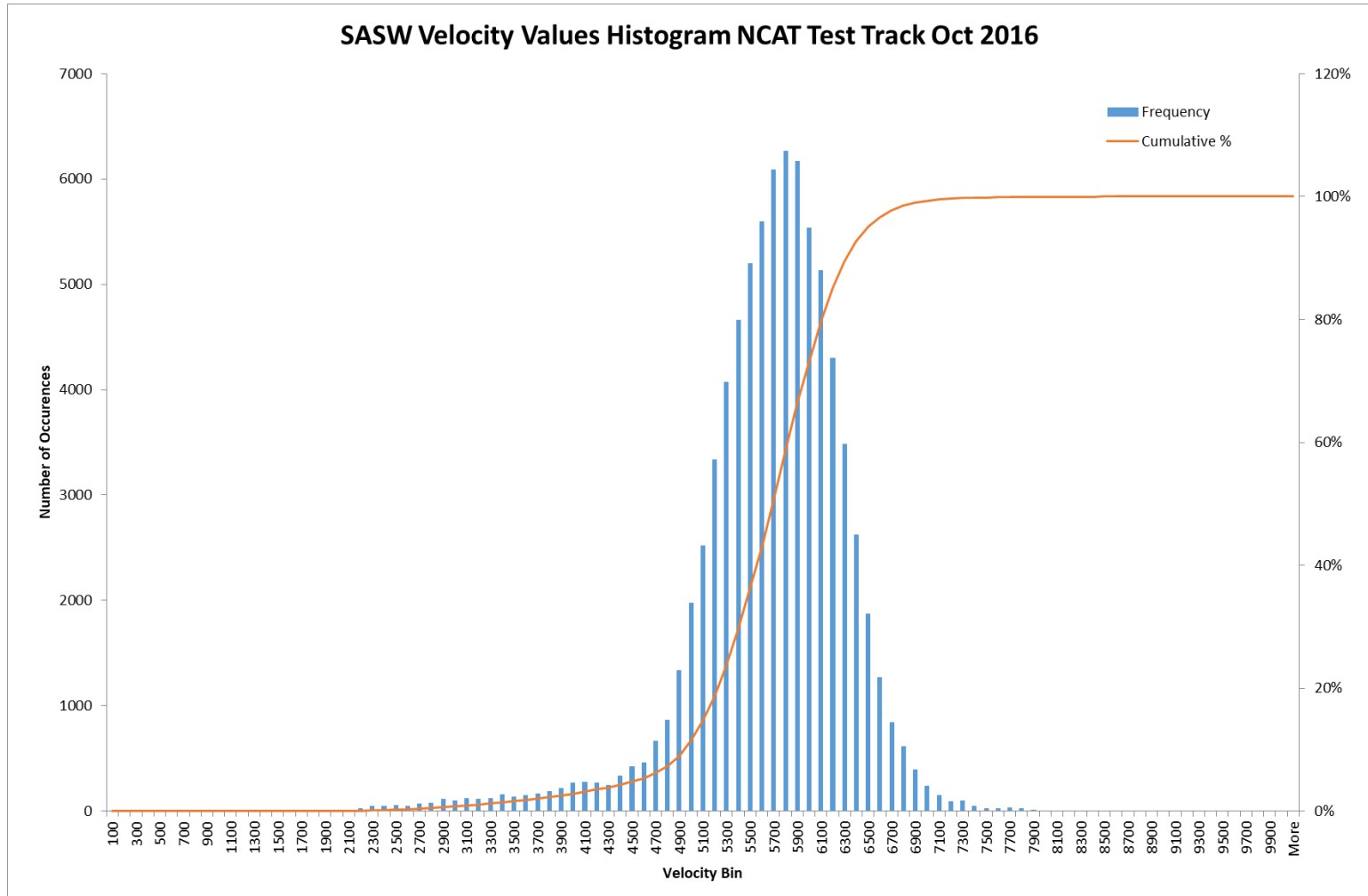
Fair
Condition
Velocity
Drop @4.5''



Surface Wave Velocity Slices View

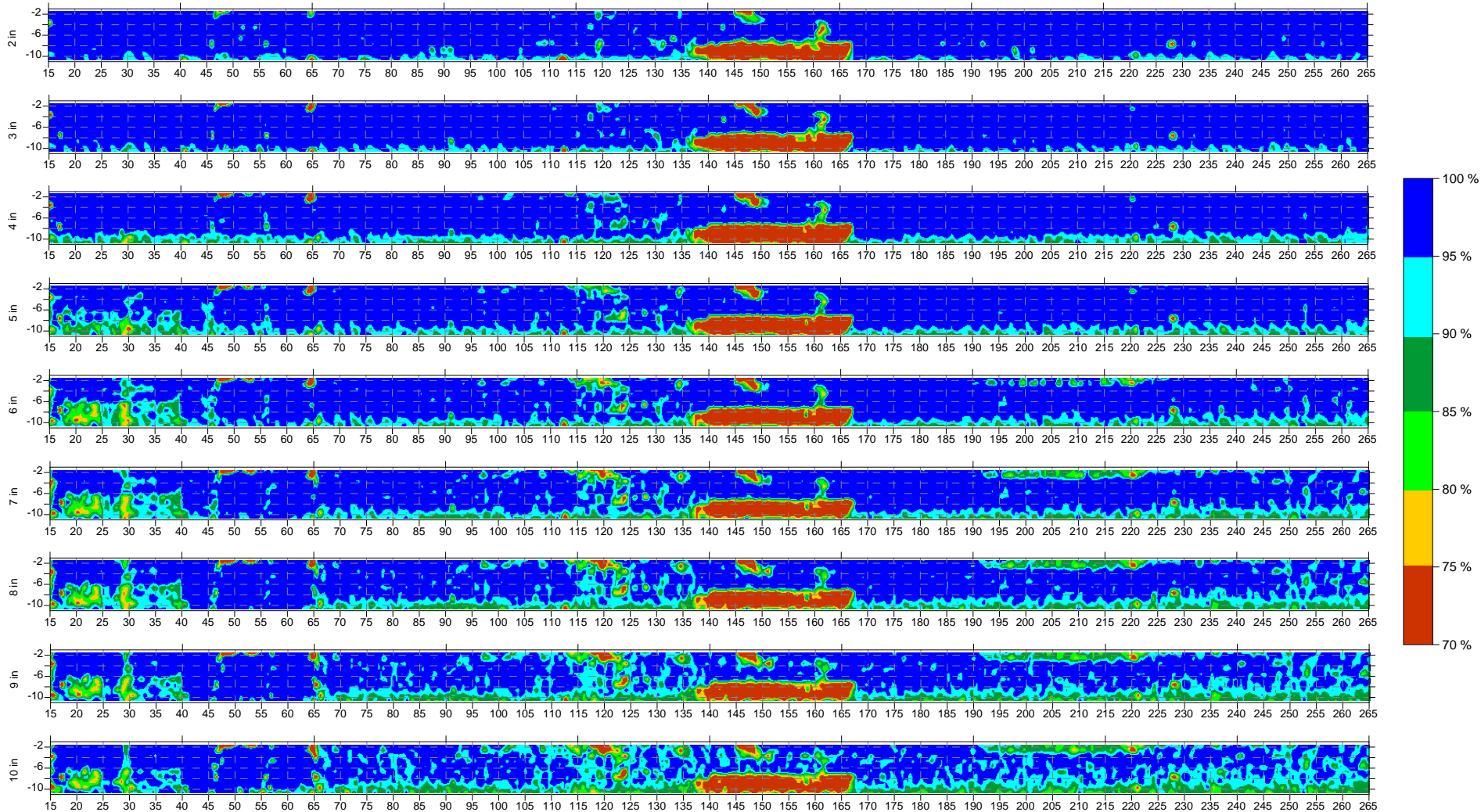


Normalized Velocity Method

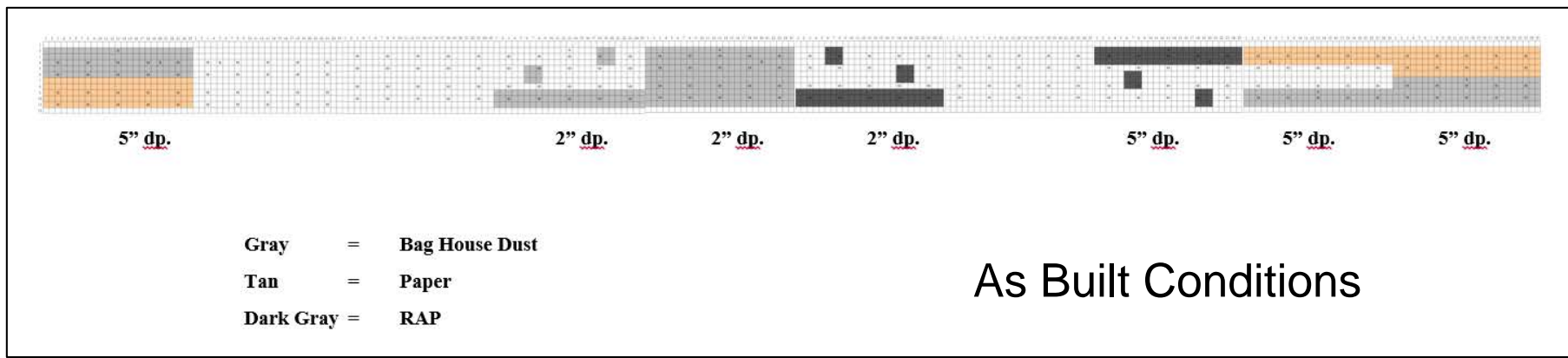
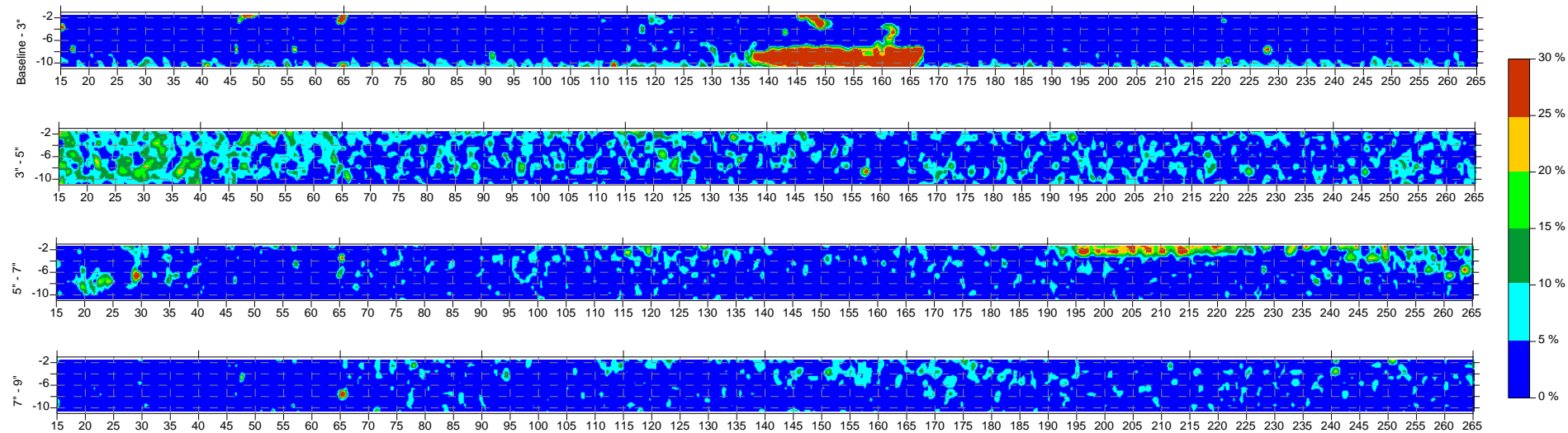


