35th SW Geotechnical Engineers Conference April 26-29, 2010

Baton Rouge, LA

Condition Assessment of Unknown Foundations

Presented by Larry D. Olson, P.E.
Olson Engineering, Inc.
Olson Instruments, Inc.
Wheat Ridge , Colorado – Rutherford, New Jersey – Socorro, New Mexico

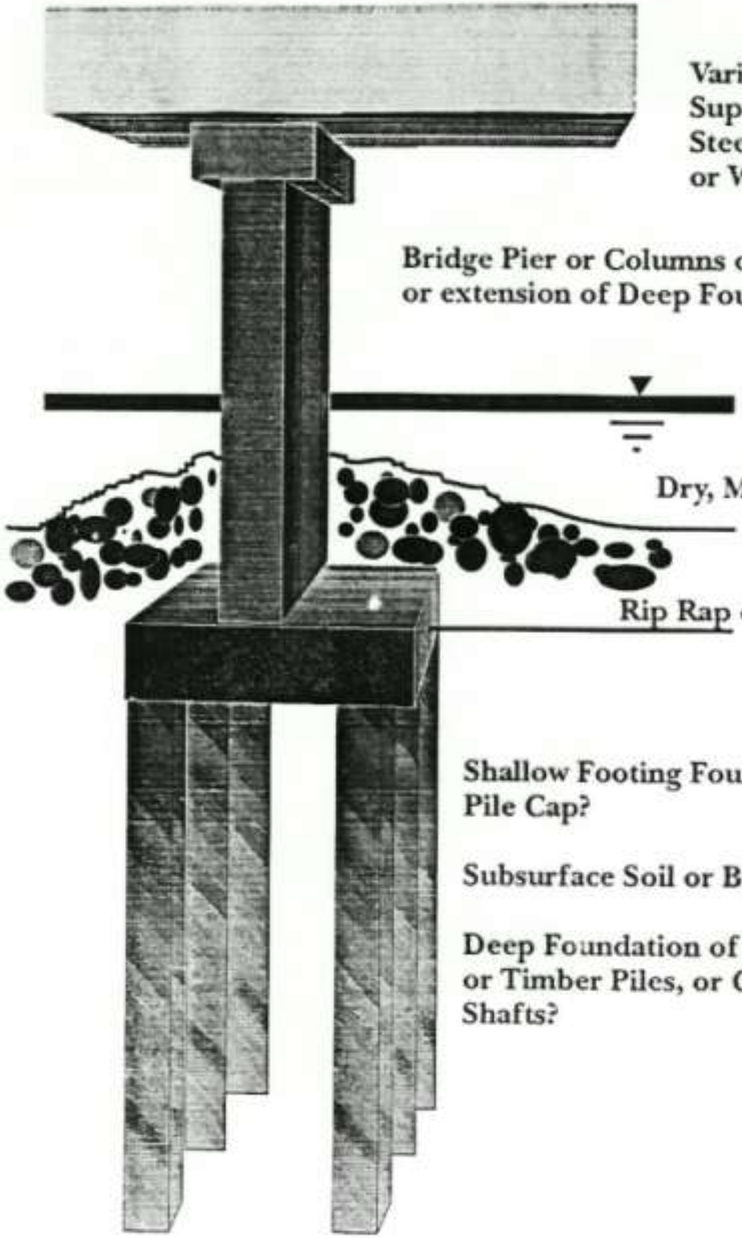
National Cooperative Highway Research Progam
NCHRP 21-5 and 21-5(2) Research Results
Unknown Subsurface Bridge Foundation Testing for Depth Determination

Larry D. Olson, PE

Principal Investigator

Unknown US Bridge Foundations

- 88,826 Bridges with unknown foundations - 2002
- 26,000 identified as scour critical risk
- Piles, Footings, Pilecaps of Concrete, Steel, Wood, Masonry
- Questions - depth, foundation type, geometry & integrity



Variable Bridge
Superstructure of
Steel, Concrete
or Wood?

Bridge Pier or Columns or Abutment
or extension of Deep Foundations?

Dry, Marsh or Water?

Rip Rap or Soil or Mud?

Shallow Footing Foundation or
Pile Cap?

Subsurface Soil or Bedorck?

Deep Foundation of Steel, Concrete
or Timber Piles, or Concrete Drilled
Shafts?

Fig. 1 - Variables of an Unknown Bridge Foundation

Unknown Foundation Surface NDE Methods

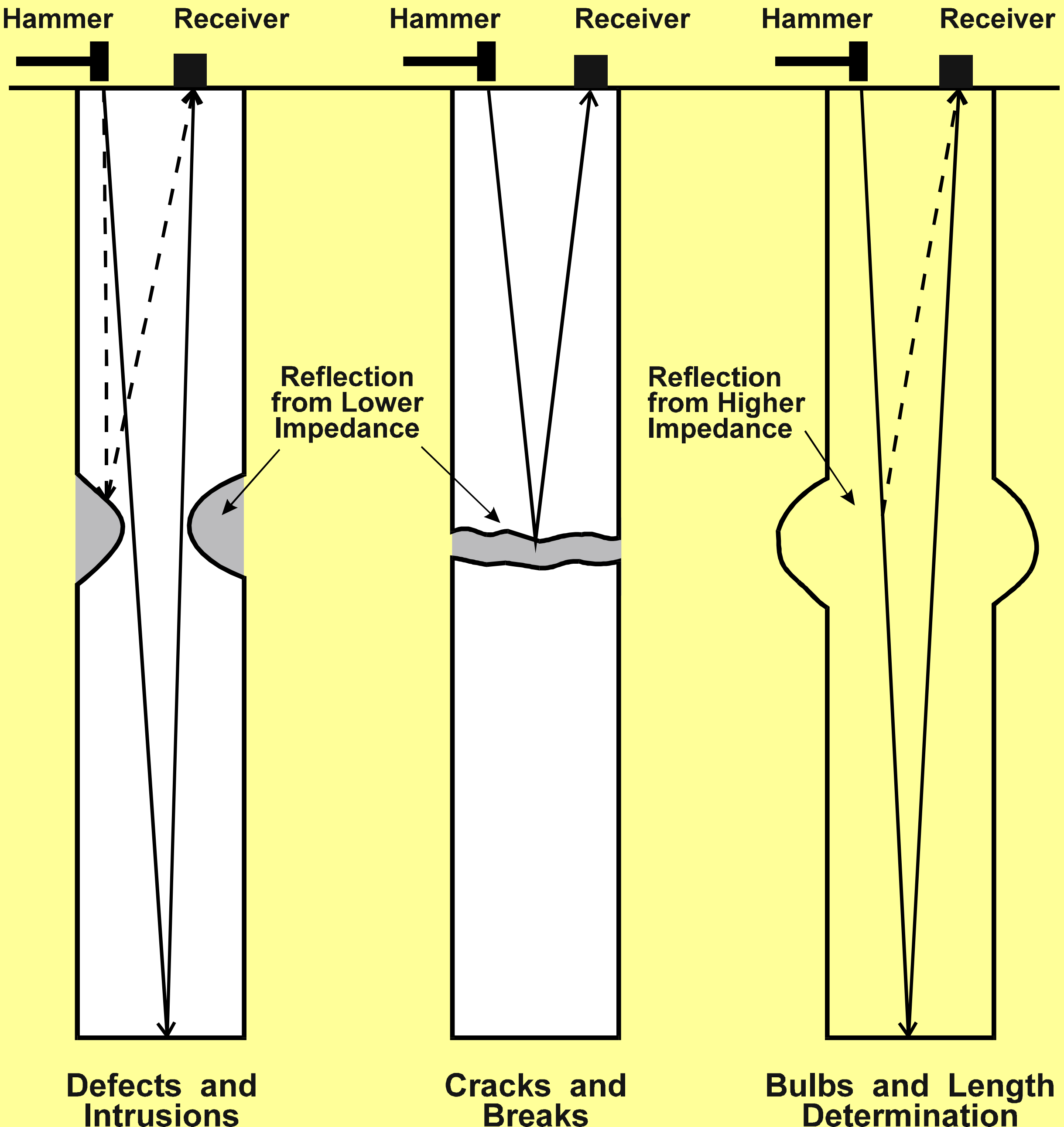
PSonic Echo/Impulse Response

PBending Wave

PUltraseismic

PSpectral Analysis of Surface Waves

Surface Echo Tests
Sonic Echo/Impulse Response

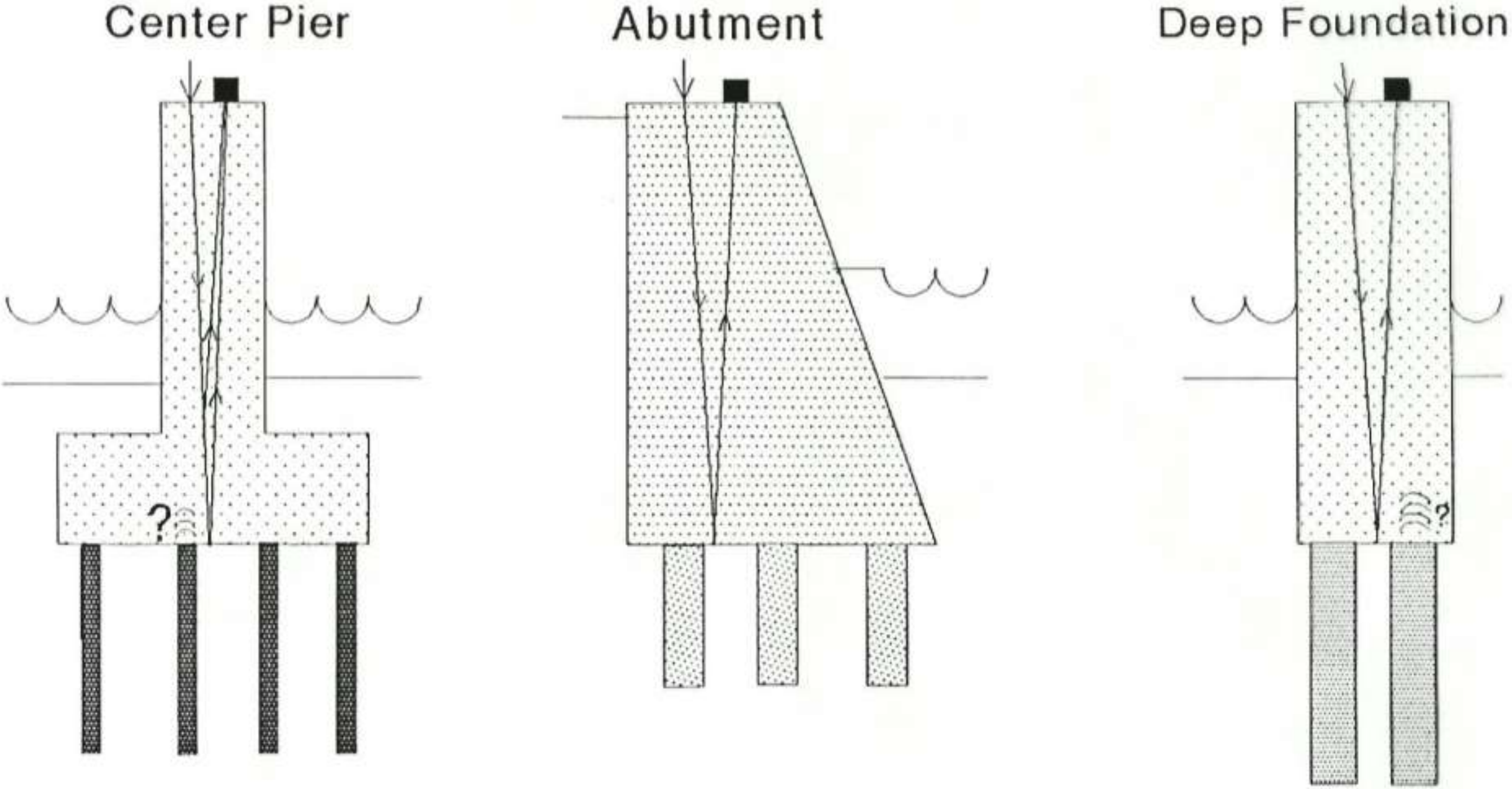


Olson Instruments Freedom Data PC – Sonic Echo/Impulse Response Systems

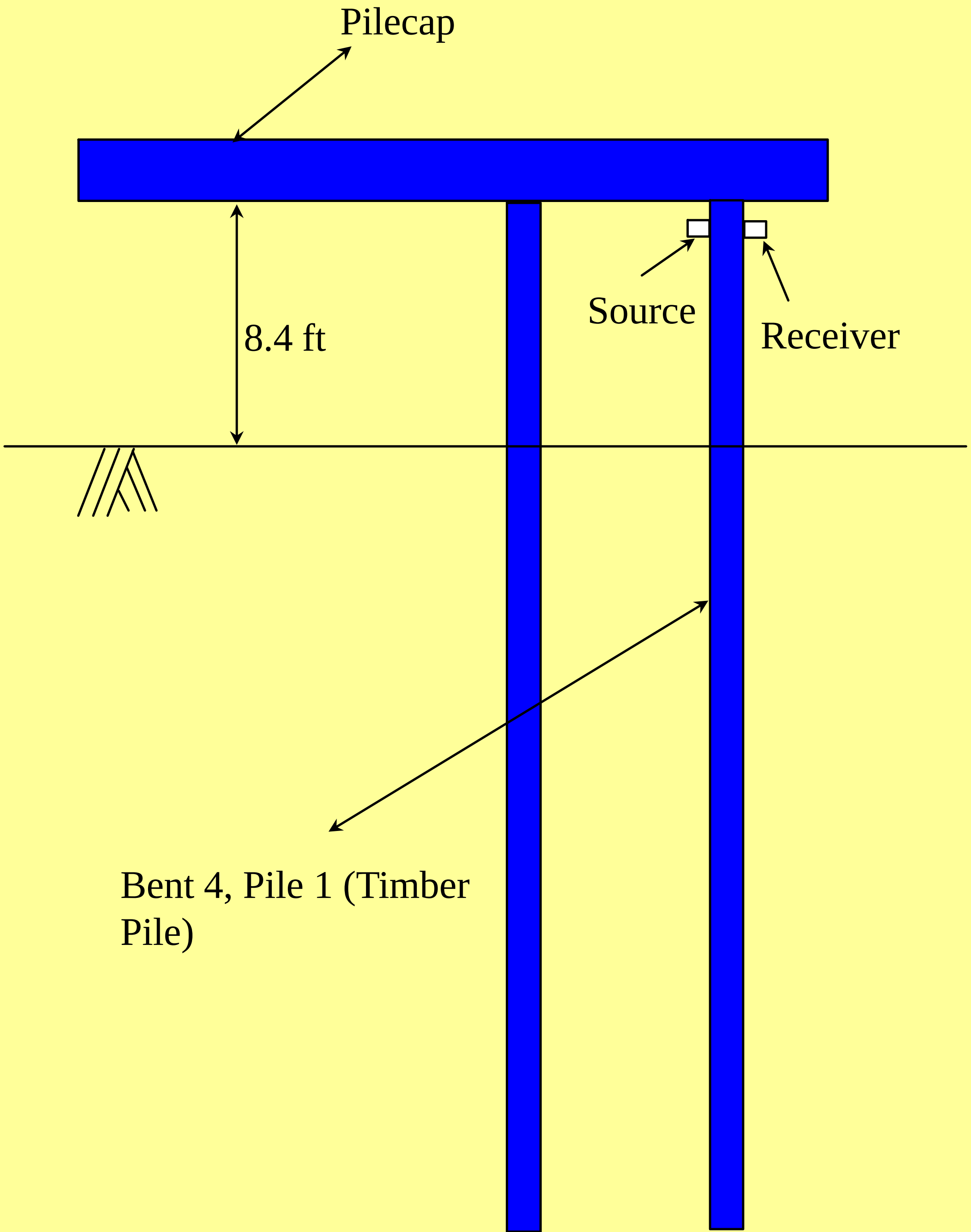
- Meets ASTM D5882
- Models available
  - SE – 1: for displaying echoes in time domain only. Includes accelerometer and dead blow hammer
  - SE/IR-1:combine the SE system with the IR system. Includes instrumented hammer, geophone and accelerometer

SE/IR – 1 System

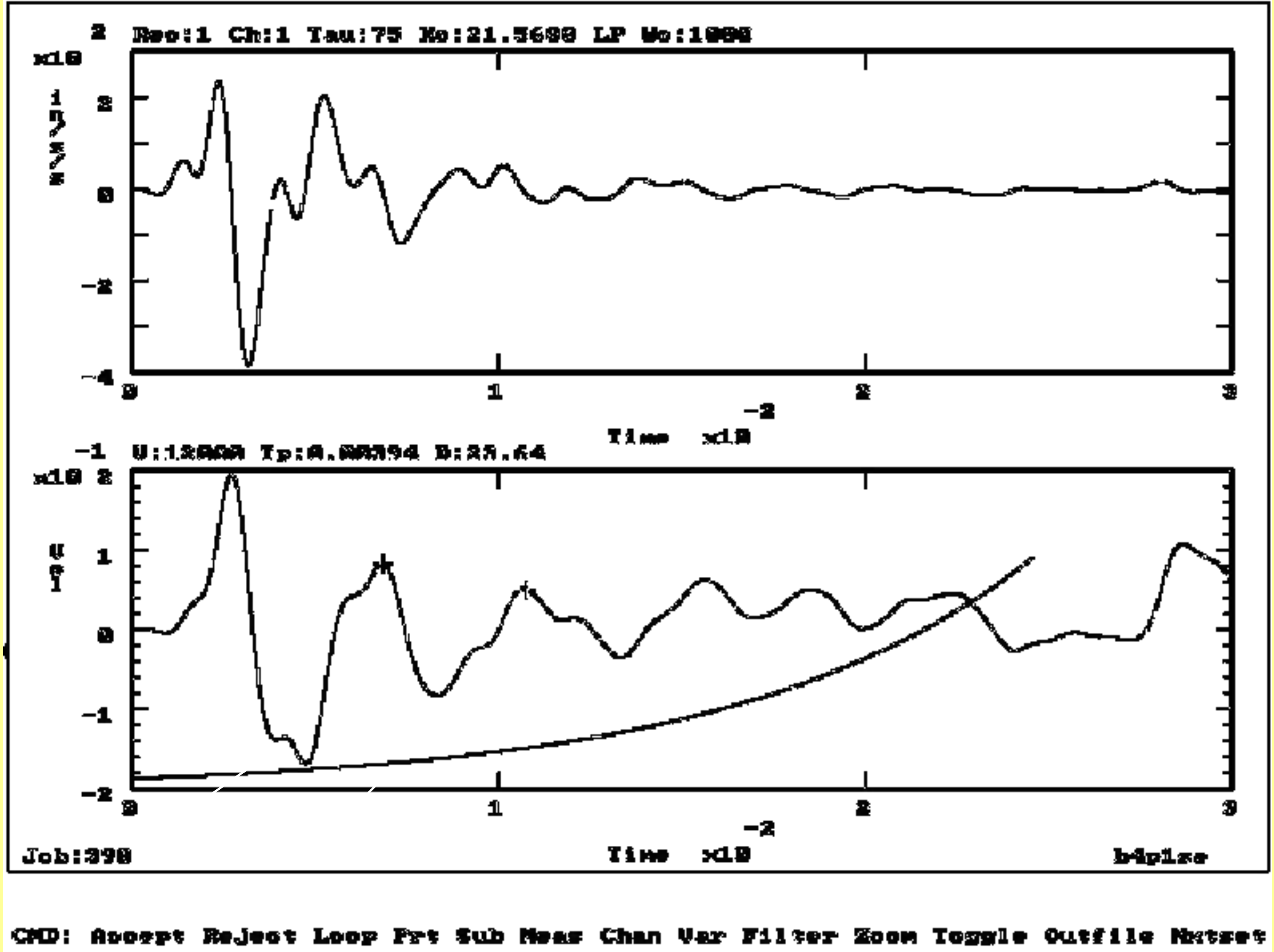
Sonic Echo/Impulse Response Testing on Timber Pile with 3-lb Impulse Hammer



Sonic Echo (SE)/ Impulse Response (IR)


Pilecap
8.4 ft
Source
Receiver
Bent 4, Pile 1 (Timber Pile)

