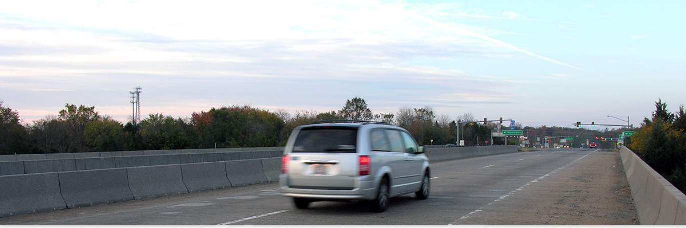


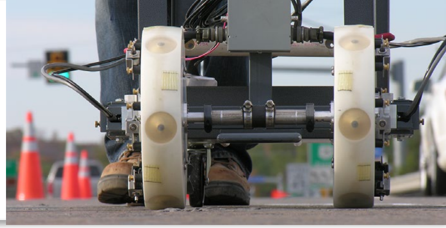

SHRP2 SOLUTIONS

STRATEGIC HIGHWAY RESEARCH PROGRAM

NDT Methods for Bridge Decks Summary and Discussion

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U.S. Department of Transportation
Federal Highway Administration

American Association of State Highway and Transportation Officials
AASHTO

Challenge: Evaluating the Full Range of Deterioration Types

Deterioration of Interest

- Delamination
- Corrosion
- Vertical cracking
- Degradation

NDT Technologies of SHRP2 R06A

NDT Technique	Mode of Deterioration Detected	System	Resolution	Lane Closure
IE	1) Deeper cracks - top and bottom rebar mat 2) Shallow delaminination 3) Concrete degradation - ASR/DEF - Freeze thaw	1) Scanning 2) Point by Point	High Grid size	Yes Yes
GPR	1) Corrosion 2) Cracks (if filled with deicing salt) 3) Concrete degradation	1) Air coupled 2) Ground coupled	Lower High	No Yes
IR	Shallow delamination - Top and bottom	1) Truck mounted 2) Handheld	High High	No Yes
Resistivity	Corrosion	Point by Point	Grid size	Yes
Half Cell/GP	Corrosion	Point by Point	Grid size	Yes
Slab IR	Cracks	Point by Point	Grid size	Yes
SASW	1) Vertical cracks 2) Concrete degradation	1) Scanning 2) Point by point	High Grid size	Yes Yes
Sounding	Only shallow delamination	Manual		Yes

Vs.

Most Commonly Used NDT Methods Based on SHRP2 Work

- Ground Penetrating radar (GPR)
- Infrared Thermography (IR)
- Impact Echo and Impact Echo Scanning (IE and IES)
- Scanning Spectral Analysis of Surface Waves (SASW)
  - (for asphalt overlaid concrete)

Infrared Thermography Testing

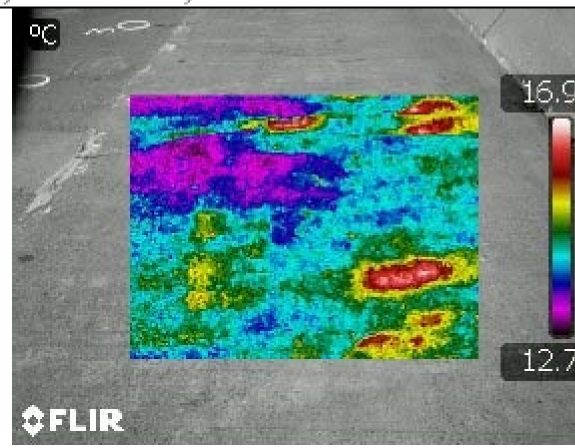
- Most commonly performed on concrete and concrete overlaid bridge decks
- Can detect delaminations at only the top rebar mat (unless done from the deck bottom)
- Cannot “see” through debonded overlays
- Not sensitive to rebar or chlorides in concrete (results will often NOT match GPR results)
- Results will generally show larger areas of delamination and incipient delamination compared to chain dragging
- Requires correct thermal environment to be effective (results affected by shading, weather, time of day, etc.)

IR Testing Performed on a Bridge Deck

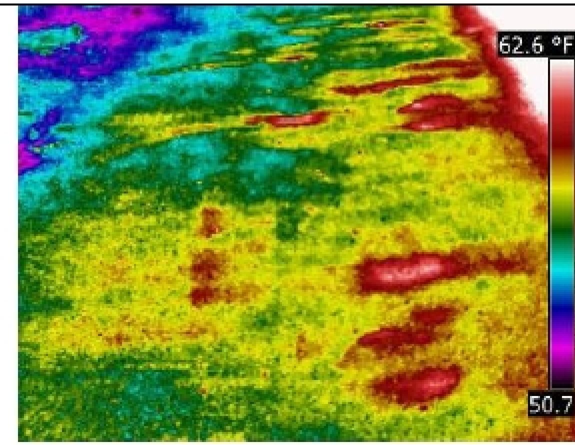
Example IR Test Results

3rd passage; 4 hrs after sunrise, T= 59 F, Rh= 45%

Photo

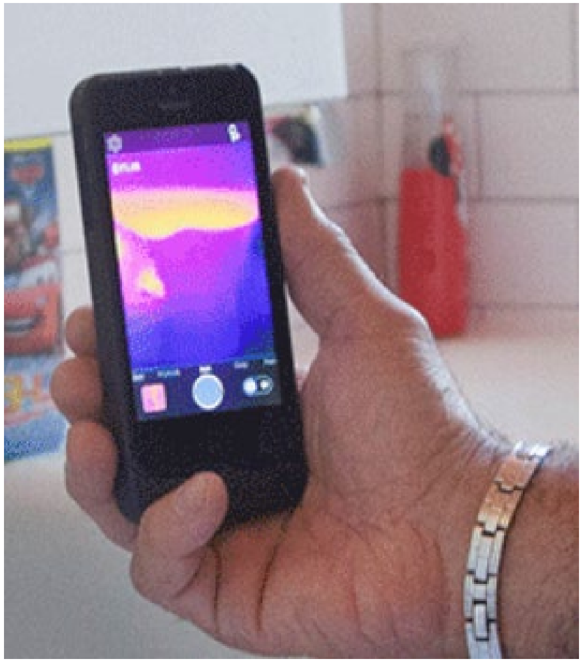


Fusion image (C)



Infrared image (F)

Infrared Imaging with Low-Cost Hand-held IR Camera

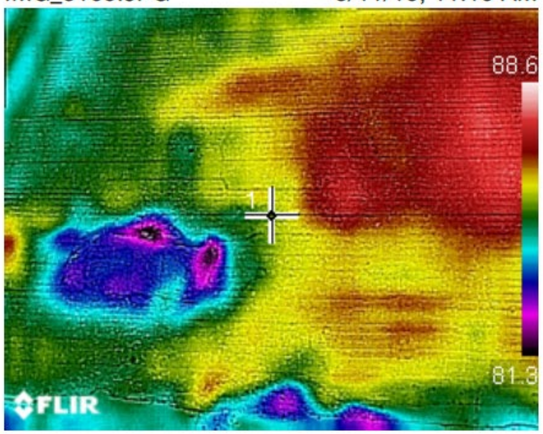


- FLIR-1 Hand-Held IR Cameras

Hand-Held IR Examples

FLIR

IMG_3105.JPG 8/11/16, 11:16 AM



IMG_3105.JPG 8/11/16, 11:16 AM

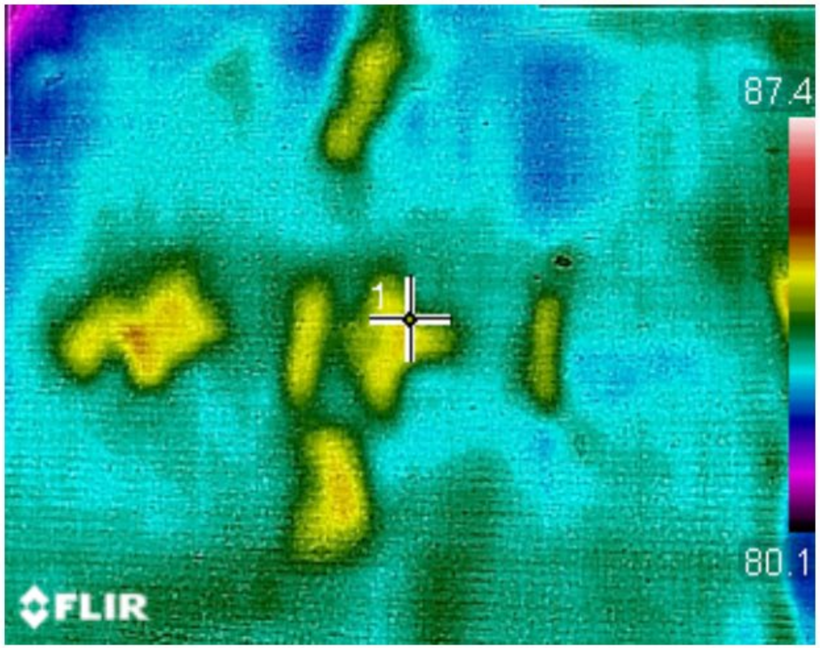
MEASUREMENTS (°F)	
Spot	85.6

PARAMETERS	
Emissivity	0.95
Refl. temp.	68.0 °F
Distance	3.28 ft
Relative humidity	50 %
Atmospheric temperature	68.0 °F
Transmission	0.94
Lat.	N 41° 49.72'
Long.	W 93° 34.73'

- Deck Spall and Nearby Delamination

Hand-Held IR Examples

IMG_3103.JPG 8/11/16, 11:05 AM



IMG_3103.JPG 8/11/16, 11:05 AM

- Deck Paint Marks PLUS Nearby Small Delaminations (above and below paint)

IR Bridge Inspection Planner Web Tool

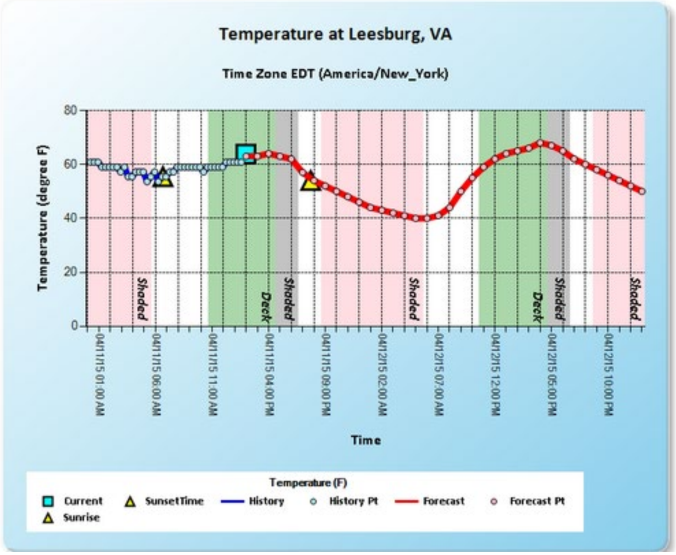
TPF-5(247) Thermography Project Phase II

IR Bridge Inspection Planner (IR BIP)