- Most common value between 5700 – 5800 ft/sec

Normalized Velocity Slices View



Depth Difference Slice View



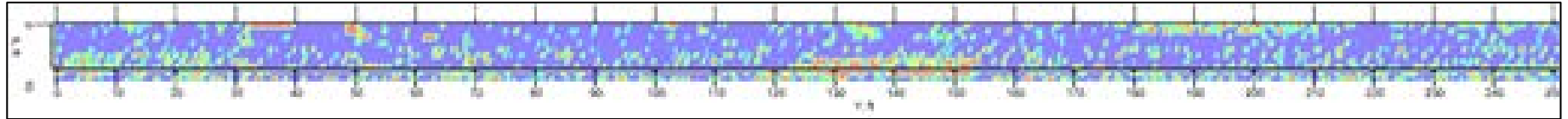
S³ Fully Automated Software In Development

- Utilizes latest high speed processors.
- Bulk data processing techniques.
- Attempting to fully automate data analysis.
 - Would make data analysis accessible to technicians.**
- Hope to reduce data processing time by 10 – 100 times.
 - What took a week could be reduced to an hour or less.**
 - Would reduce costs of testing.**
 - Potential to provide same day test results.**

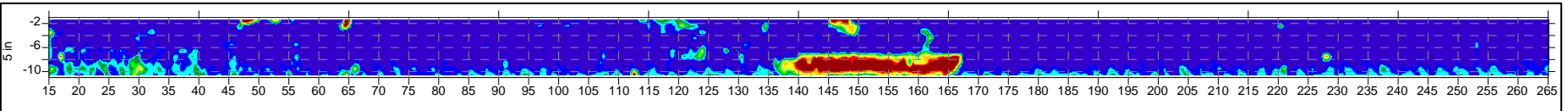
S³ Fully Automated Software In Development

- Promising Initial Results

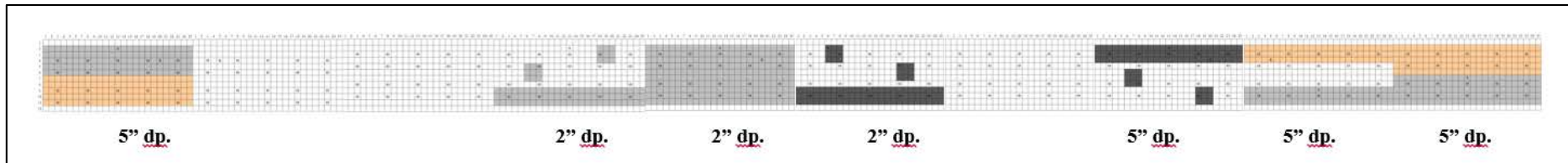
Fully Automated Analysis - Velocity @ 5" deep



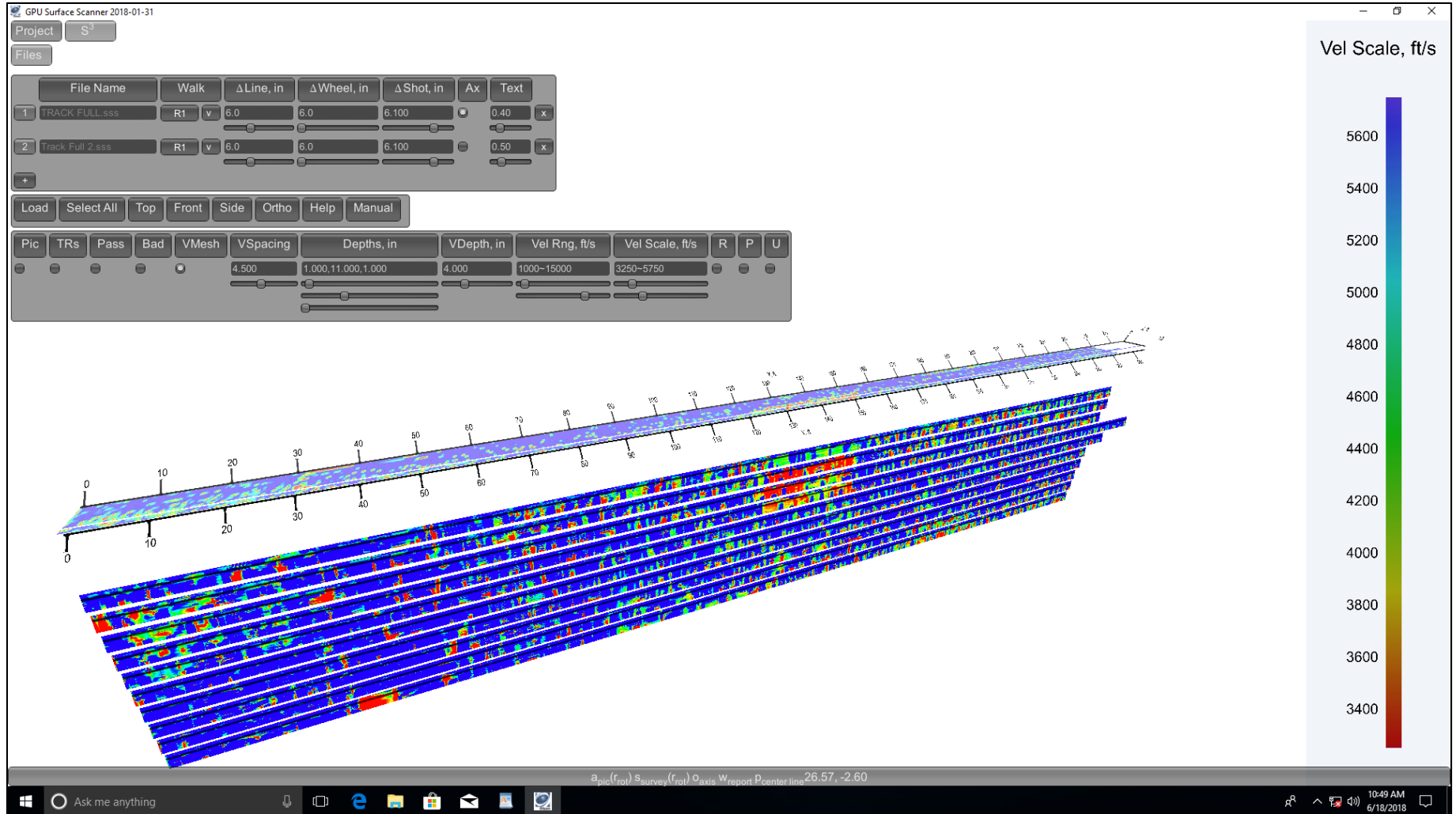
Current Analysis – Velocity @ 5" deep



As Built Conditions



S³ Fully Automated Software In Development



S³ System Hardware



- Current system is cart based
- Cart is adequate / preferred on Bridge Decks
- Full Lane Width would be ideal for asphalt pavements



S³ System Hardware

- Next Iteration will include temperature sensor for SASW
- Improvements to cart to make assembly easier/ faster.
- Improvements to lifting / turning mechanism.
- Improvements to cable routing and waterproofing.



Olson Questions for DOT's

- NM and TX – 6 passes per lane, KY – 3 passes per lane – which was preferred?
- Which data presentation method(s) was preferred?
- What features / abilities would you like to see added/improved?