Bent 4, Wake County Bricge #207, North Carolina

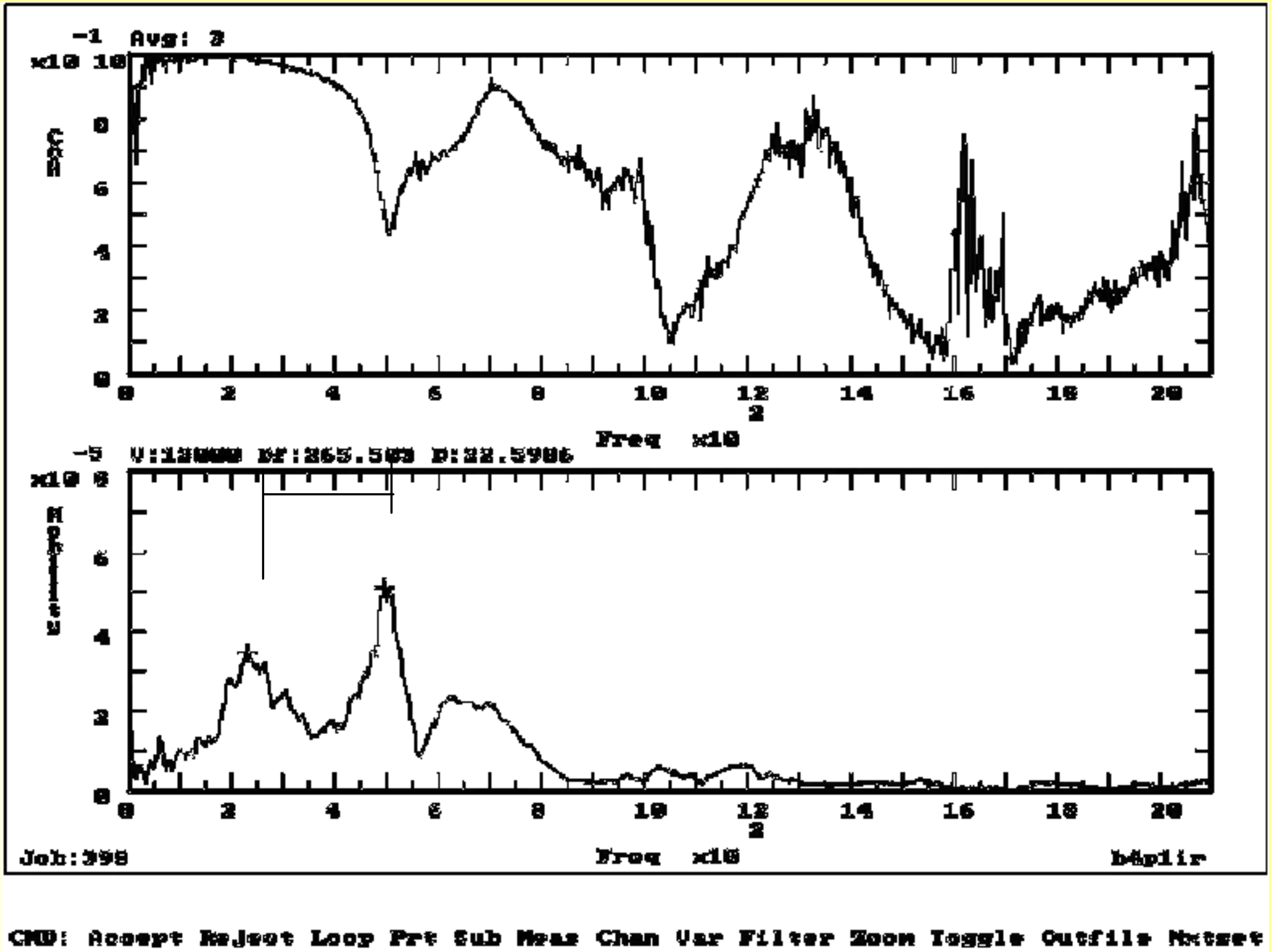


Receiver and source are placed at 1 ft below the top of the pile

Echo identified at t = 3.95 ms

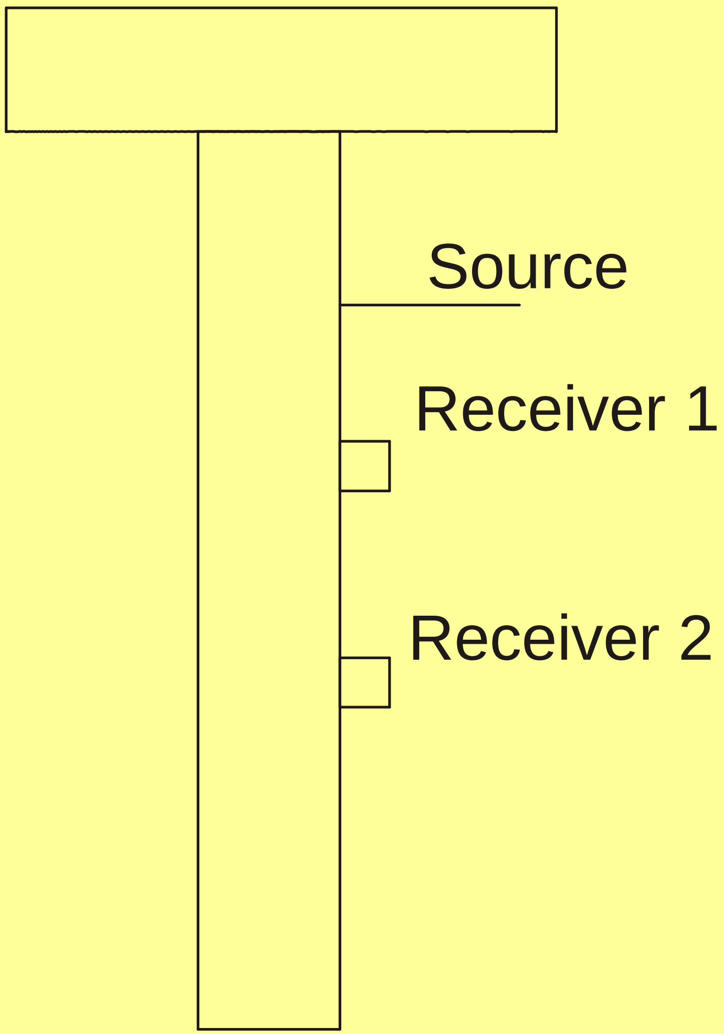
Assumed wave velocity of 12,000 ft/sec

Bottom depth = (V* t/2) = 23.7 ft (reference is top of pile)



Receiver and source were placed at 1 ft below the top of the pile.
A possible echo was identified at f = 265.5 Hz. Then for
an assumed wave velocity of 12,000 ft/sec, a predicted pile bottom is at
depth = (V/ f*2) = 22.6 ft (reference is top of pile)

Bending Waves Method

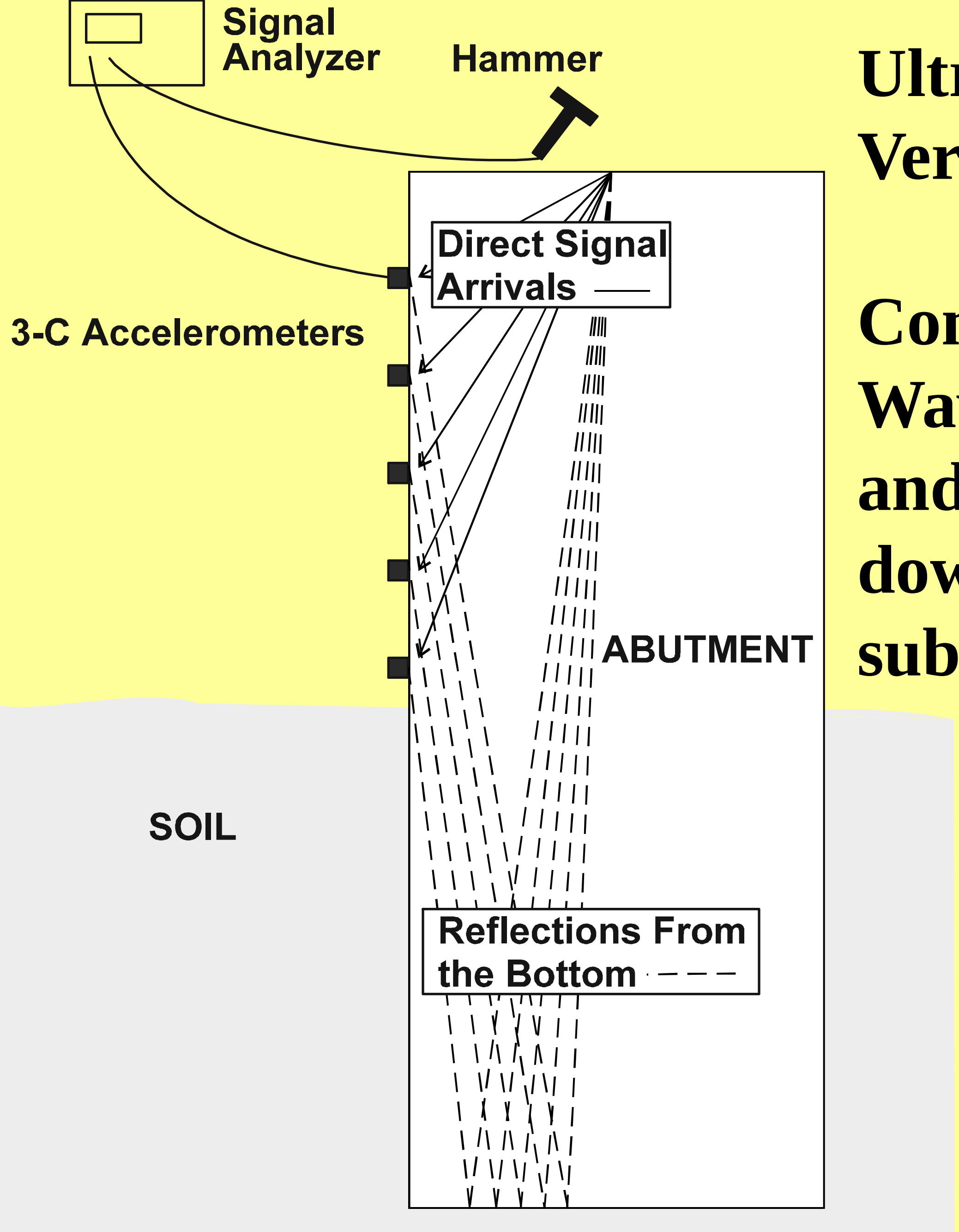


Timber Pile

Bending Waves Test Method

Ultraseismic Method for Vertical Profiling –

Combined Sonic Echo/Bending Waves to track compressional and/or flexural bending waves down and back the first substructure/pile element

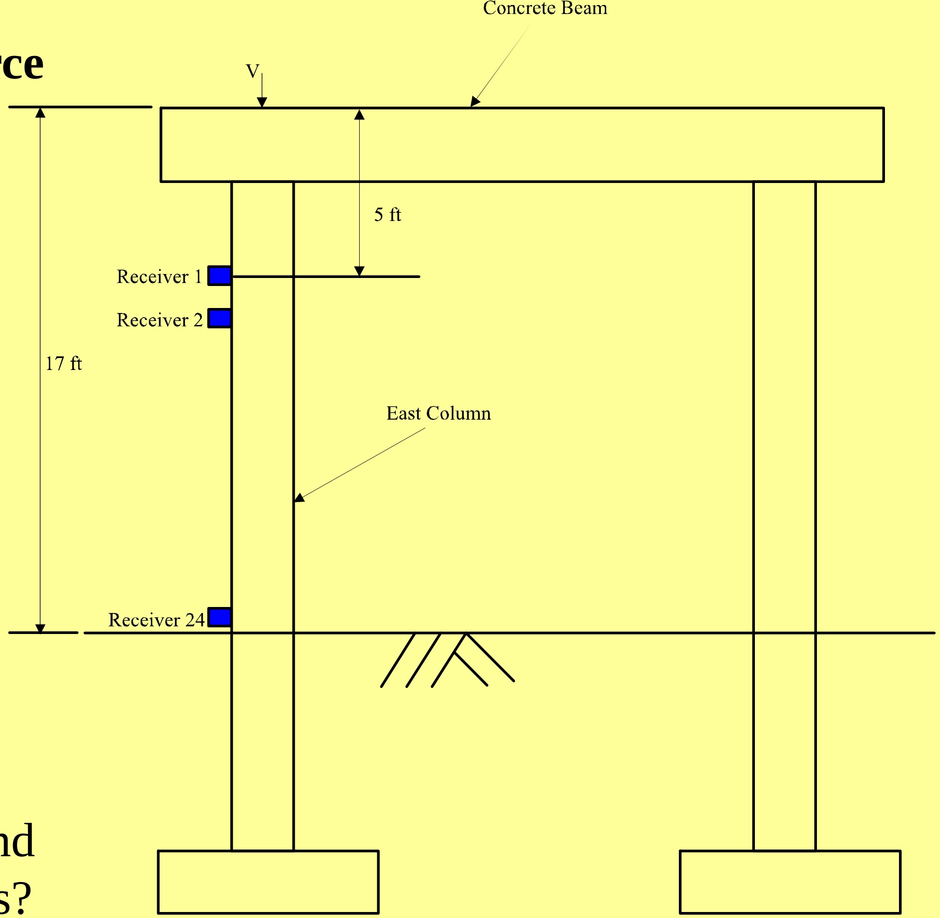


Ultraseismic Testing Method

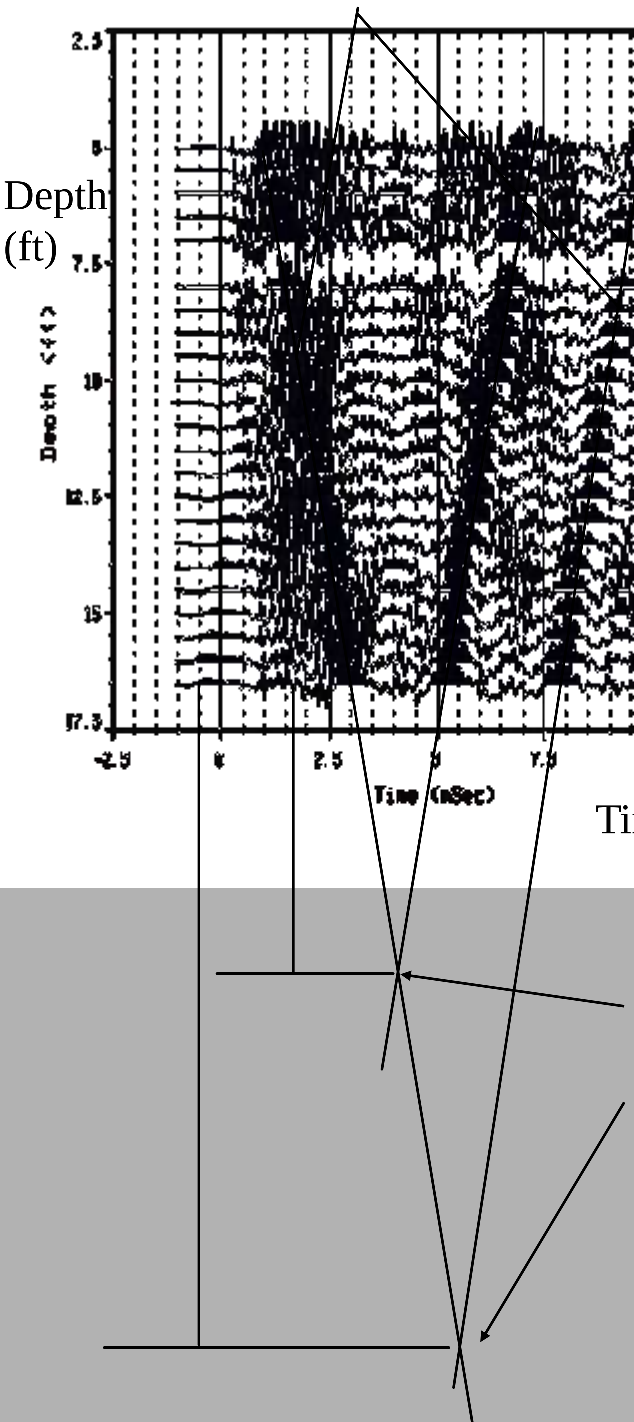
Triaxial Accelerometer for Ultraseismic Tests

Bridge No. 5188, Minnesota Highway 58, Zumbrota, Minnesota

Ultraseismic Source Receiver Layout



Footing Top and
Bottom Depths?



5' below top of pier

15'

Ultraseismic Test Results - Vertical hit on pier top generating flexural waves traveling down and up pier in radial accelerometers of Ultraseismic test

1st echo at 23' – top of footing and
2nd echo at 30.5 ft – bottom of footing

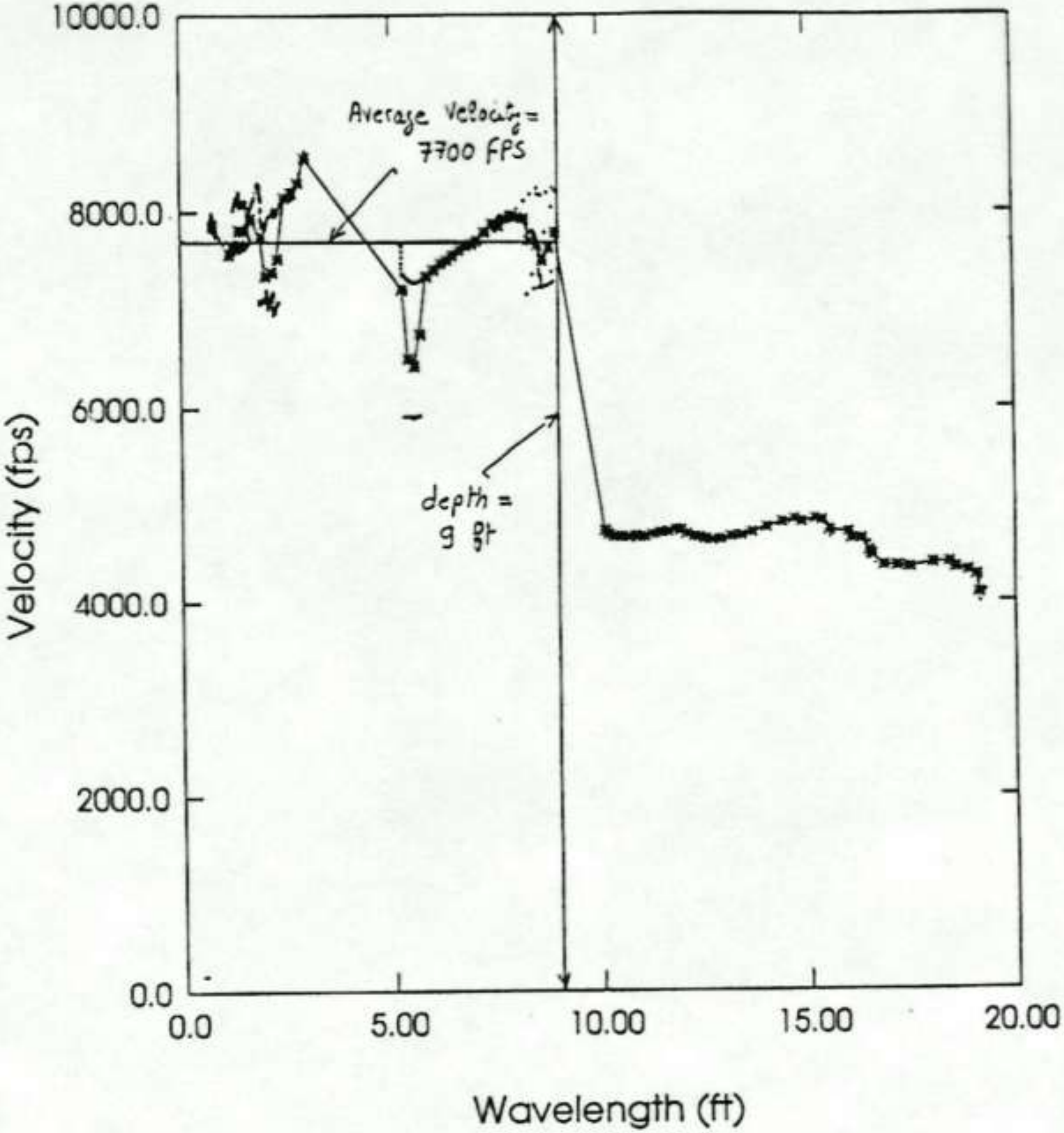
Spectral Analysis of Surface Waves (SASW) for Concrete Wall Piers & Abutments

