Emerging NDE Methods for Evaluating and Monitoring Bridges

- Impact Echo and Surface Waves Scanning of Bridge Decks

- Imaging by Interferometric Survey for Bridge Monitoring and Stay Cable Forces

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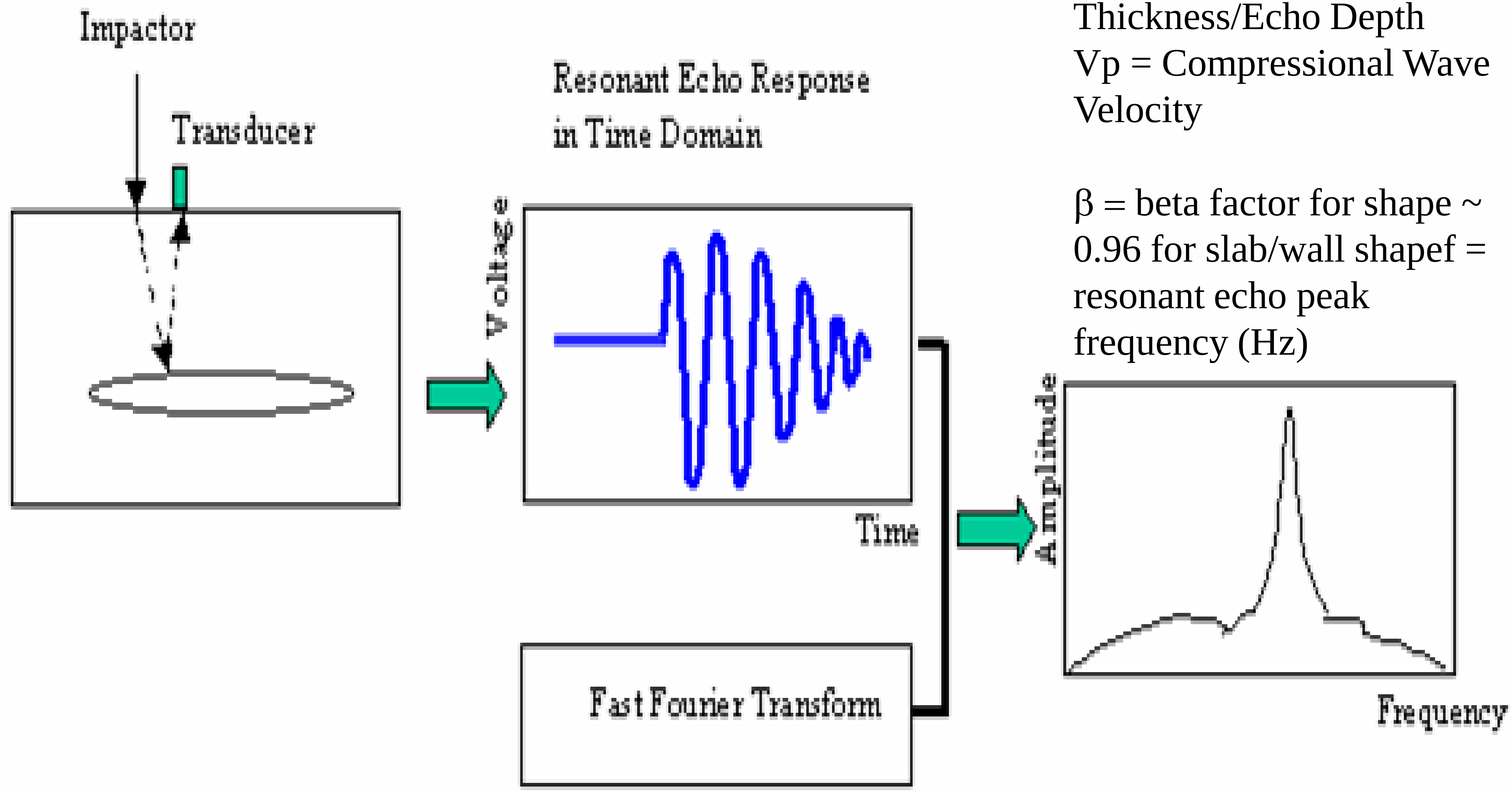
Nondestructive Testing Methods Utilized in the Sonic Surface Scanner (S^3)

- Impact Echo (IE) – ASTM C1383 and ACI 228.2R
- Spectral Analysis of Surface Waves (SASW) – ACI 228.2R

Impact Echo Test

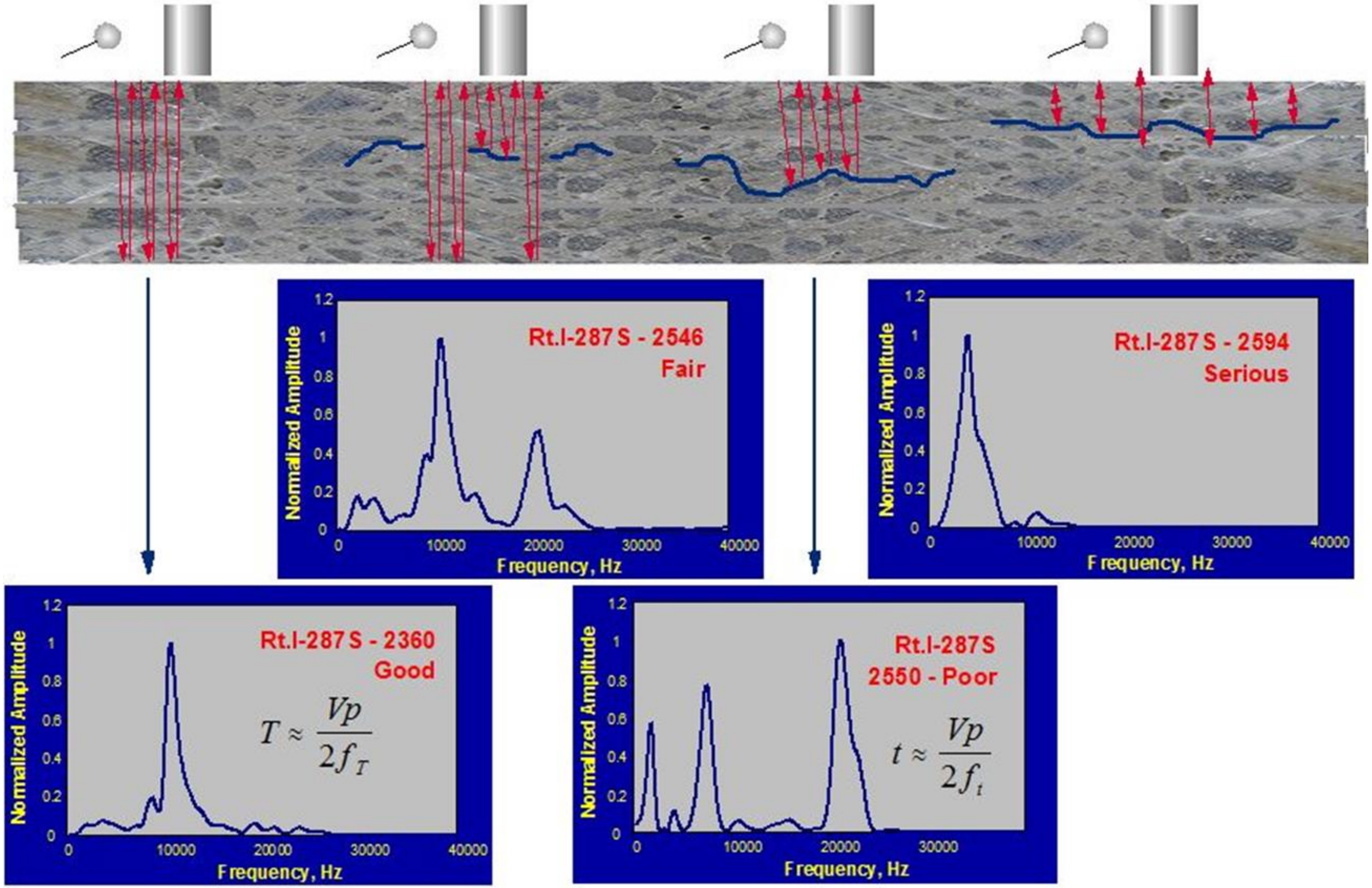


D = βVp/(2*f) = Thickness/Echo Depth

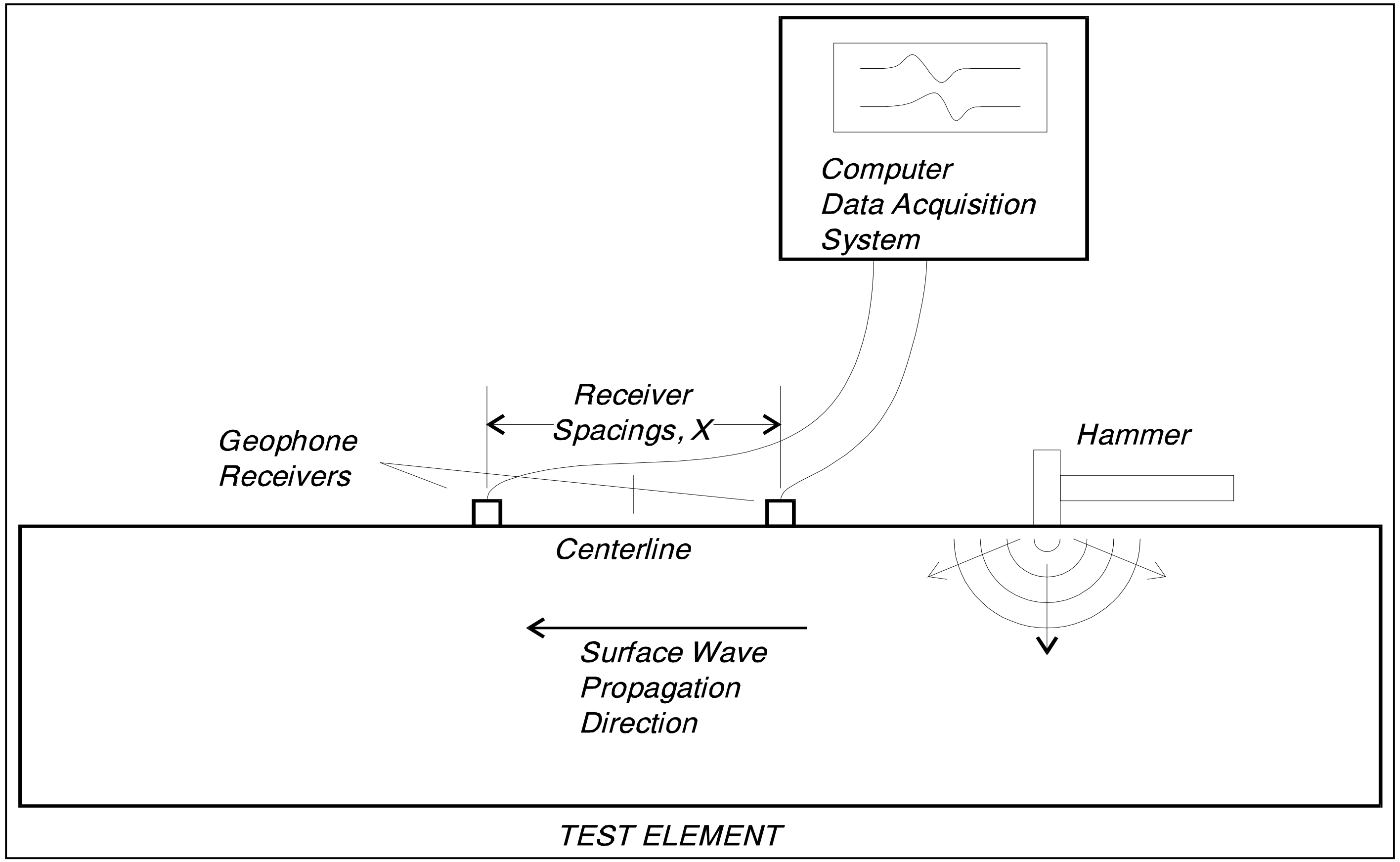
Vp = Compressional Wave Velocity

β = beta factor for shape ~ 0.96 for slab/wall shapef = resonant echo peak frequency (Hz)