Other Applications of S³ System

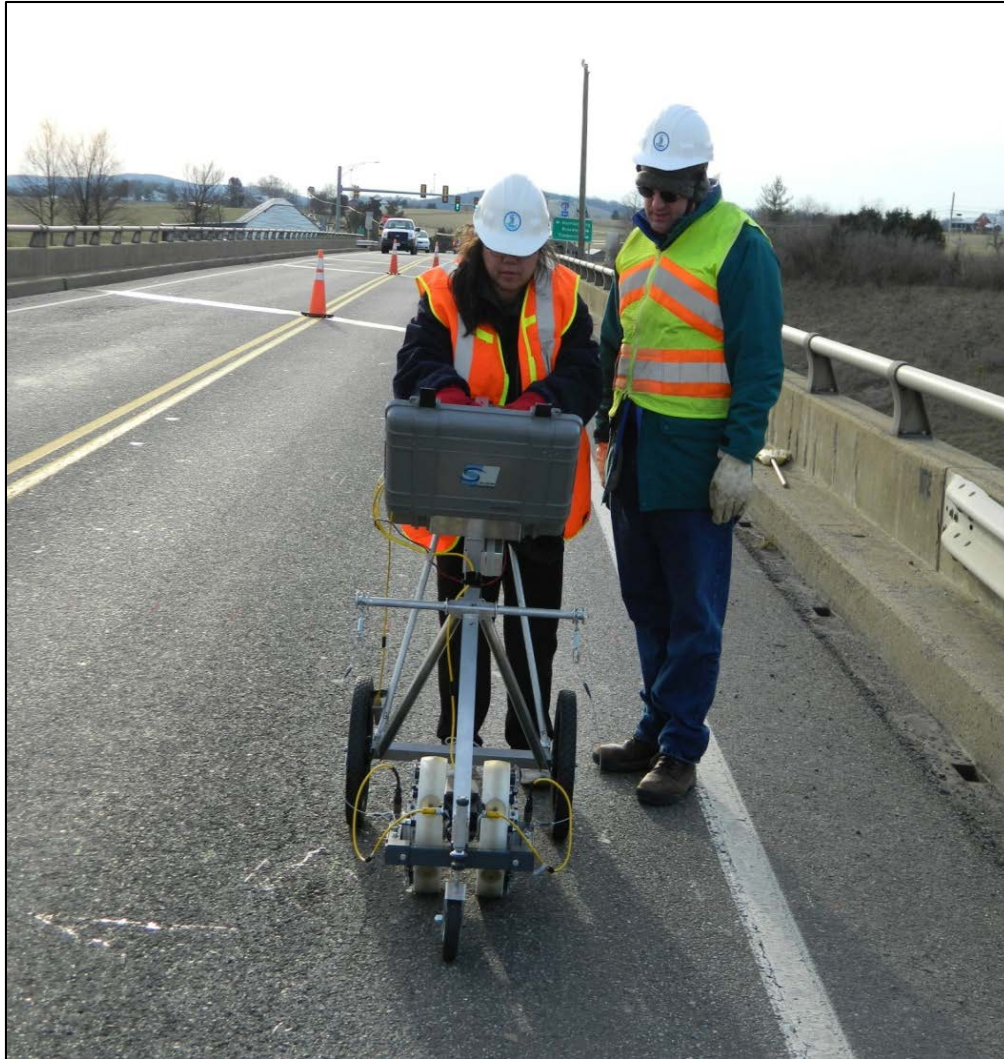
- SASW/IE Testing

- Asphalt Pavements
- Asphalt overlaid concrete bridge decks

- IE Only Testing

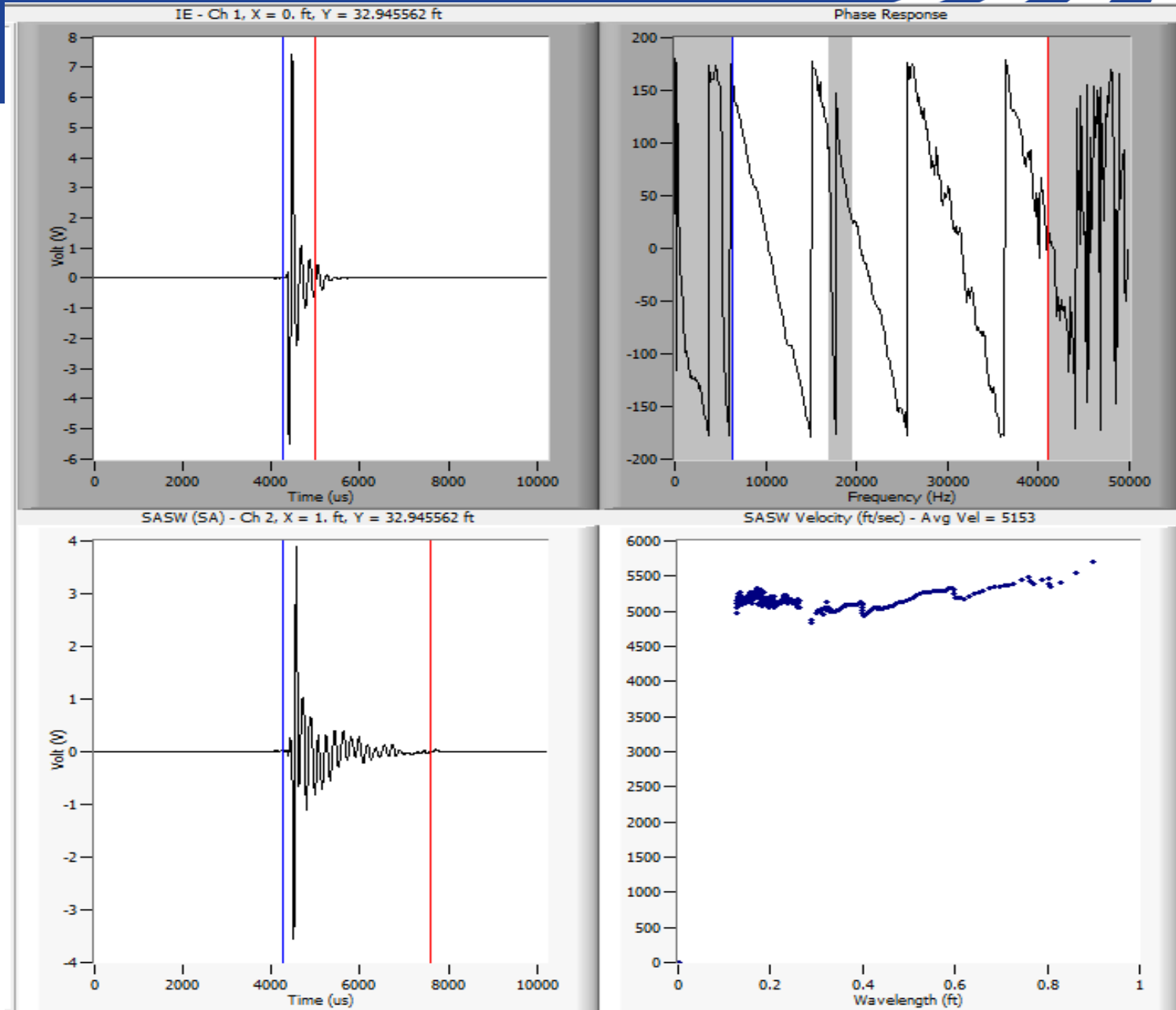
- Concrete Bridge Decks – Delamination / Condition
- Parking Structures / Ramps – Delamination / Condition
- Elevated Concrete Slabs – Condition / Thickness
- Concrete Slab on Grade – Condition / Thickness

Asphalt Overlaid Concrete Deck in Colorado



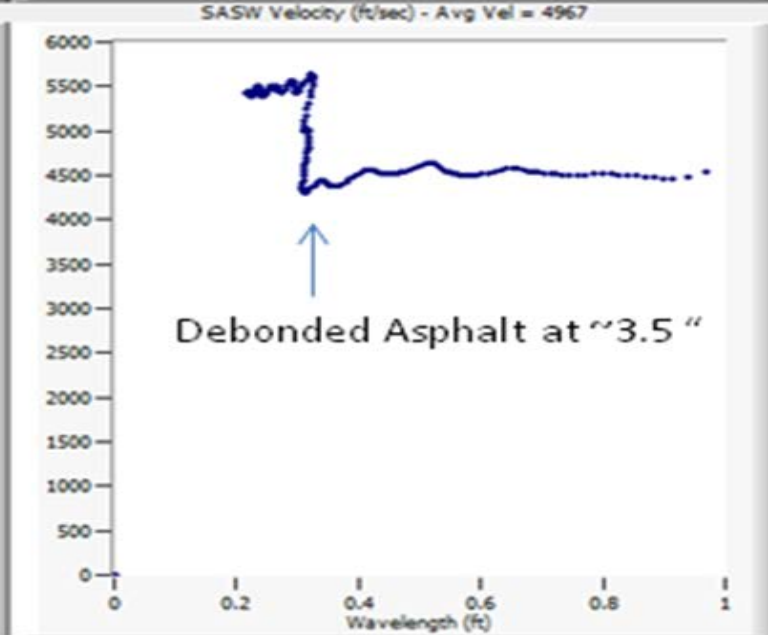
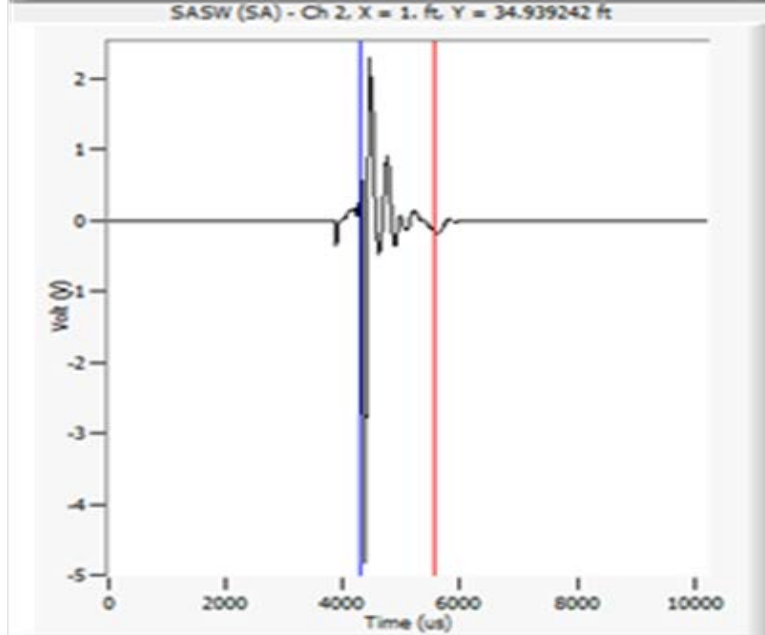
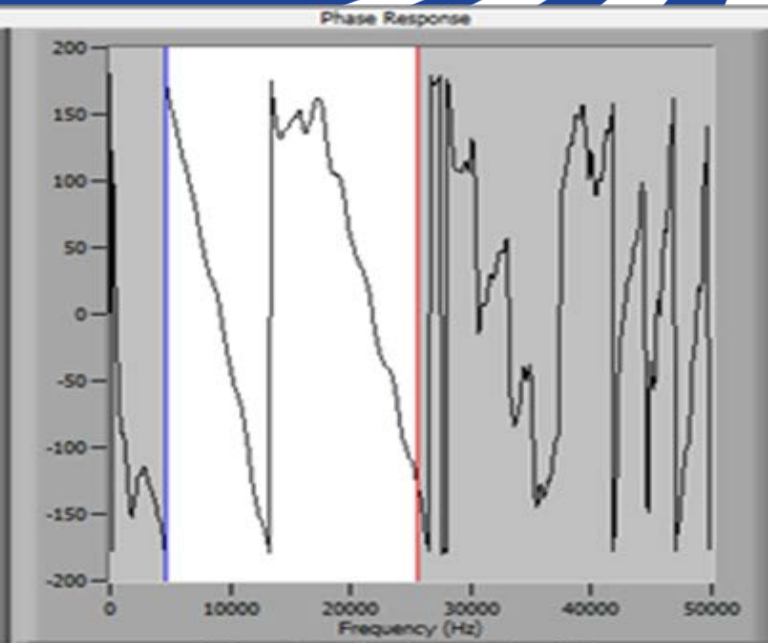
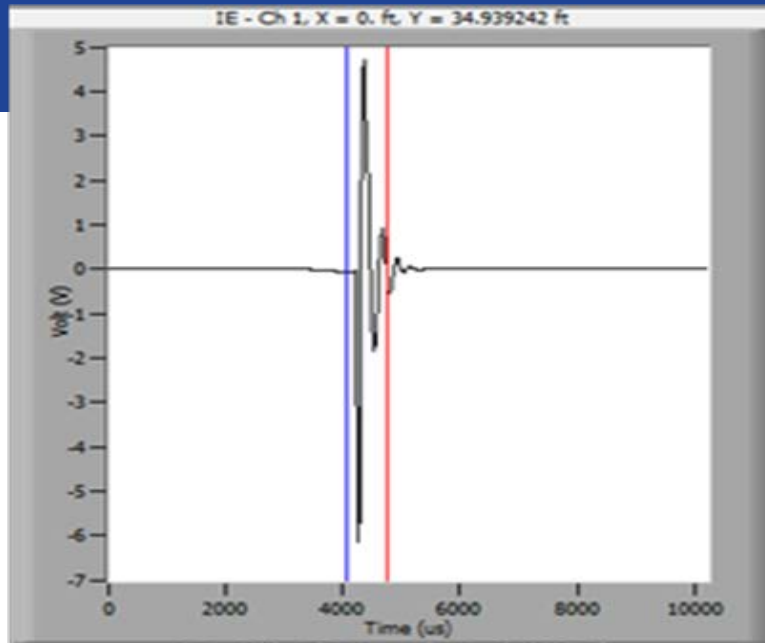
Example Conditions