Find depth by velocity/stiffness change

Applicable to depths up to 2/3 of substructure width

Provides seismic velocity profile for modeling and seismic liquefaction/design

SPECTRAL ANALYSIS OF SURFACE WAVES

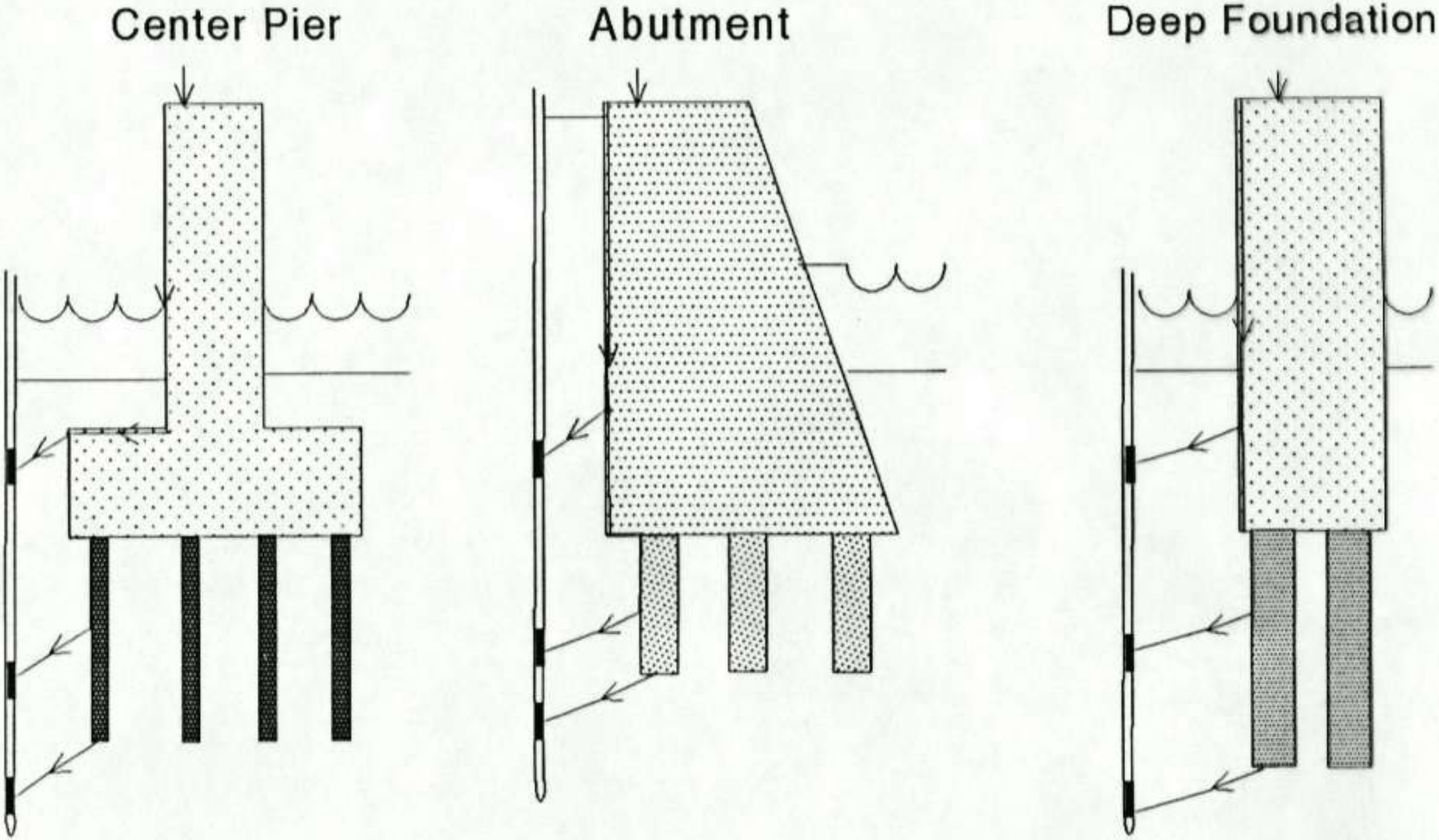

Velocity (fps)
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
0.0
5.00
10.00
15.00
20.00
Wavelength (ft)
Average Velocity = 7700 FPS
depth = 9 ft

Unknown Foundation Borehole NDE Methods

- Parallel Seismic
- Induction Field
- Borehole Radar
- Parallel Seismic with Cone Penetrometer

Parallel Seismic Method

- Determination of Foundation Depths, Typically with Superstructure on Top of Foundation
- Requires Drilling a Hole Next to the Foundation
- Hole Should be at Least 15 ft Deeper than Expected Foundation Bottom

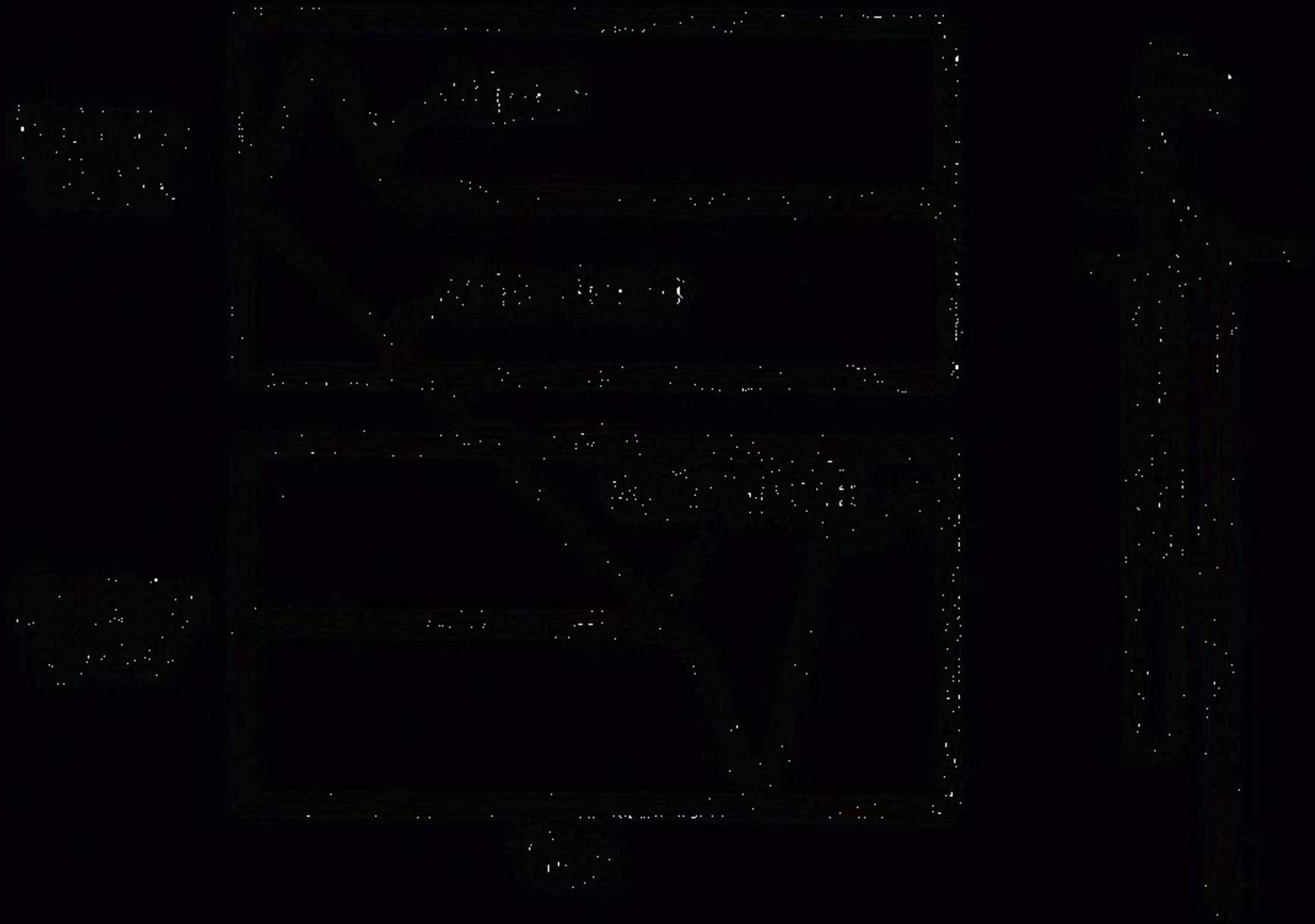


Center Pier

Abutment

Deep Foundation

Parallel Seismic (PS)



Parallel Seismic Equipment

- PC Based Signal Analyzer
- Single Hydrophone or 8-Channel Hydrophone for Rapid Testing
- Receiver Amplifier and Filter
- Impact Source, Usually 3 to 12 lb Hammers
- Hydrophone is Placed in Drilled Hole
- Hammer Impact is on Superstructure or Exposed Portion of Foundation if available

Olson Instruments NDE 360 with Parallel Seismic and other Foundation, Structural/Pavement and Seismic Geophysical options for ultimate flexibility and portability

- Models available
  - Foundations
    - Parallel Seismic
    - Ultraseismic
    - Sonic Echo/Impulse Response
  - Structures and Pavements
    - Impact Echo
    - Ultrasonic Pulse Velocity
    - Surface Waves
    - Slab Impulse Response
  - Seismic Geophysics
    - Surface Waves
- NDE 360 is easy to use with Touch Screen, Compact Flash, Battery Powered, Handheld Design

NDE 360 with PS-1G Hydrophone & Triaxial Geophone

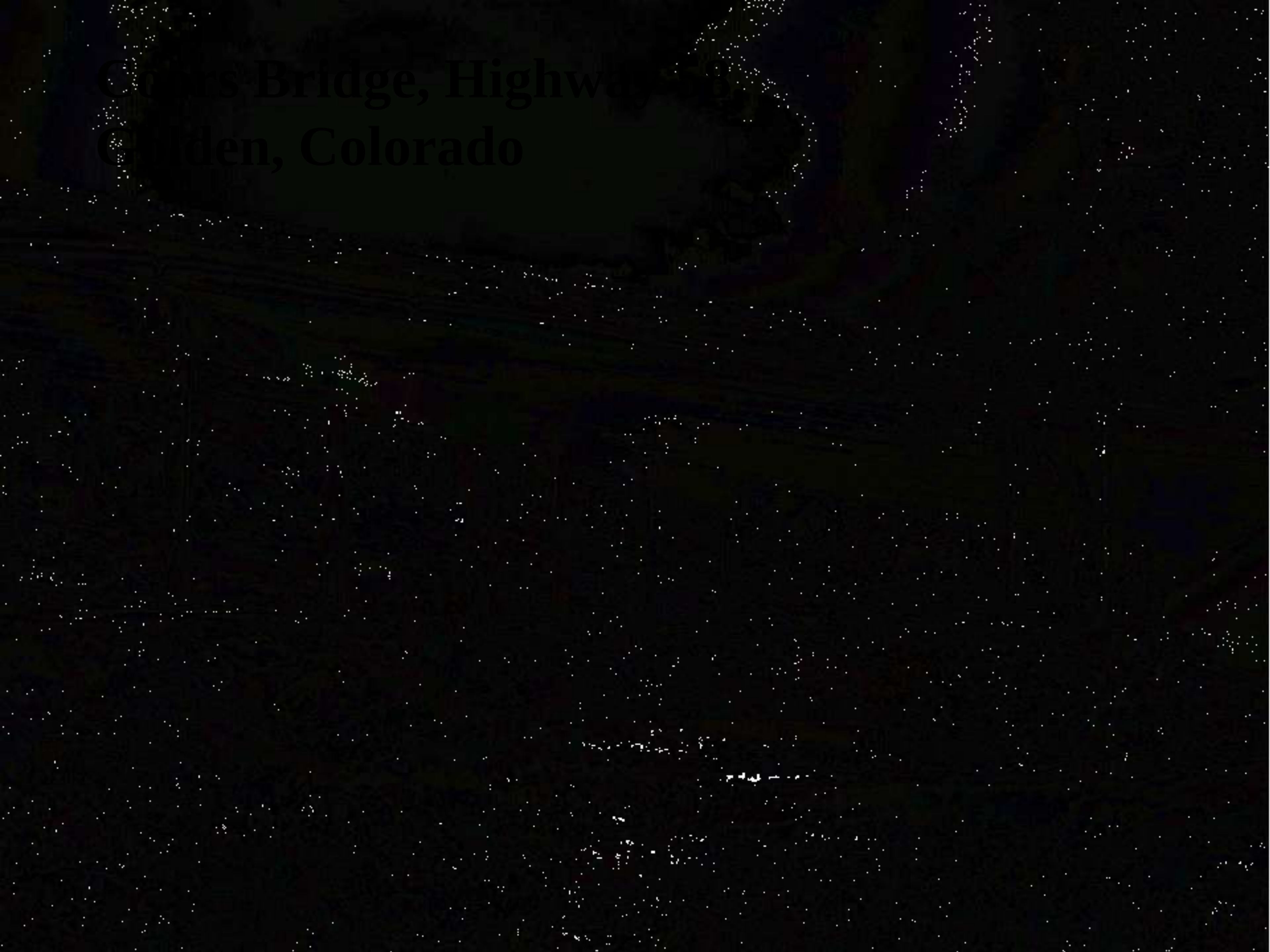
NCHRP 21-5
Determination of Unknown Bridge Foundation Parallel Seismic Method Research Results

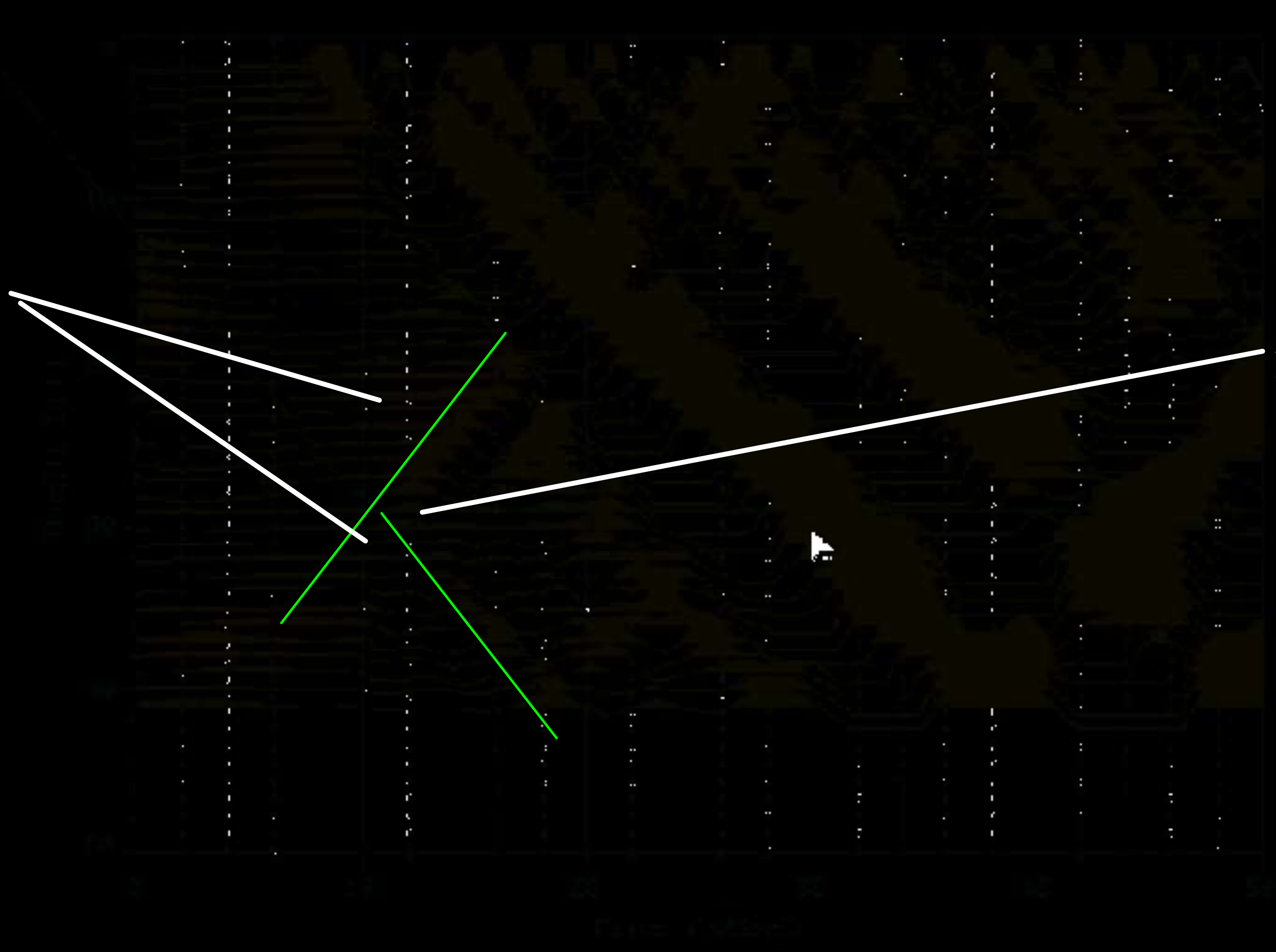
$ Concrete Piles below Surface Exposed Pilecap
and Concrete Pier and Geophone
vs. Hydrophone Receivers

$ Steel H-Piles below Buried Pilecap
with Concrete Columns and Hydrophones

Concrete Pile Pier
Old Bastrop Bridge
Bastrop, Texas

Coors Bridge, Highway 58, Golden, Colorado



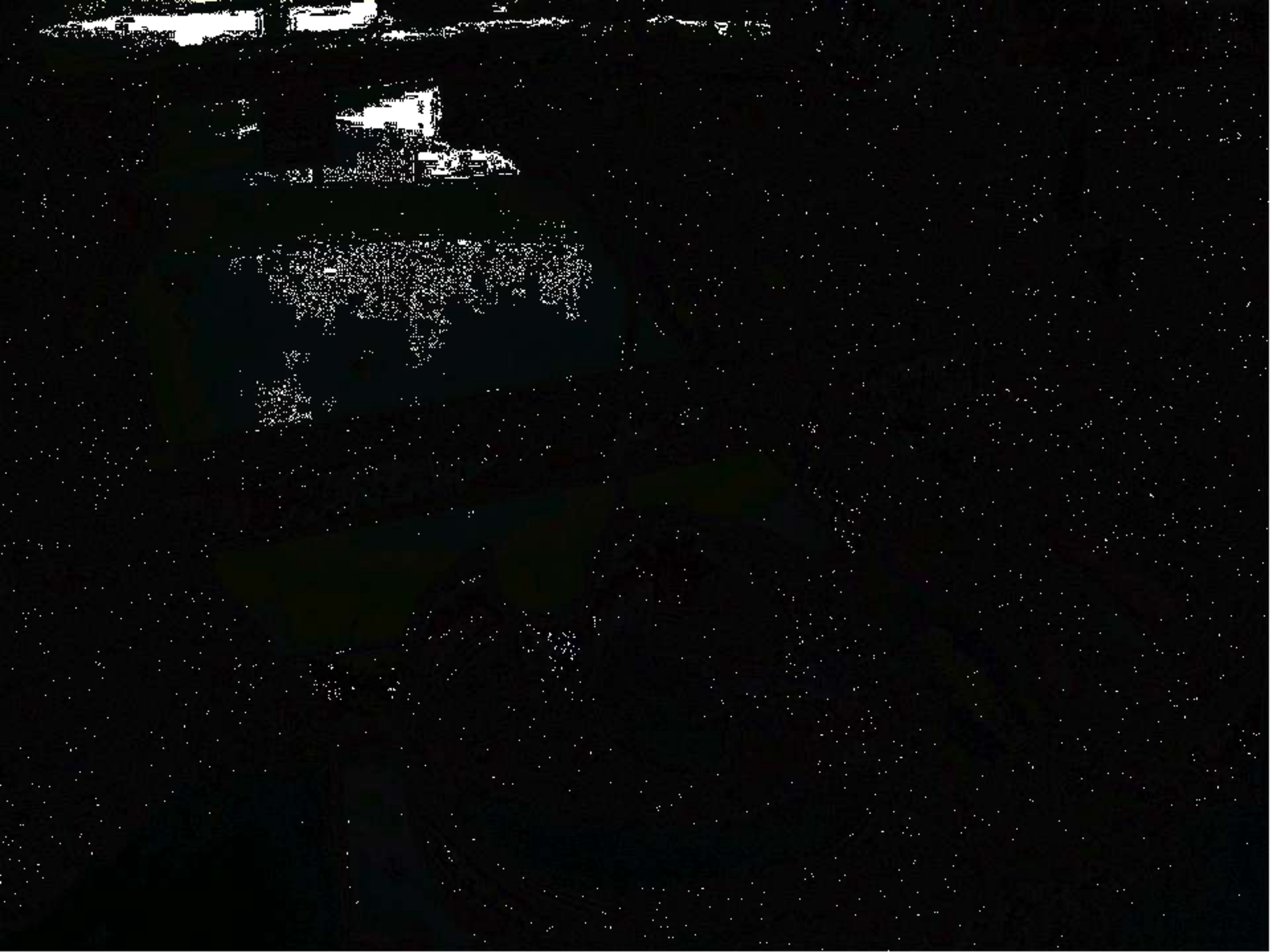


Tube Wave Velocity = 1600 ft/sec

Bottom of Foundation at 29 ft

Parallel Seismic Results from a Steel H-Pile Foundation with Concrete Pilecap on Top

Length Determination of Timber Piles with Parallel Seismic Method Railroad Bridge Southern California