Auto Locate

Current Location: Leesburg, VA

Current Conditions	Deck Daytime	Shaded Daytime	Shaded Nighttime
Inspection Window	4/11/2015 10:39:00 AM to 4/11/2015 4:39:00 PM	4/11/2015 10:39:00 AM to 4/11/2015 6:39:00 PM	4/11/2015 8:43:00 PM to 4/12/2015 5:43:00 AM
Time until Inspection (hh:mm)	03:20	03:20	06:44
Time left to Inspect (hh:mm)	02:40	04:40	09:00
Temperature Increase/Decrease 6 Hr After/Before Sunrise/Sunset(Degree F)	N/A	+5.4	-9.0
Past 3hr Temperature Change (degree F/Hr)	+0.8	+0.8	+0.8
Temperature Change Maximum (degree F)	N/A	10.4	-24
3 Hr Windspeed Average (mph)	+15.3	N/A	N/A



http://www.fuchsconsultinginc.com/FCIWeatherChecker1.aspx

Impact Echo Testing

- Most commonly performed on concrete and concrete overlaid bridge decks

- Can detect delaminations at BOTH the top and bottom rebar mats when testing from the top

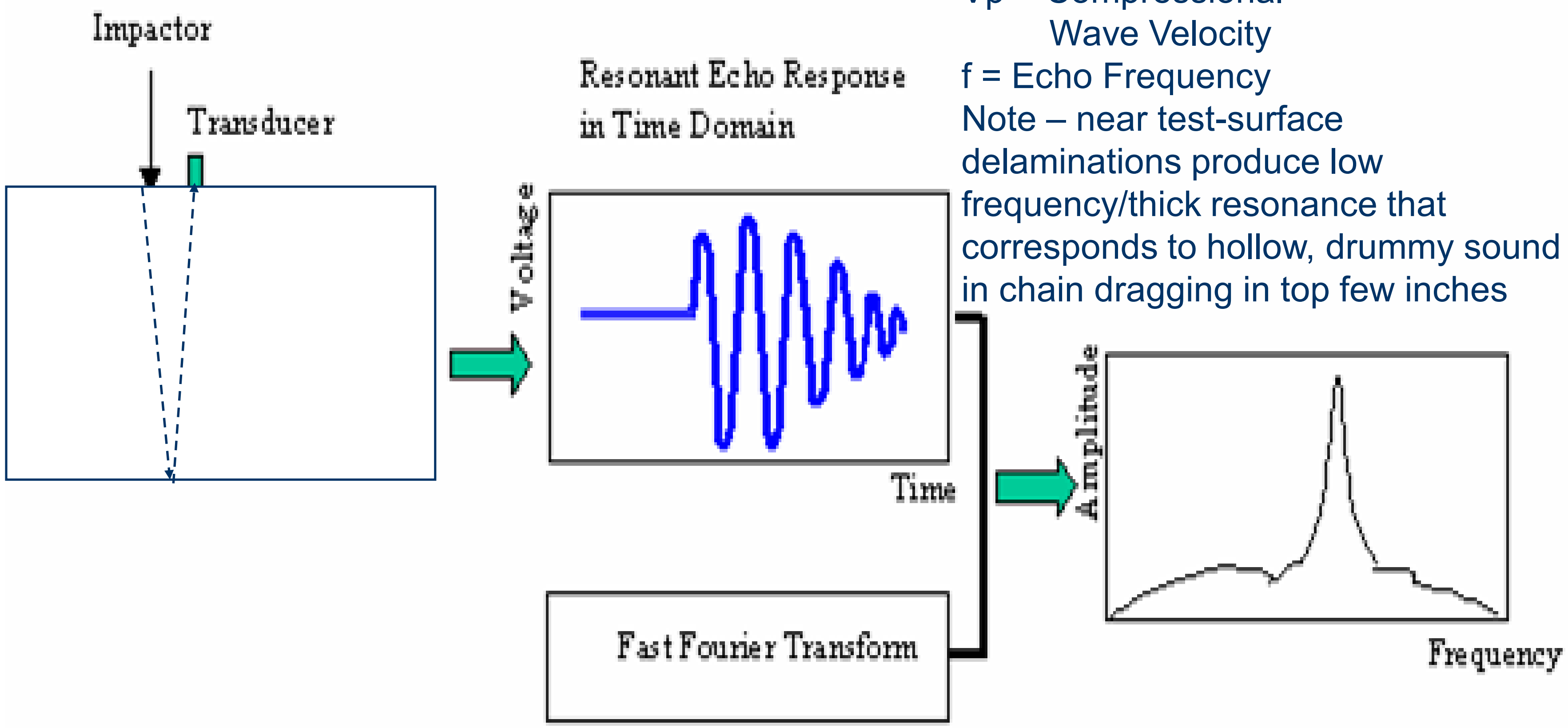
- Cannot "see" through debonded overlays

- Not sensitive to rebar or chlorides in concrete (results will often NOT match GPR results)

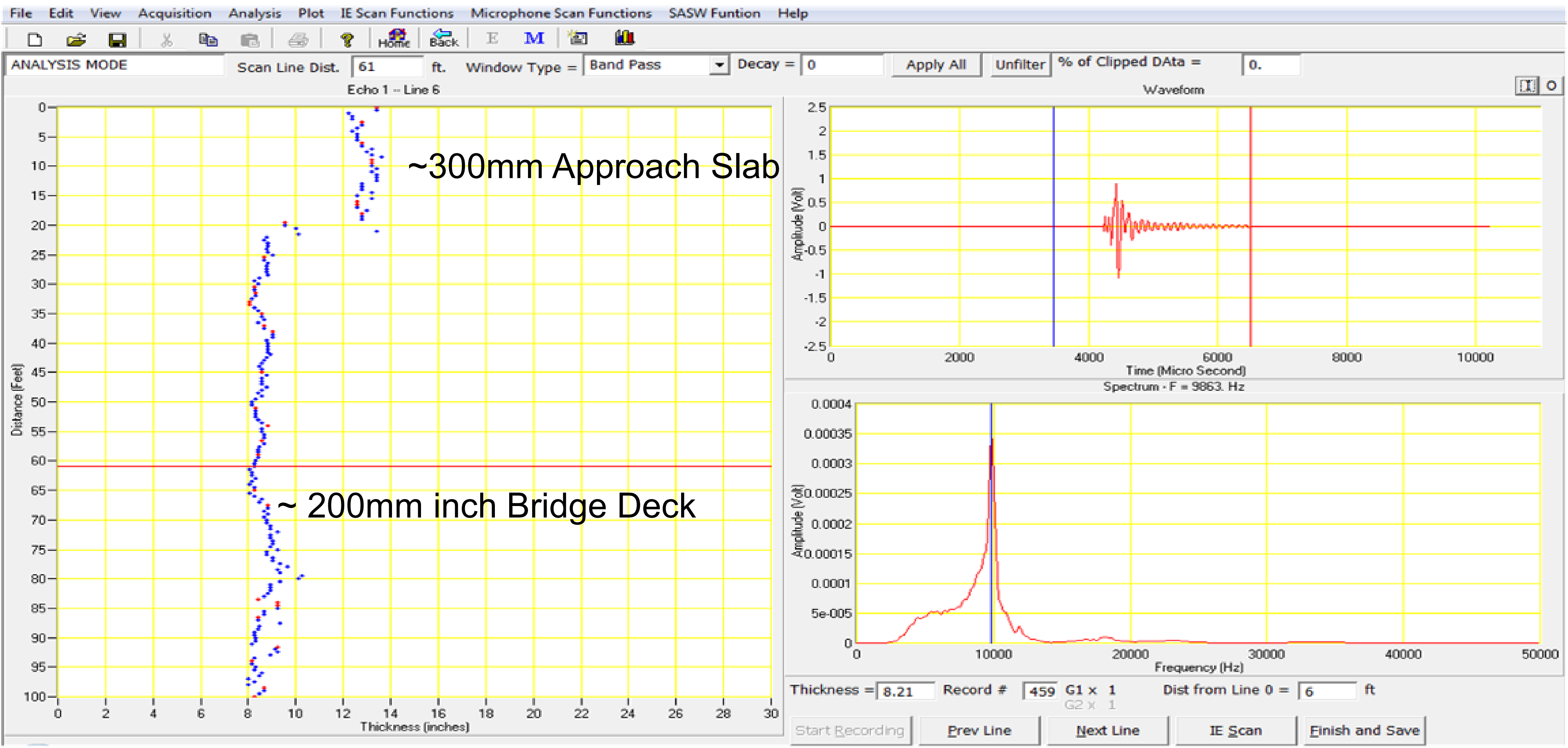
- Results will generally show larger areas of delamination and incipient delamination compared to chain dragging

Impact Echo Test for Delamination/ Cracking/Thickness of Decks

D = bVp/(2*f)
b= Shape Factor (0.96 for slab)
D = Thickness
Vp = Compressional Wave Velocity
f = Echo Frequency
Note – near test-surface delaminations produce low frequency/thick resonance that corresponds to hollow, drummy sound in chain dragging in top few inches



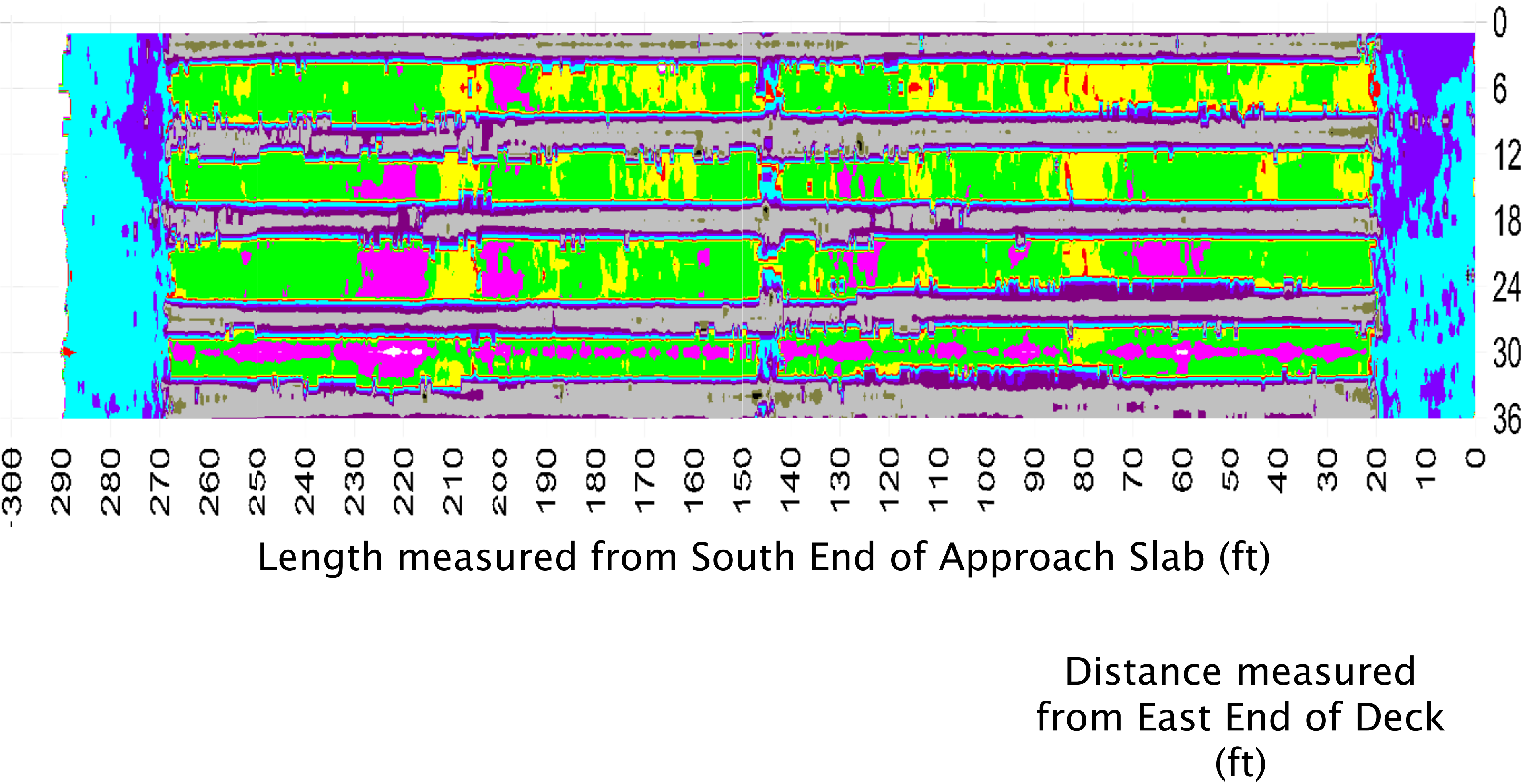
Sample Single IE Scanning Line Result



IE Thickness Plot vs. 100 ft Distance for a scan line on a bridge deck

Time Domain IE Signal at left cursor (Top Plot) and Frequency Domain Echo Depth Resonance=8.3 inches (Bottom Plot)