Impact Echo Results – Sound, Tight Crack, Deep Crack and Delamination



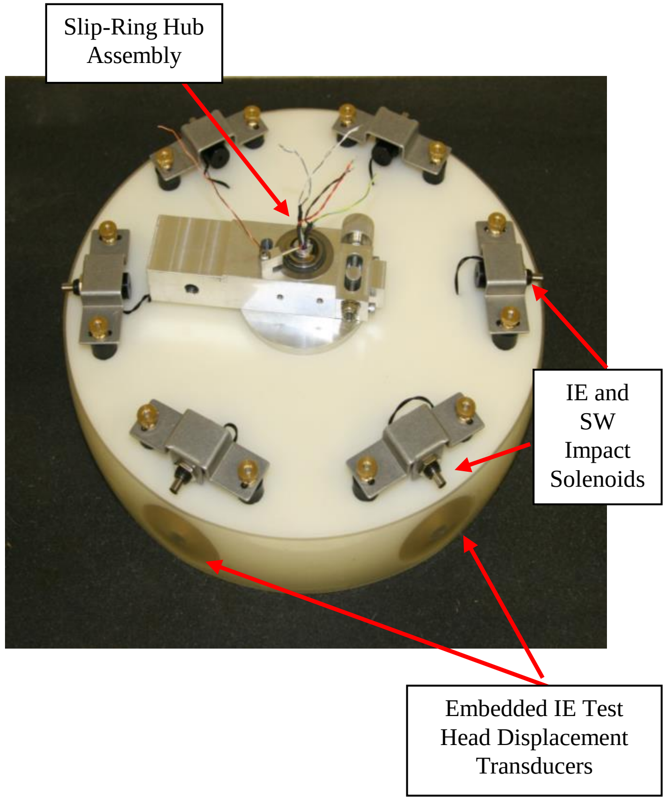
Spectral Analysis of Surface Waves (SASW) Method – Cracking and Concrete Quality Evaluation



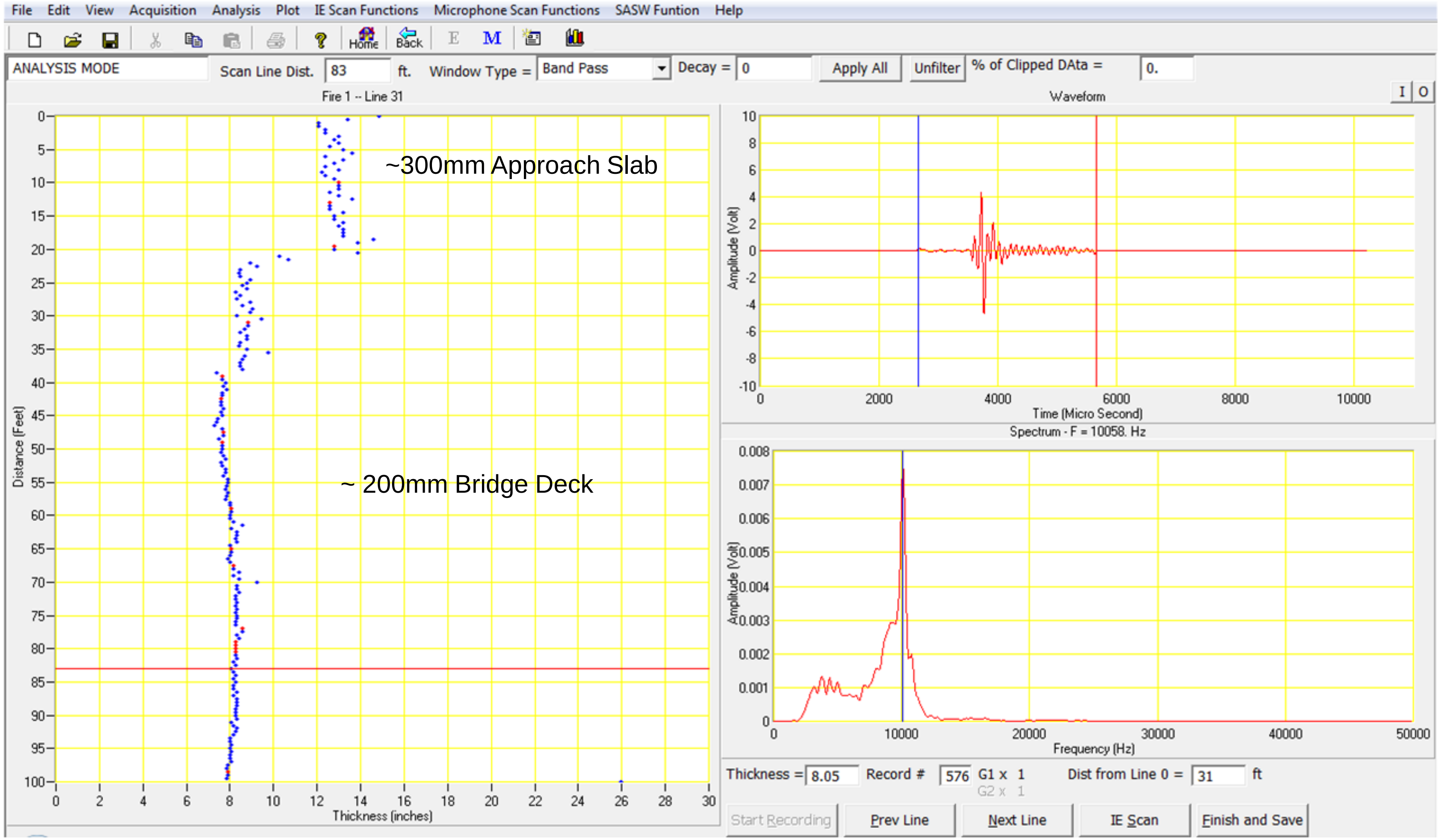
Surface Sonic Scanner S^3 slow-rolling IE/SASW on Cart on Virginia Asphalt Overlaid Deck with tests every 6 inches and latest S^3 on right with bright sunlight viewable screen

Scanning Impact Echo Testing

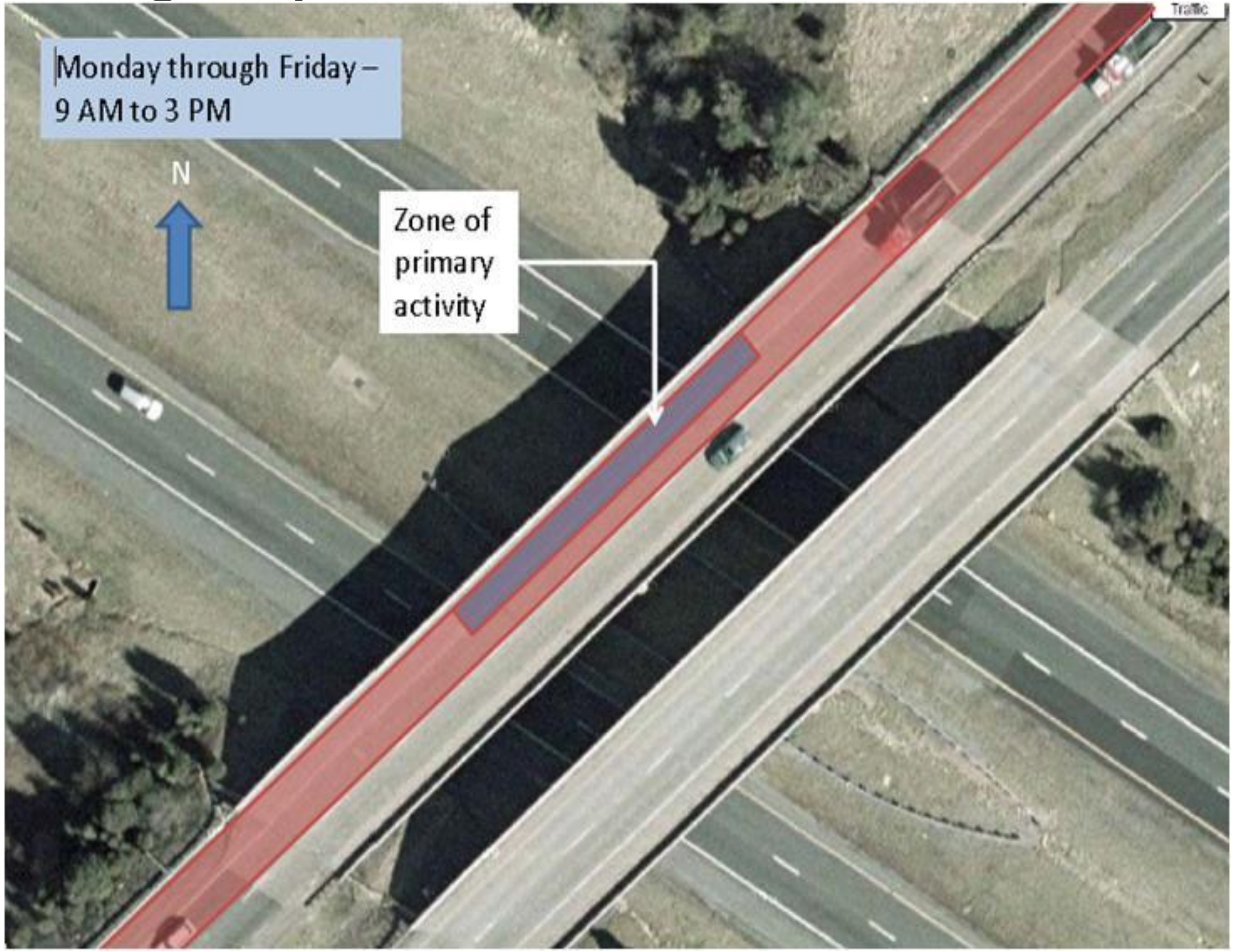
- Diameter of Wheel = 293 mm (11.5 inches)
- Six individual displacement transducers
- Six individual impactors
- Impacts spaced 150 mm (6 inches) apart along a scan line (around the wheel circumference)
- The 6 transducers were spring mounted with rubber isolators and captured with a thin urethane tire approximately 60 mm (2.5 inch) wide
- The thin urethane tire was added as a dust cover and to improve coupling