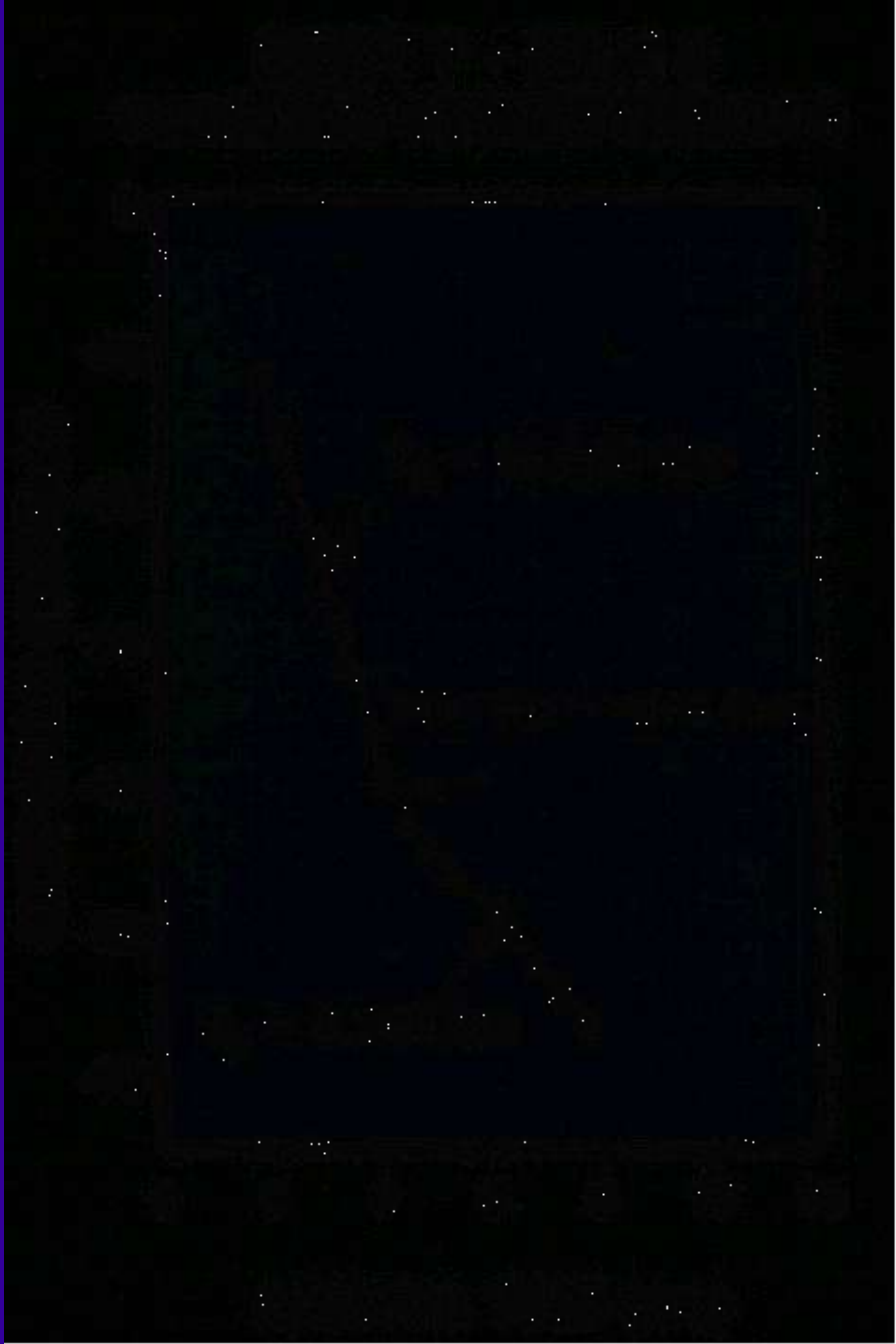
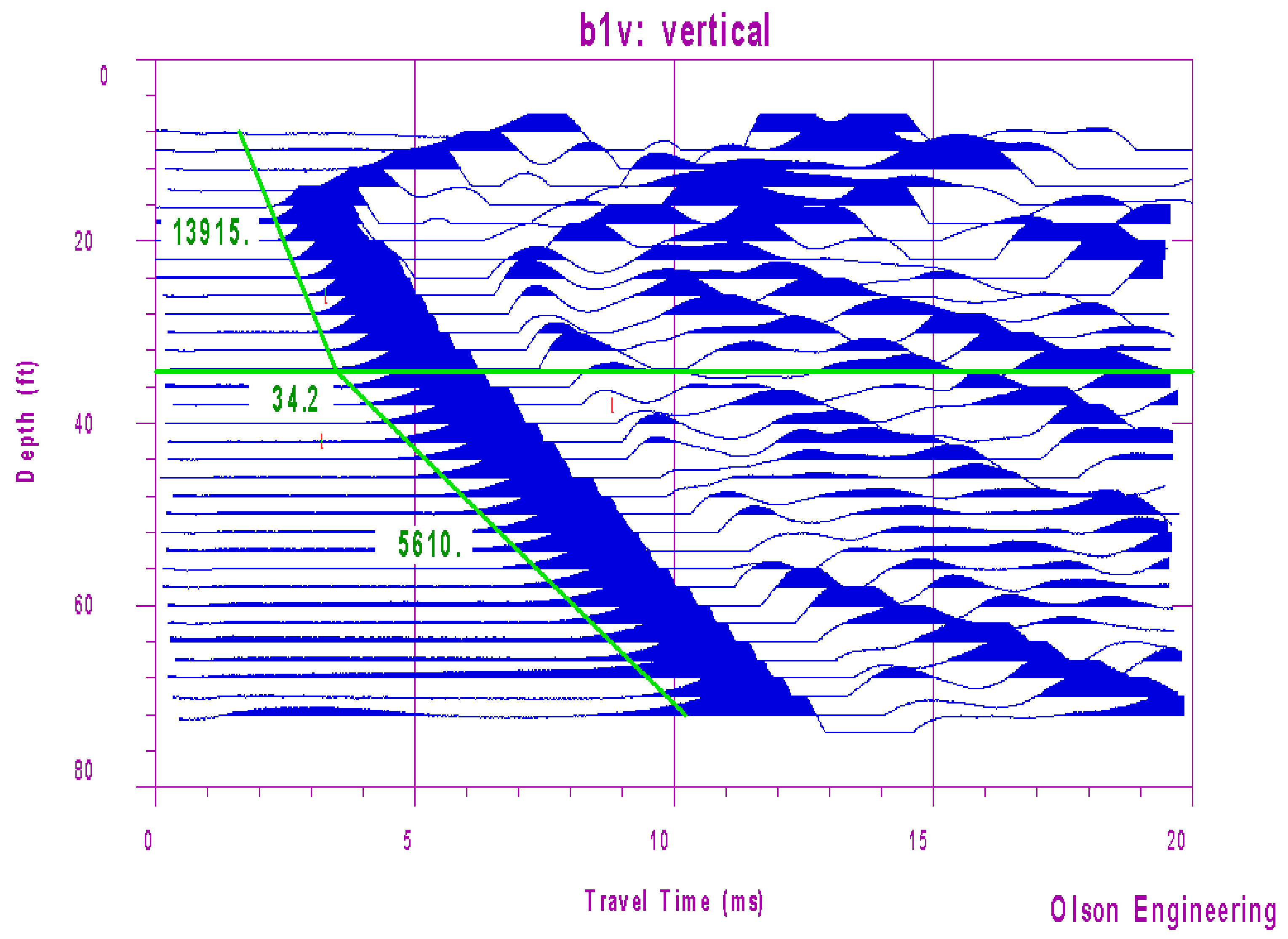
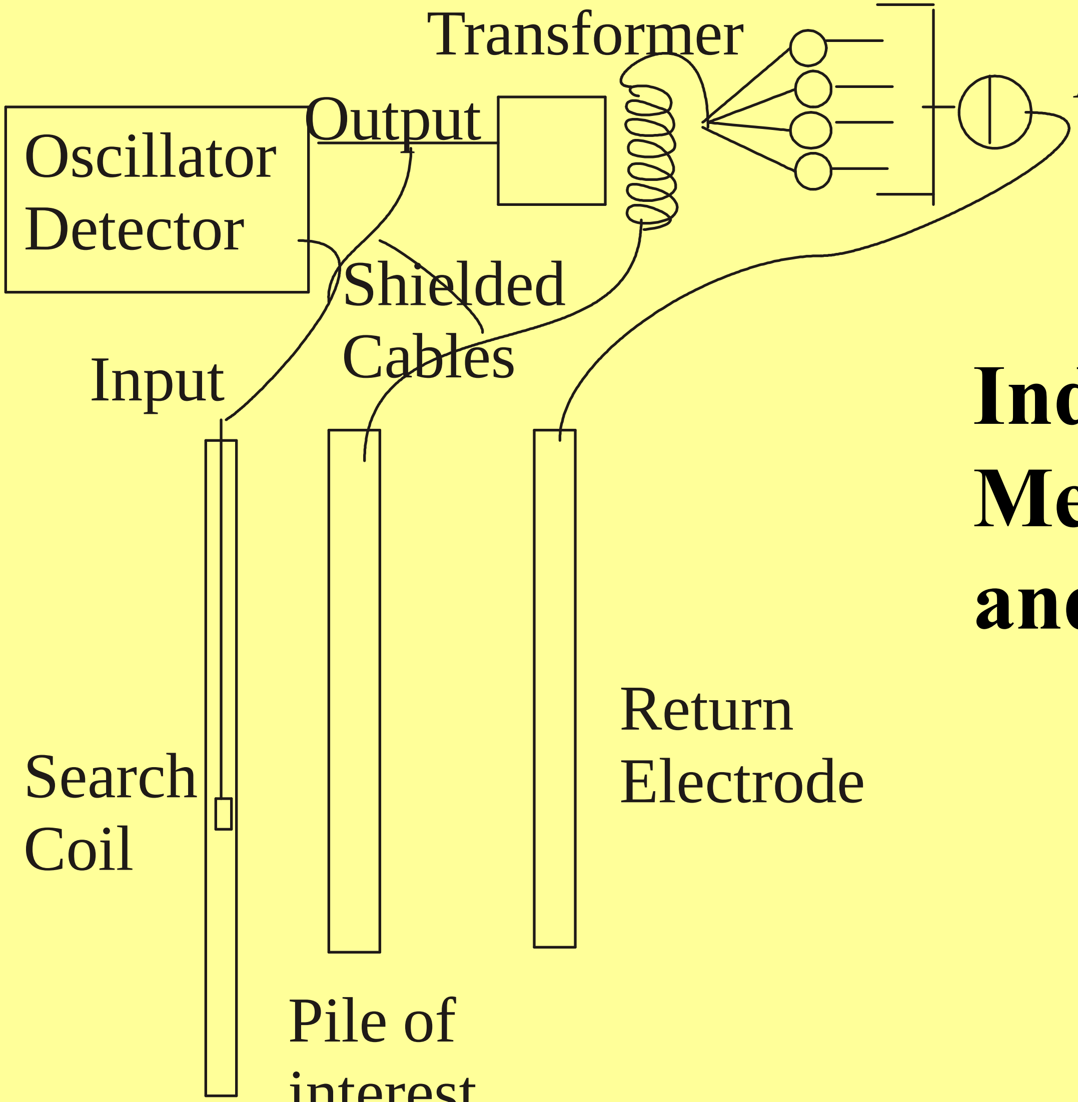


Figure 2 - PS data collected from Beaufort county bridge number 060041, north abutment, vertical impact. Apparent depth = 34.2 ft.



Induction Field Method for Steel H- and Pipe Piles



Choose tapping to maximize current A

Transformer

A

Output

Oscillator Detector

Shielded Cables

Input

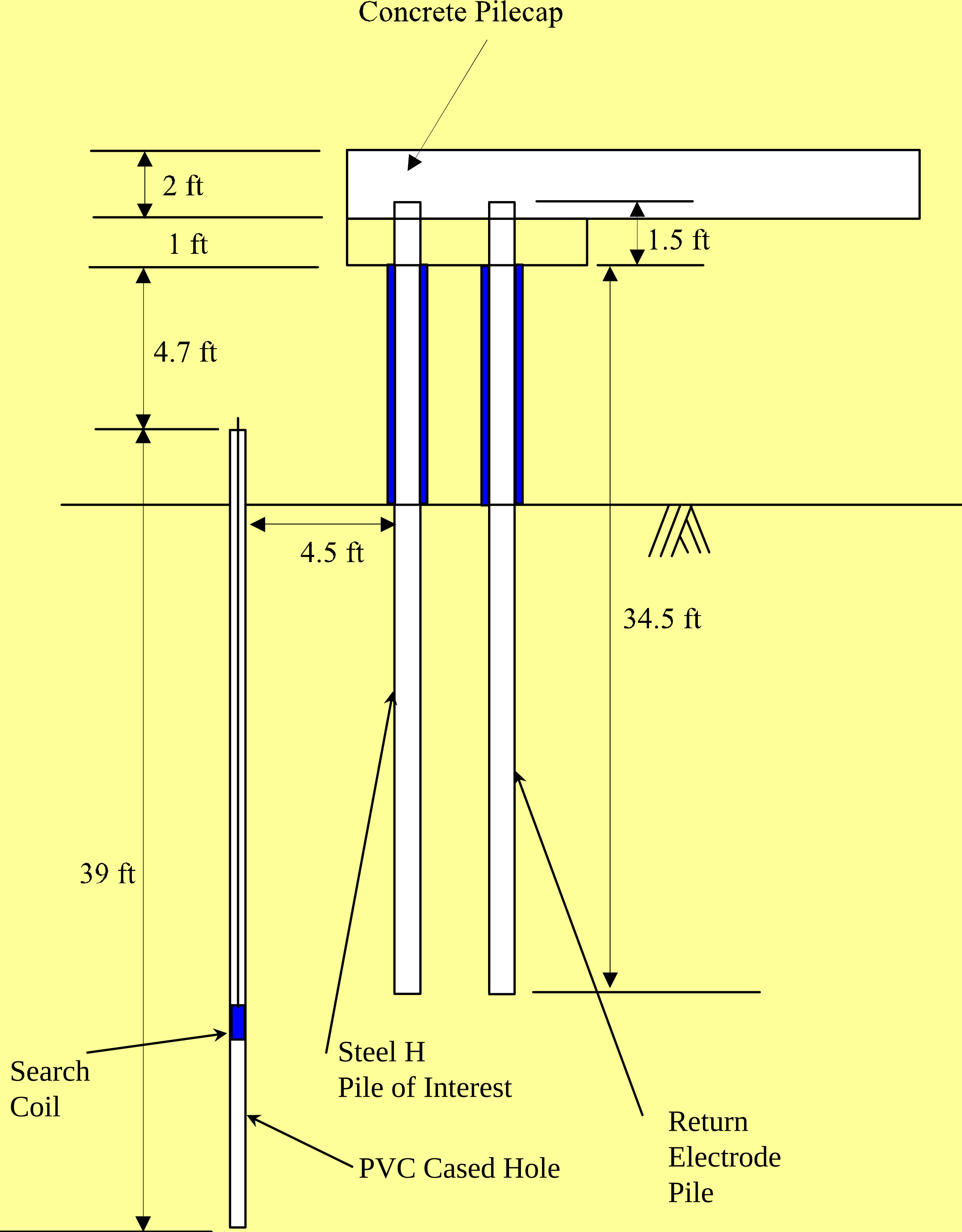
Return Electrode

Search Coil

Pile of interest (steel)

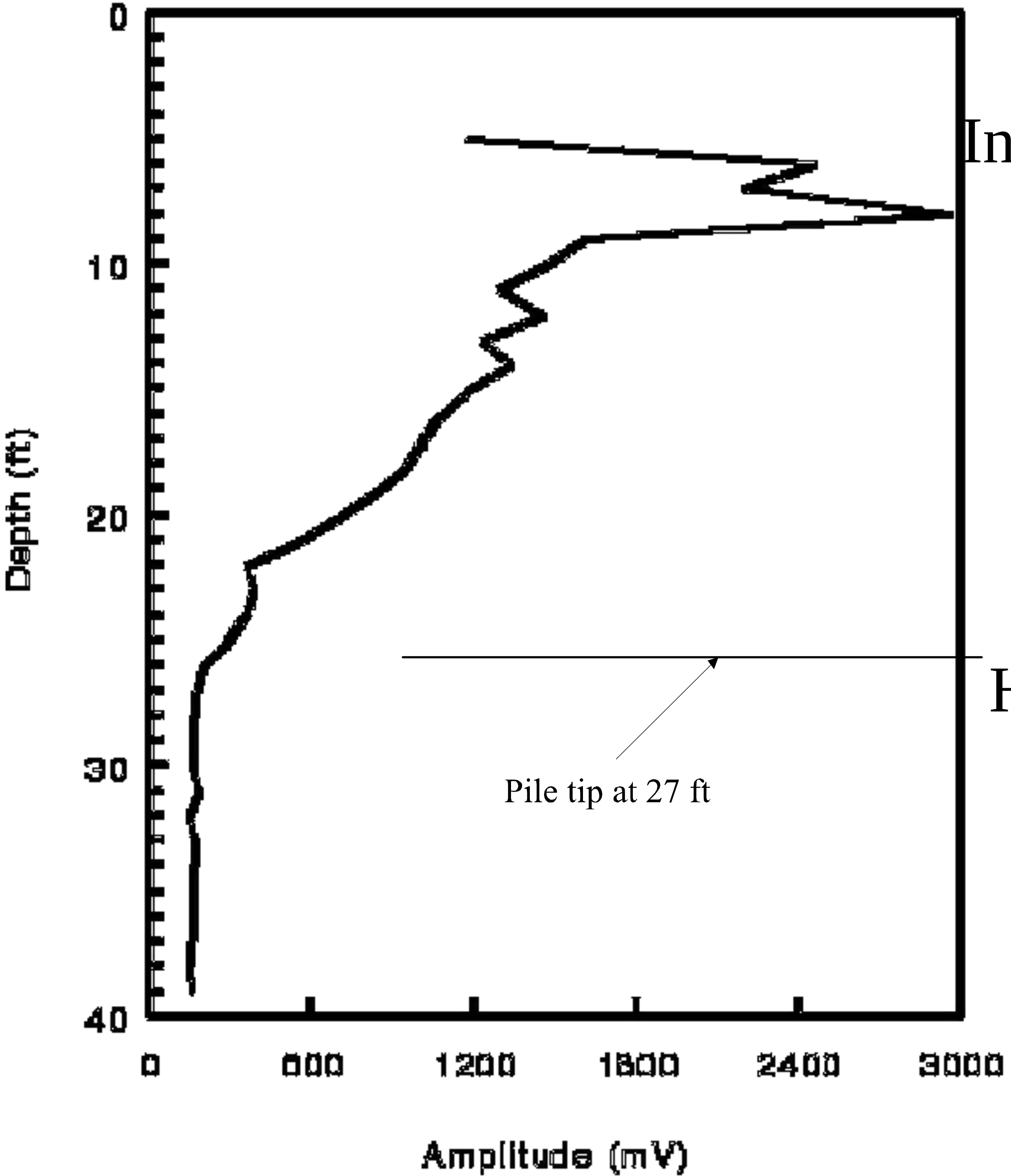
PVC cased hole

Source/Receiver Layout for US 287 over Little Thomson River, Longmont, Colorado



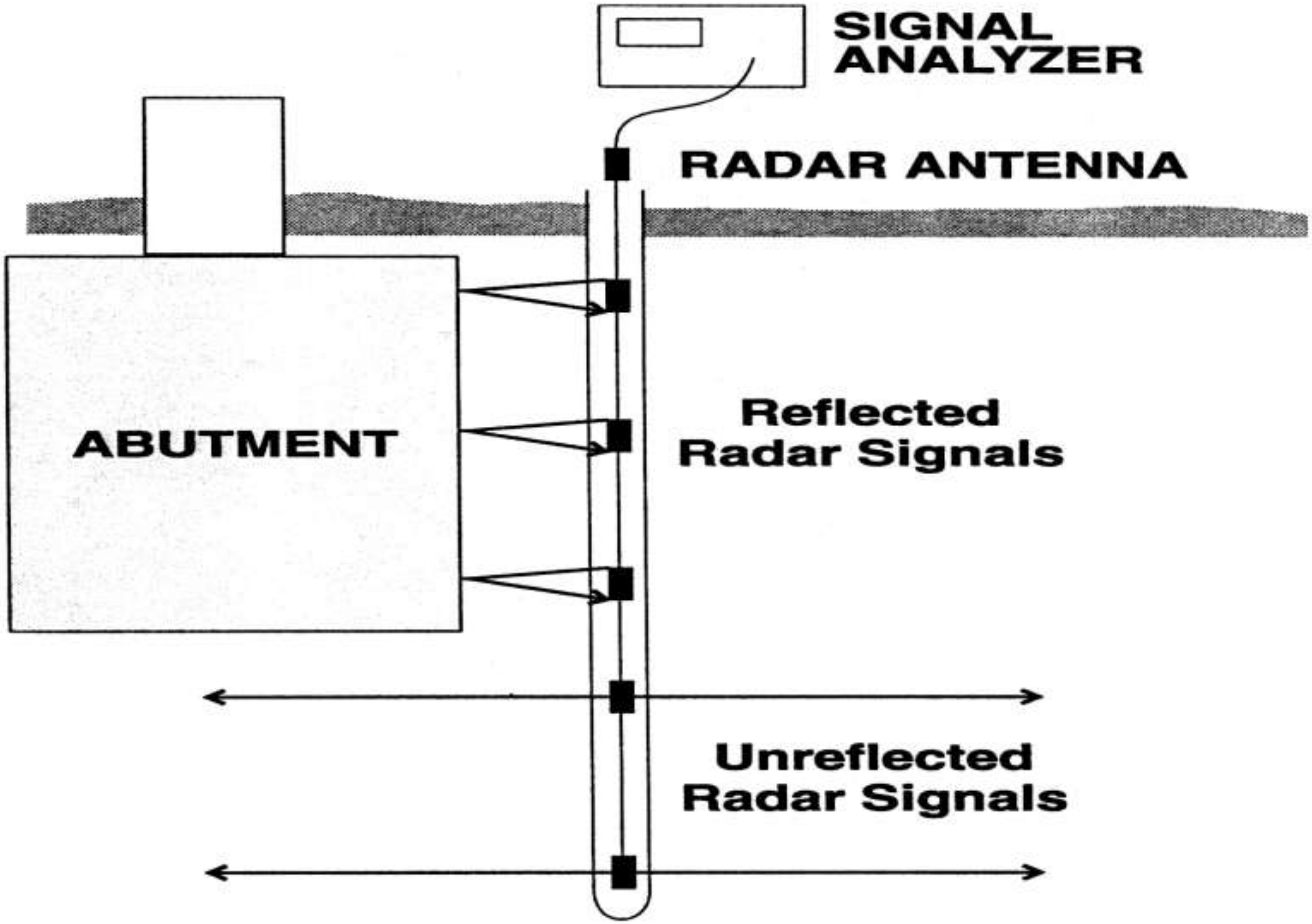
Triaxial Magnetic Field Coil for Induction Field NDE