**Bonded
Asphalt to
Sound
Concrete**



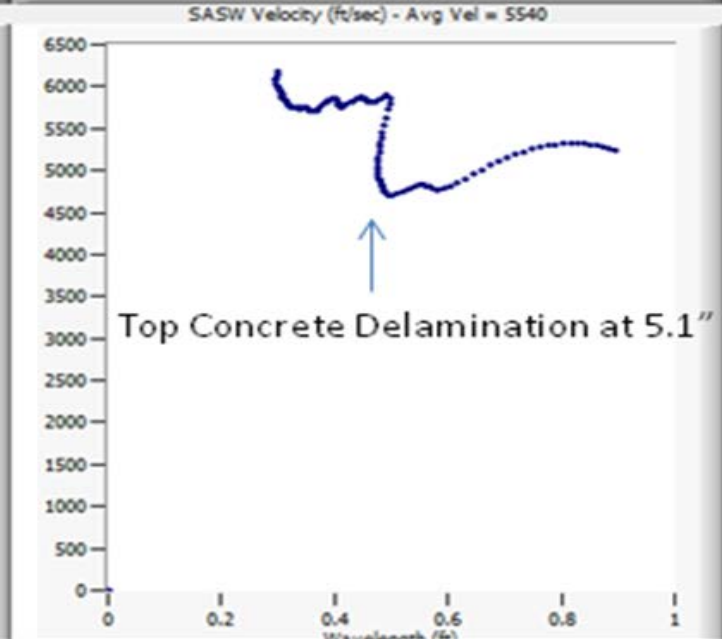
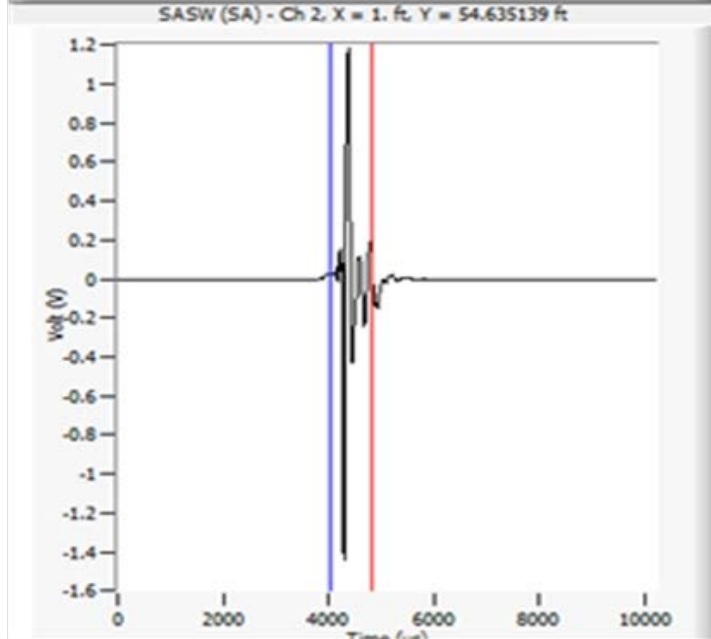
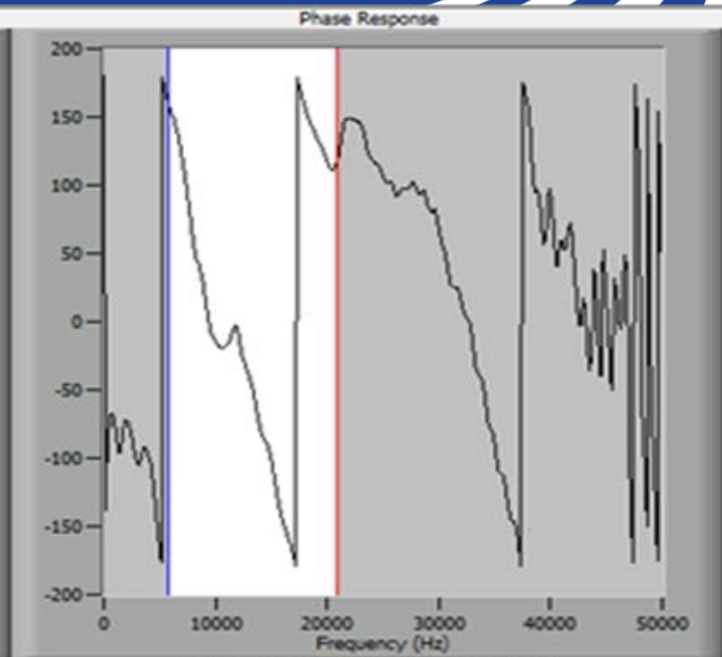
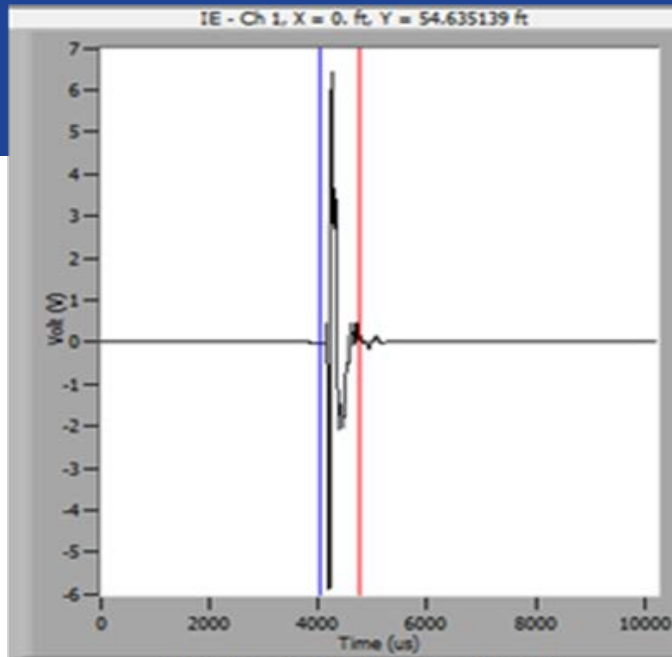
Example Conditions