Surface Sonic Scanner Impact Echo Thickness Plot Single Scan Line along Deck 1



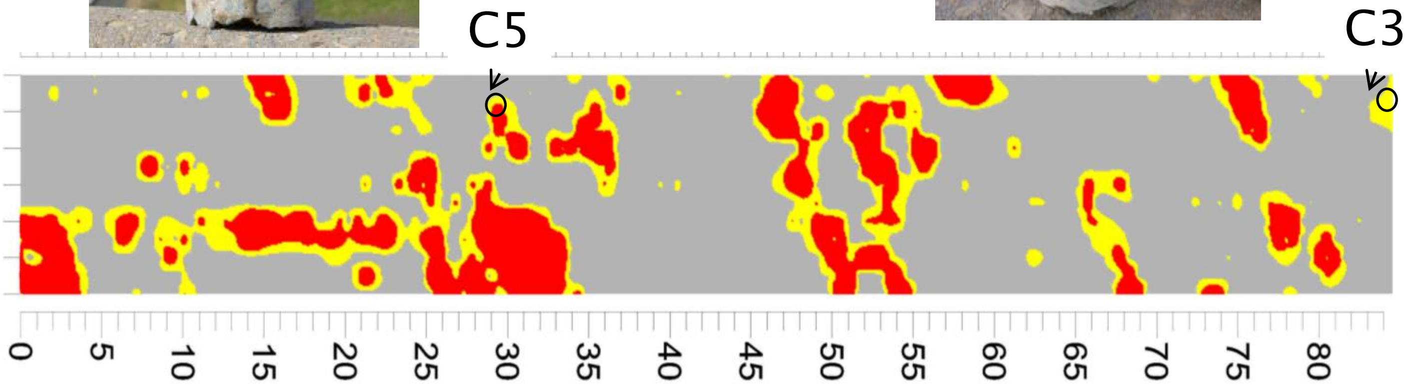
SHRP 2 R06A Rutgers University Research
Olson Case Study – Corroded Delaminated Virginia Bridge Deck, James Madison US Highway 15 over I-66

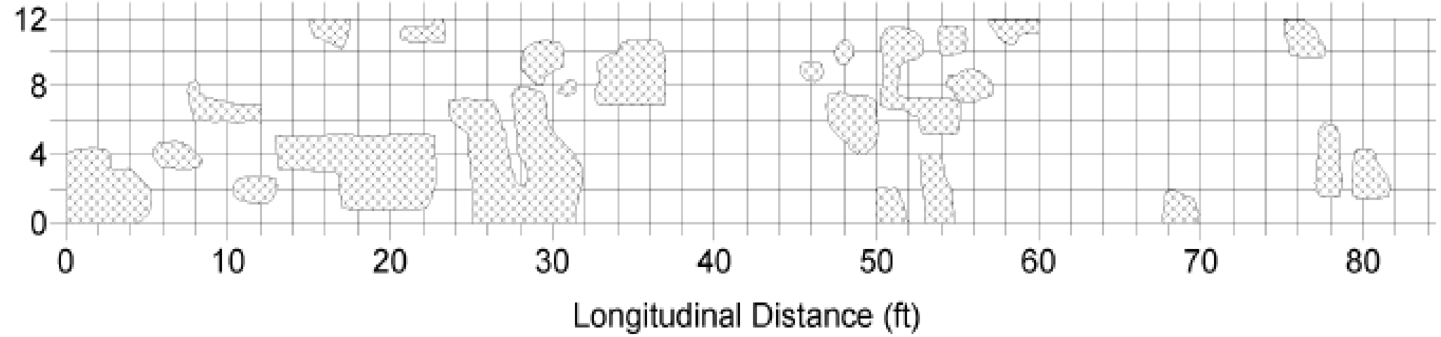


Comparisons between Sonic Surface Scanner IE Test Results, Acoustic Soundings and Cores

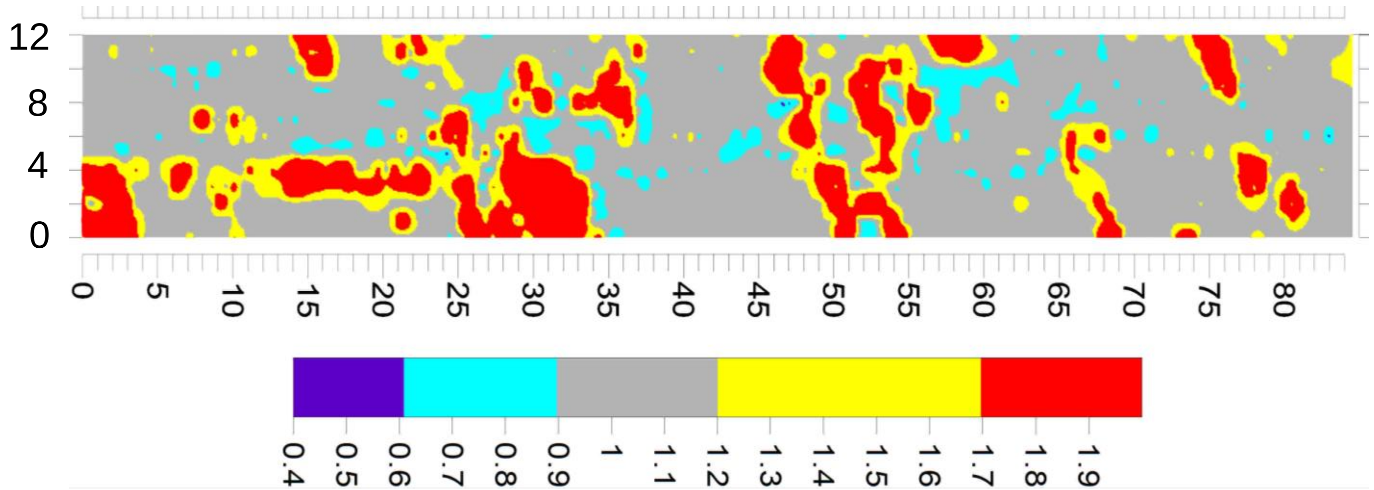
C5 – delamination at 2.5 inches

C3 – delamination at 3.5 inches



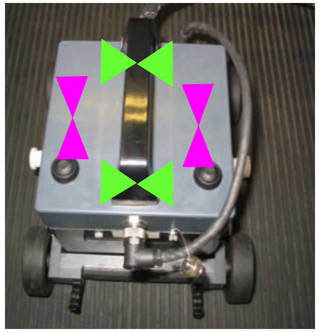


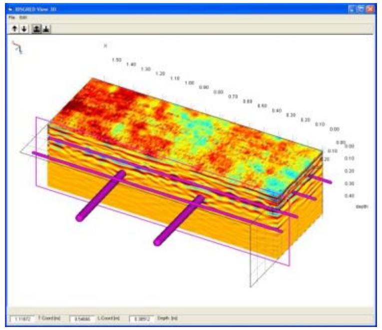
Impact Echo Scanning Test Results
VA Deck – Full Deck Depth Results



Areas with Probable Top Delaminations = 14%
Areas with Probably Incipient Top Delaminations = 13%
Areas with Probable Bottom Delaminations (or Thin Section) = 5.7%

IDS Aladdin GPR





1
OPERATIONAL CASE

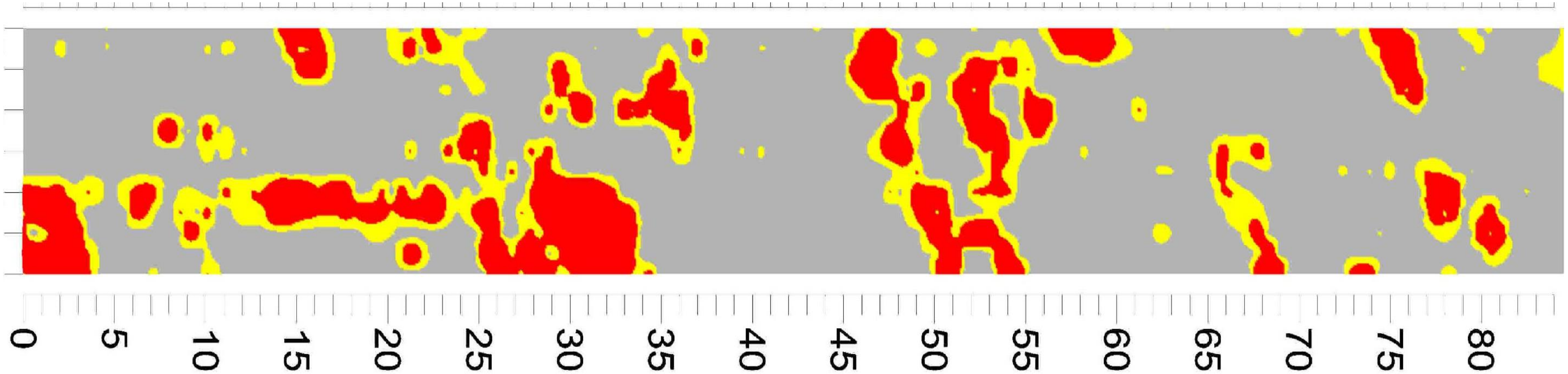
2
PSG: INNOVATIVE SURVEY KIT-
THE "MAGIC GROOVED CARPET

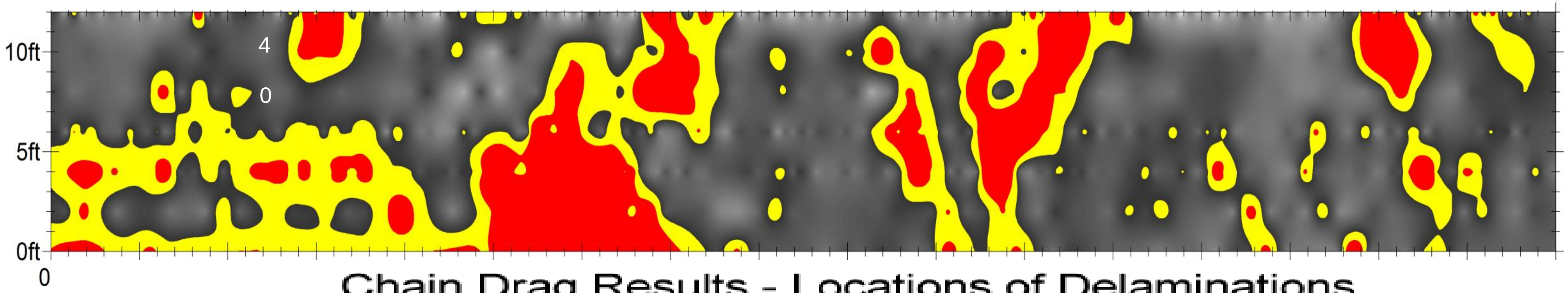
3
FULL POLAR ANTENNA-
UP TO 4 COMBINATIONS

4
3D SOFTWARE FOR ON-SITE
PROCESSING FOR REBAR IMAGES

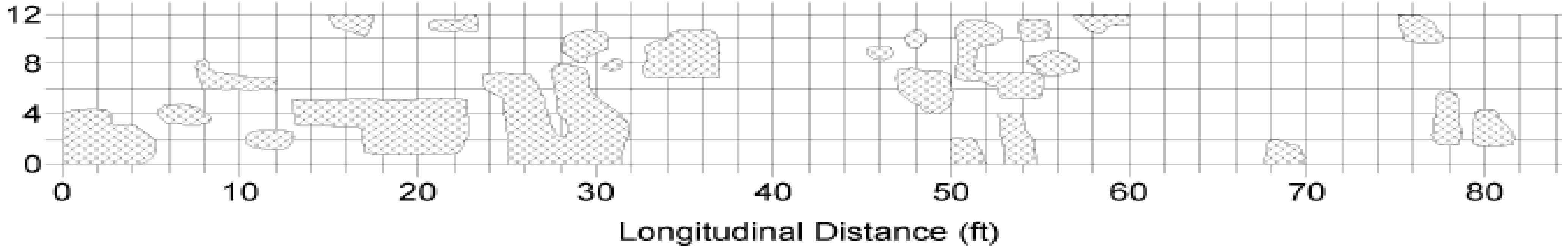
1. DEDICATED TRANSPORT/OPERATIONAL CASE
2. PSG: INNOVATIVE SURVEY KIT FOR AN EASY AND TOTAL 3D ACQUISITION DATA WITH GROOVED RUBBER CARPET
3. FULL POLAR ANTENNA (2 GHz): IMPROVES THE IMAGING OF SHALLOW AND DEEP REINFORCING BARS FOR REBAR MATS AND ANGLED BARS
4. QUICK ON-SITE DATA PROCESSING