Overall IE Scanning Result Map from a Bridge Deck – Showing Beams and Deck Areas

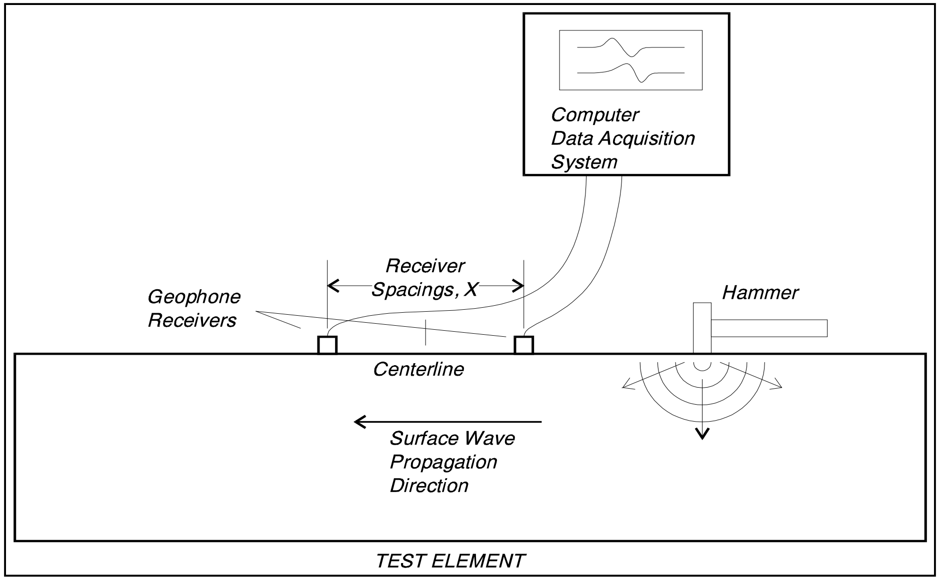


SASW Testing

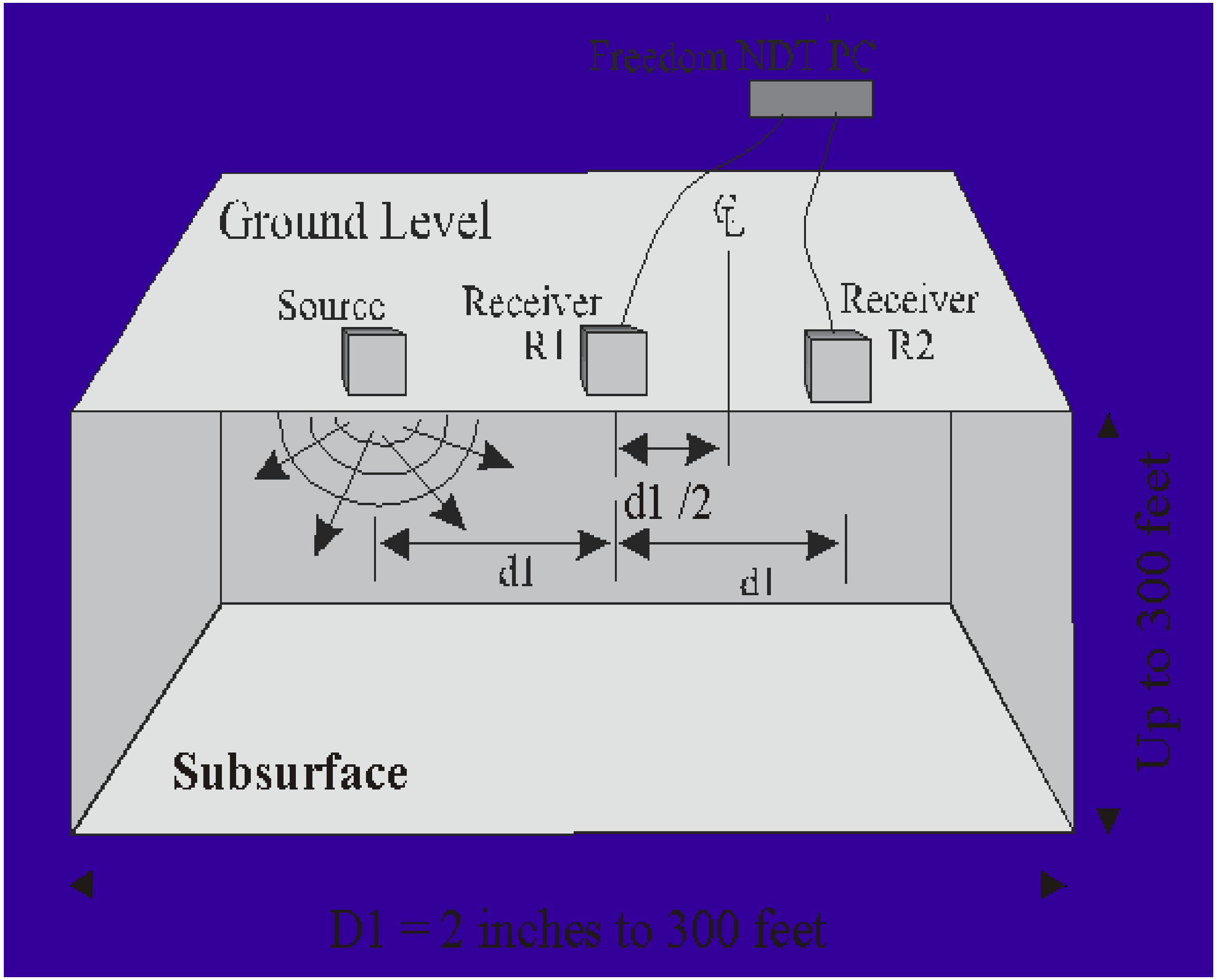
- Most commonly performed on asphalt-overlaid bridge decks
- Can detect delaminations in concrete under asphalt
- Requires accurate asphalt thickness information for best results

Spectral Analysis of Surface Waves Method (SASW)

- **Acoustic method – measures the propagation speed of surface waves with various wavelengths**
- **Short wavelength waves sample shallow, longer wavelengths sample deeper**
- **Allows the measurement of the velocity profile versus depth into the structure, which can be related to the strength and condition of the concrete versus depth**

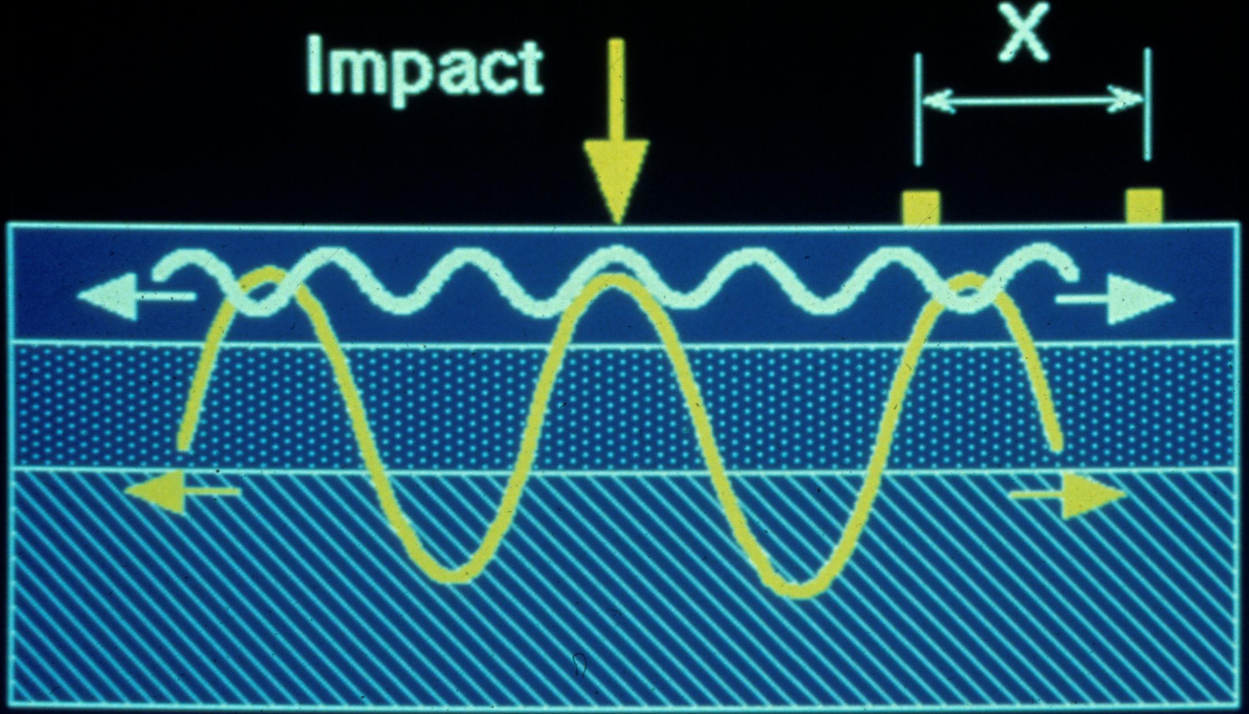


Field Setup



Freedom NDT PC
Ground Level
℄
Source
Receiver
R1
Receiver
R2
d1 /2
d1
d1
Subsurface
Up to 300 feet
D1 = 2 inches to 300 feet