Asphalt
Debonded
Sound
Concrete



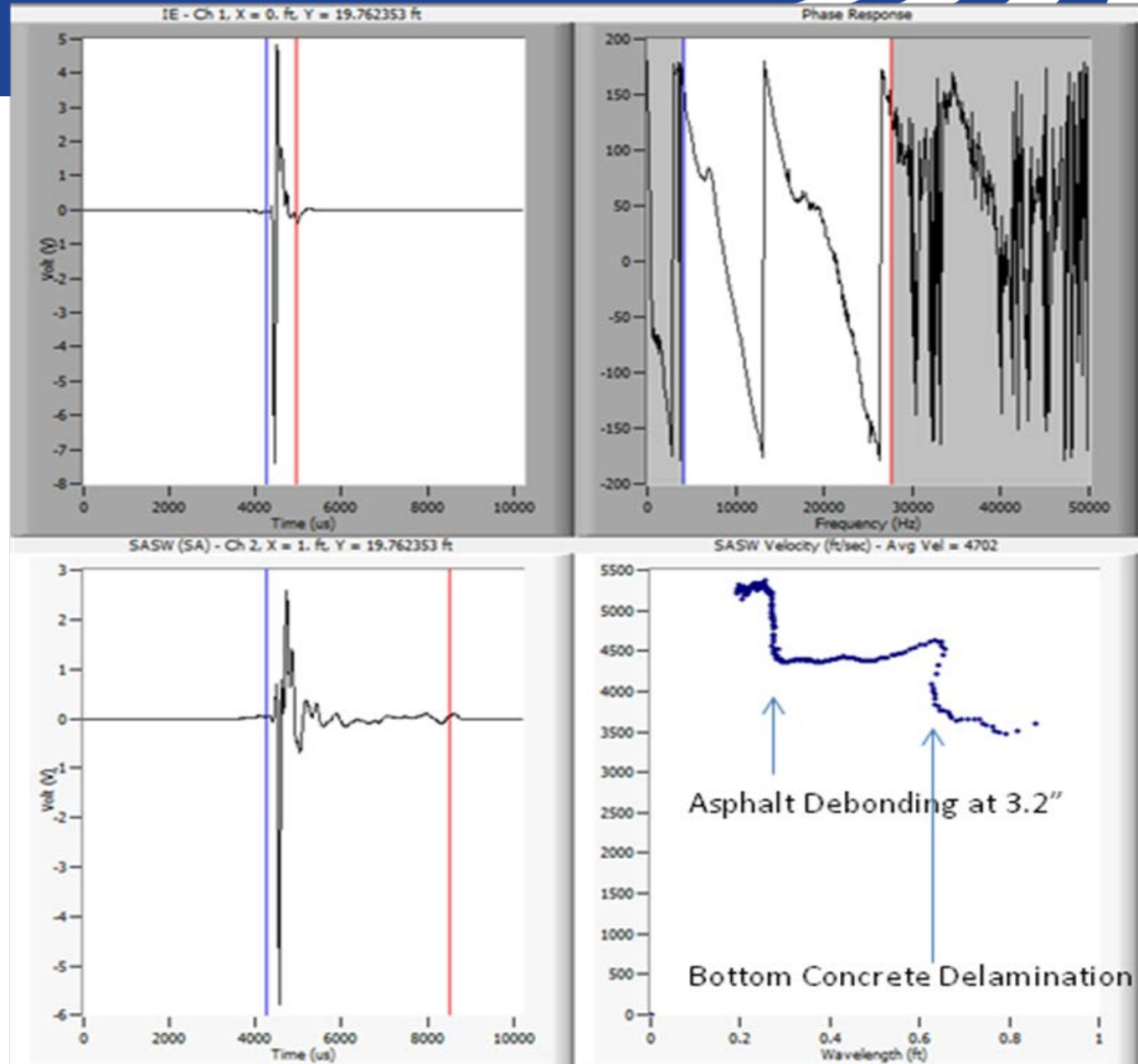
Example Conditions

**Bonded Asphalt
Concrete Top
Delamination**

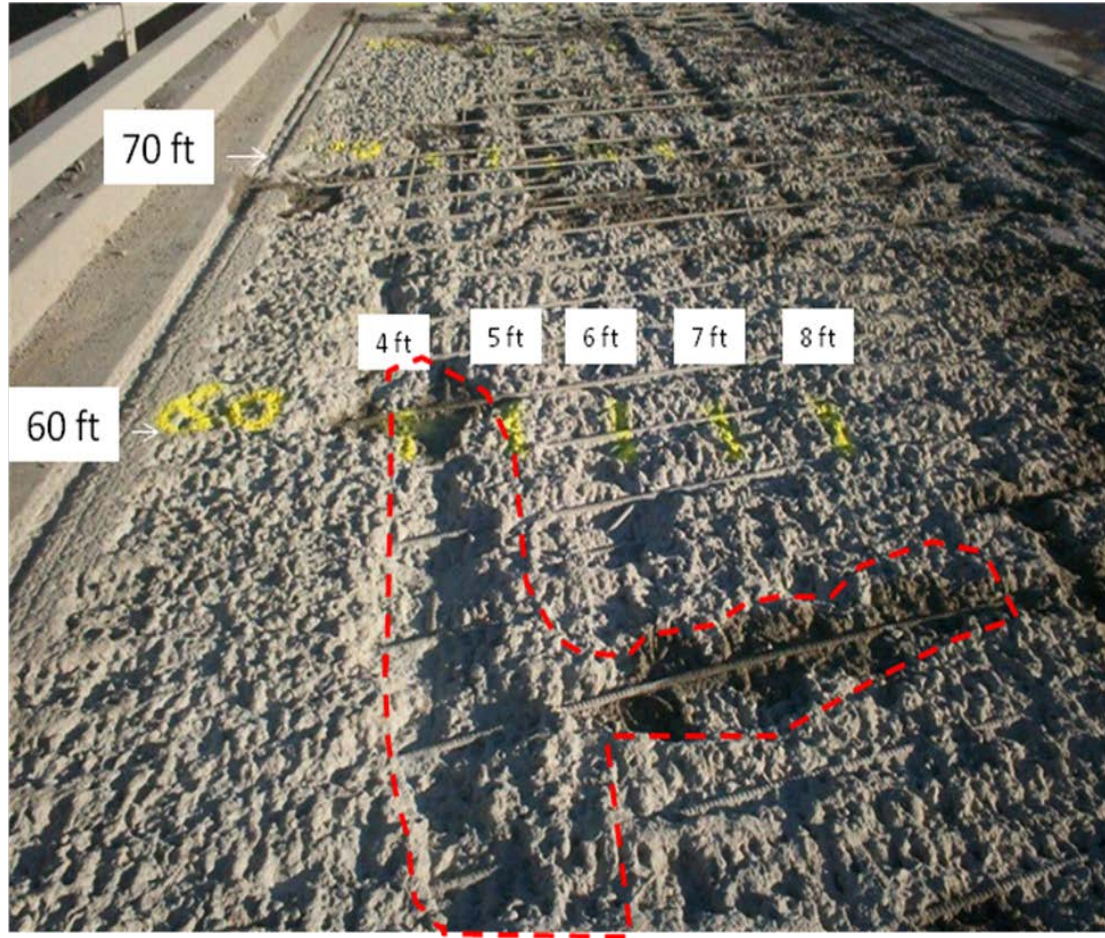
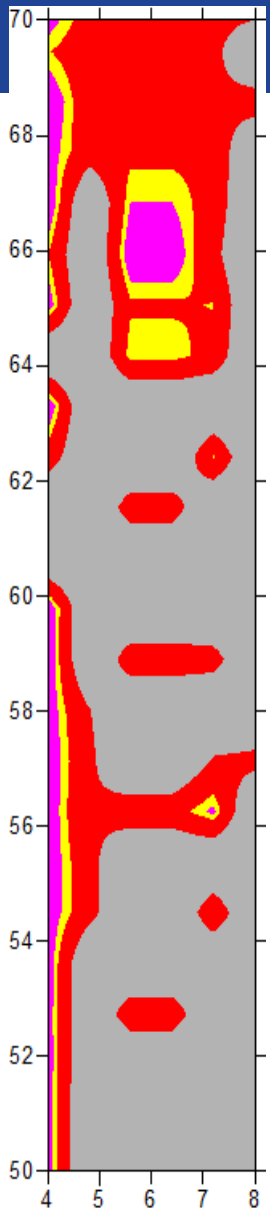


Example Conditions

Debonded
Asphalt
Concrete
Bottom
Delamination



Hydro-demolition to Expose Delaminations



Case Study: 1st Street Bridge in Casper, Wyoming, DOT



Note thickened concrete deck over steel girders was identified in IES tests

Delaminations due to corrosion of top reinforcement in bridge deck



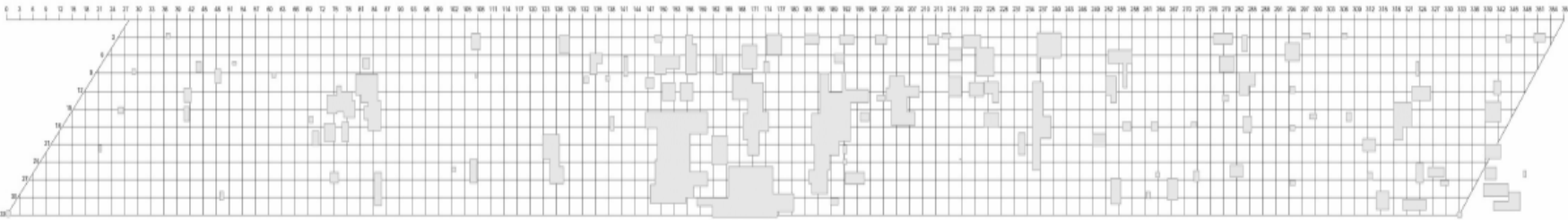
Case Study: 1st Street Bridge in Casper, Wyoming, DOT



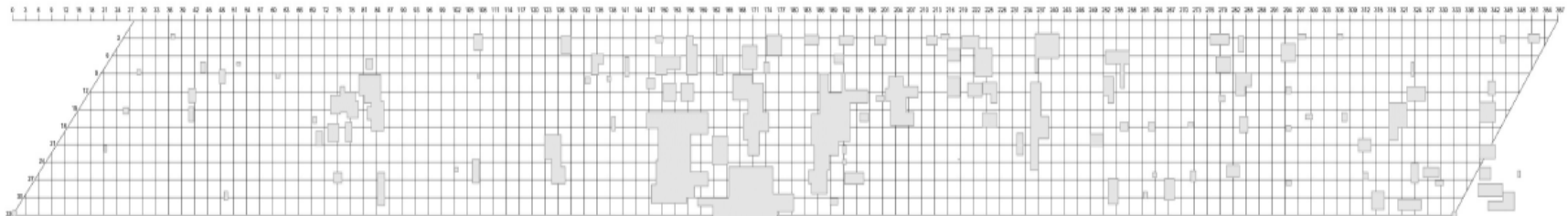
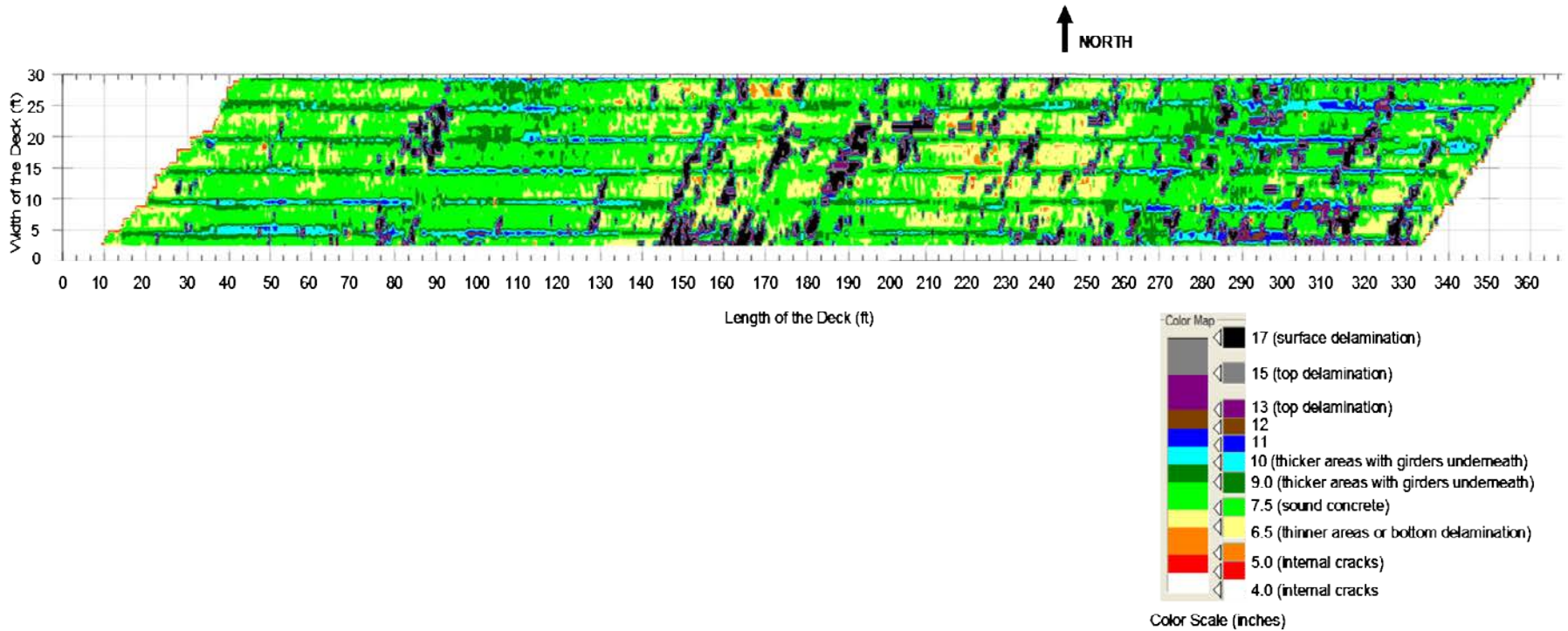
Chain Drag Acoustic Sounding Results for Top Deck Delaminations by Wyoming DOT



- Time consuming process requiring multiple people, multiple field days and lengthy traffic closures.
- Test results must be translated manually into drawings or tables



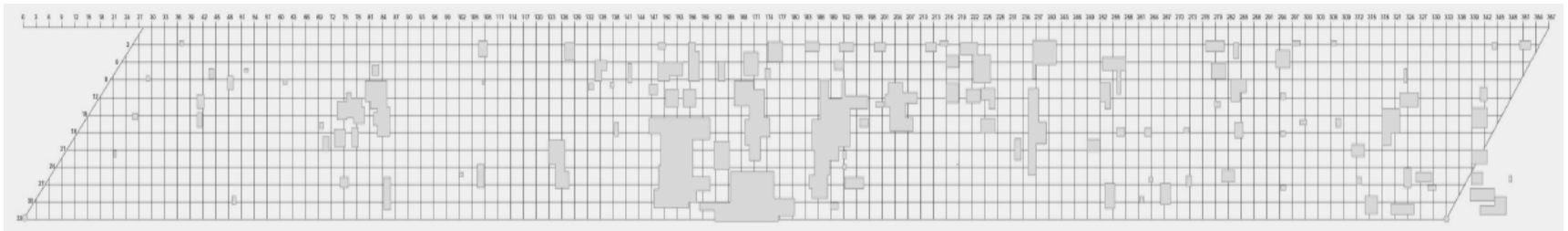
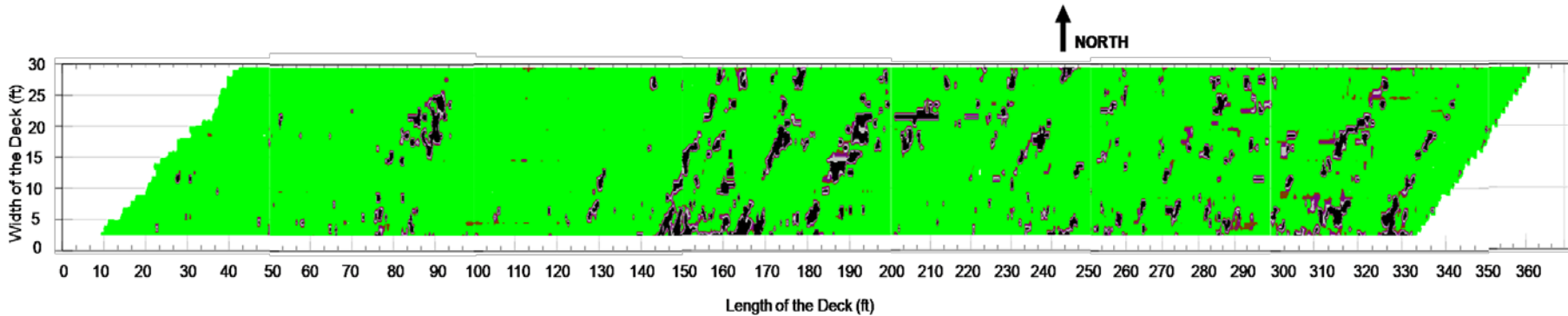
S³ Impact Echo Results (Full-Depth)