Induction Field



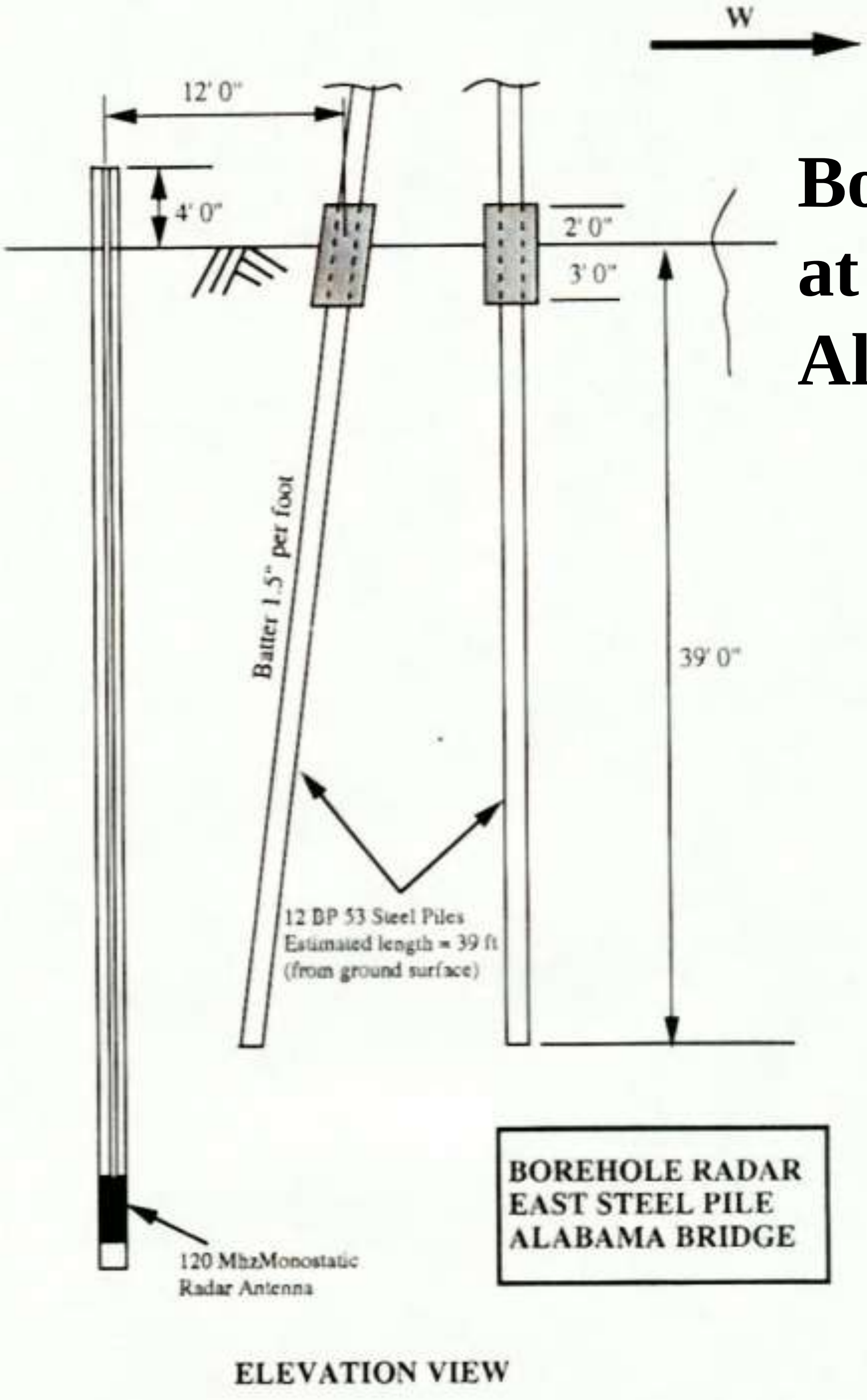
H-Pile at 27 ft

millivolts

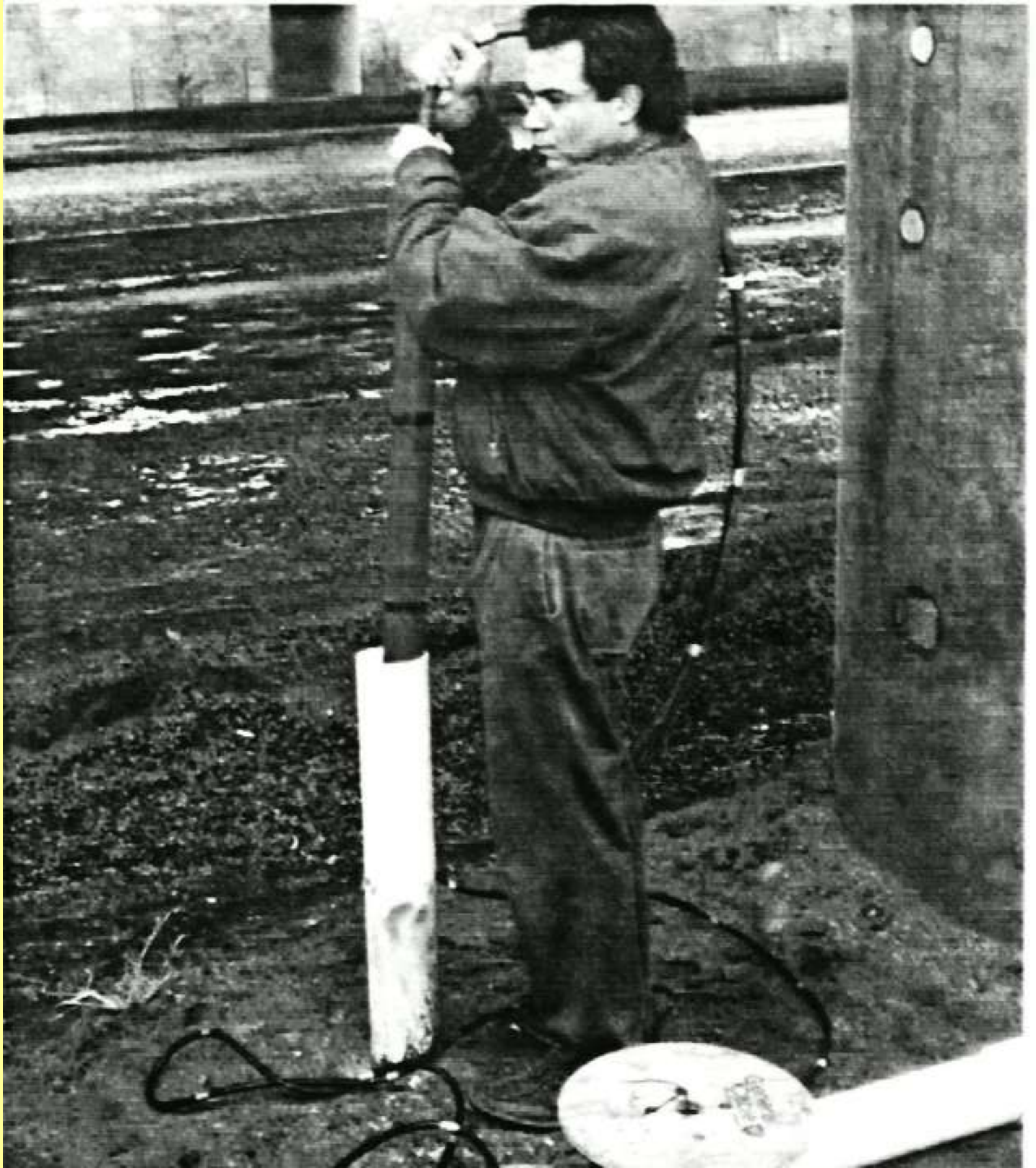


BOREHOLE RADAR METHOD

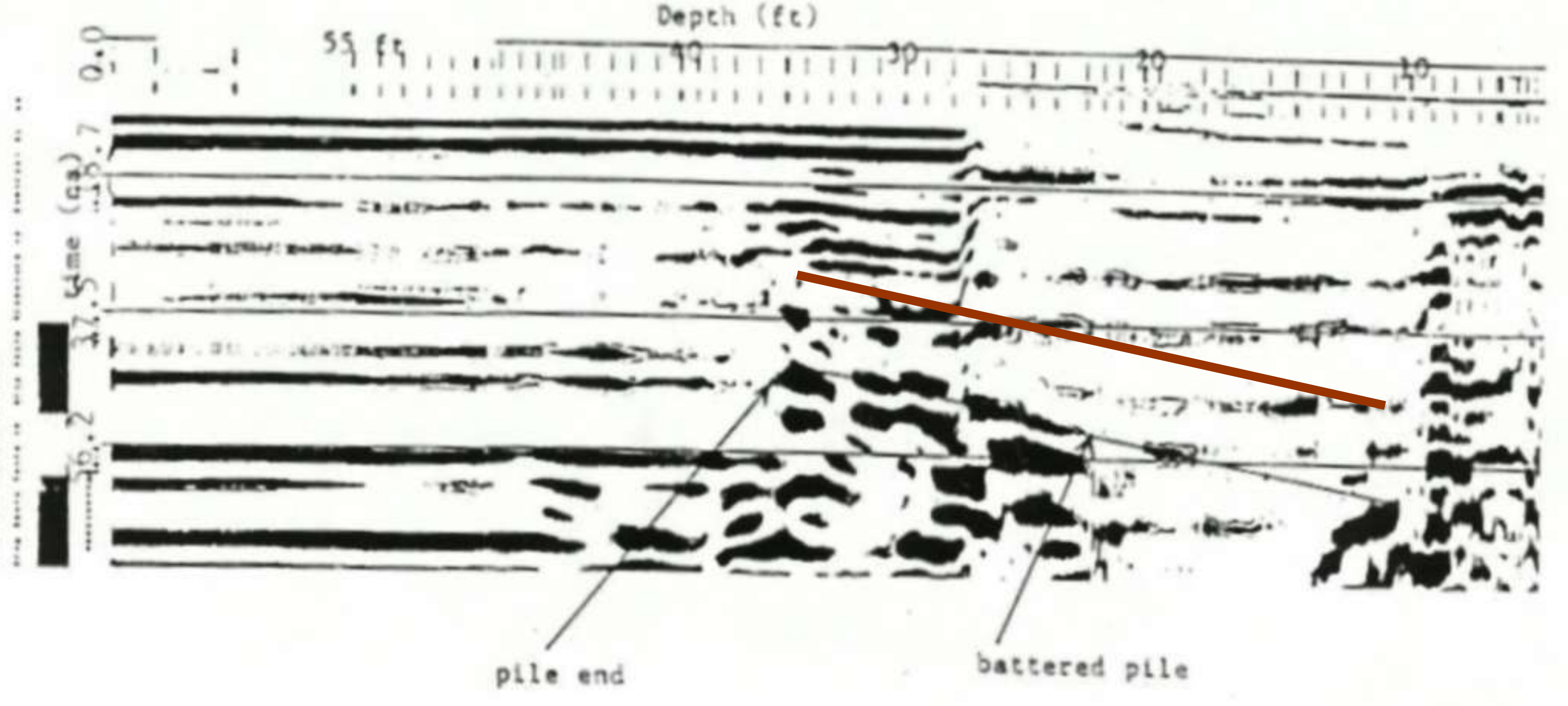
Borehole Radar at Steel Piles of Alabama Bridge



Borehole Radar Tool



Borehole Radar Showing H-Pile tip to 35 ft but no signal in conductive clay layers



35 ft

IDS Georadar RIS Configuration for Borehole Applications

COMPONENTS:

- Data Logger (PC Panasonic CF 19 or other PC)
- Single Channel Control Unit (DAD 1CH)
- Bore Hole Antenna: 150 and 300 MHz
- Survey kit: Tripod and Survey Wheel Kit

Data Logger: PC Panasonic CF 19

Data Logger: PC Hammerhead HF54

Single Channel Control Unit

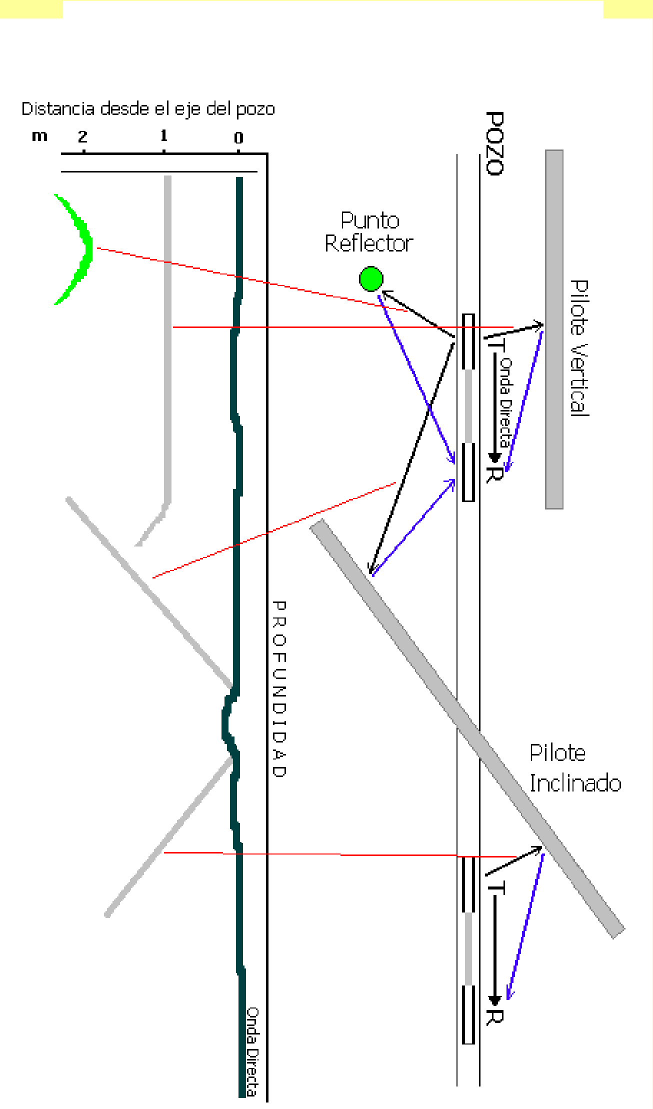
Bore Hole Antenna with Tripod and Survey Wheel

BOREHOLE ANTENNA FEATURES

Bore Hole Antenna with Tripod and Survey Wheel

- Borehole antenna cable (40 m) (BAC 4000)
- Antenna Type: Unshielded Dipole
- Nominal Frequency: 150 or 300 MHz
- Operation Mode: Single hole reflection, Cross-hole tomography
- Length: 1.6 or 1.0 meter (5.4 ft or 3.4 ft)
- Diameter: 40 mm (1.8 inches)
- Weight: 1.5 Kg (3 lb)
- Water-proof: up to 5 bars

Bore Hole Investigation for Geotechnical Application



Sketch of GPR Bore Hole Technique

Borehole Application for Piles investigation in Caracas – Venezuela:

- Pile Depth Evaluation
- Pile Integrity

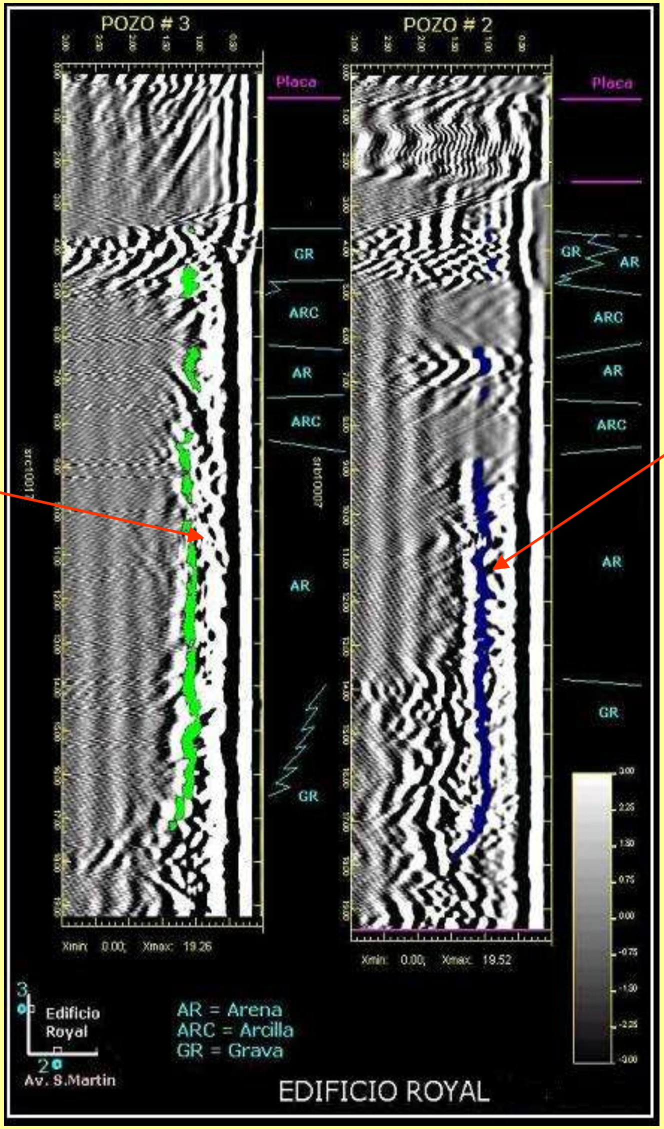
- Used Configuration: RIS One with 300 MHz BoreHole Antenna

Caracas - Venezuela

Bore Hole Investigation for Geotechnical Application

Hole for GPR investigation

Edificio Royal



Pile wall

Pile wall

Bore Hole Results

NCHRP 21-5 CONCLUSIONS

- Parallel Seismic borehole test Advanced for All Foundations
- Ultraseismic surface test for 1st element depth or piles with compressional and flexural waves
- Induction Field, Radar, Sonic Echo, Surface Waves have specialized uses
- Suggest 1 Parallel Seismic test and Ultraseismic tests for correlation on piles, etc.
- Surface tests did not see below pilecap