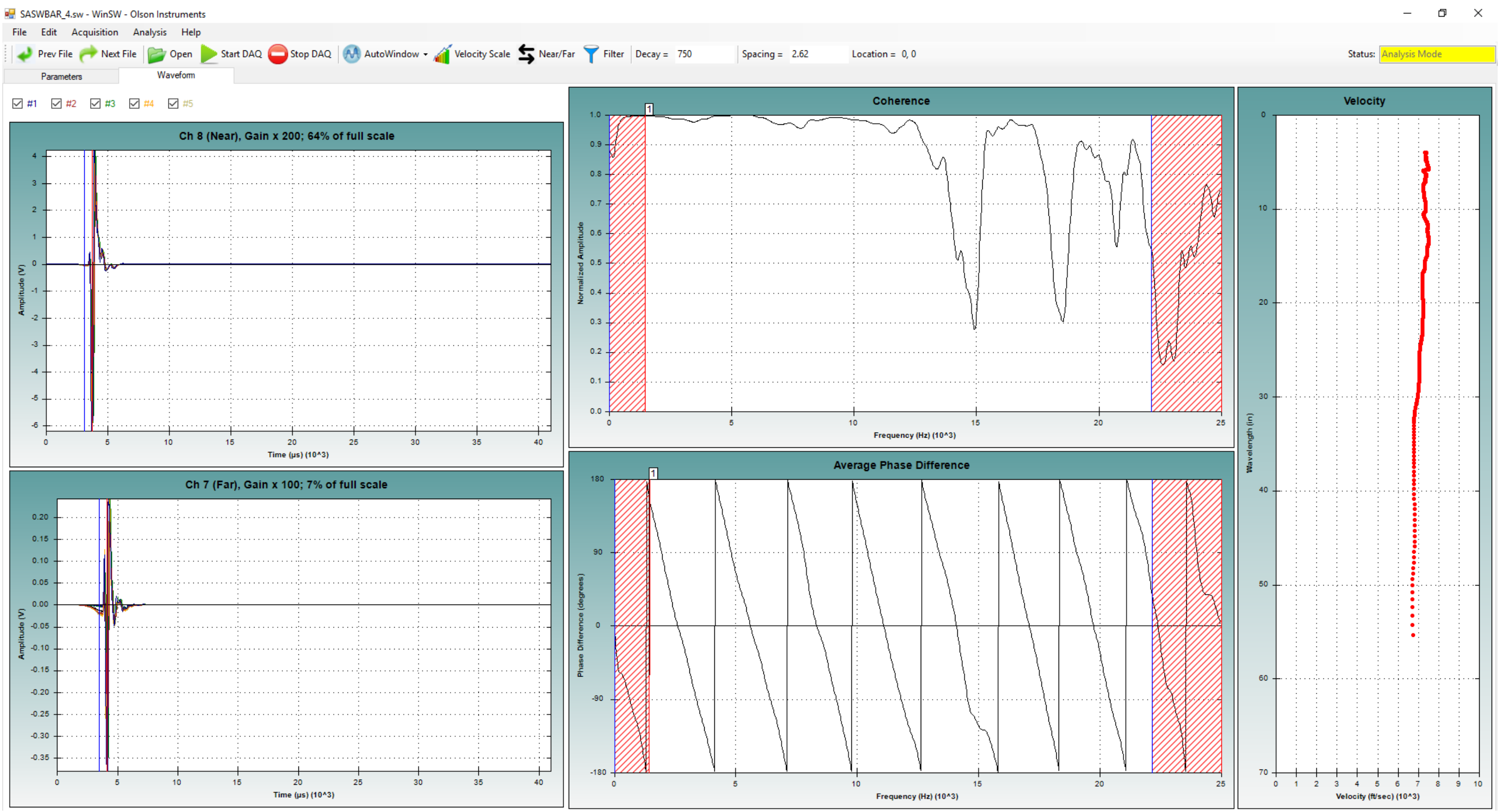
PROPAGATION OF COMPONENTS



$$c_f = \frac{X}{\Delta t_f}$$

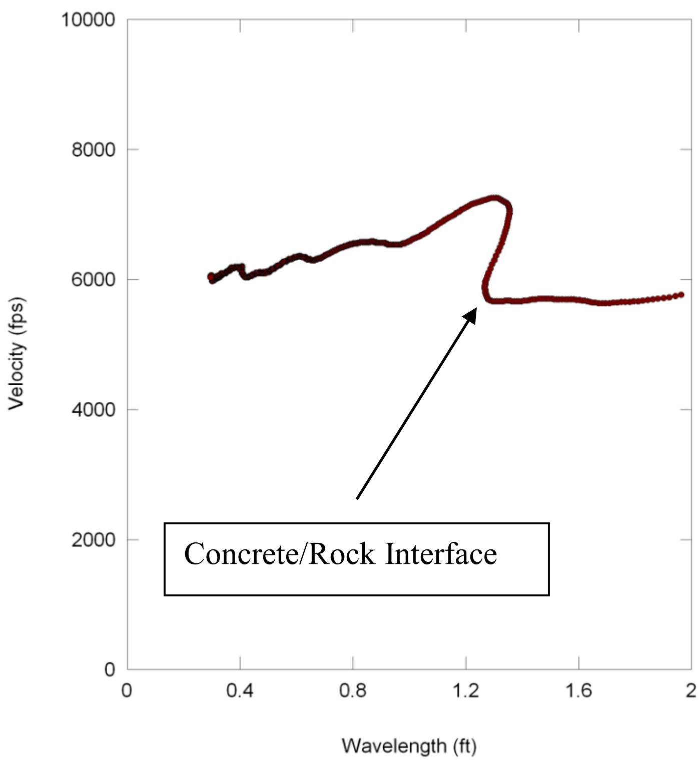
Measure Δt_f

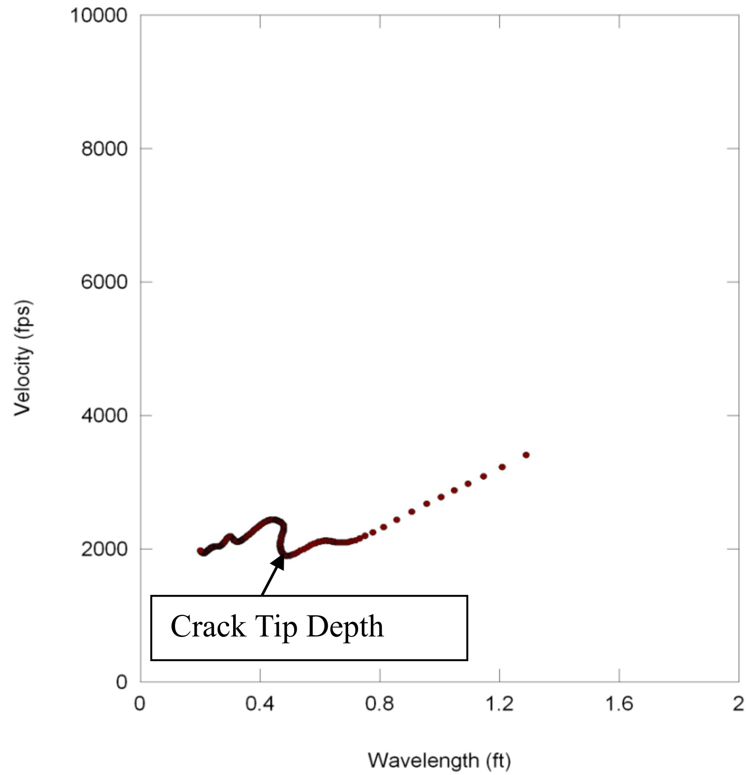
SASW Raw Data and Analysis Overview



Time Data → Phase and Coherence Data → Dispersion Curve (velocity Data)