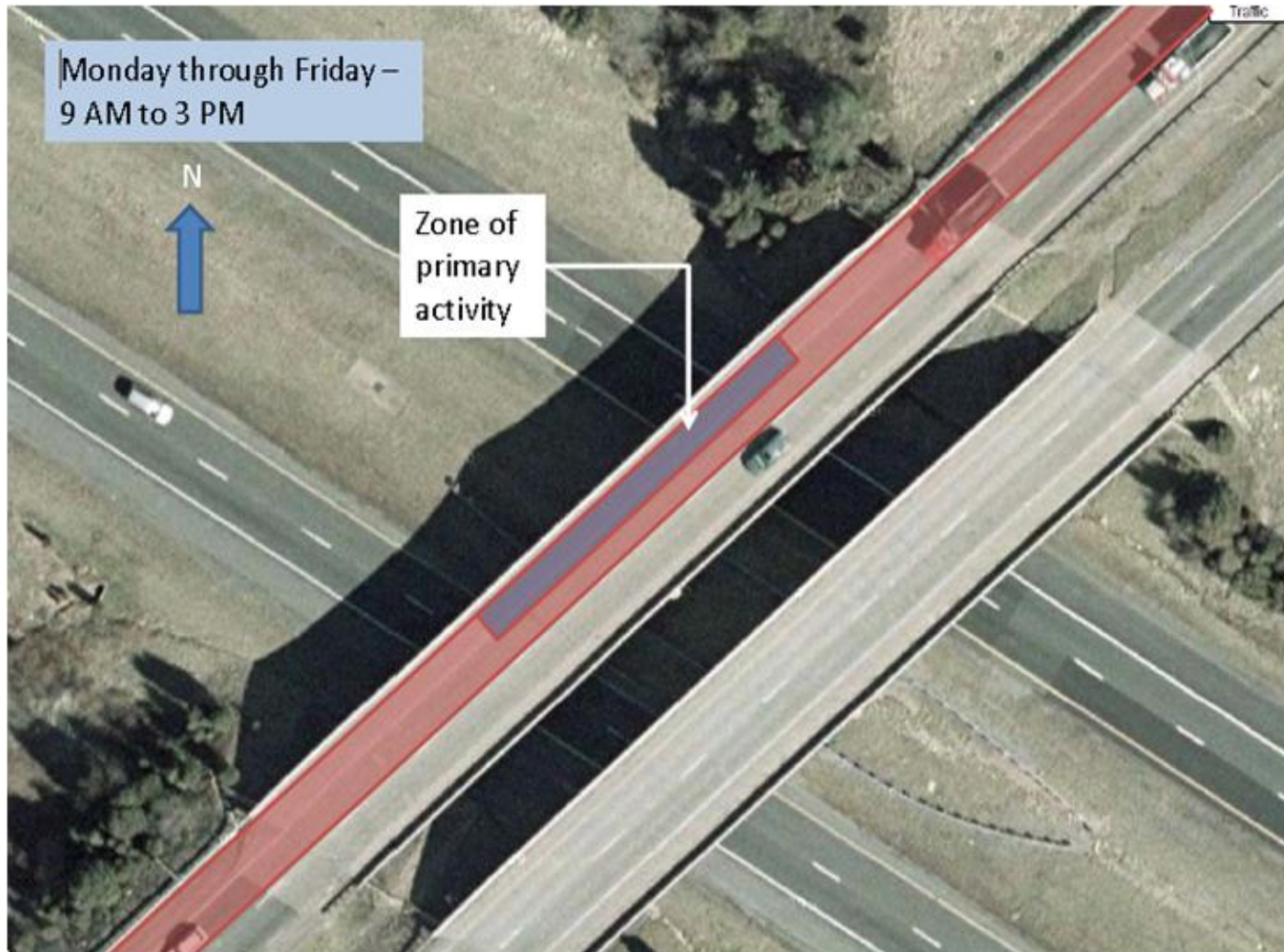
S³ Impact Echo Results (Top)

Impact Echo Top Delamination Results from the S³ versus Acoustic Sounding Top Delamination results from Chain Dragging

- 100 m² (1126 sq ft) of Top Deck



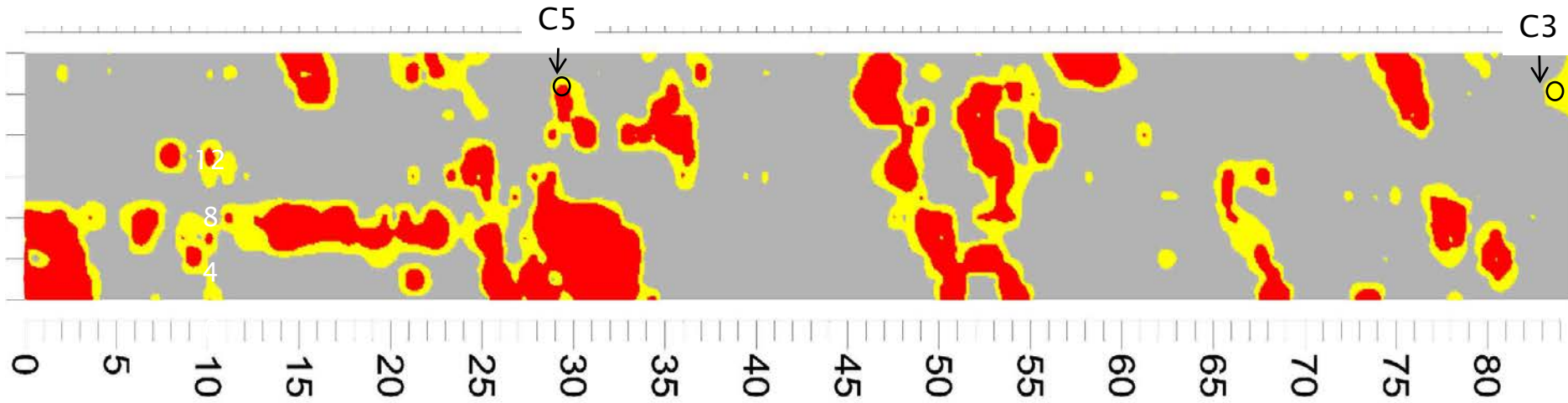
Case Study – Virginia Bridge Deck, James Madison US Highway 15 over I-66



Virginia Bridge Deck (Concrete) - SHRP 2 R06A



S³ IE Test Results and Cores

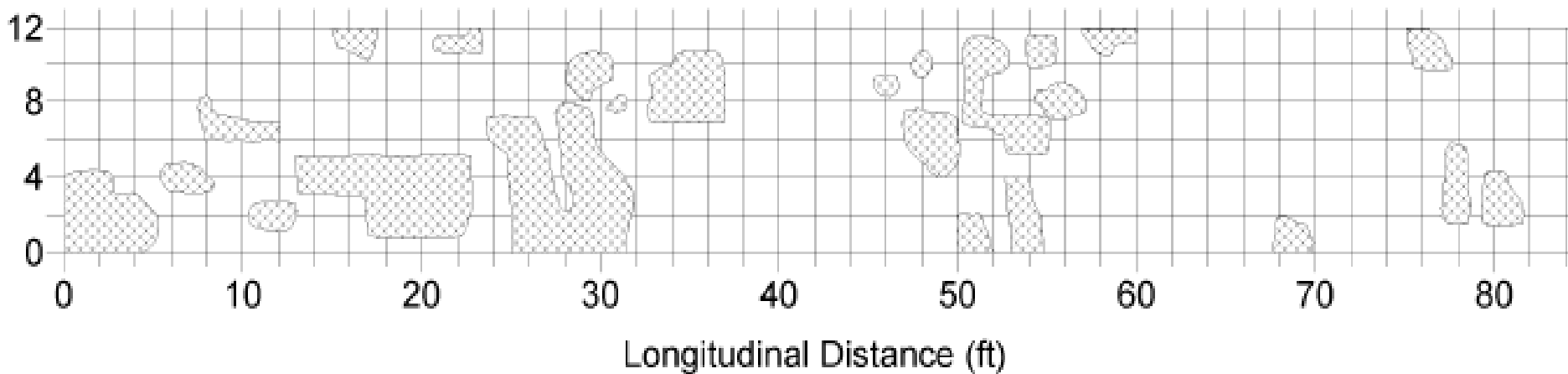
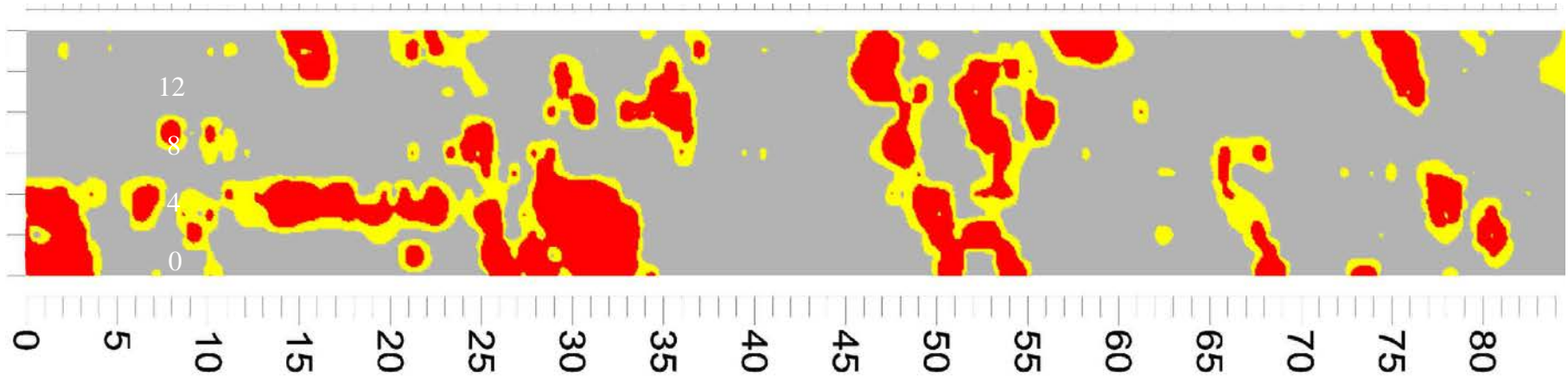