Top Delamination Test Results from the Impact Echo (top), GPR (middle) and Acoustic Sounding – VA Deck





Chain Drag Results - Locations of Delaminations

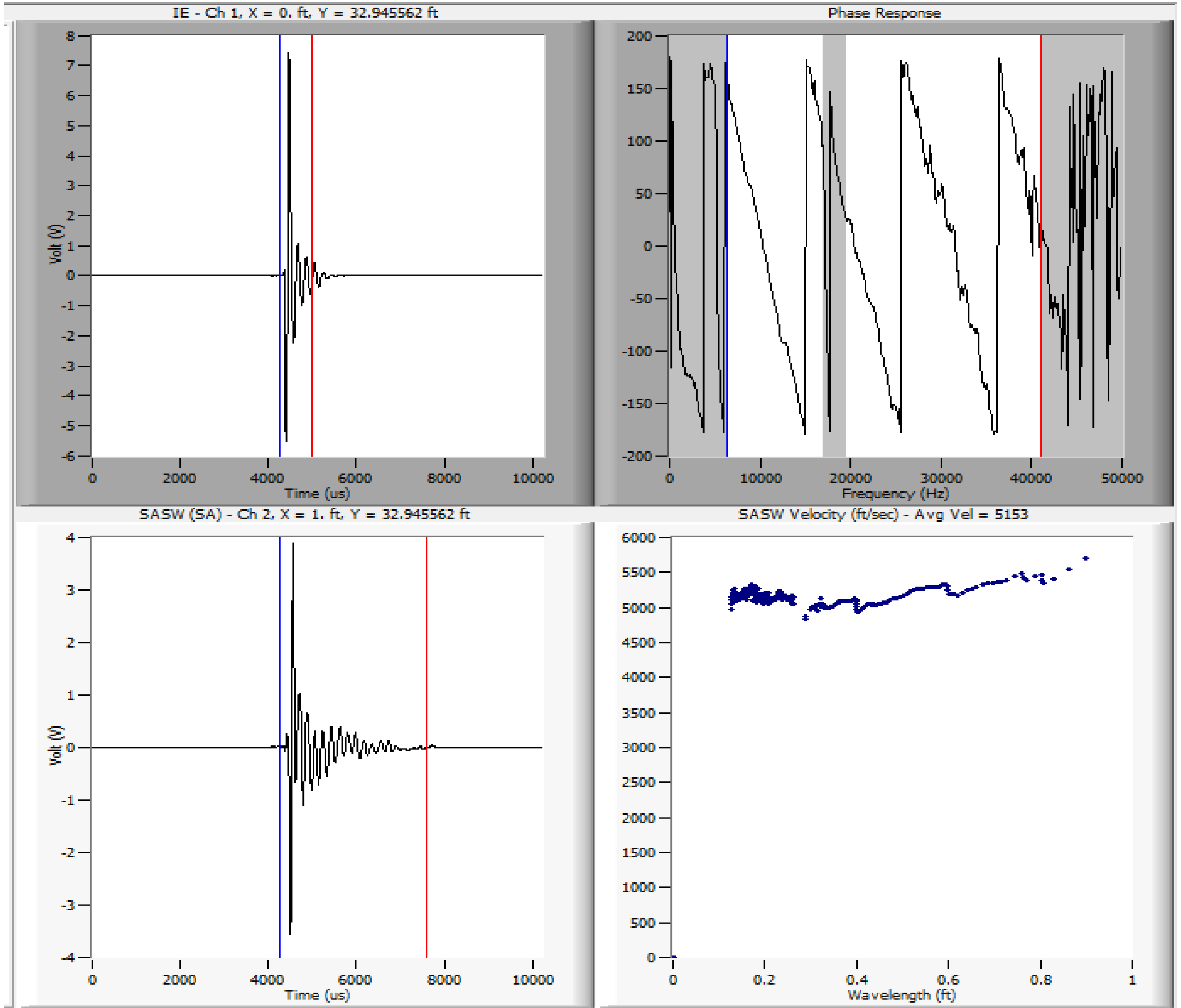


Internal Research Project on 2 Asphalt Overlaid Decks with the Colorado DOT using BDS with Surface Waves and Impact Echo

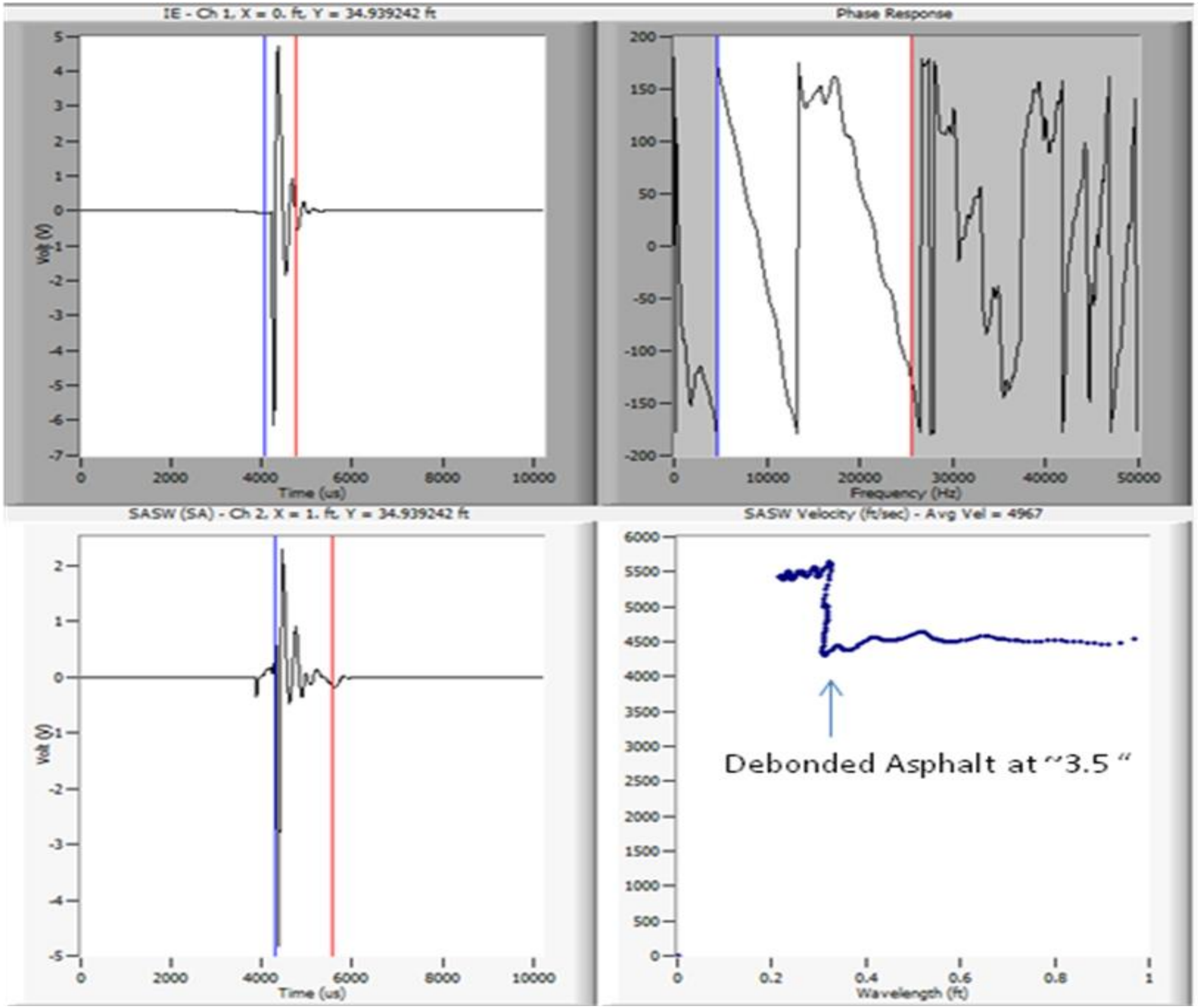
- Structure E-17-IN: I-270 westbound bridge over Dahlia Street (asphalt covered concrete deck with water-proofing membrane)
- Structure E-17-IE: I-270 eastbound bridge over South Platte River (asphalt covered concrete deck without water-proofing membrane)

Over 30 asphalt overlaid decks have been tested since this successful demonstration along with GPR and coring

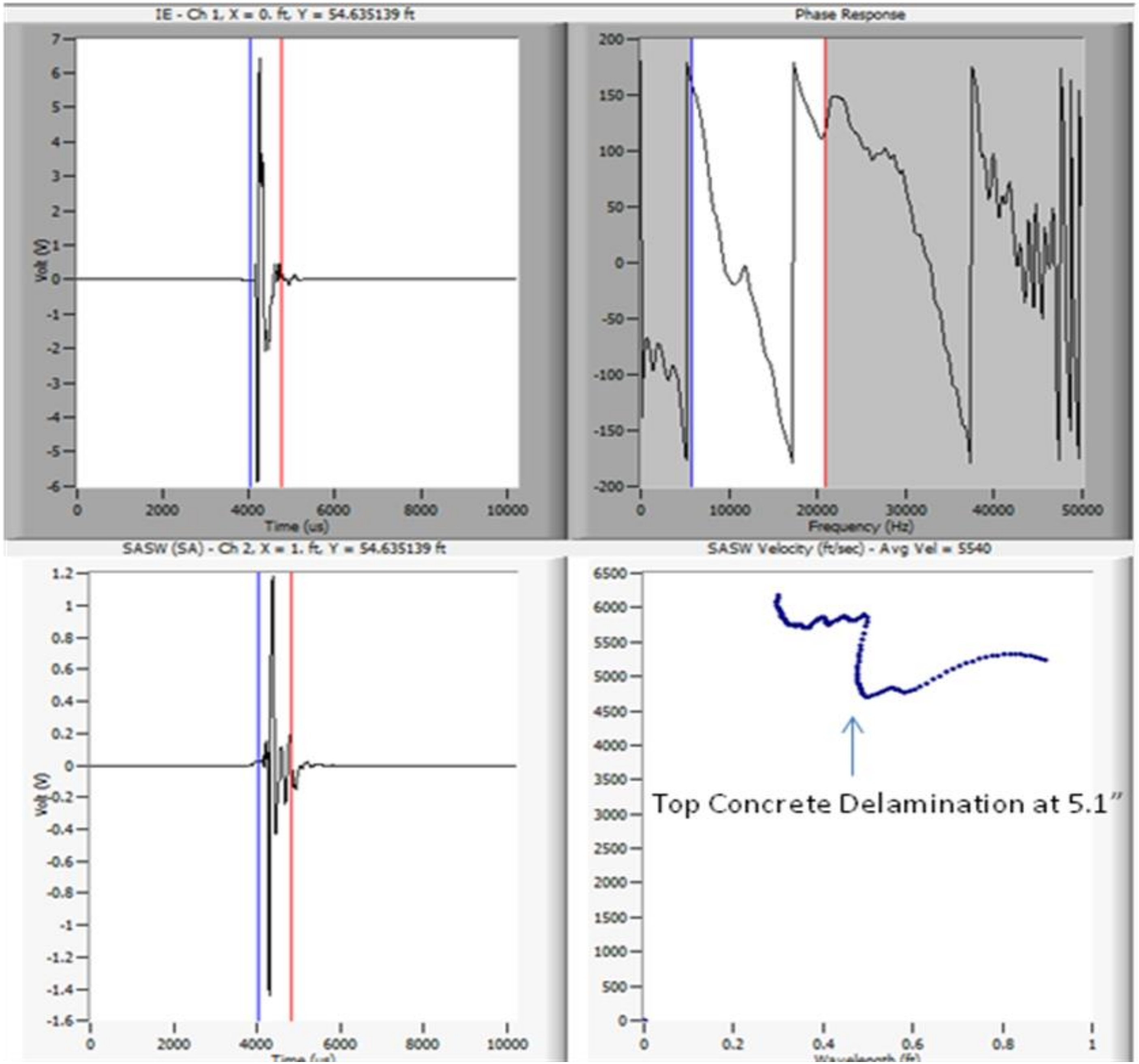
Findings – Bonded Asphalt on Sound Concrete