CPT/Parallel Seismic at Orange Beach, Alabama

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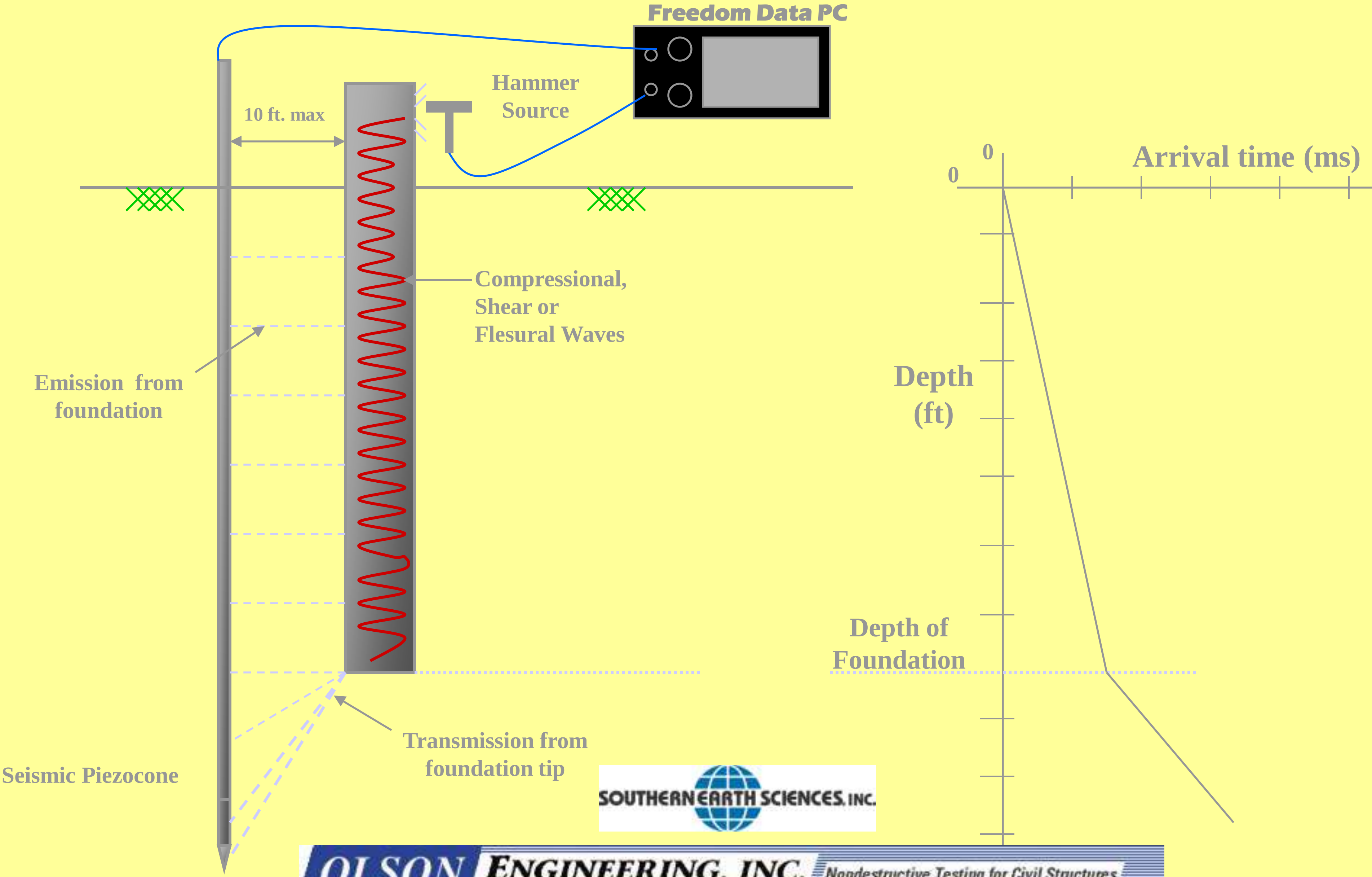
SOUTHERN EARTH SCIENCES, INC.

CPT/PARALLEL SEISMIC METHODS FOR UNKNOWN FOUNDATION DETERMINATION



CPT/Parallel Seismic Method for Pile Length Determination

Calculated Pile Length

14.079 m x 3.28 = 46.2 ft.

46.2 ft. + 4.1 ft (exposed) = **50.3** ft.

Actual Pile Length = **50.0** ft.

```
VELOCITIES: GROUND: 1796.5 CONCRETE: 4271.3 DEPTH: 14.079
DIST:  29.3727 TIME: 5.108 TRACE: NONE SAMPLE:   511  VALUE: NONE
Press and hold mouse button to drag endline for concrete
Quit
```

Soil Properties and Foundation Determination in a single Test Procedure

Fig. A-1 - Parallel Seismic - ACIP Pile 4 West

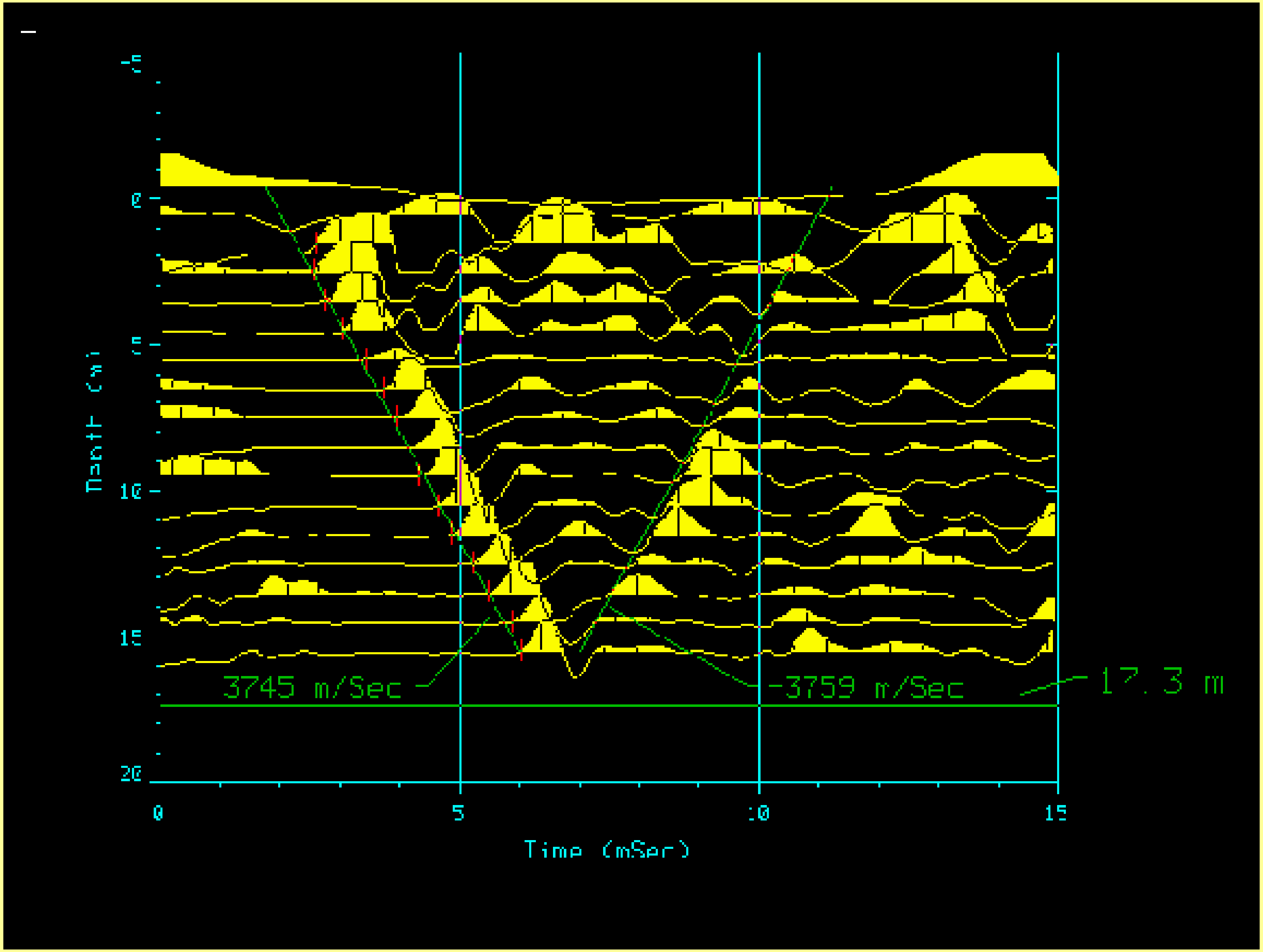


Fig. A-4 - Parallel Seismic - PSPC Concrete Driven Piling 5

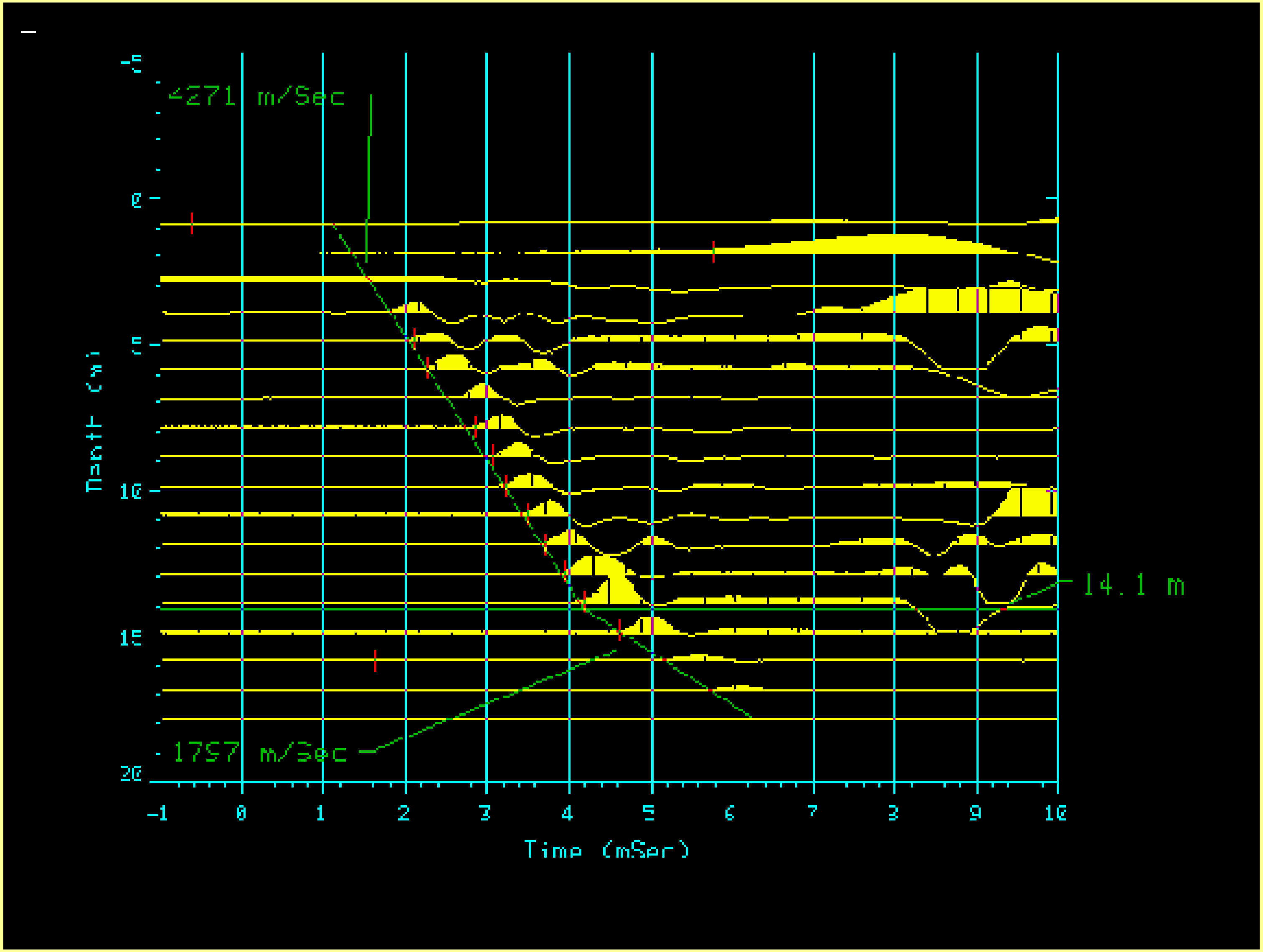


Table I - Summary of Parallel Seismic (PS) Results

Foundation	Figure Nos.	Known Depth (m)	PS Predicted Pile Depth (m)	PS Compressional Wave Velocity of Foundation Material (m/s)	Velocity of Soils below Foundation (m/s)
ACIP 4 West	A-1	15-18	17.3	3745	Not available
ACIP 4 East	A-2	15-18	17.0	4442	Not Available
PSPC 4 South	A-3	14	14.6	4865	2467
PSPC 5	A-4	14	14.1	4271	1797
Telephone Pole	A-5	3	3.6	4290	1908

New Orleans & Hurricane Katrina Sheet Pile Depth Determination

- Hurricane Katrina August 2005
- Levee Failure
- Storm surges of up to 25 feet
- Top sustained winds of 160 mph

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Damage

PS Testing

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Parallel Seismic Method with Geoprobe Seismic Cone Penetrometer

Seismic Cone Probe with Triaxial Geophones & Hydrophone & Small and Large Hydrophones for PS Testing in PVC Casing

Impacting the Top of the Levee Wall & Freedom Data PC for PS Borehole Test

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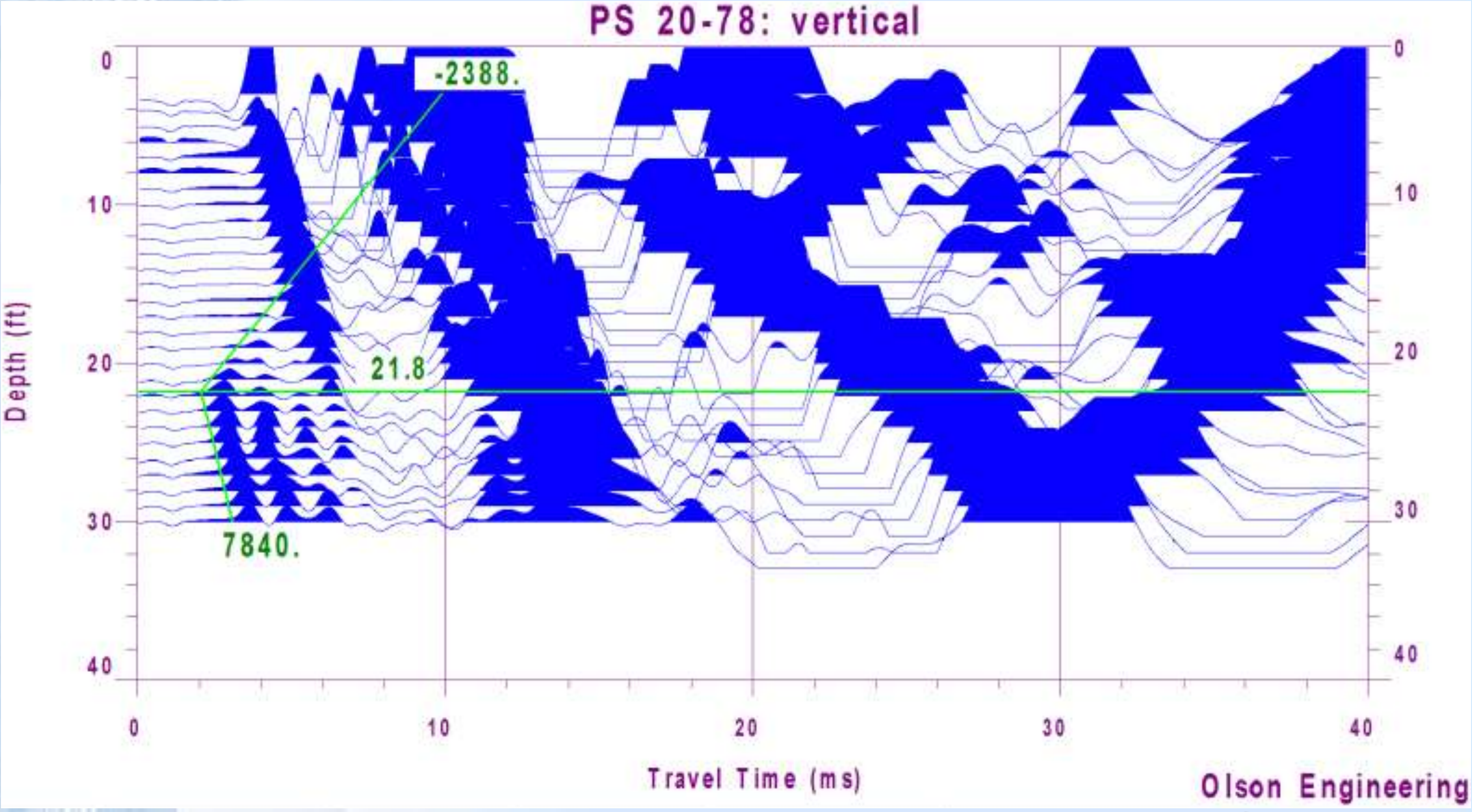
PS Results Showing Diffraction Event from 21.8 ft deep tip of Sheet Pile



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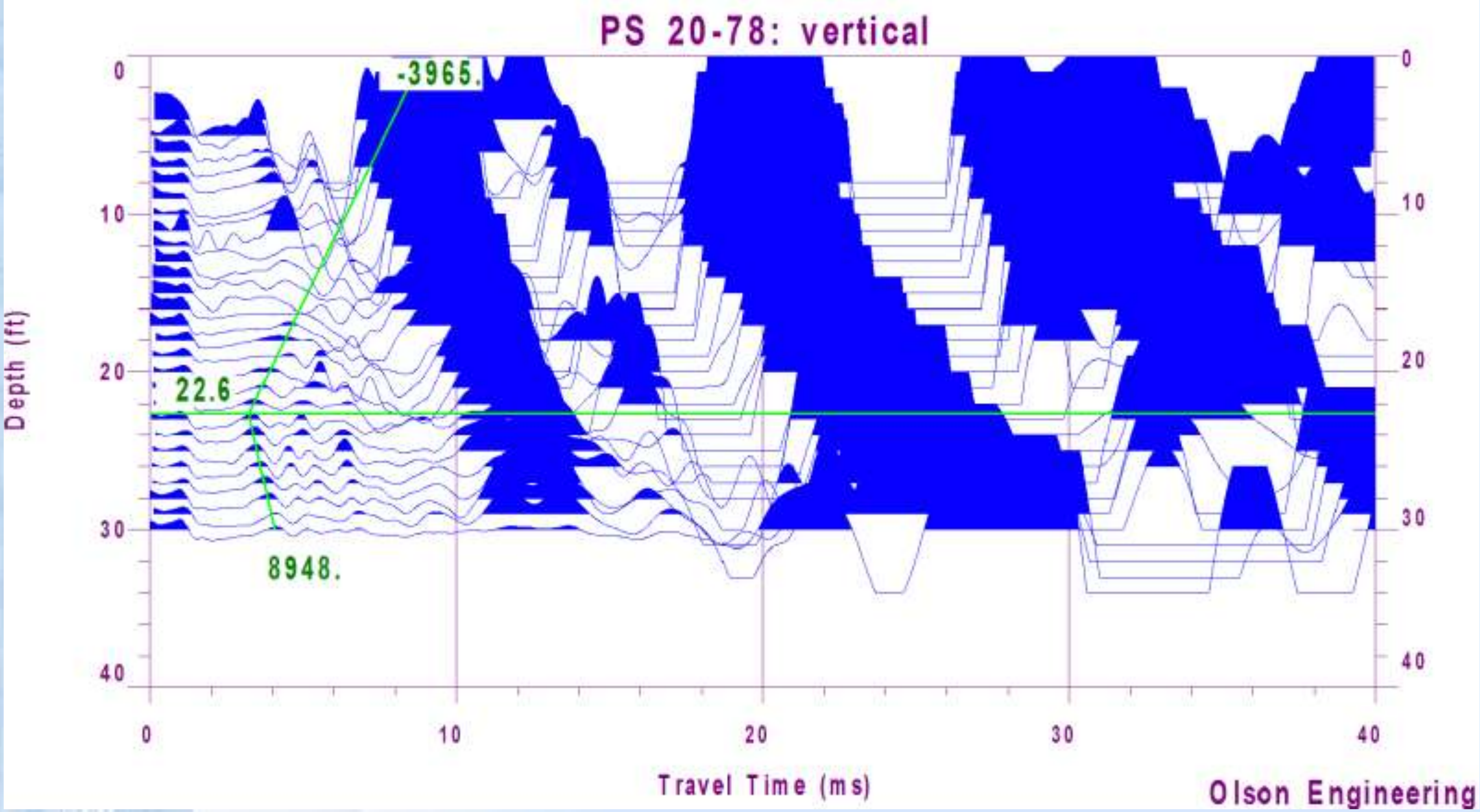
More PS Results – Sheet Pile 22.6 ft