C5 - delamination at 2.5 inches

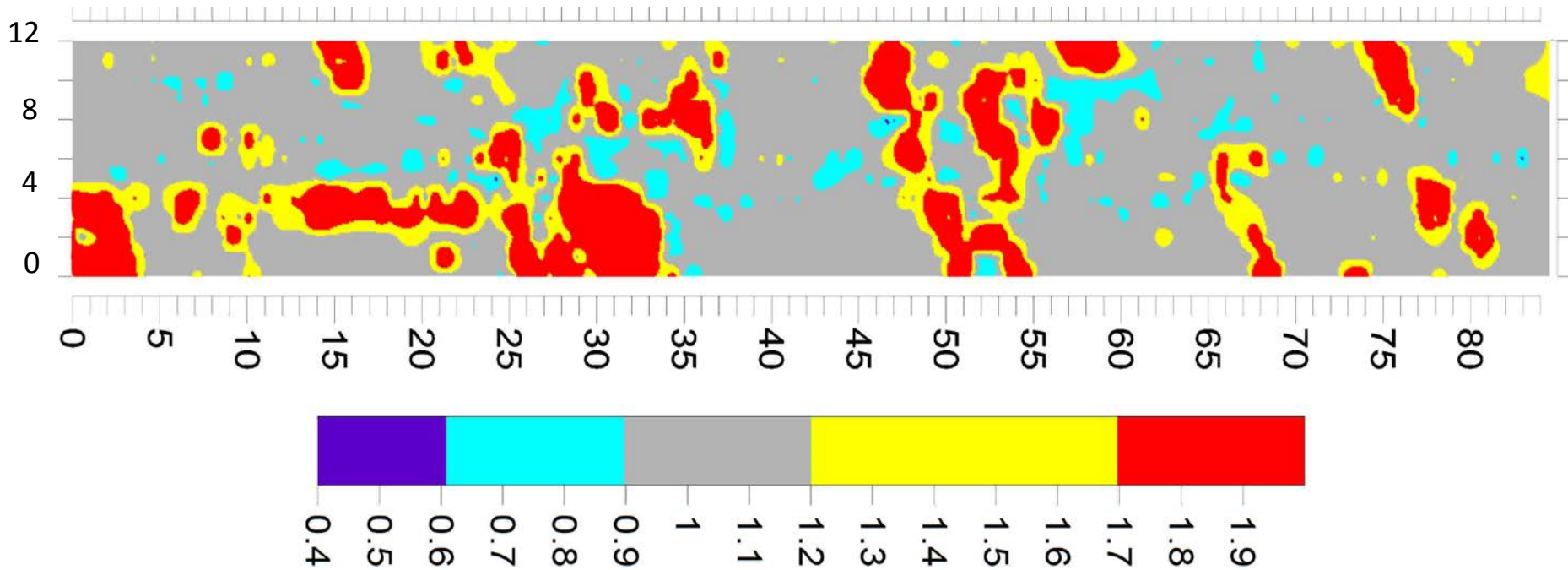


C3 - delamination at 3.5 inches

S³ Top Delamination Results and Chain Drag Results



S³ - IE - Full Deck Depth Results



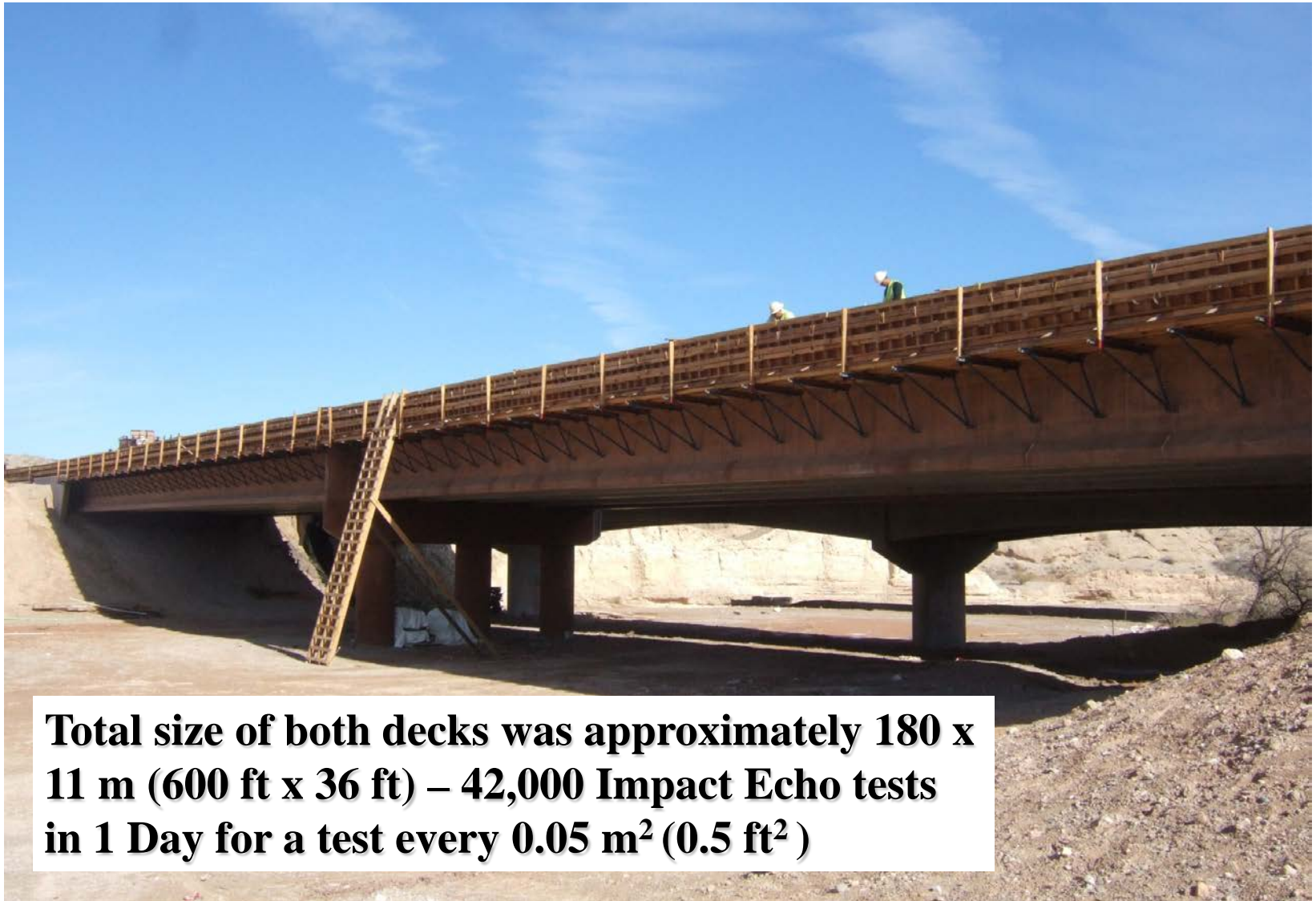
Areas with Probable Top Delaminations = 14%

Areas with Probably Incipient Top Delaminations = 13%

Areas with Probable Bottom Delaminations (or Thin Section) = 5.7%

Case Study: Two Concrete Bridge Decks

Detection of Void/Honeycomb Conditions



Total size of both decks was approximately 180 x 11 m (600 ft x 36 ft) – 42,000 Impact Echo tests in 1 Day for a test every 0.05 m² (0.5 ft²)