SASW Results Plot

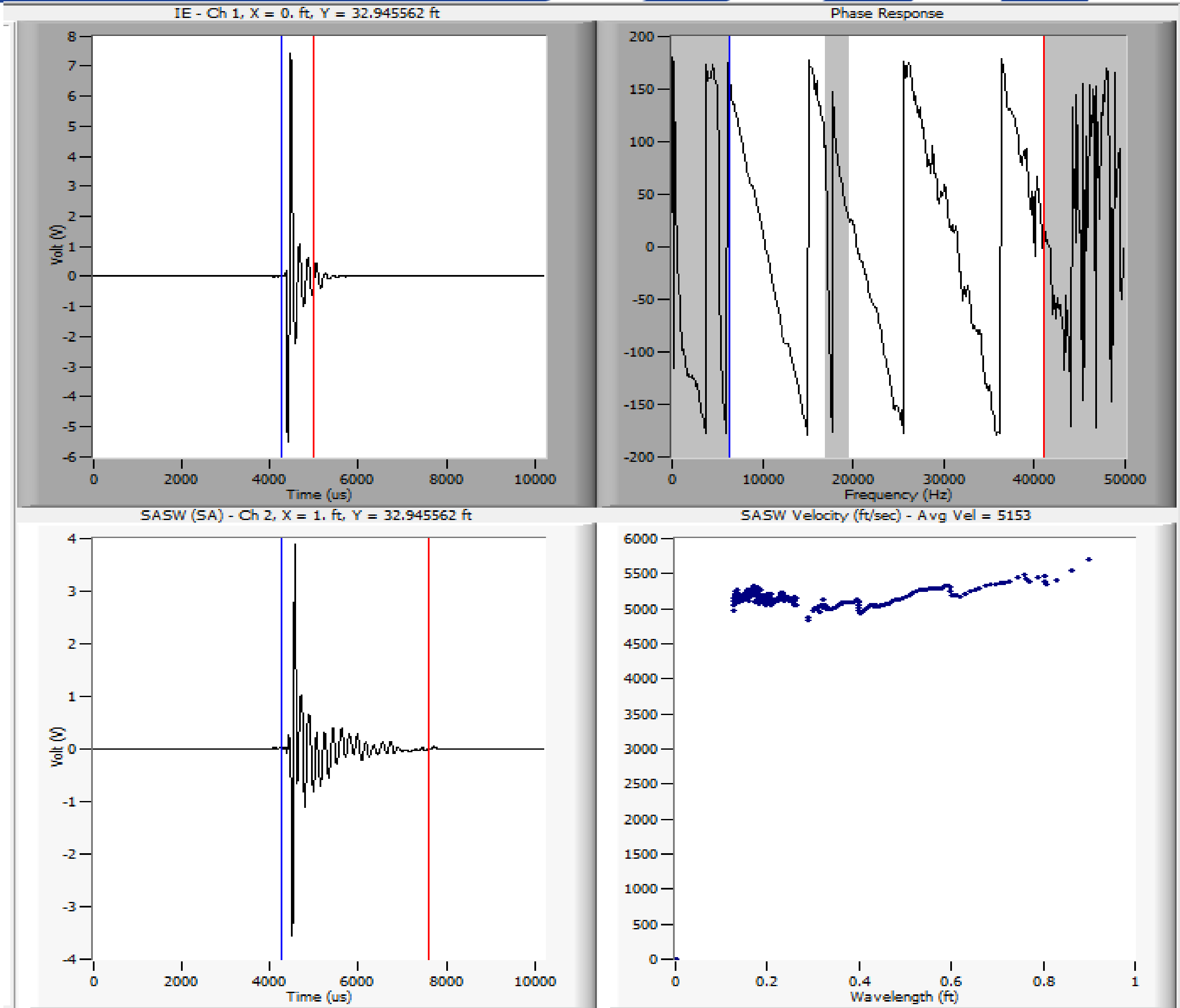




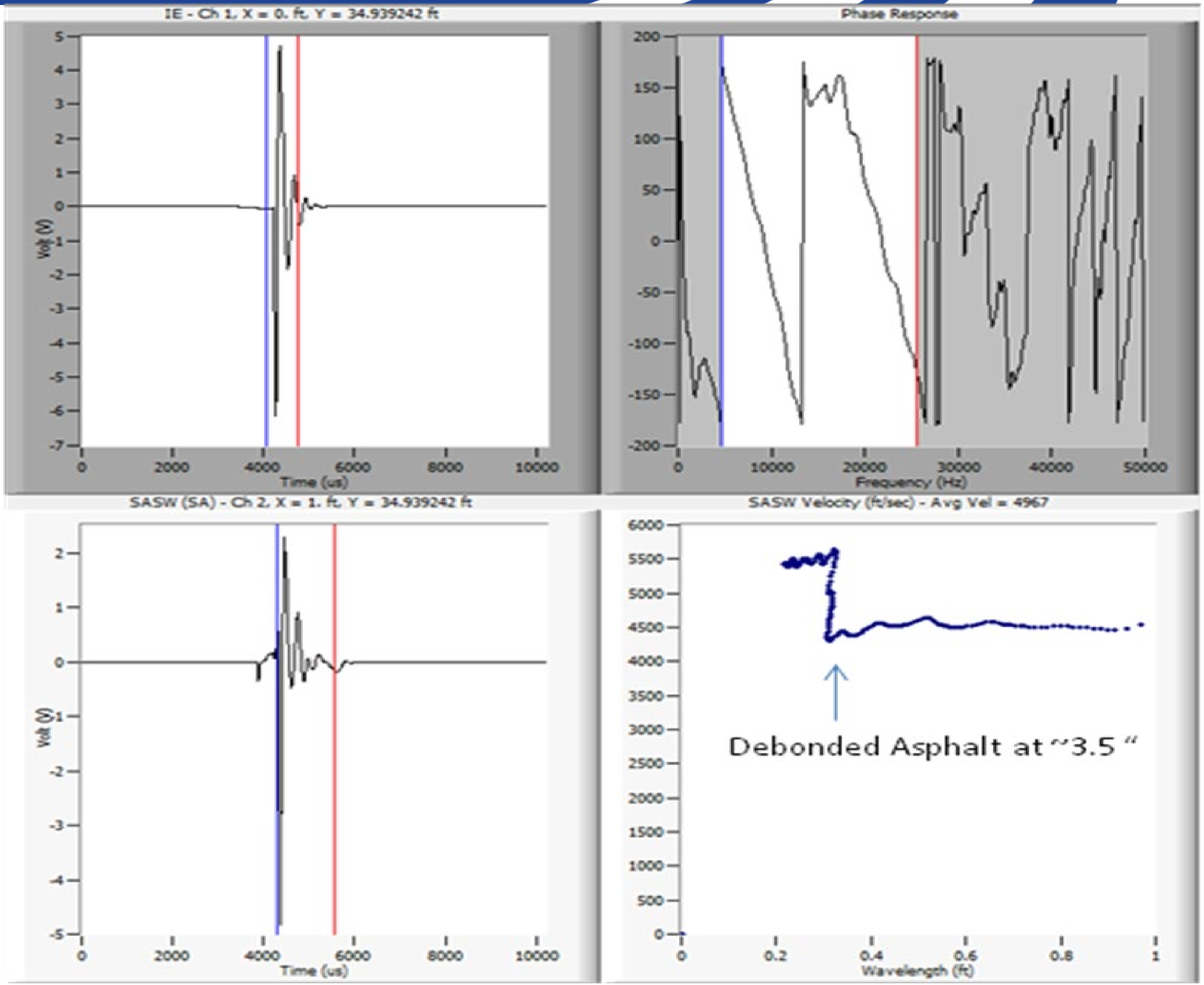
These plots show typical SASW results – The left plot shows sound concrete bonded to rock, the right plot shows the depth measurement of a surface-opening crack

Bridge Deck Scanner with IE/SASW on Cart on Virginia Asphalt Overlaid Deck

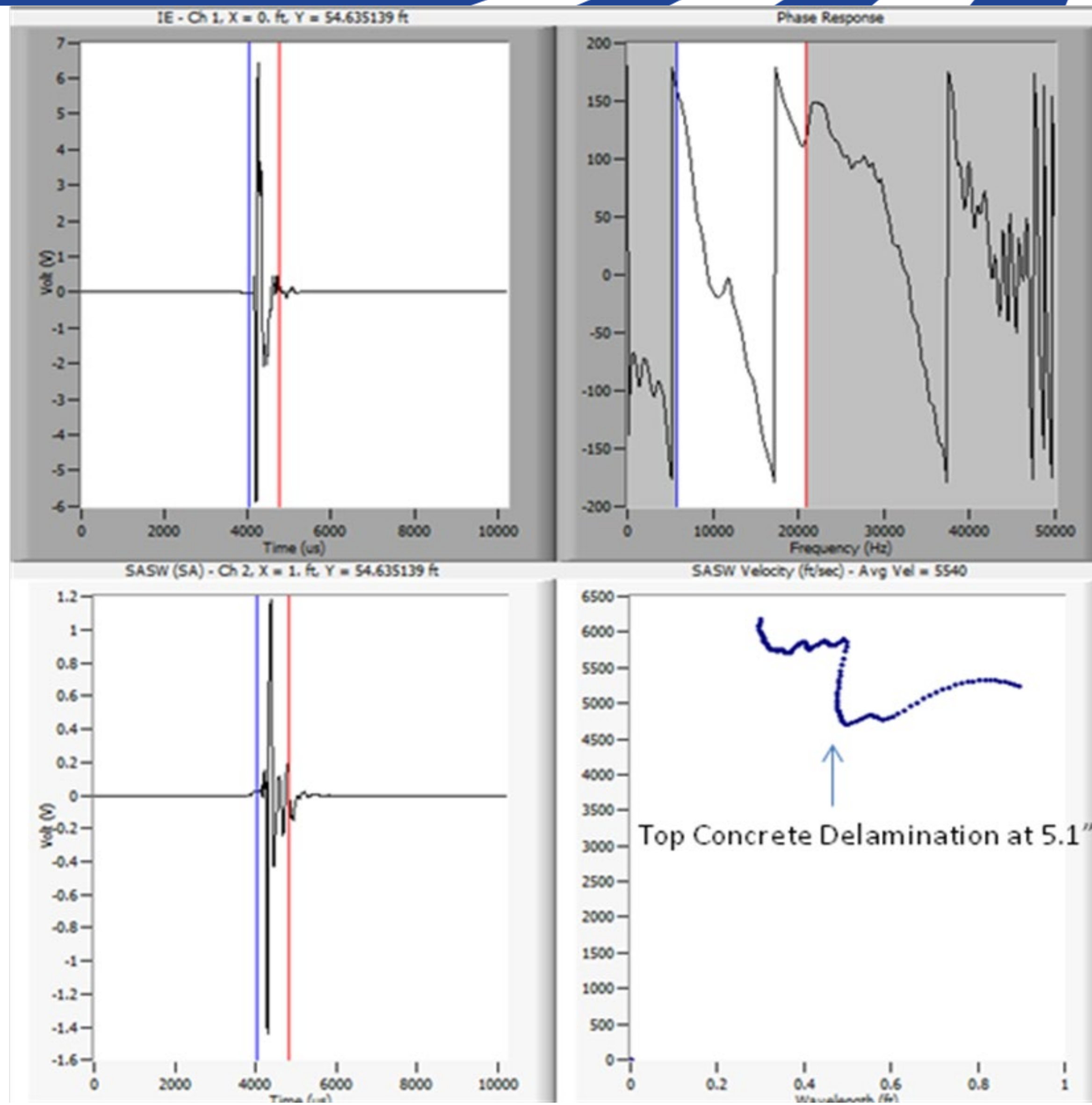
Findings – Bonded Asphalt on Sound Concrete



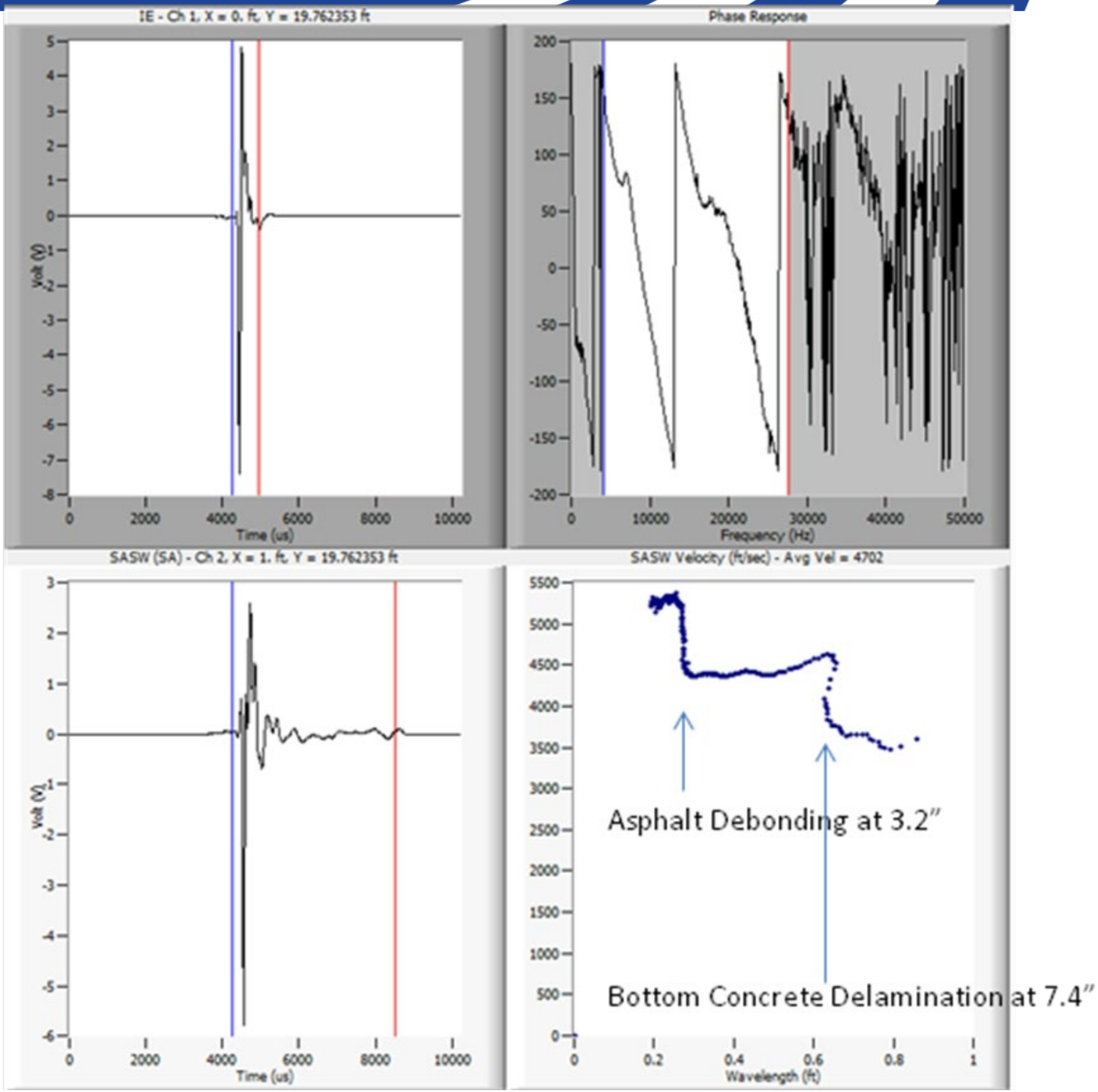
Sound Concrete with Asphalt Debonding



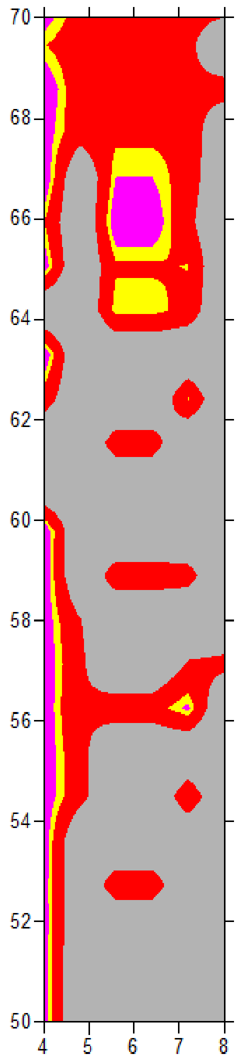
Bonded Asphalt on Concrete with Top Delamination