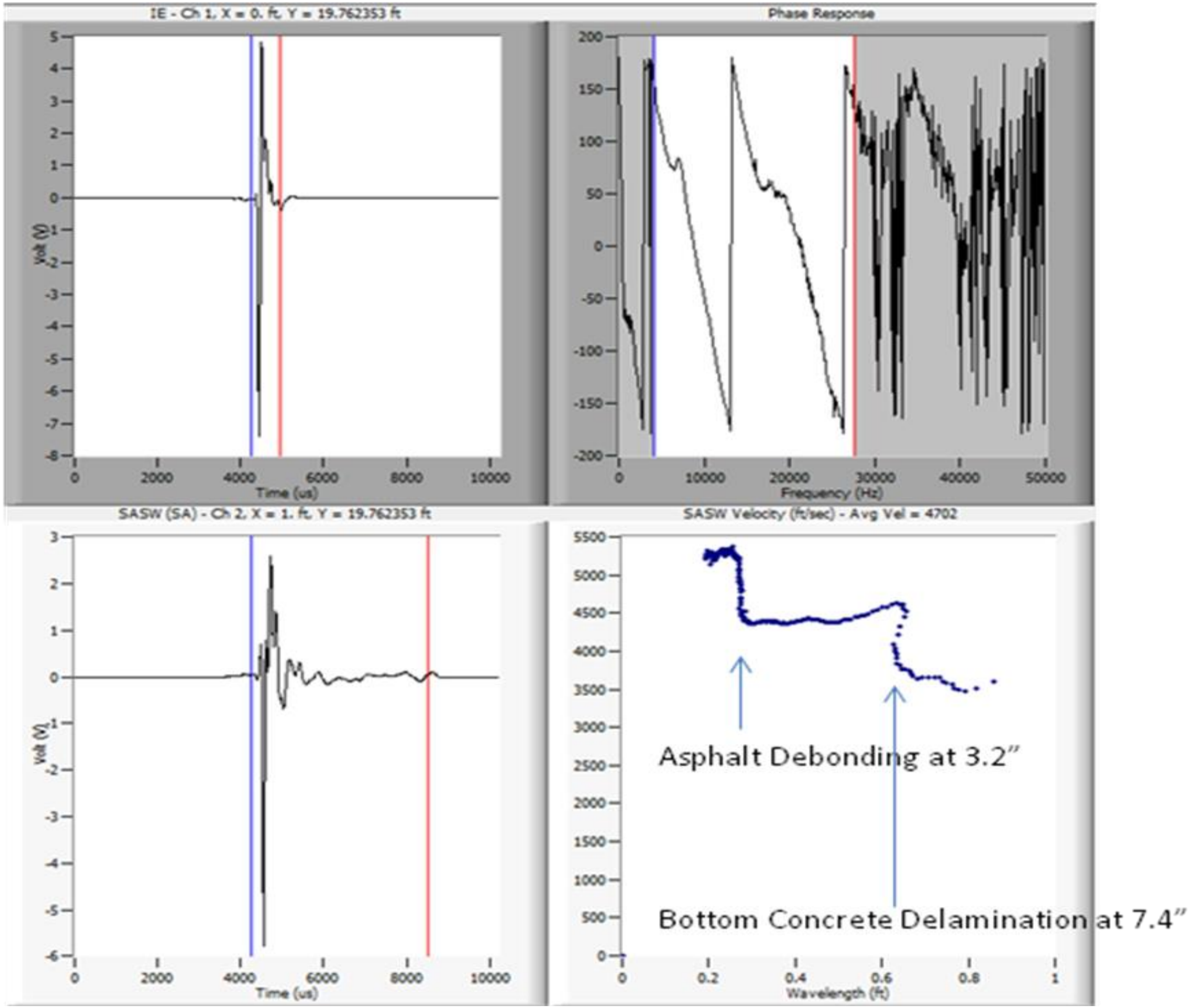
Sound Concrete with Asphalt Debonding



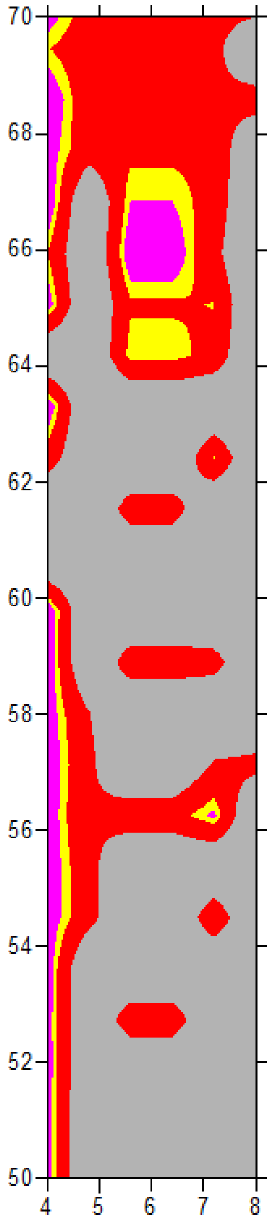
Bonded Asphalt on Concrete with Top Delamination

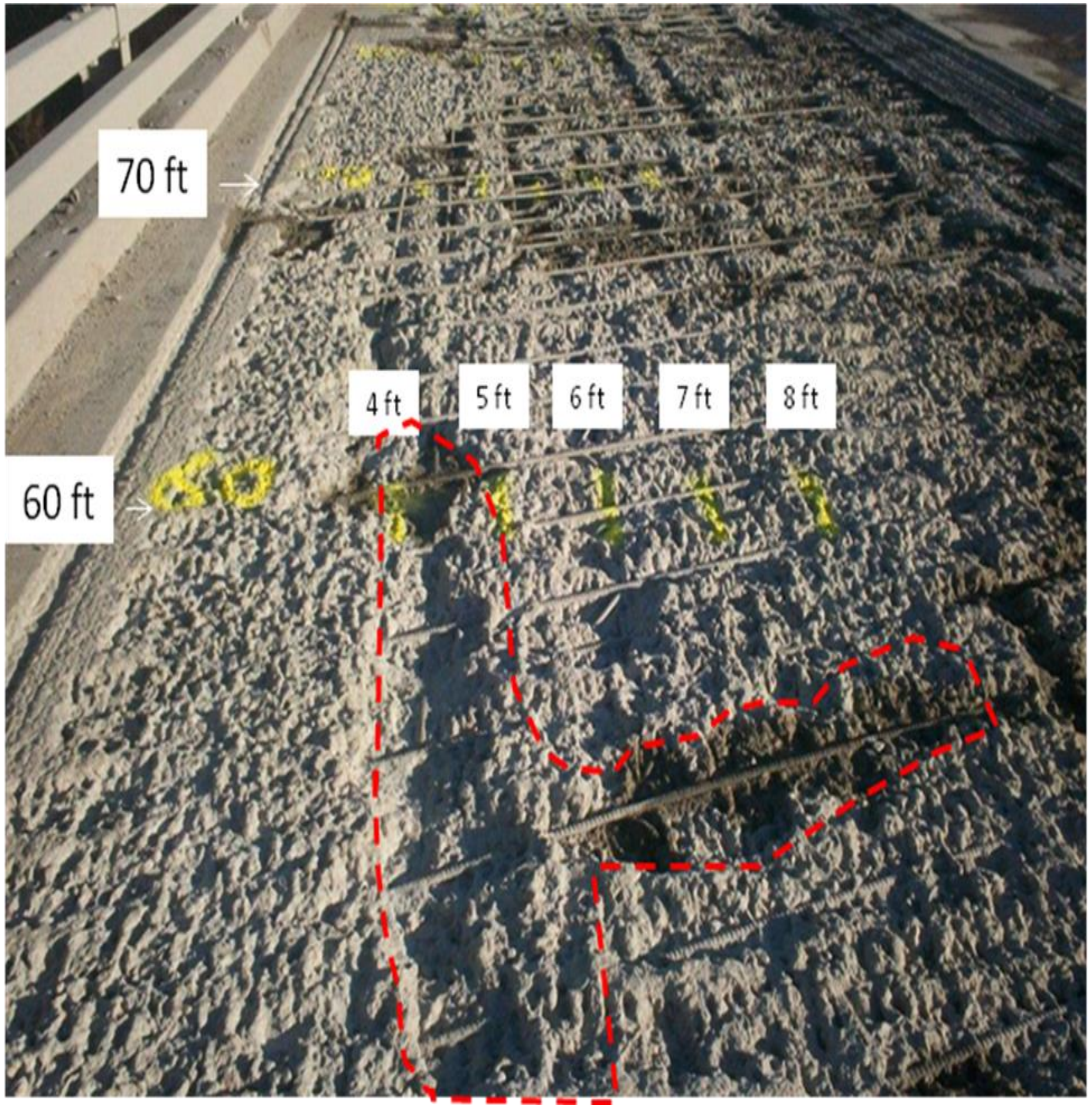


Debonded Asphalt / Concrete with Bottom Delamination



Ground Truthing – Hydrodemolition revealed Delaminations with Excellent Correlation with SASW Results on left showing slower velocities in Delaminations





Impact Echo and Surface Waves Scanning Applications

- 1 mph Slow-rolling scanning with Impact Echo on Bare Decks
- Detects top delaminations and can find bottom delaminations where no top delaminations are present
- Combined Impact Echo and Surface Waves to detect top and bottom delaminations in asphalt overlaid decks and for debonding of asphalt pavement lifts
- Most accurate damage mapping for bridge decks due to corrosion of reinforcing steel causing concrete delamination

IBIS by IDS GeoRadar
Image by Interferometric Survey

A Ground Based Microwave Interferometer with Imaging Capabilities for the Remote Measurement of Displacements and Vibrations – Landslide & Dam Monitoring and Bridge & Structures Monitoring

IBIS System remarks

IBIS system is a Stepped-Frequency Continuous Wave (SF-CW) coherent radar with SAR and Interferometric capabilities, dedicated to remote monitoring of static or dynamic displacement such as terrain deformation or structure vibrations.