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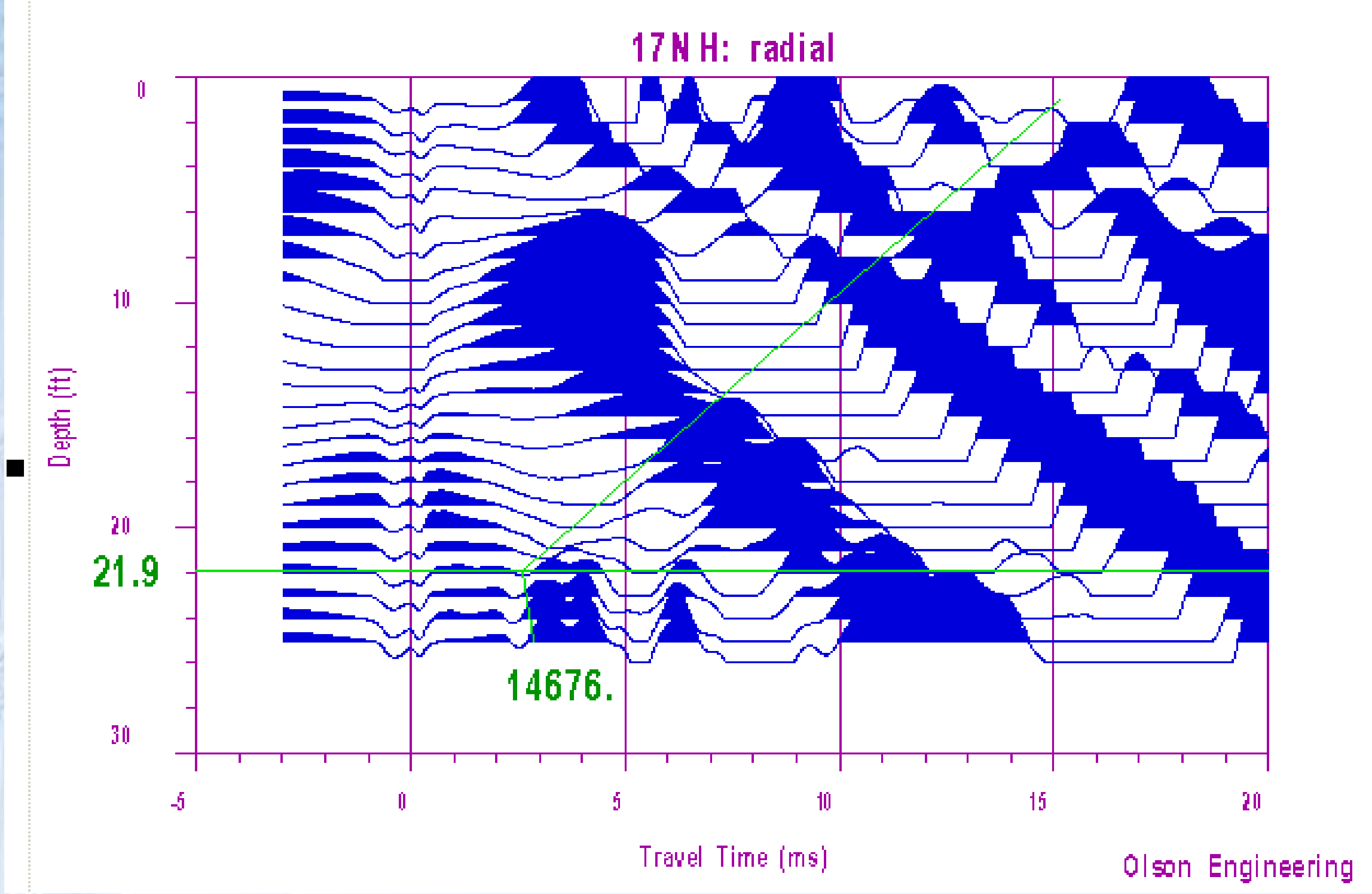
More PS Results – Sheet Pile at 21.9 ft depth



Hawaii Renovation Project at Pearl Harbor

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PS Testing

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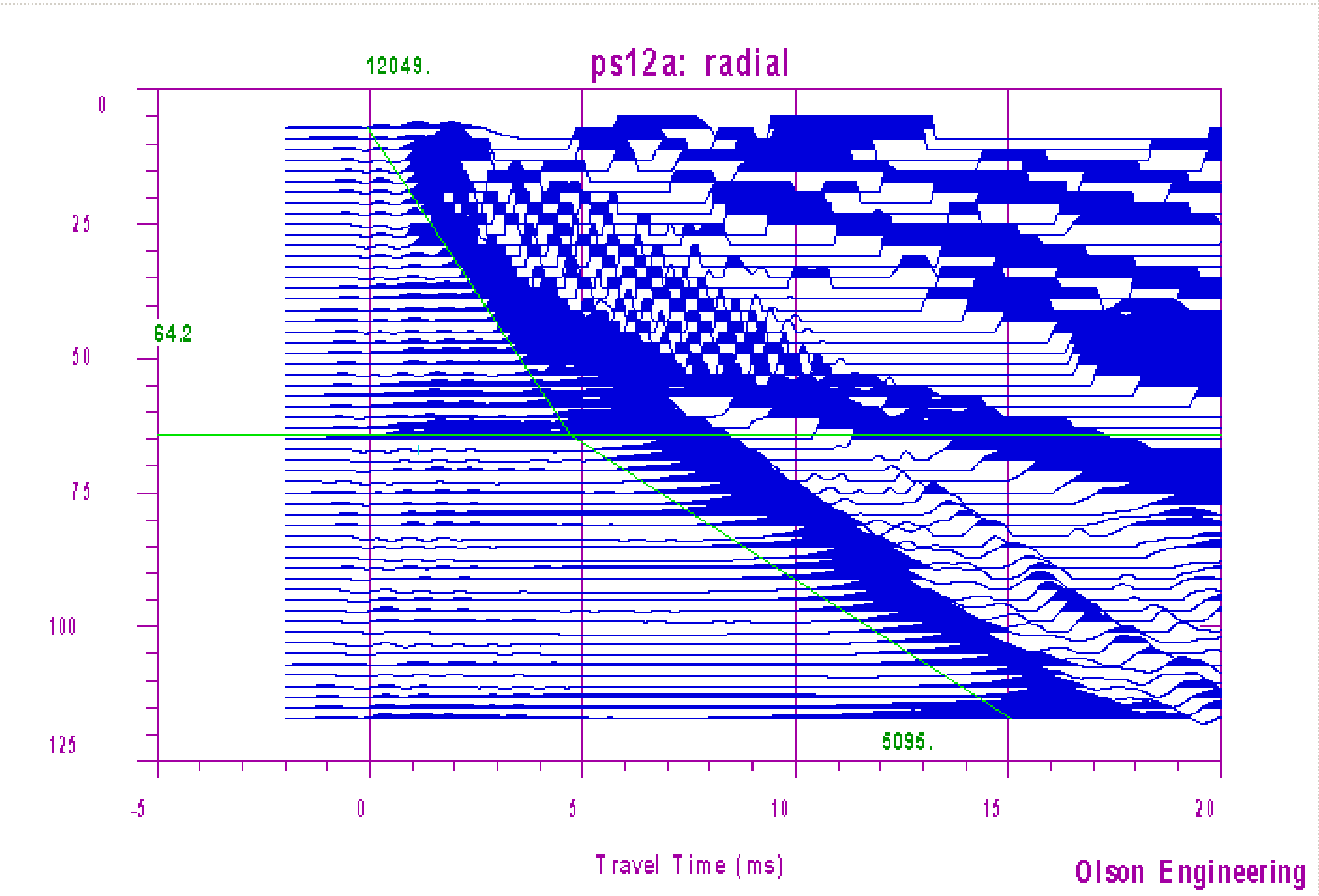
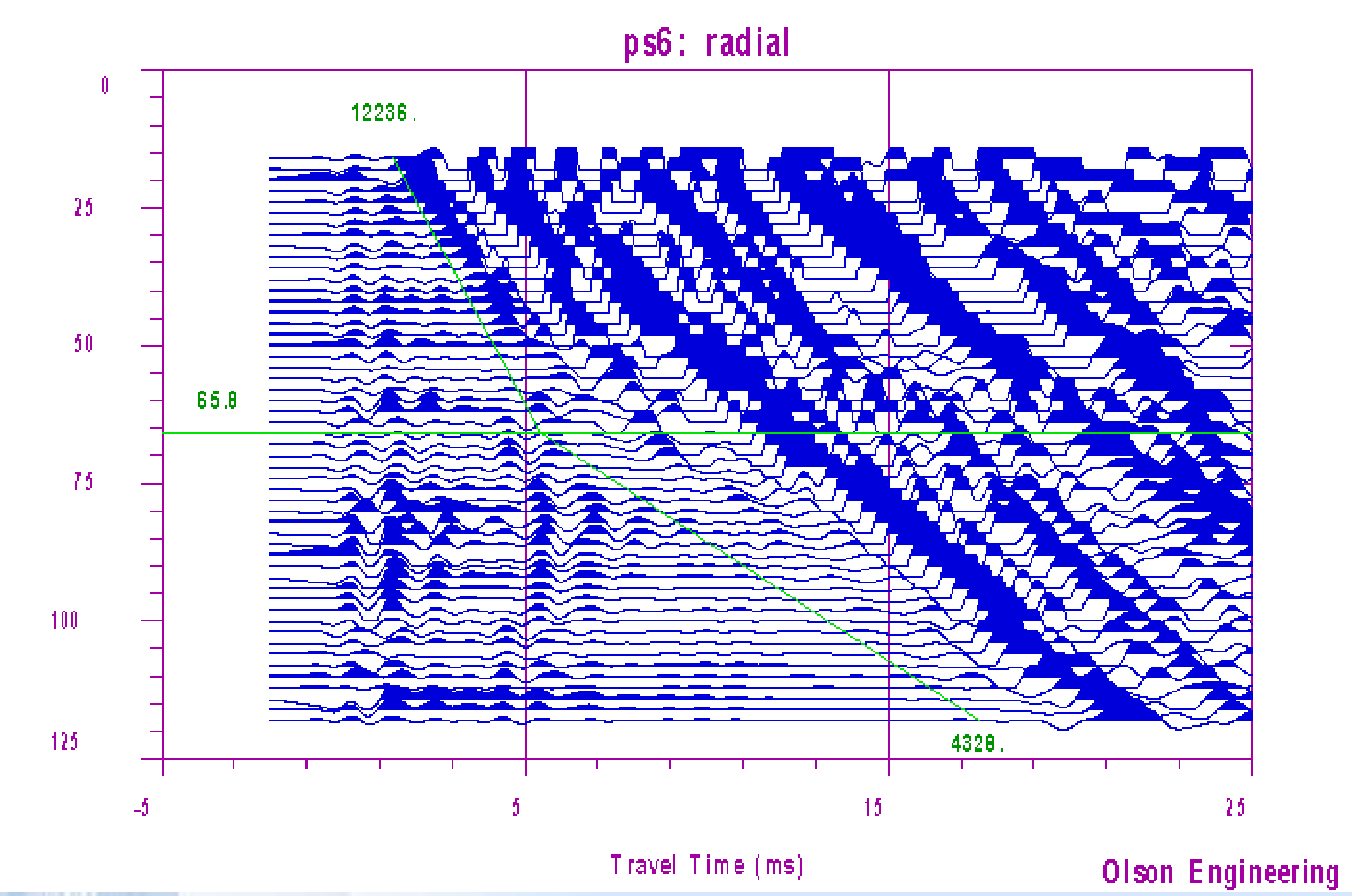
PS Results for Concrete Piles



More PS Results



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Conclusions and Thanks!

- The PS test method has been found in previous research to be the most accurate and versatile method for unknown foundation depth determination for scour safety at bridges and for old buildings and buried piles below pilecaps.

- Diffraction from the tip of a sheet pile can be used to identify its depth in advance of the large tube waves from a surface concrete footing.

- The combined PS/CPT system allows the collection of both soil data from cone penetrometer and PS foundation length data where the soil profile allows direct pushing of the cone probe to depths below the pile tip depth.

- For sites with stiffer soils, the same cone probe rig can be used to install a cased borehole (1 inch diameter PVC casing) and a vibratory hammer.

- The ability to determine soil conditions in parallel with PS data collection results in a more “complete package” of information for engineers who ultimately need both sets of data to estimate the actual capacity of the foundation element being tested.

OLSON ENGINEERING, Inc.

PS/CPT Conclusions

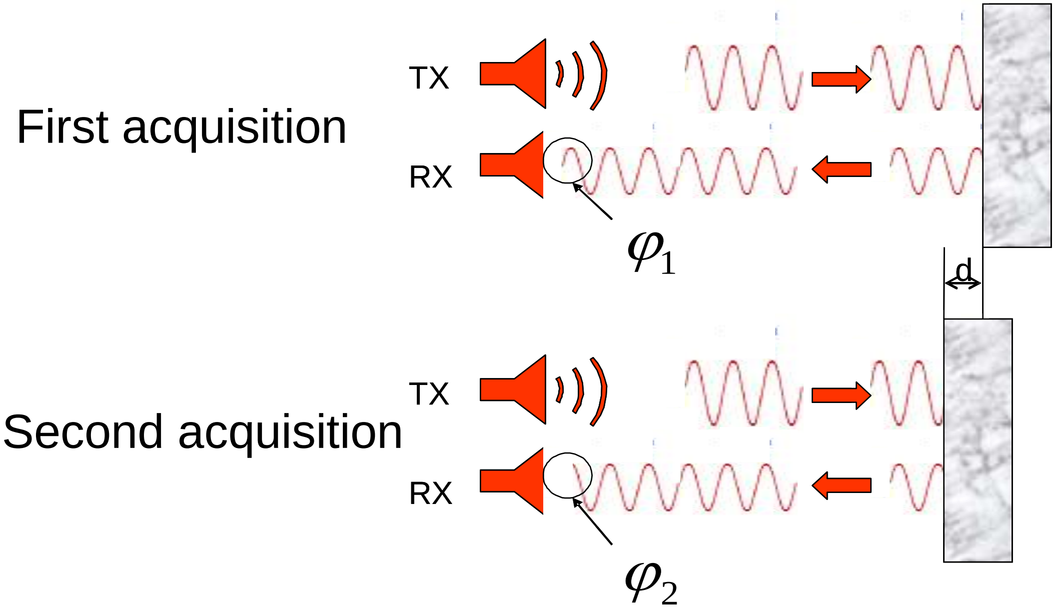
- PS/CPT Tests Gave Pile Tip Depths
- Faster, more economical testing than with borings for PS test
- Applicable to soft to stiff soils – not rock
- PS/CPT with dummy tip and plastic casing
- Added benefit of soil bearing/skin friction profile for scour susceptibility studies
- US Patent by Larry Olson and Scott Slaugter
- THANKS!

IBIS
Image By Interferometric Survey

An innovative non-contact technology based on radar interferometry for monitoring displacements of slopes and displacements/vibrations of structures

Interferometric capability for Structures

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 **0.0004 inch (0.01mm)** (intrinsic radar accuracy in the order of 0.00004 inch or 0.001 mm.)

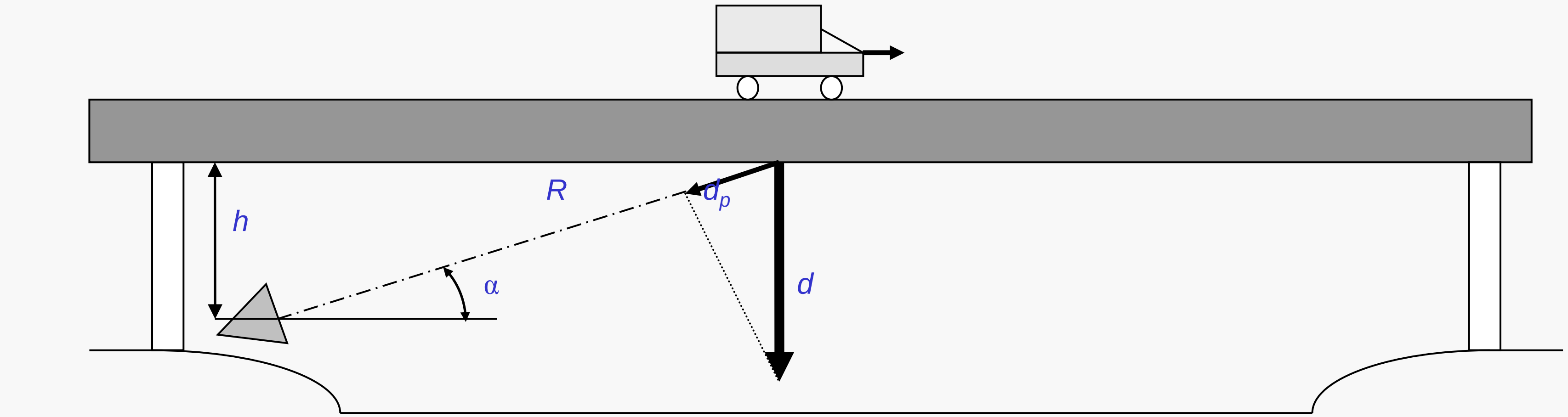


$$d = -\frac{\lambda}{4\pi}(\varphi_2 - \varphi_1)$$

IBIS-S 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

Manhattan Bridge

BRIDGE TOP VIEW

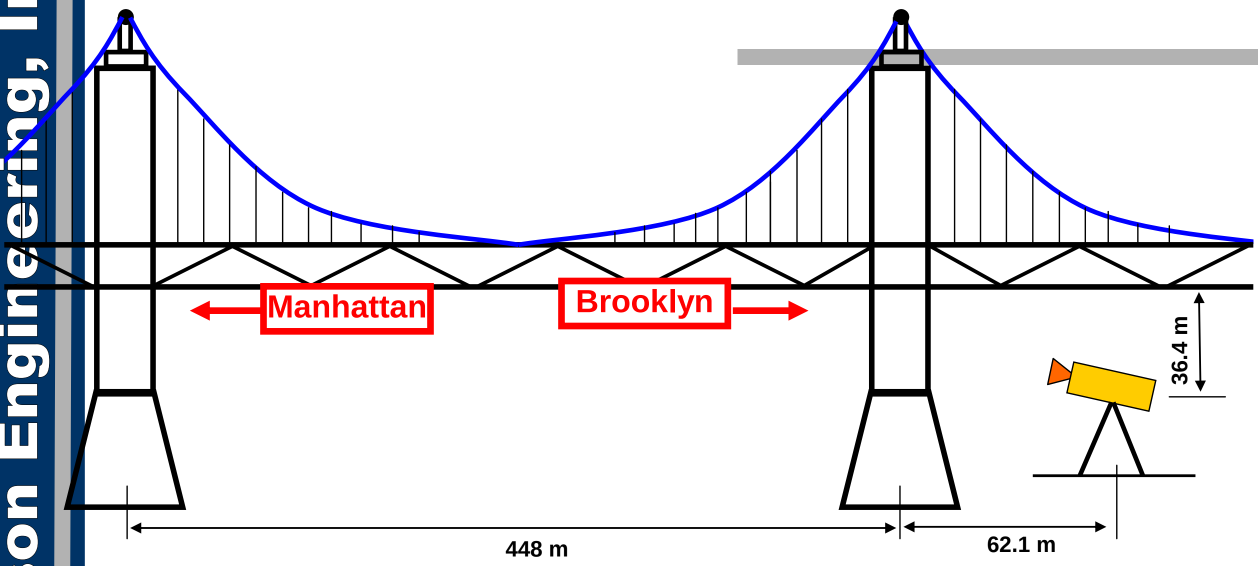
BRIDGE SIDE VIEW

TECHNICAL INFORMATION

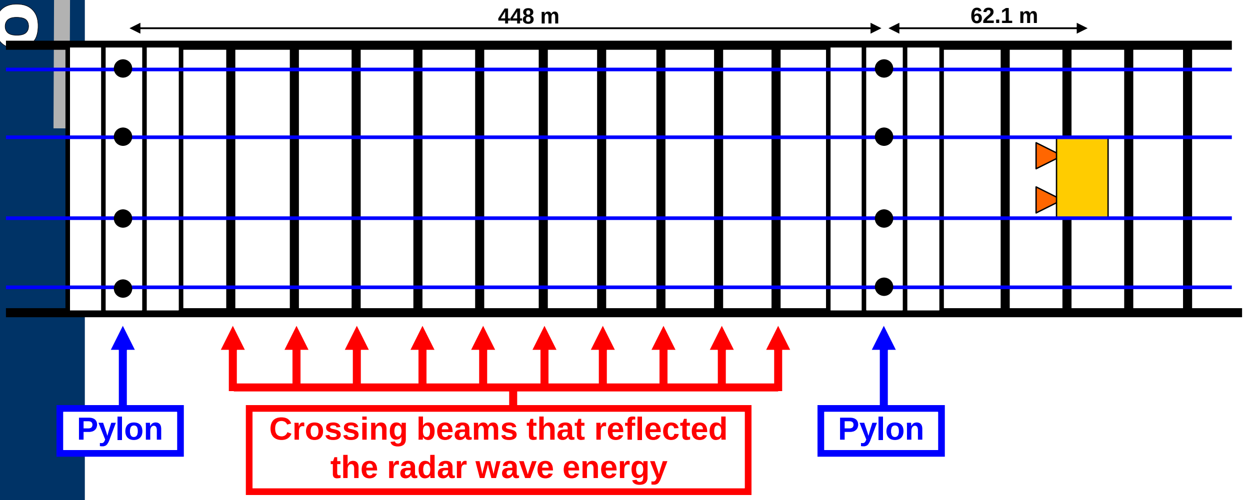
MATERIALS	cables	steel
	deck	steel
	foundations	masonry
	pylons	steel
	anchorages	masonry
DIMENSIONS	main span	448.1 m
	total length	2089 m
	number of cables	4
	strands per cable	37
	wires per strand	256
	height above water	41.1 m
	span lengths of main bridge	221.0 m - 448.1 m - 221.0 m
	cable diameter	53.975 cm
	number of wires per cable	9 472
	deck depth	7.3 m
	deck width	36.6 m
	pylon height	102.4 m