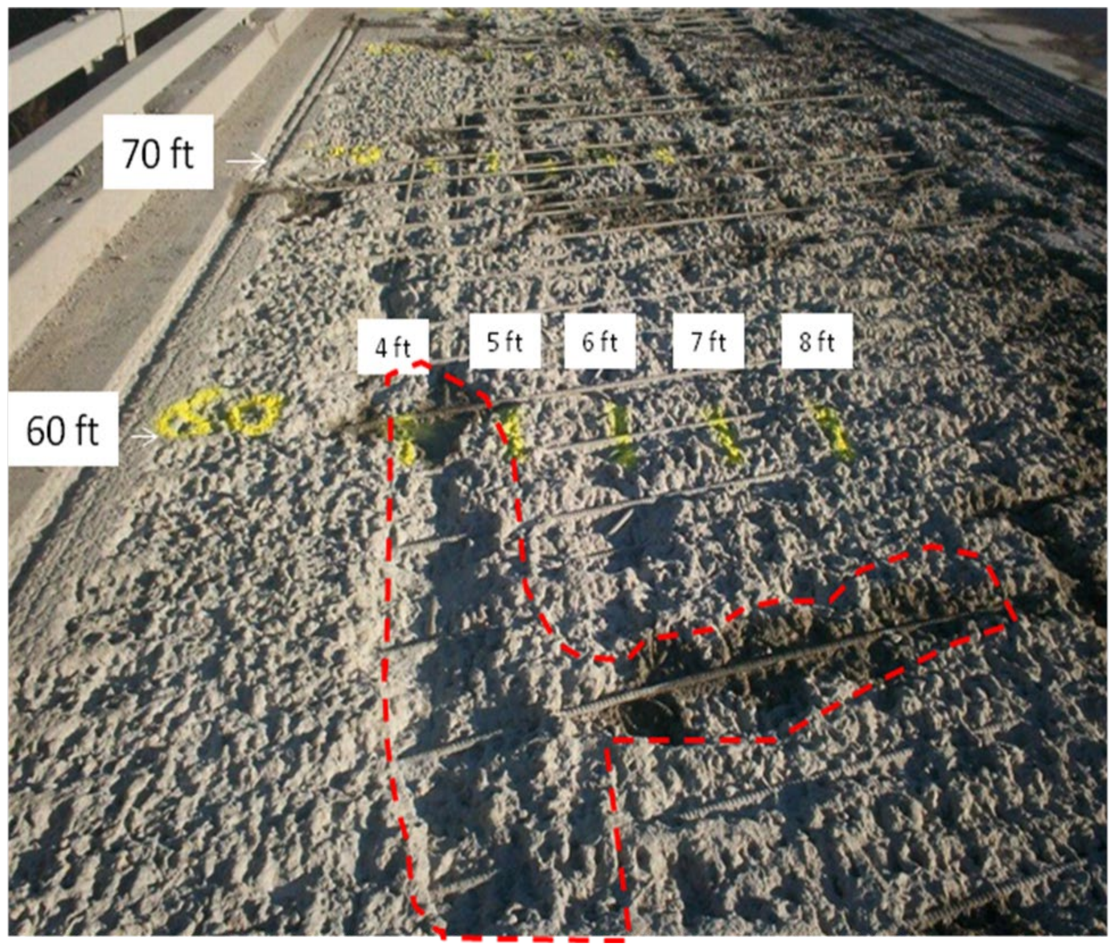


Debonded Asphalt / Concrete with Bottom Delamination



Ground Truthing - Hydrodemolition to reveal Delaminations





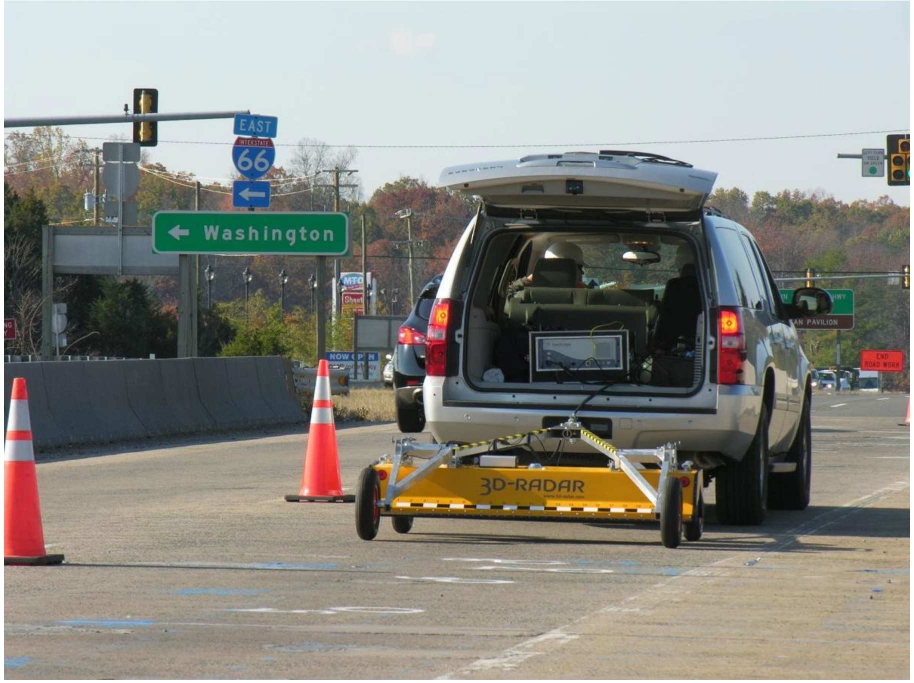
GPR Testing

- Most commonly performed on concrete and concrete overlaid bridge decks
- Can detect chlorides and areas of likely future delamination
- NOT sensitive to current cracking and delaminations unless the cracks or delaminations have salts, corrosion products, or other GPR-reflective material present (results will often NOT match IE, IR or Sounding results)
- Can also map out rebar depth and geometry

Applications

- Applicable for **structures with one side access** – good for bridge deck
- **Measurement** of the concrete cover and **verifying or mapping** rebar configuration
- **Assessing potential for concrete deterioration and delamination** based on attenuation mapping
- **Deck thickness and mapping** of cables, conduits, other embedments
- **Identification** of heterogeneities such as rock pockets, honeycombing, voids

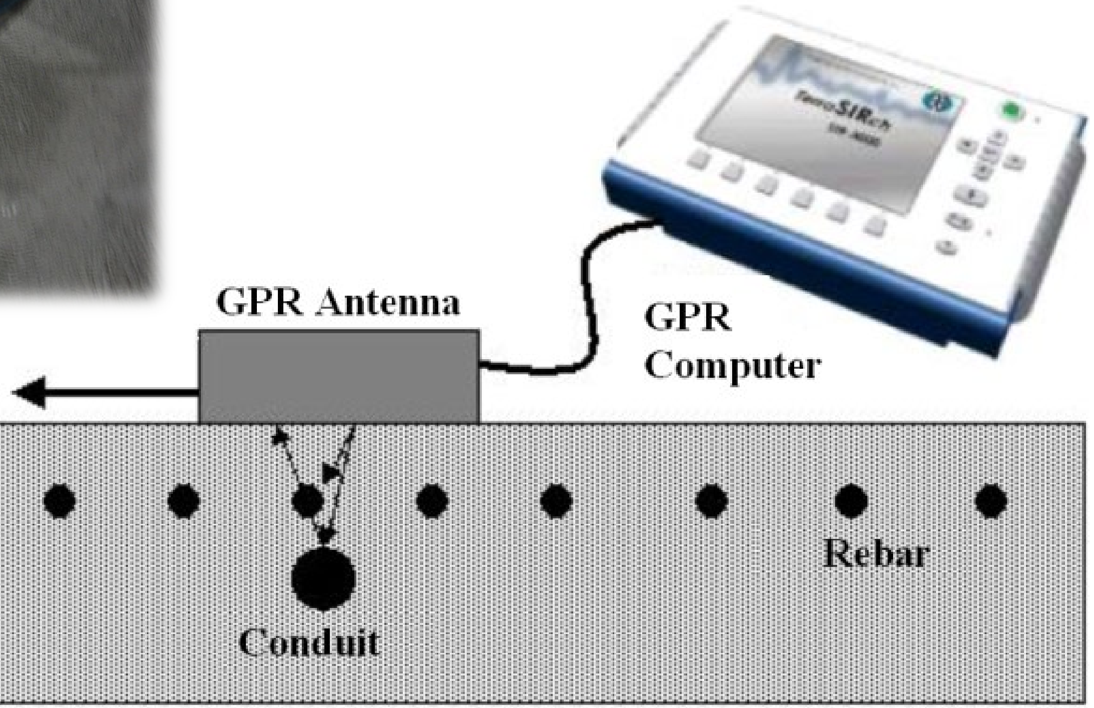
- To locate buried objects (steel) within concrete structures
  - Quality assurance (QA) tool for new bridge deck (reinforcement spacing and concrete cover)
- To locate areas of steel corrosion on an existing bridge deck



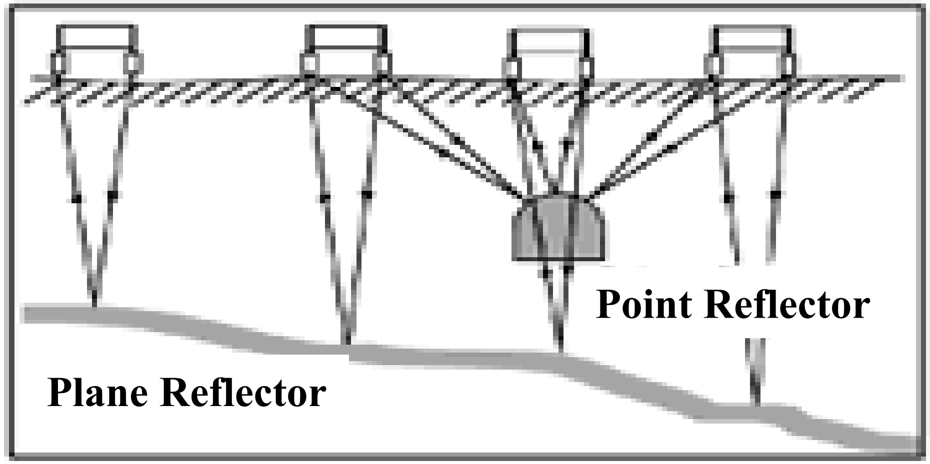
Description of the GPR Method

- **Reflection test**
  - Using electromagnetic waves
  - Sending tiny pulse of energy through its antenna
  - Reflecting back from different material or anomalies.
- **A rapid nondestructive testing method**
  - Ground Contact (single antenna and multiple antennas)
  - Air Horn (multiple antennas)