For Static monitoring

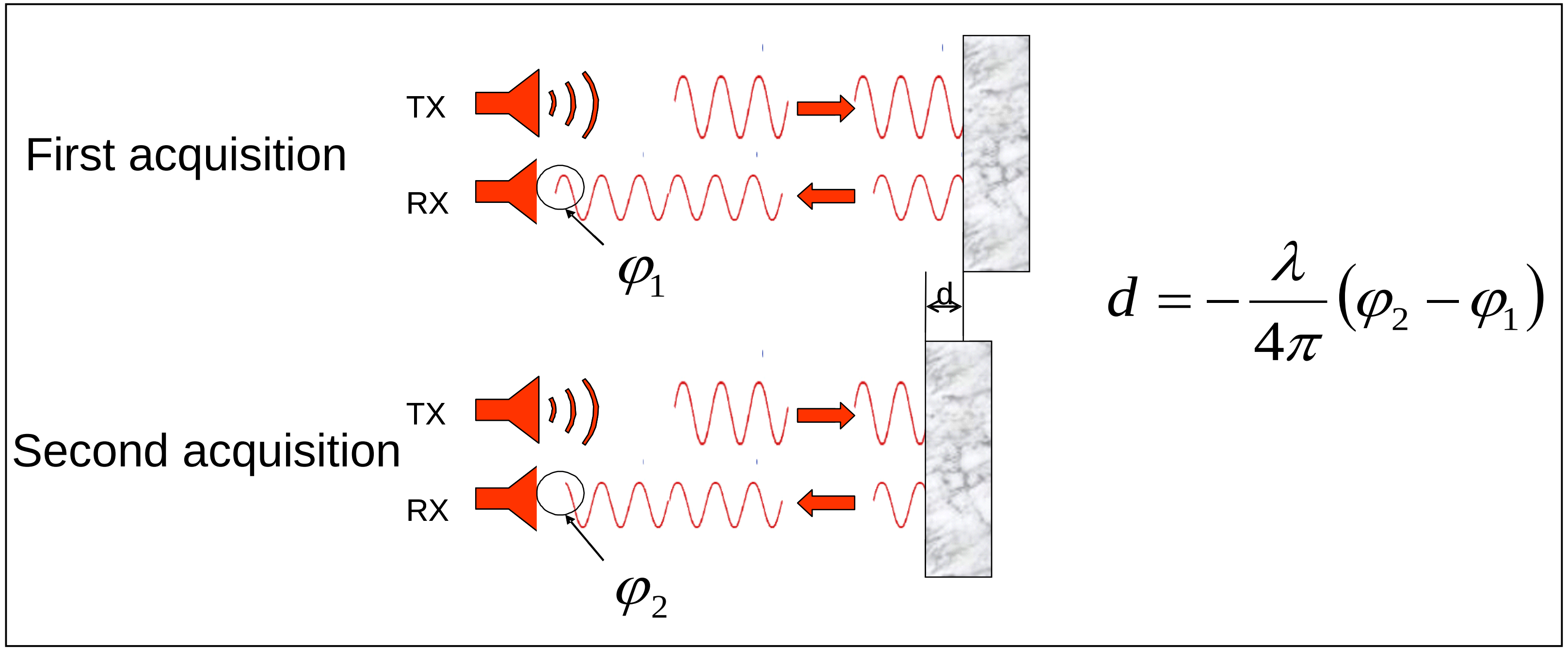
IBIS – L configuration


For Dynamic and Static monitoring

IBIS – S configuration

Interferometric capability

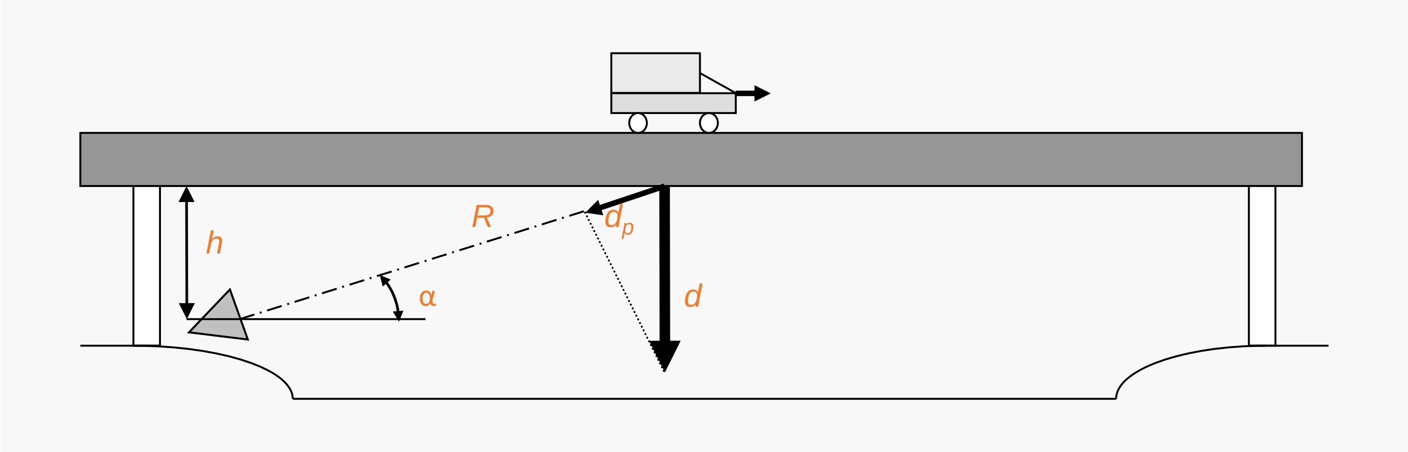
The interferometric analysis provides data on object displacement by comparing phase information, collected in different time periods, of reflected waves from the object, providing a measure of the displacement with an accuracy of less than 0.01mm (0.0004 inch intrinsic radar accuracy in the order of 0.001 mm.)



Interferometric capability

The displacement is measured in the direction of the line of sight of the system.

To calculate the real displacement is needed to know the acquisition geometry



$$d = \frac{d_p}{\sin(\alpha)} \quad \Rightarrow \quad \sin(\alpha) = \frac{h}{R} \quad \Rightarrow \quad d = d_p \cdot \frac{R}{h}$$

The distance R is measured by IBIS-S

IBIS - Image By Interferometric Survey

17.1-17.3 GigaHertz Radar

COLORADO BRIDGE STATIC DISPLACEMENT AND DYNAMIC VIBRATION MONITORING

I-70 EB to CO HWY 59 WB FLYOVER POST-TENSIONED SEGMENTS

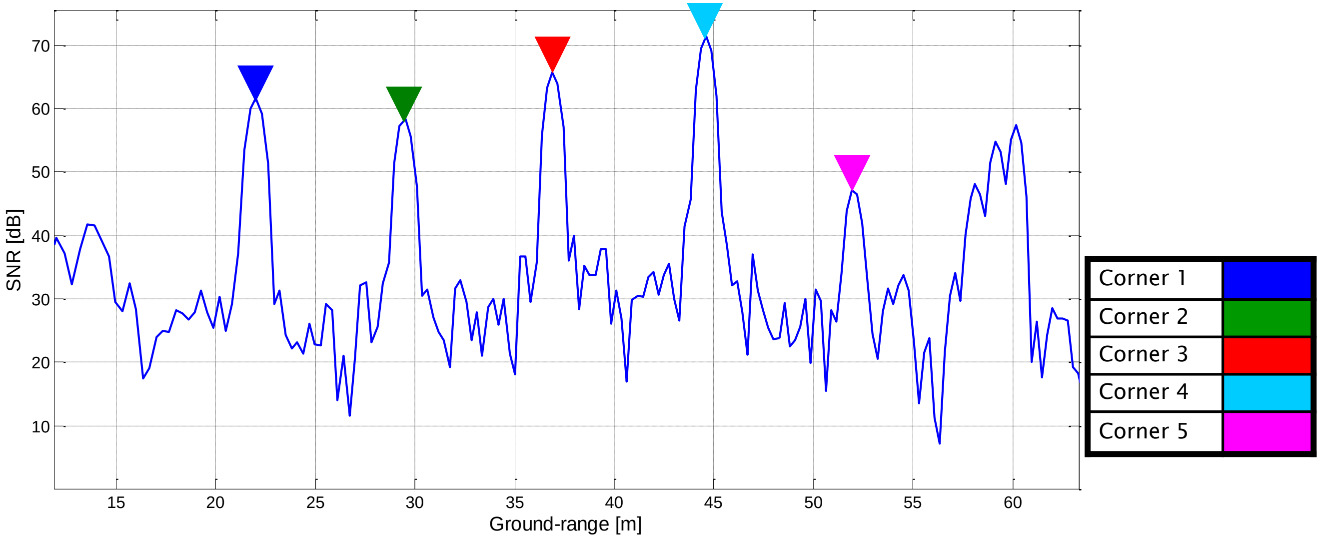
WHEAT RIDGE (CO), USA

Measurement Points Identification

IBIS-S VIEW ON THE MONITORED BRIDGE SPAN

A sharp peak corresponding to each corner reflector installed on the bridge can be clearly identified in the ibis-s power profile