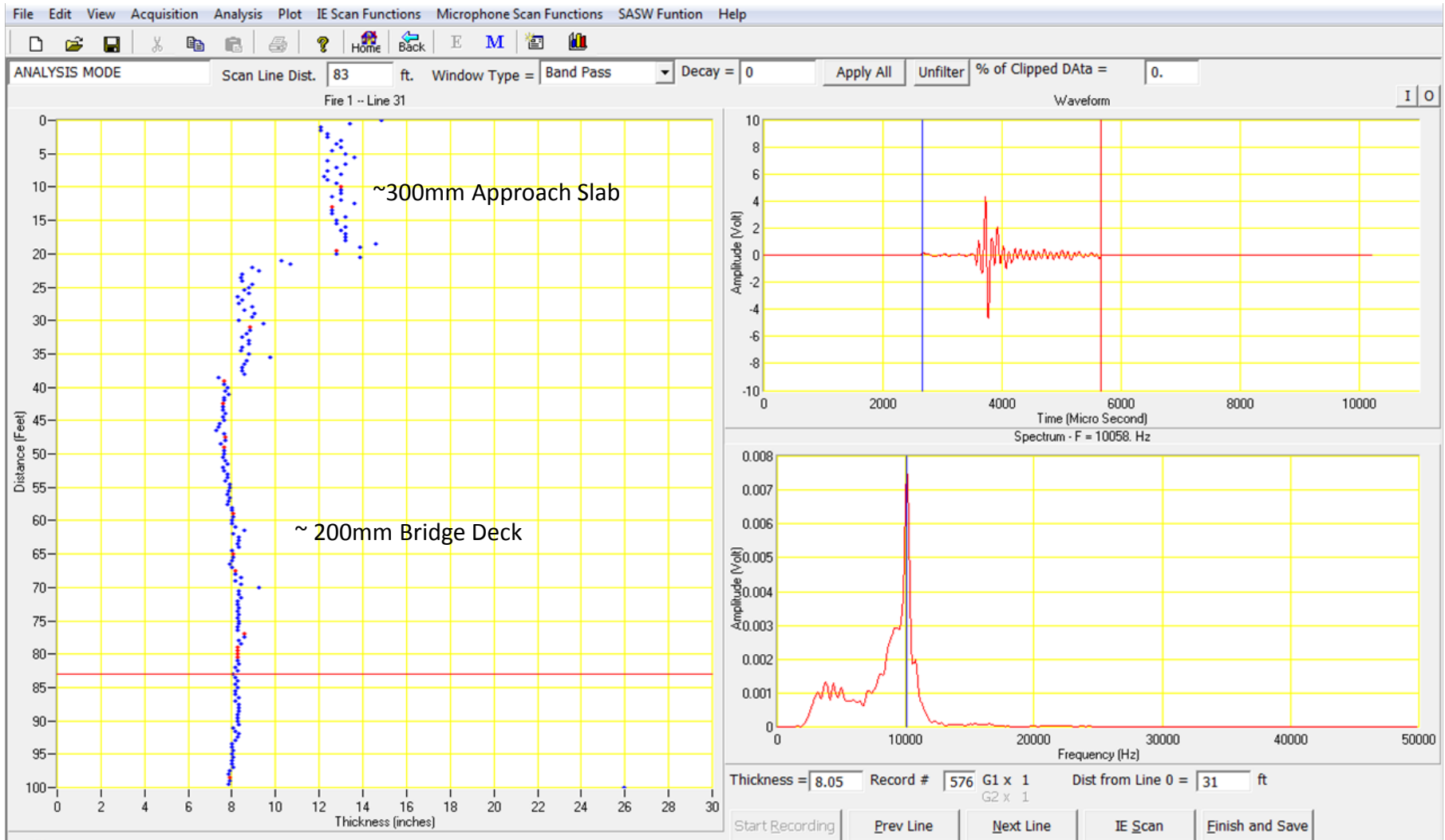


Bridges supported by concrete I-beams, diaphragms, and piers

**Tests on Grid Lines at 0.3 m (1 ft) spacing
across width of decks with cart.**

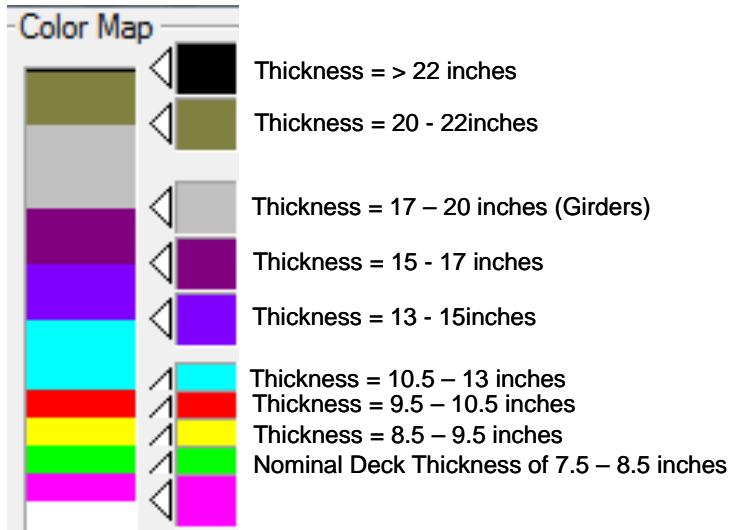
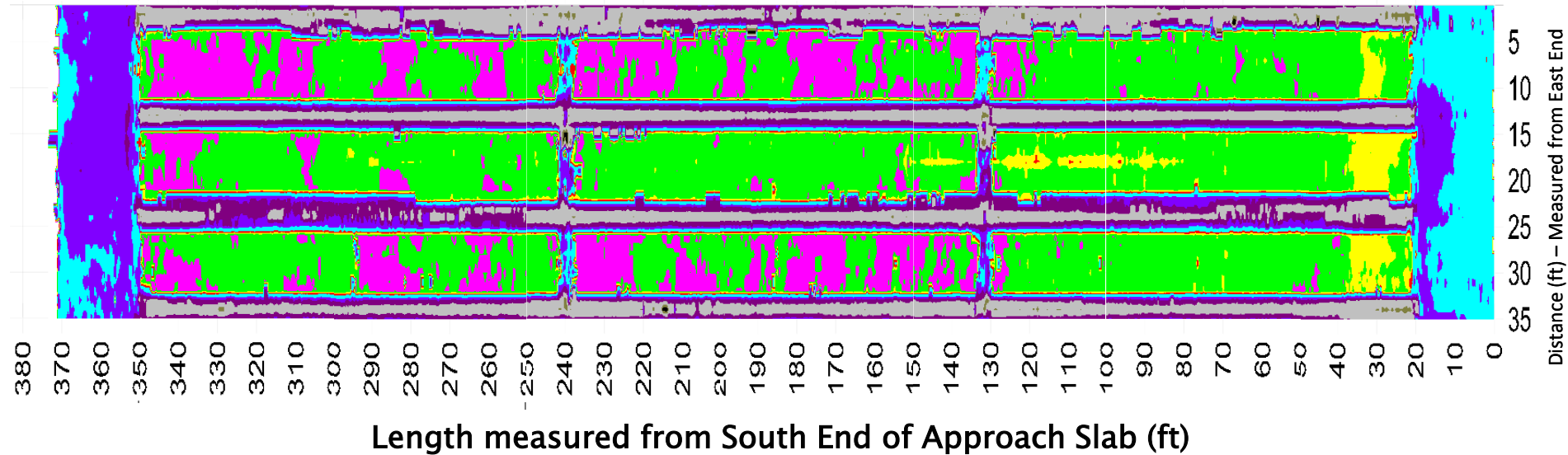


S³ IE Data – Single Scan Line



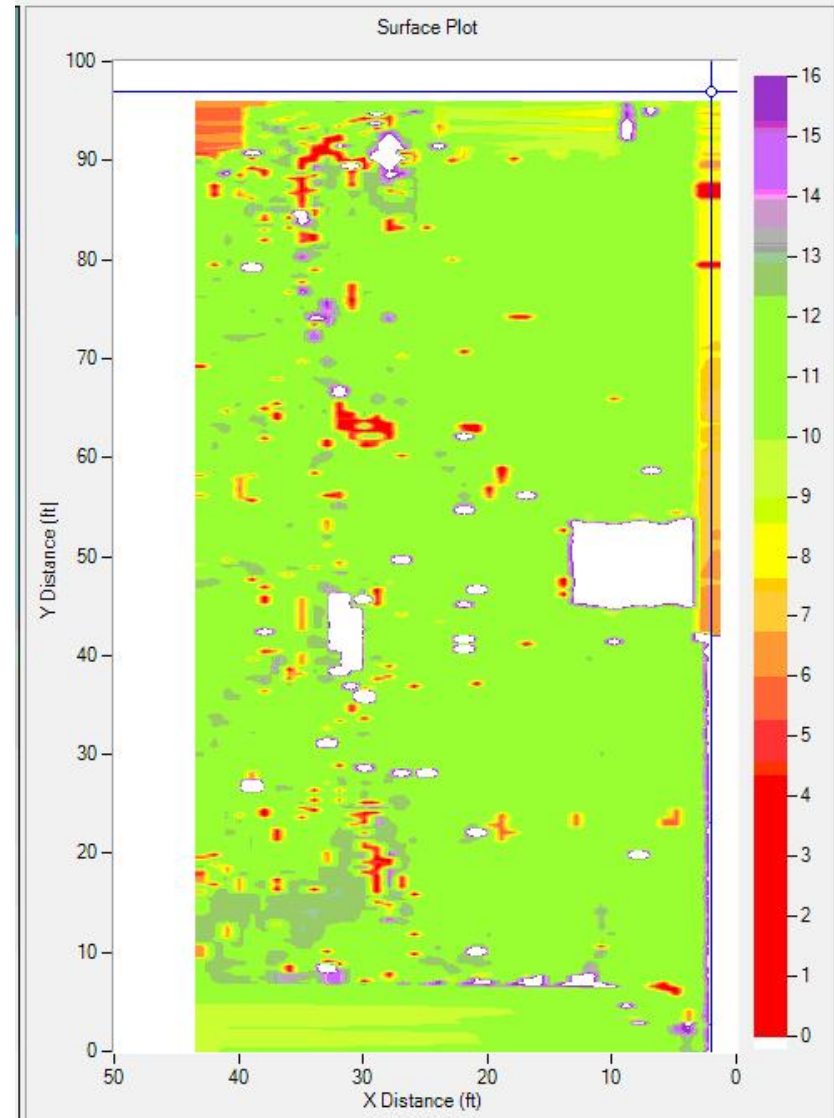
S³ – IE Results

No significant void/honeycomb



Thickness changes such as the approach slabs, piers, diaphragms and girders can all be observed in the IE thickness data.

S³ – IE Testing New Concrete Slab



S3 – IE Helix Ramp in Parking Structure

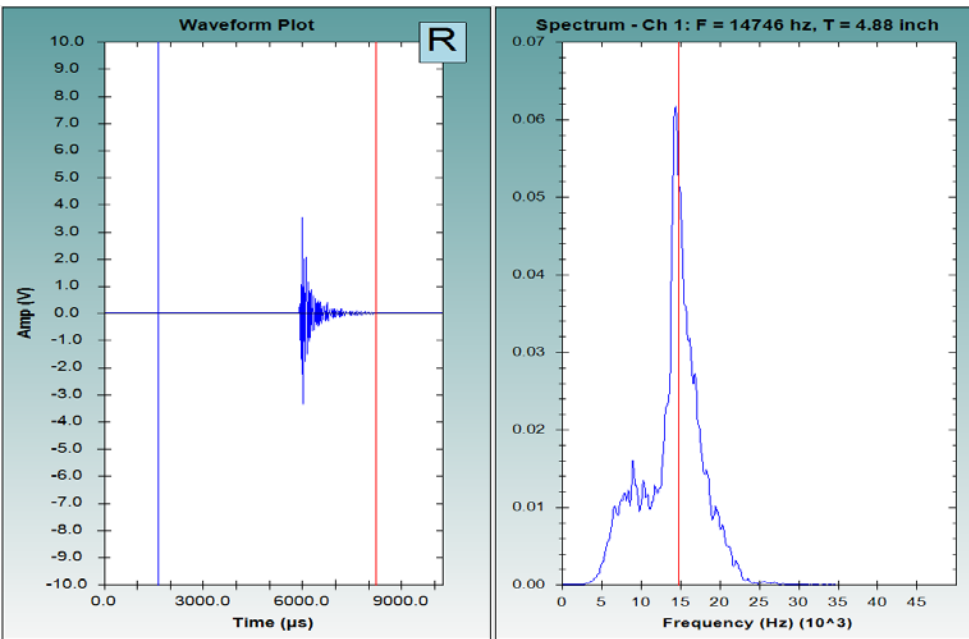


Very Rough Helix Ramp Concrete Surface

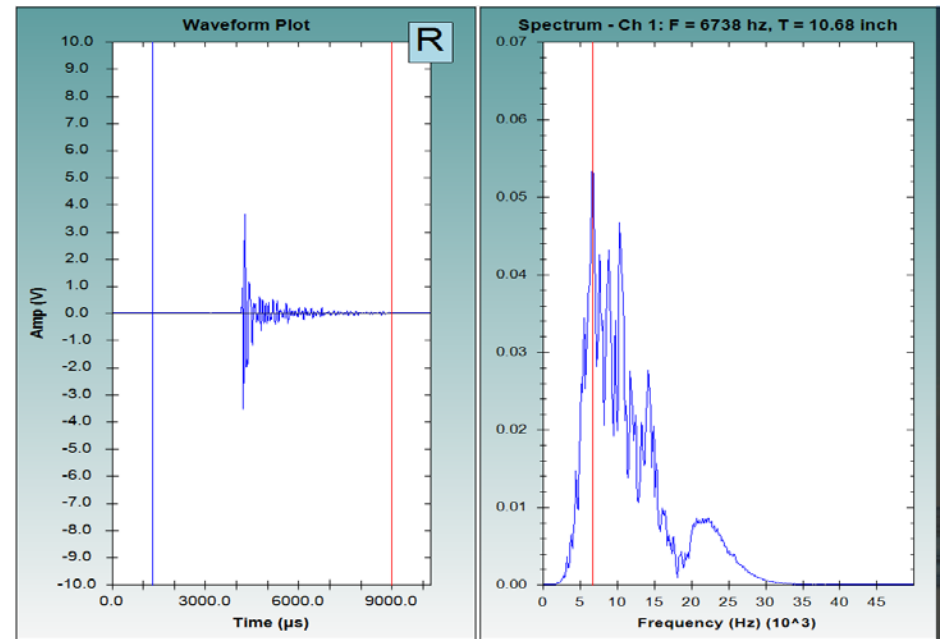


S3 – IE Helix Ramp Example Data

Impact Echo Sound 4.88 inch thick Results



Impact Echo Delaminated Flexural Response (showing 10.68 inch resonance)



S3 – IE Helix Ramp Results