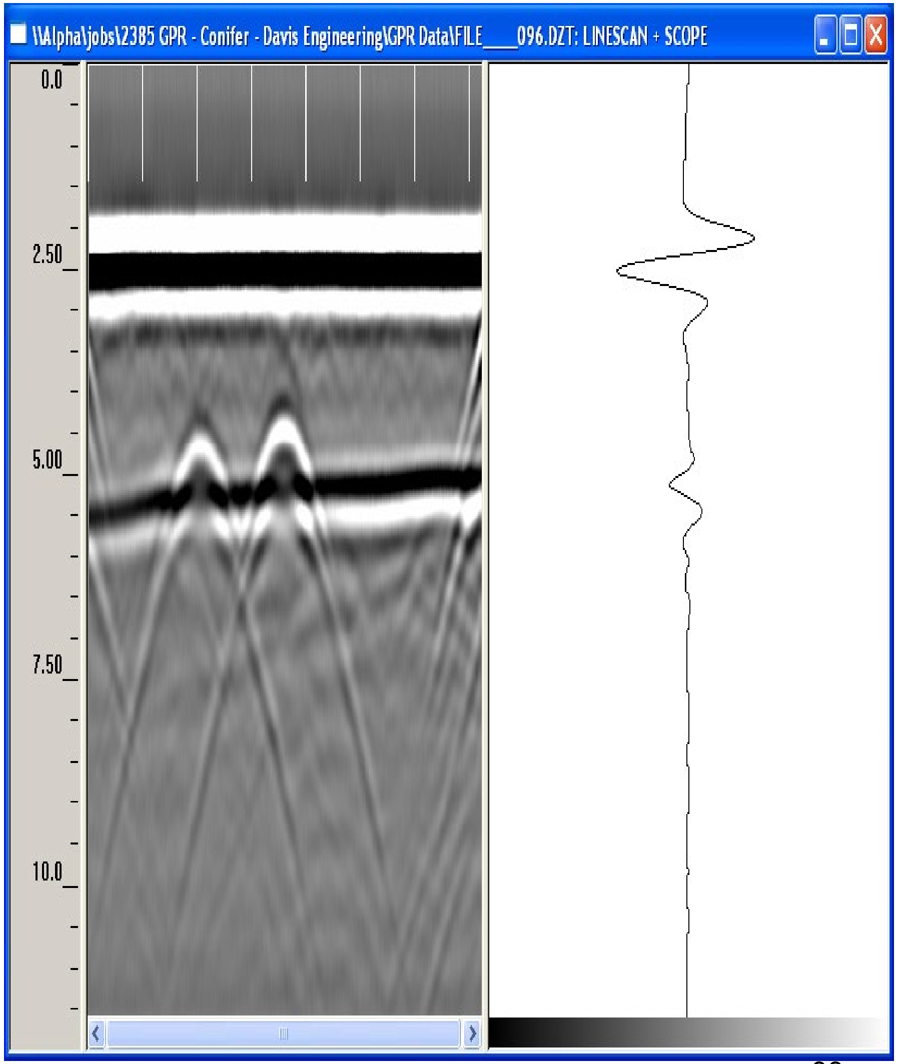
Physical Principle



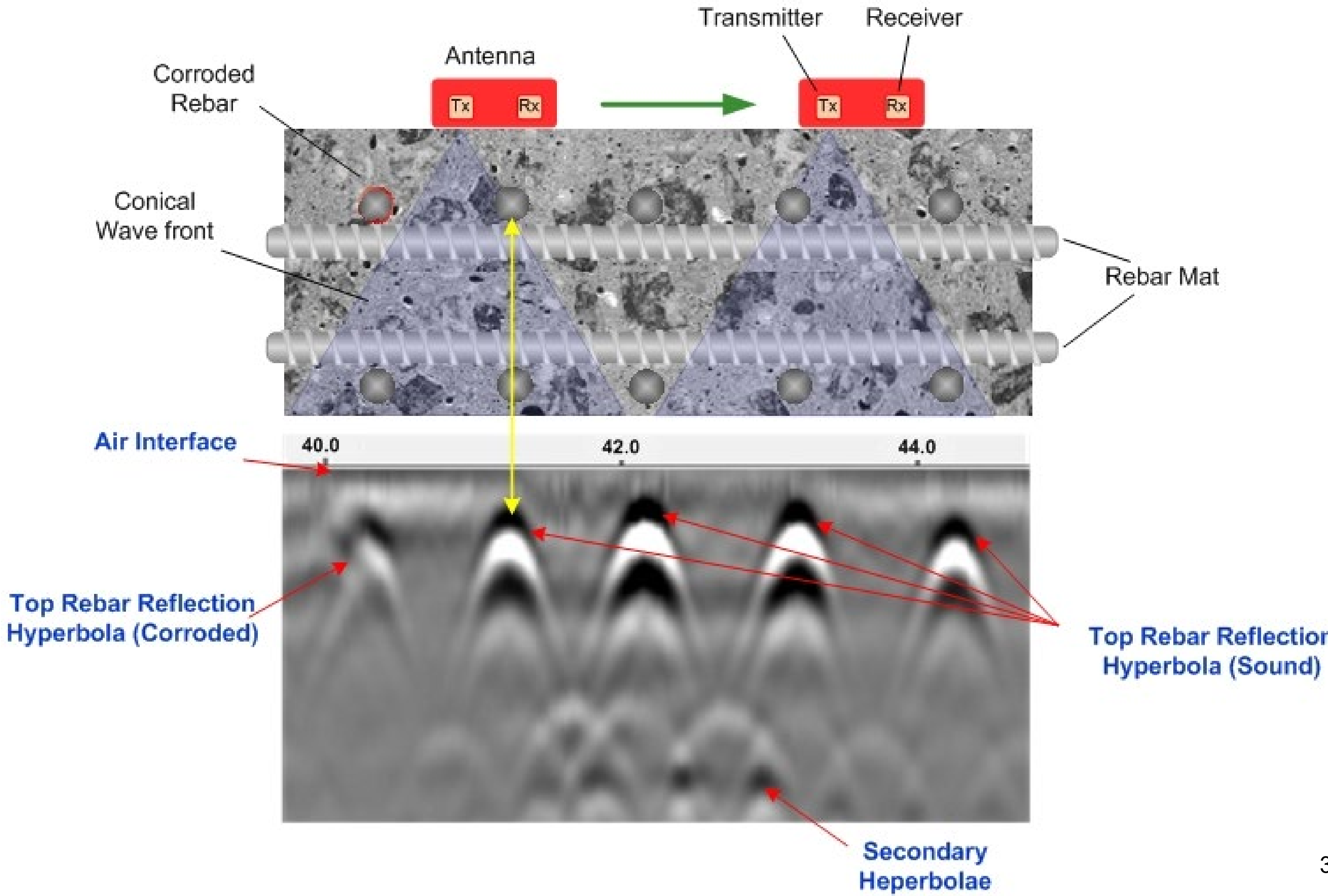
Physical Principle *(continued)*



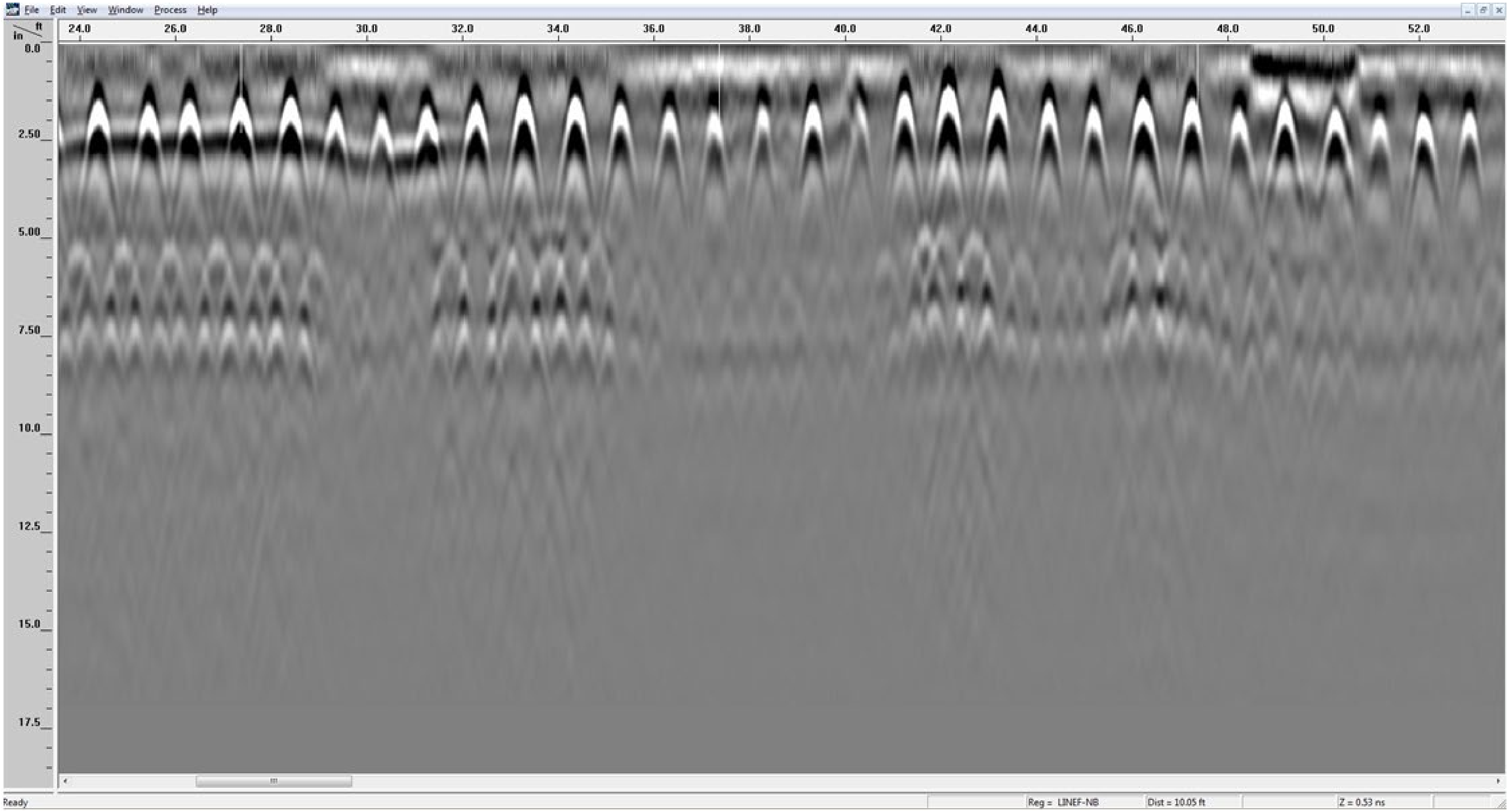
Reflection Concept



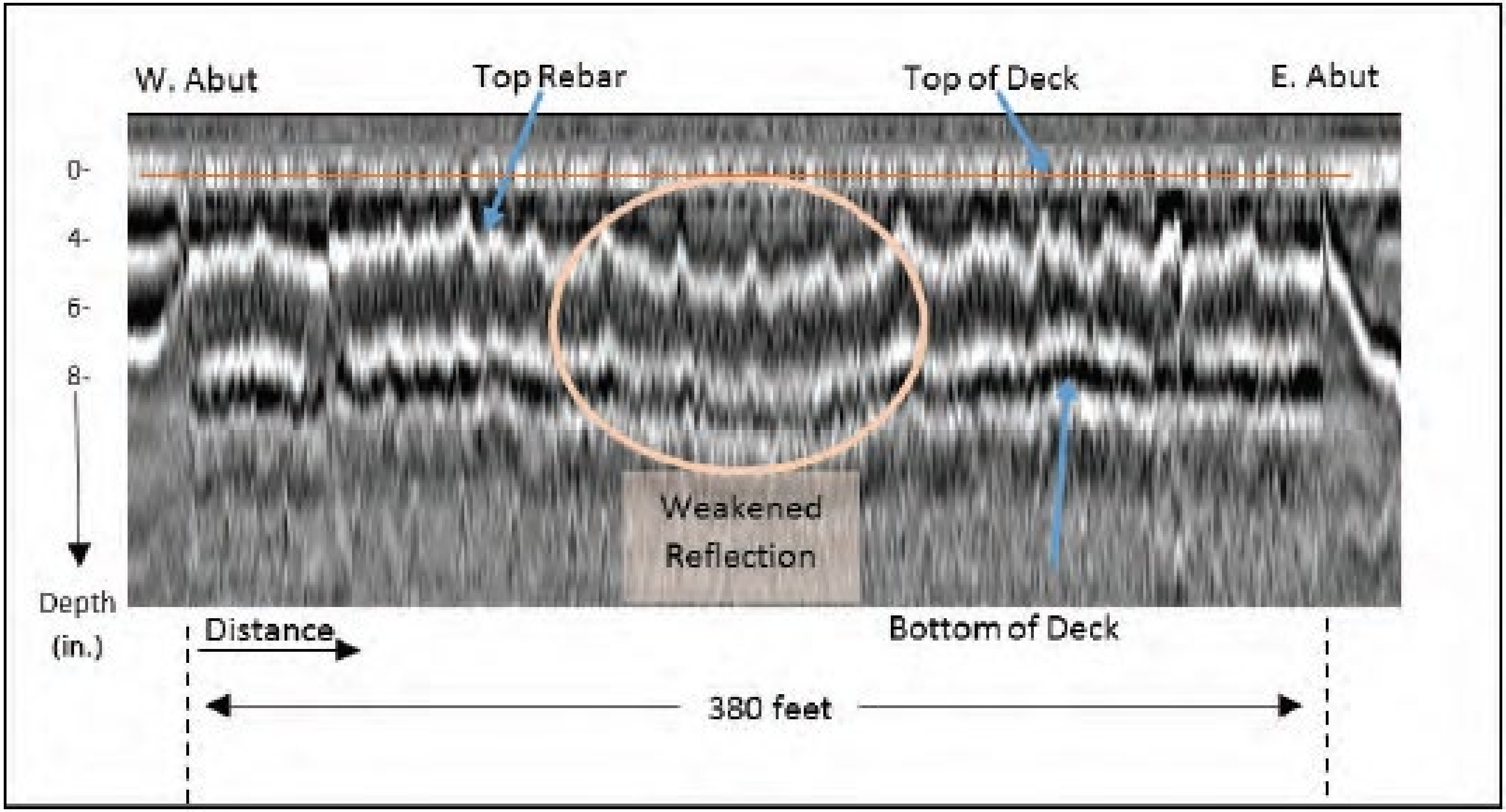
Physical Principle *(continued)*



Example GPR Reflection Data



GPR Showing High Chlorides or Corrosion Example



Weakened reflection zone is area of concern

Recommended Equipment Specifications

- **Ground coupled or air horn antennas** – dependent on the required accuracy and speed (network level or project level).
- In general, an **antenna with a higher center frequency** (smaller antenna) results in a higher resolution but less penetration, while the **lower frequency antenna** (bigger antenna) provides less resolution and deeper penetration.
- Generally, a **single frequency antenna will not cover all types of applications** and different antennas with various center frequencies should be used – however swept frequency antennas cover wide ranges.
- In the US, all radar equipment should **meet the FCC regulations**.

Example Equipment (Ground Contact Antennas)

3D Radar

GSSI

Sensors and Software

MALA

IDS

Example Equipment (Air Horn Antennas)

3D Radar

IDS Georadar

GSSI

Deterioration Modes Detected By GPR Testing

- Locations with dielectric contrast between the two materials (see table)
- Large concrete cracks/voids (air filled)
- Smaller gaps/voids filled with salty water – larger dialectic contrast
- Smaller amplitude of the reinforcement reflector indicates possible reinforcement corrosion due to diffraction by rust byproducts as well as attenuation by chlorides

Performances of GPR Test on Concrete Bridge Decks

- **Speed** of data collection - Rapid and reliable
- **Analysis** - Takes more time and requires a high level of expertise
- **Ease of Use** - Requires significant expertise and training