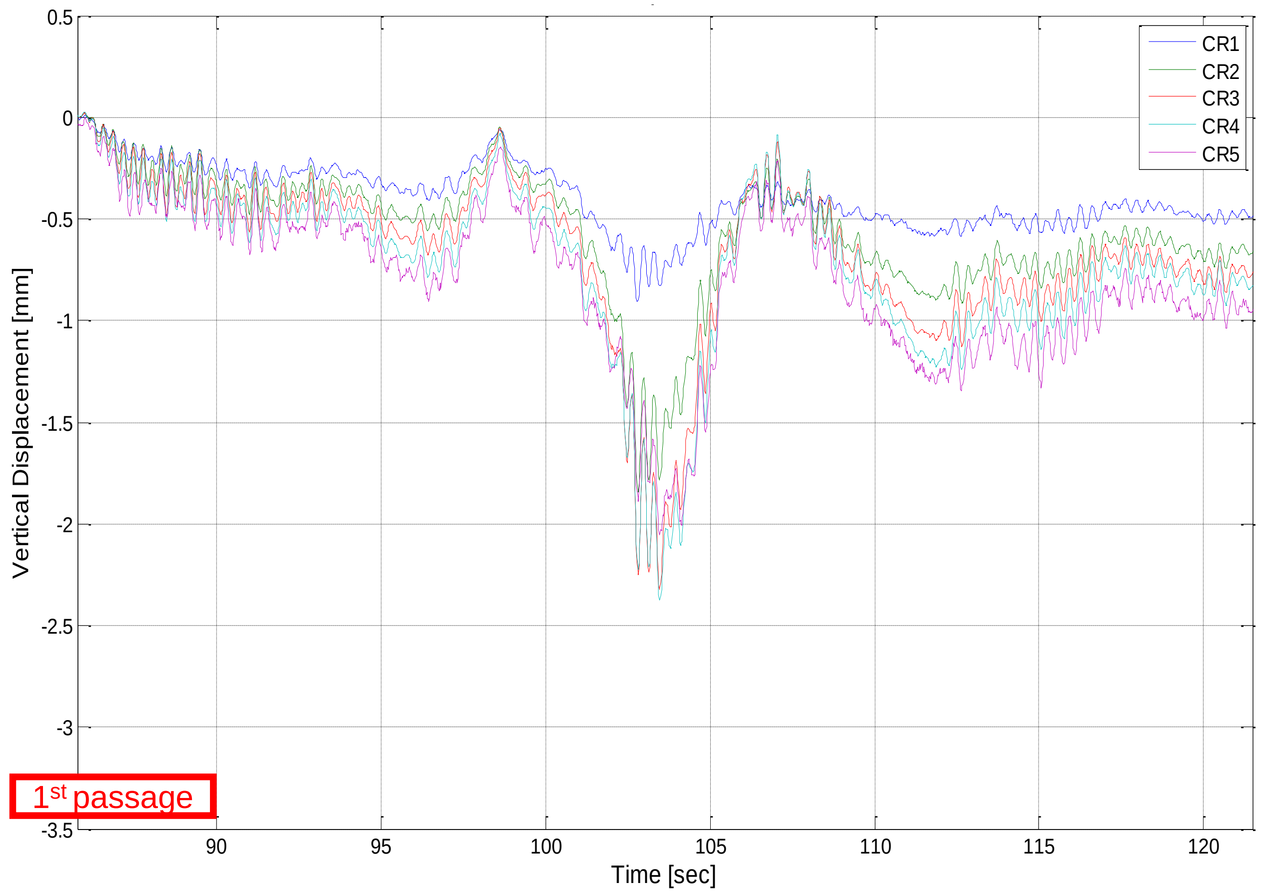
POWER PROFILE



CORNER REFLECTORS

Displacement Time Series

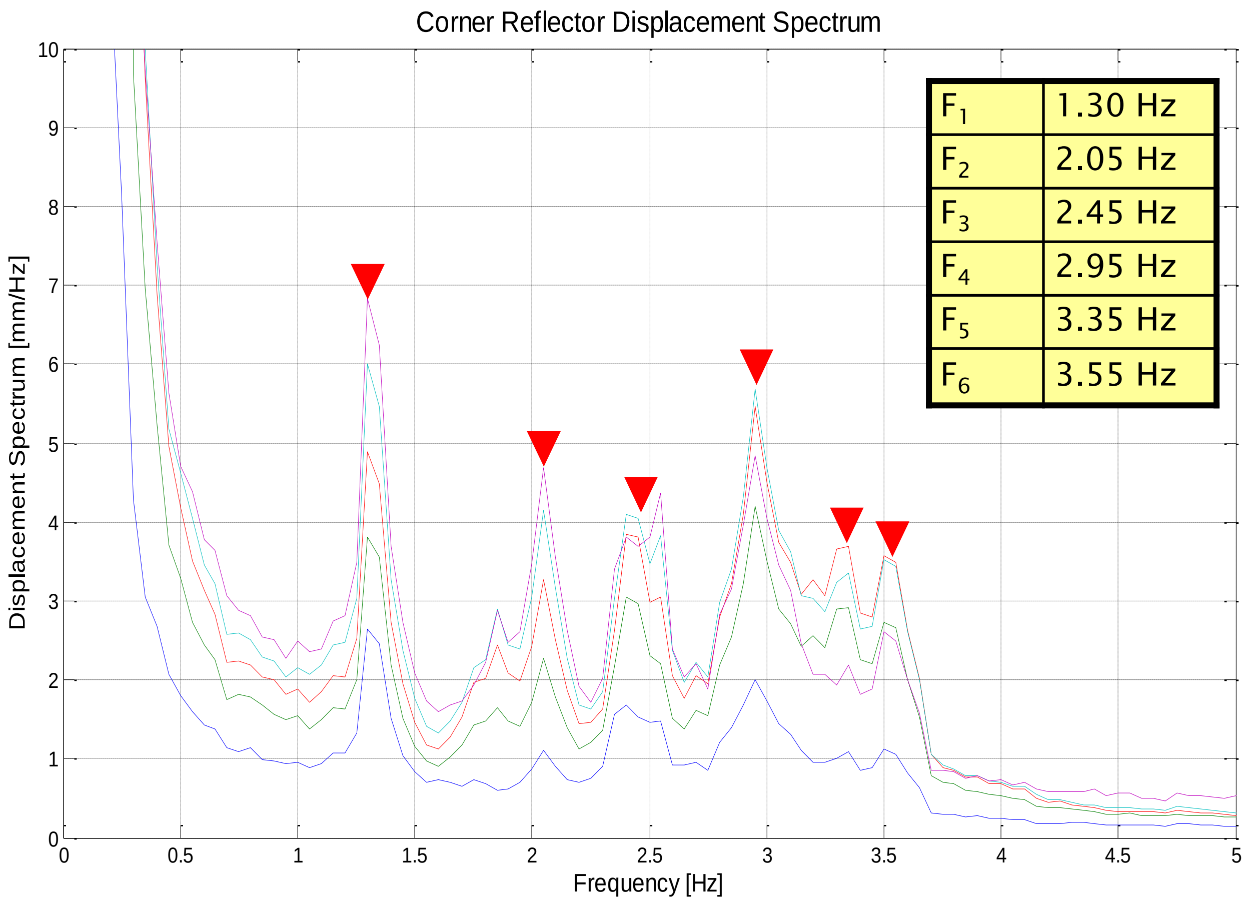
First passage of the 40,000 lb testing truck - vertical displacement of the five passive metallic reflectors installed on the bridge side



A 2.26 millimeters peak to peak vertical displacement can be observed in the middle of the monitored span (CR3) during the testing truck passage

Displacement Spectrum

Displacement Spectrum of the five corners Displacement Time Series computed using the periodogram algorithm (window size 20 seconds, overlap 66%)



F_1	1.30 Hz
F_2	2.05 Hz
F_3	2.45 Hz
F_4	2.95 Hz
F_5	3.35 Hz
F_6	3.55 Hz

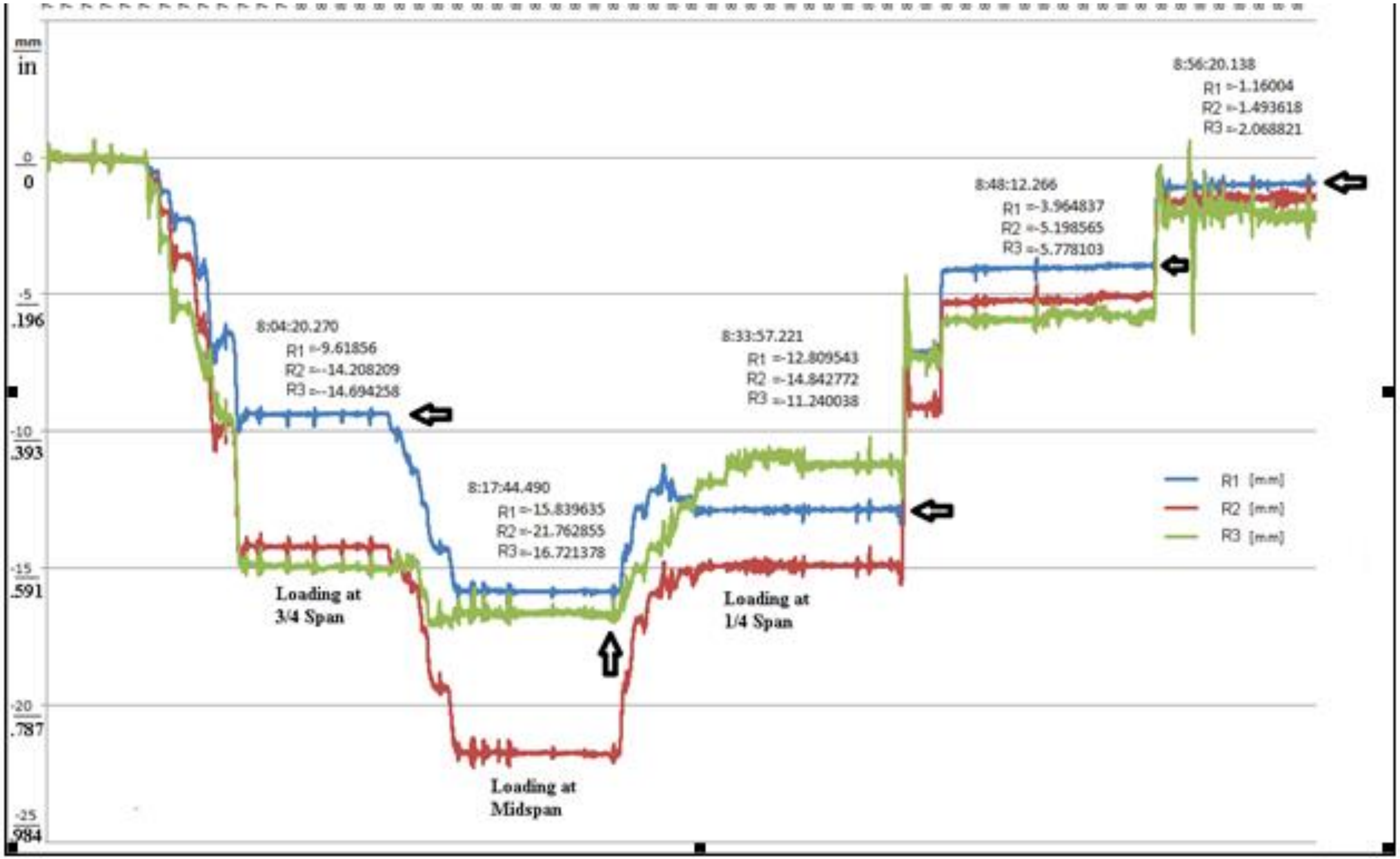
Six peaks corresponding to the first structural resonant frequencies can be identified in the Displacement Spectrum of the five corners.

The first three frequencies should correspond to mainly flexional modes while the last three should be related to mainly torsional modes

FHWA Long-Term Bridge Performance Monitoring of NJ Bridge with IBIS-S

IBIS-S and installation of Corner Reflectors in NJ

Load Tests at ~ ¾, ½, and ¼ Spans with 6 trucks and Corner Reflector Displacements over ~ 1 hr- agreed with string displacement potentiometers to ground



IBIS-S & Cable-stayed bridges

Application goal: dynamic analysis done through ambient vibration testing (AVT) aimed at:

- Identify the amplitude of the cable vibrations;
- Identify the natural resonant frequencies and the cable dumping factors
- Evaluate the tension and the operating strain of cables to verify the correct distribution of loads and the temporal variation of tensions along the bridge life

IBIS-S & Cable-stayed bridges

Economical advantages in the use of IBIS-S:

- Example of standard use for a cable stayed bridge with 48 cables

Item	Test with accelerometers	Test with LDV	Test with IBIS-S
Personnel (n° of units)	3-4	1-2	1-2
Number of devices	10-15	1	1
Install./disinstall. time	30’ for each cable	10’ for each cable	20’ for 12 cables
Acquisition duration once installed*	60’	60’	60’
Field activity duration (days)	3-4	4-6	1
Personnel costs (Euro)**	7.200-12.800	3.200-9.600	800-1.600
Need for crane truck	Yes	no	no
Need for traffic shut-down	Yes	no	no

*Once installed all the equipments need at least 60’ of acquisition to obtain reliable results using AVT

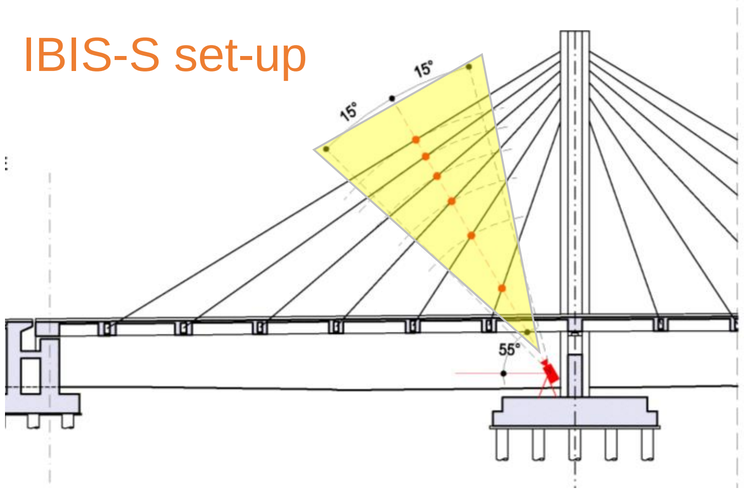
**Personnel costs are calculated on an average rate of 800 €/day per personnel unit