- **Cost** – Moderate-to-expensive system
- **Repeatability** - Repeatable test
- **Accuracy** – Good (better with ground-coupled antennas)

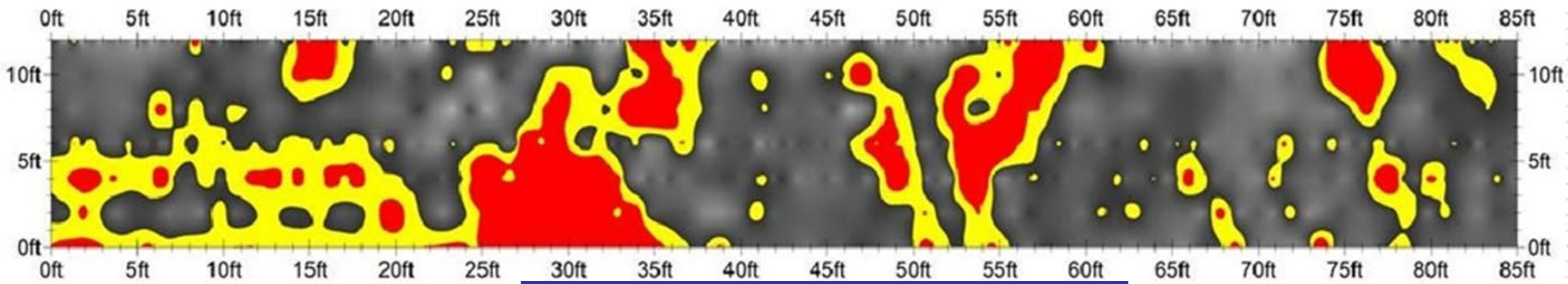
Limitation of GPR Test on Bridge Deck

- Detect delaminations **only when** they are epoxy-impregnated and/or filled with water in decks
- Not good in **extreme cold conditions**
- **De-icing salts** can limit the depth of signal penetration
- **Limited test results** – cannot provide any information about the mechanical properties of the concrete (strength, modulus, etc.).
- **FCC restrictions**
- Need **validations** from other NDE methods or ground truth

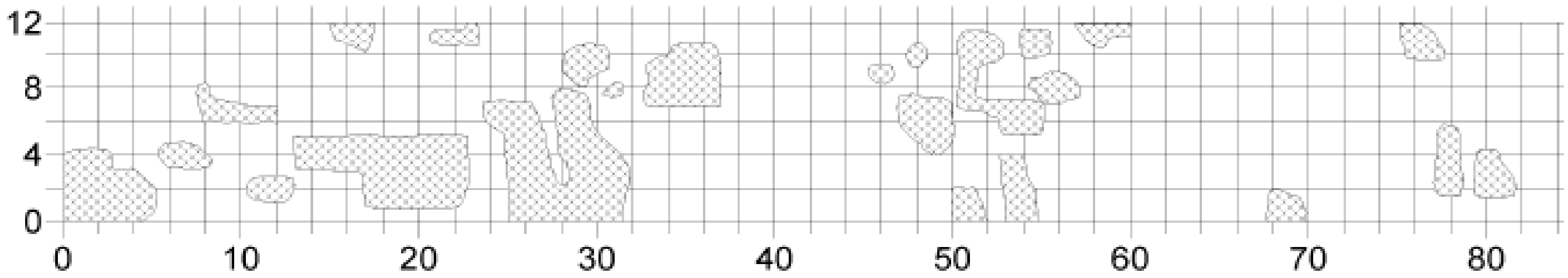
Limitations (continued)

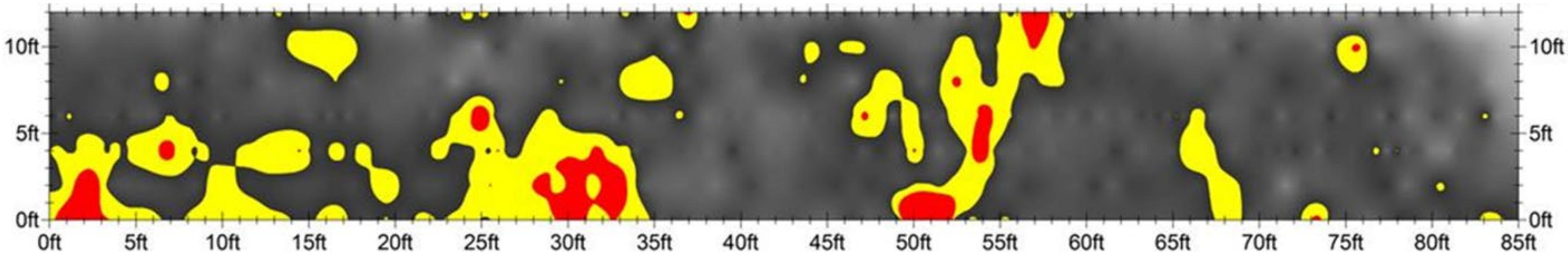
- **Cannot "see"** through dense rebar
- **Does not directly detect cracks** – need "conductive" cracking
- **Depth of air voids** can not always be estimated
- **Depth of the penetration** depends on the antenna frequency
  - 2600 MHz – 12 inch max penetration in concrete
  - 1500 MHz – 18 inch max penetration in concrete
  - 400 MHz – 6 – 10 foot penetration in concrete

Comparisons GPR Test Results Between 2 Different Antennas



Test Results from bi-polar Antenna





Test Results from mono-polar Antenna

Summary from the GPR Test

- **Two types of antennas are available in the market**
  - **Ground coupled**: provide better accuracy but lane closures are required
  - **Air coupled**: provide a rapid assessment with poorer accuracy than the ground coupled technique but no lane closures required due to high-speed testing
- **Detect corrosion** of the steel reinforcement by grading the reflection amplitude
- Different **antennas with various center frequencies** perform better than using a single center frequency antenna
- **Bi-polar antenna** can give better details of the reinforcement/pre-stress/post-tensioning than mono-polar antenna