***Post-Processing times for data acquired by the three equipments are comparable (the output is the same)

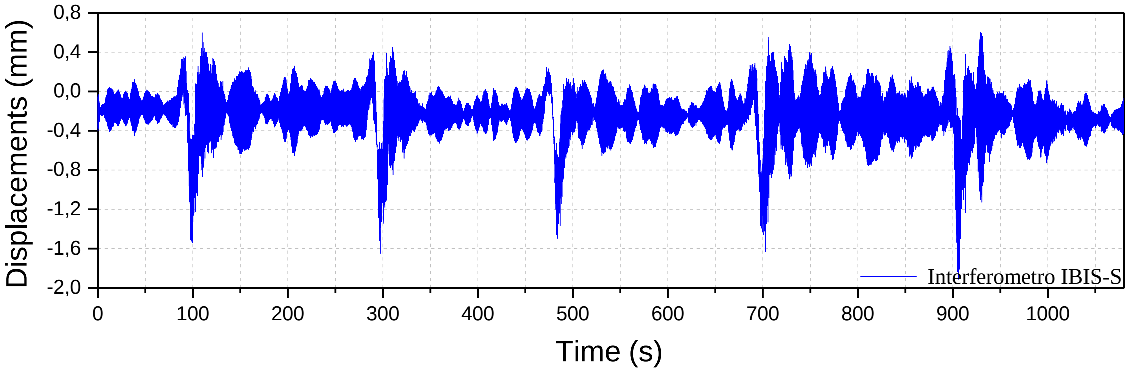
IBIS-S & Cable-stayed bridges: case studies

Example: Olginate bridge (Italy)

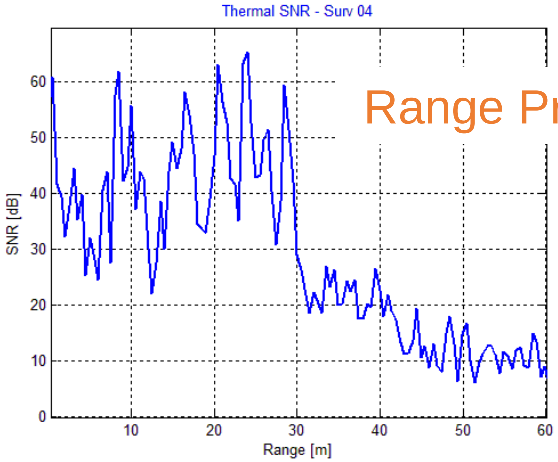
IBIS-S set-up



Displacement graph



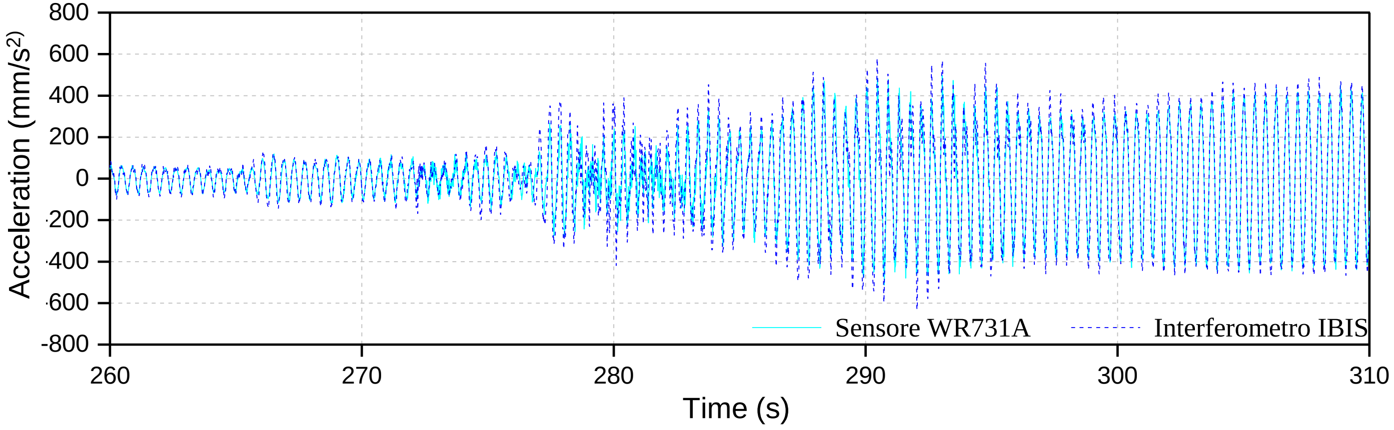
Range Profile

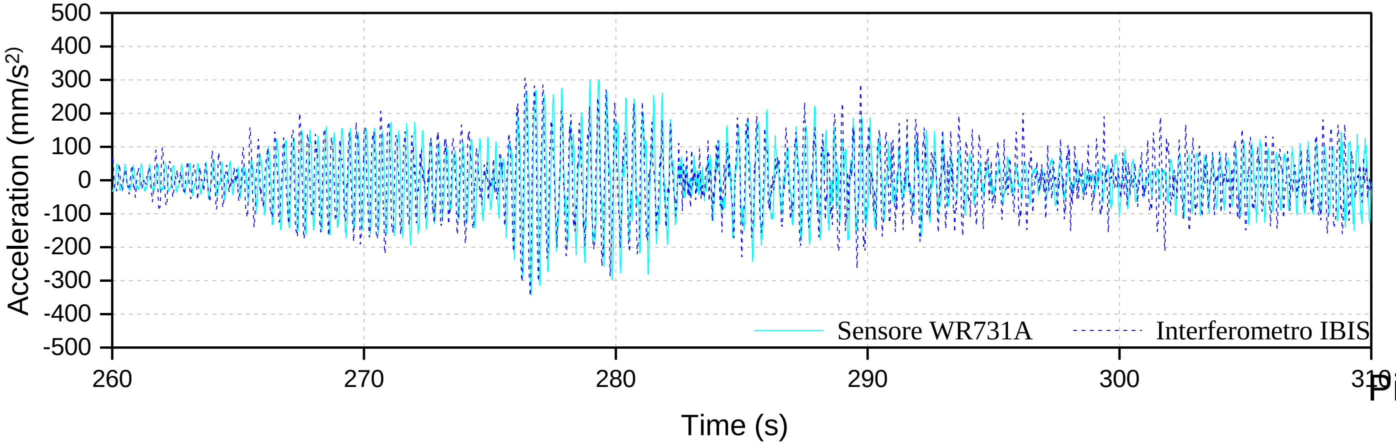


IBIS-S & Cable-stayed bridges: case studies

Example: Olginate bridge (Italy)

Comparison with accelerometers



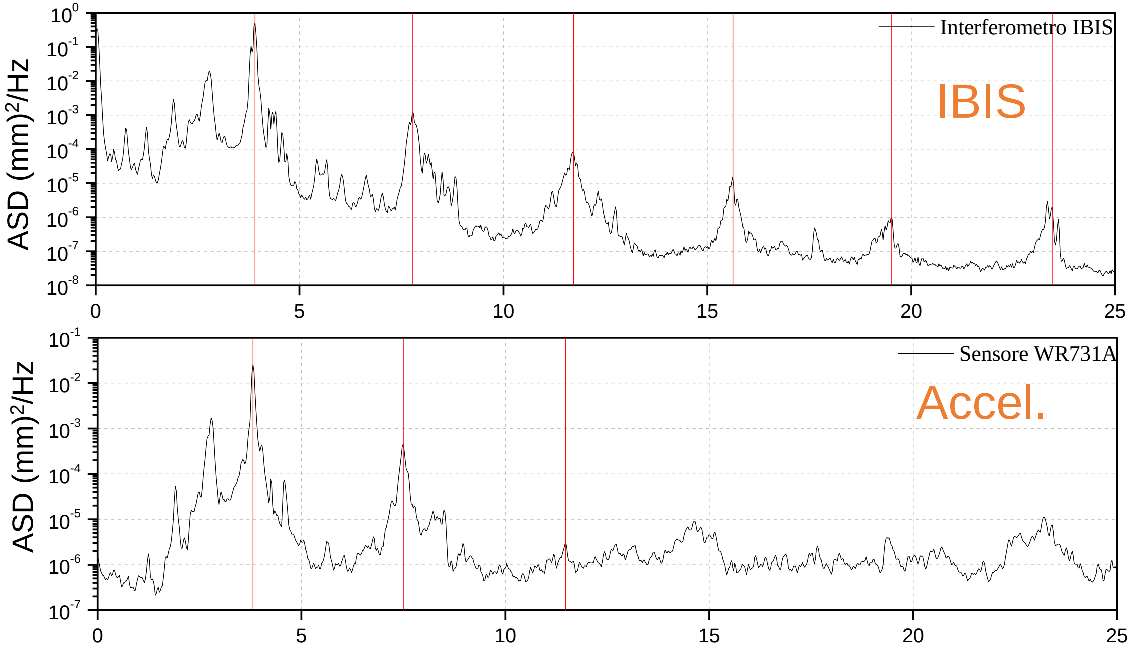


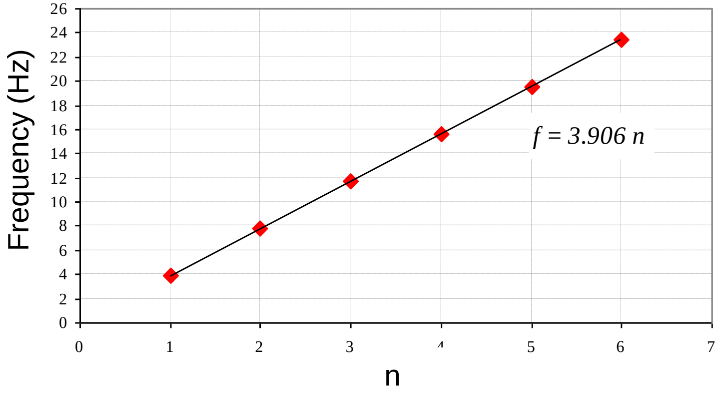
Piezo-electric accel. WR 731A

IBIS-S & Cable-stayed bridges: case studies

Example: Olginate bridge (Italy)

Frequency Domain Analysis





Resonant frequencies

	f_1 (Hz)	f_2 (Hz)	f_3 (Hz)	f_4 (Hz)	f_5 (Hz)	f_6 (Hz)
IBIS-S	3.906	7.764	11.720	15.630	19.510	23.460
Accel.	3.809	7.495	11.470			

Tension

Cable S09'			
IBIS-S		Accelerometer	
f_{exp} (Hz)	Tension (kN)	f_{exp} (Hz)	Tension (kN)
3.906	1883.1	3.809	1790.7
7.764	1860.0	7.495	1733.3
11.720	1883.7	11.470	1804.2
15.630	1884.5		
19.510	1879.2		
23.460	1886.9		
	1880		**1776**

Summary of IBIS-S Applications

- **Rapid Bridge Load Tests with displacement accuracy to 0.01 mm (0.0004 inch) – corner reflectors needed on concrete bridges**

- **Modal vibration measurements from 0 to 100 Hz**

- **Vibration monitoring to predict Stay-Cable forces from natural frequencies on many cables at a time**

- **Remember – Line of Sight, Speed of Light Technology requires that reflectors be visible and clearly identified as to distance in data**

- **Ideal for medium to large span bridges to 500 m up to 40 Hz and static displacement to 1000m**