Manhattan Bridge IBIS-S System Configuration and Survey Geometry

SIDE VIEW



TOP VIEW



INSTALLATION OVERVIEW

SYSTEM PARAMETERS

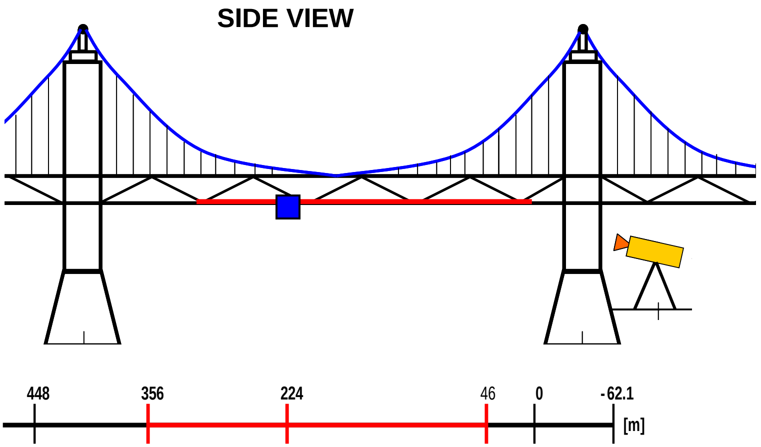
SAMPLING FERQUENCY	Hz	45
SURVEY DURATION	[min]	30
MAXIMUM RANGE	[m]	450
RANGE RESOLUTION	[m]	0.5
HALF POWER BEAM WIDTH	[deg]	15

Displacement Time Series

Vertical Displacement of the center of the main span during the whole survey

Displacement variations corresponding to the passage of vehicles and trains over the bridge deck can be observed in the graph

PASSAGE OF TRAINS OVER THE BRIDGE DECK



Point ID	Position [m]	Color
583	226.7	🟦

Slope instability monitoring within a quarry

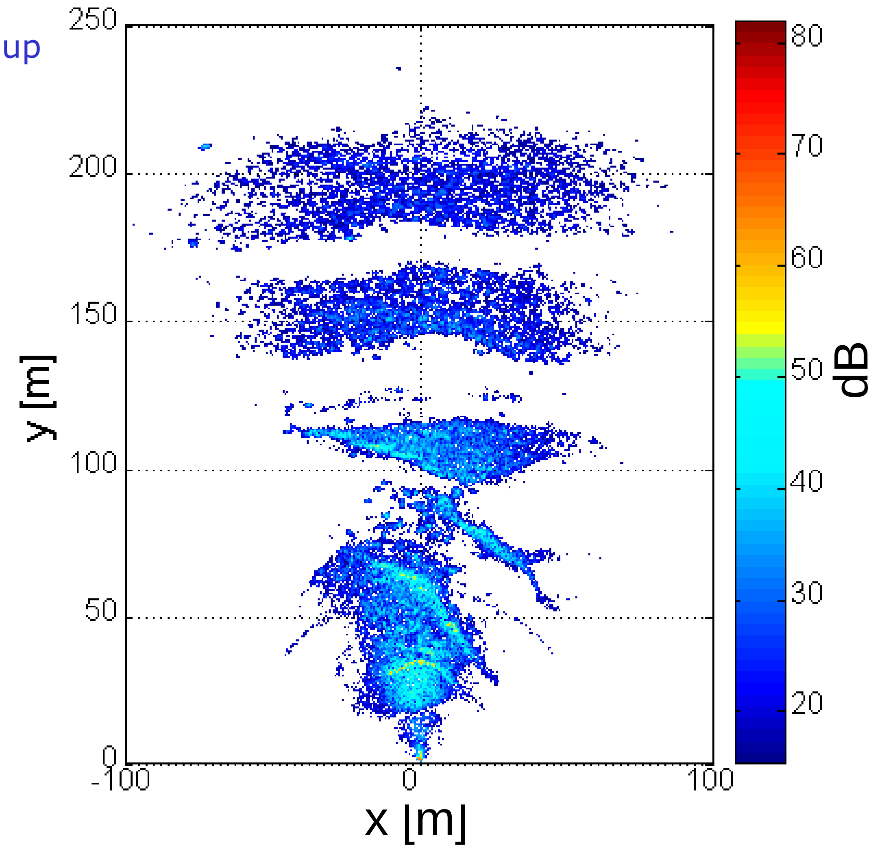
- Use of IBIS-L for long-term monitoring of slope instability within quarries or openpit mines

Slope instability monitoring within a quarry

Maximum range	500 m
Range resolution	0.5 m
Cross-range resolution	4.5 mrad
Antenna Tilt	25°
Antenna Aperturre (- 3 dB)	30°
Acquisition lenght	**6 days 29 min**

IBIS-L System set-up

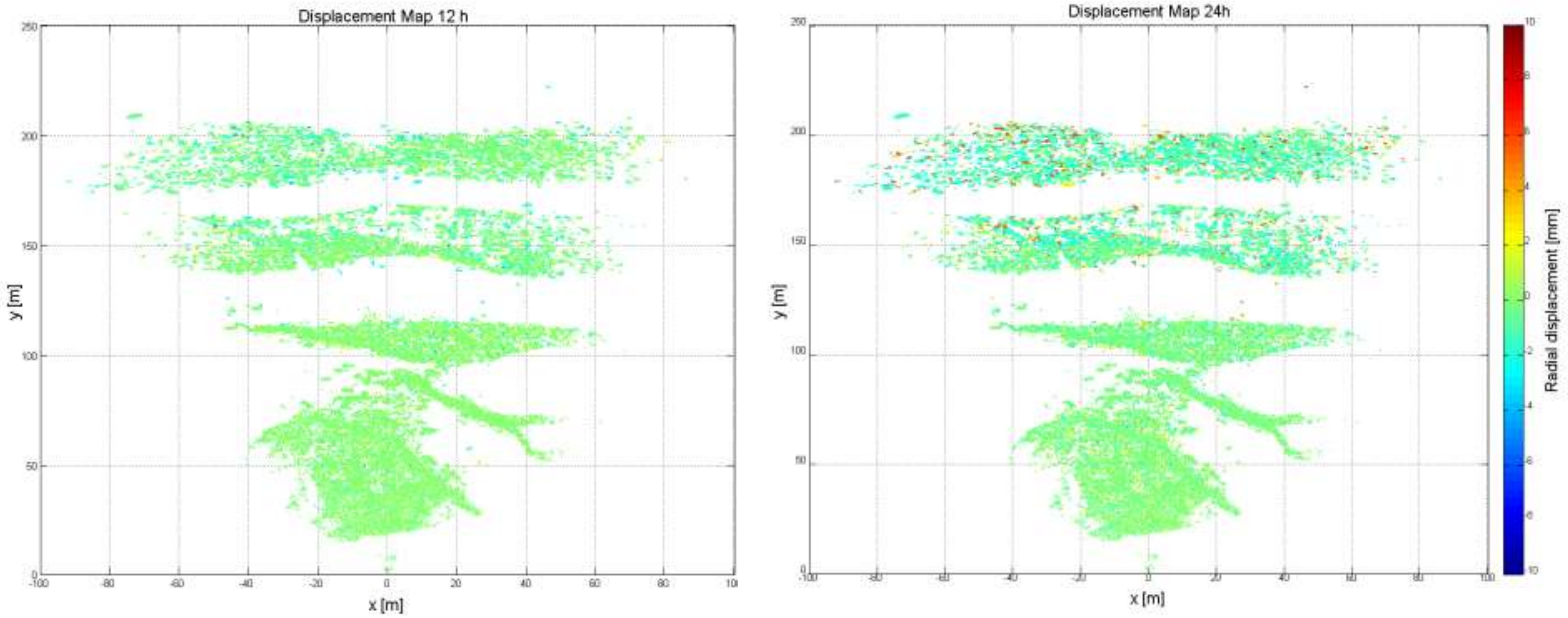
Power image



Slope instability monitoring within a quarry

Cumulative displacement maps

12 h **24 h**

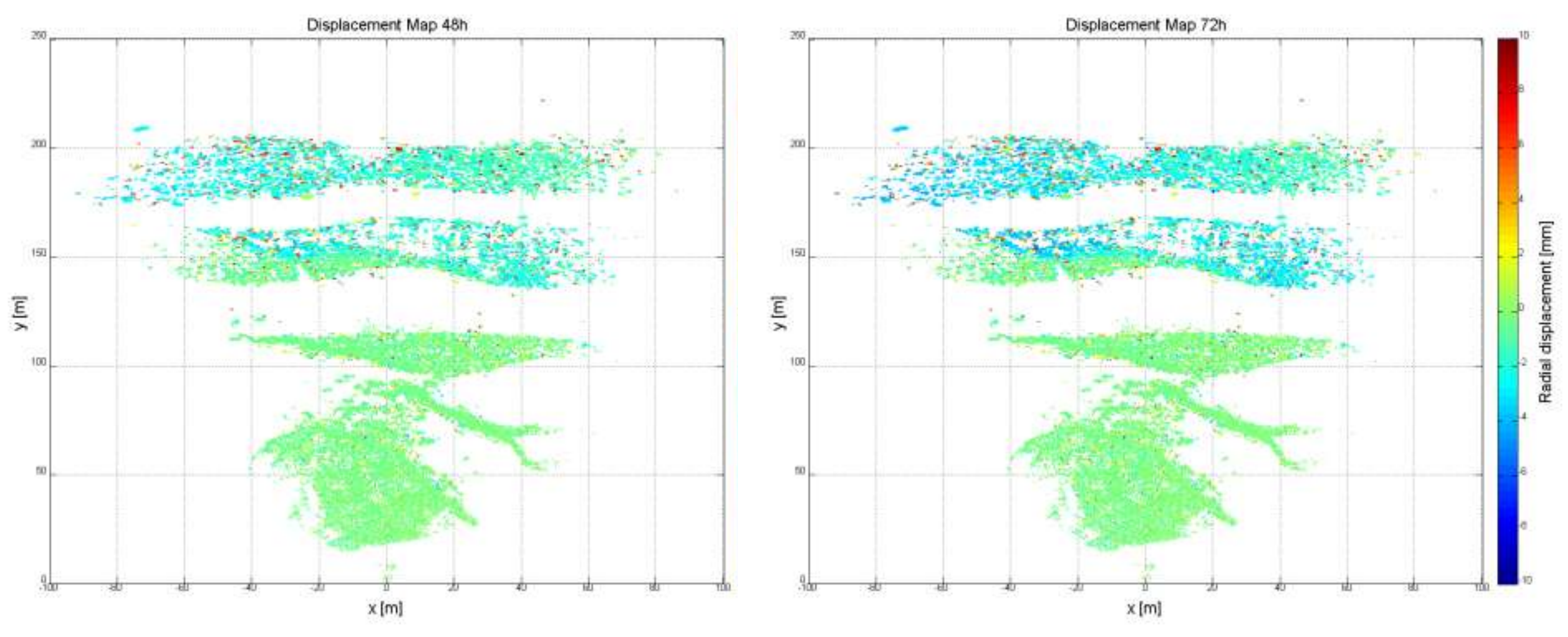


- After 24 h a maximum L.O.S. displacement of 1.2 mm is visible in the upper part of the slope, while the lower portions are stable

Slope instability monitoring within a quarry

Cumulative displacement maps

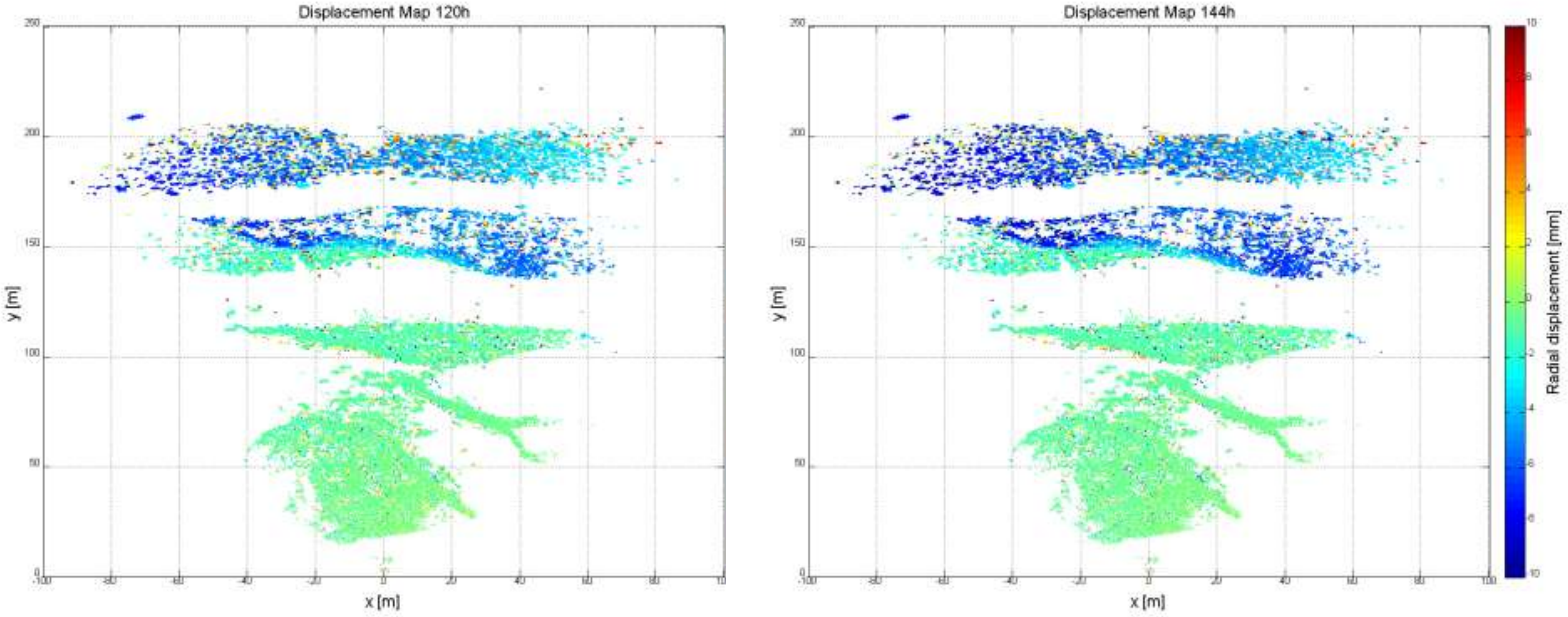
48 h **72 h**



- After 3 days a maximum L.O.S. displacement of 2,4 mm is visible in the upper part of the slope, while the lower portions are still stable

Slope instability monitoring within a quarry

Cumulative displacement maps

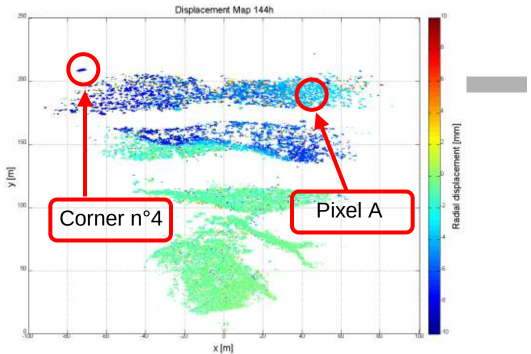

120 h

144 h

- After 6 days a maximum L.O.S. displacement of 7,5 mm is visible in the upper right part of the slope, the upper left portion records 4 mm, while the lower portions are stable

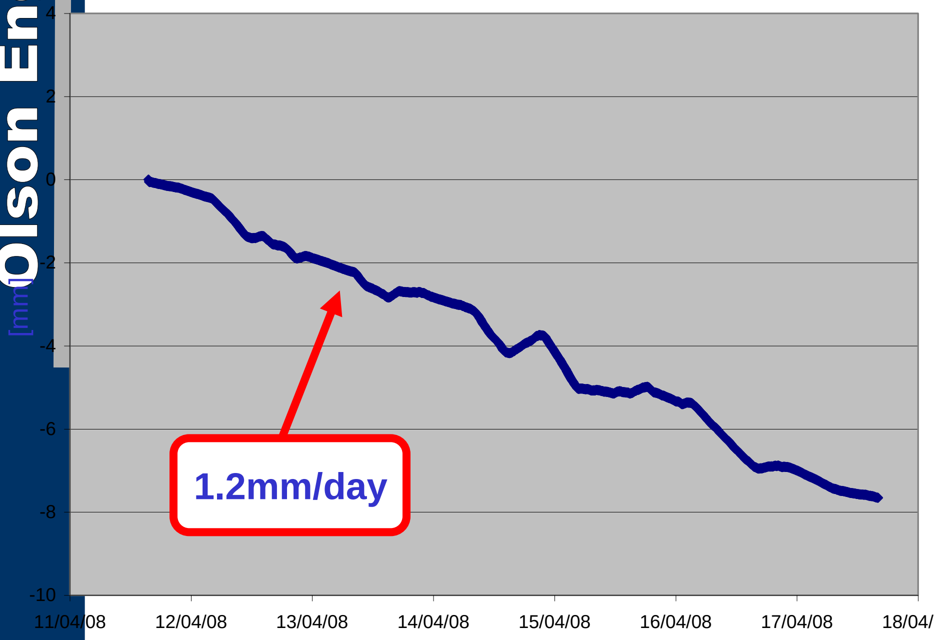
Slope instability monitoring within a quarry

Displacement time series

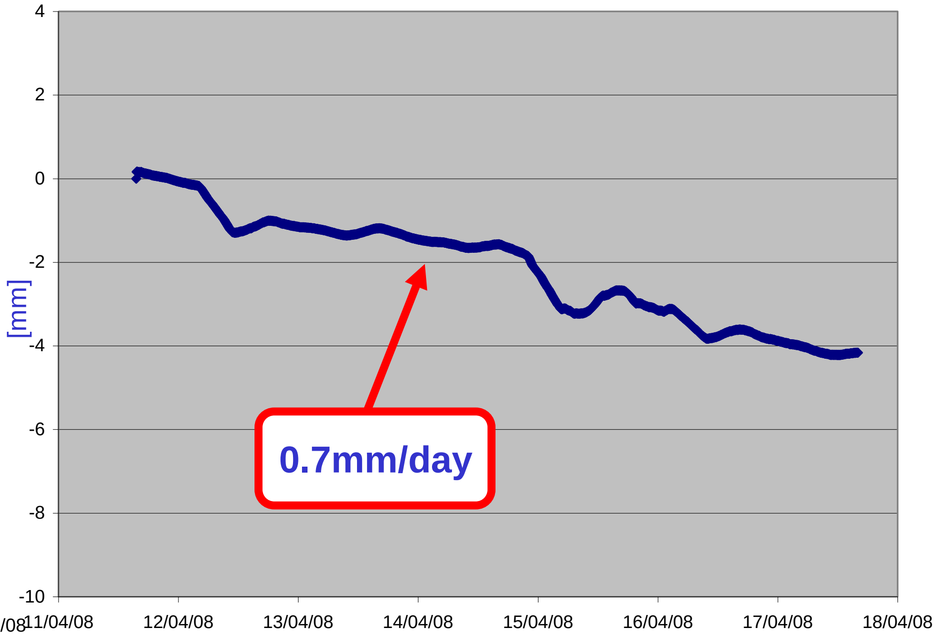


Temporal period: 11/04/08 – 17/04/08
Measurement time span: 6 days and 30 minutes
Type of filter : 80 samples moving average

CR4 displacement



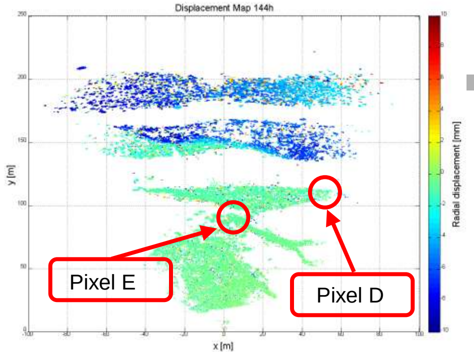
Pixel A displacement



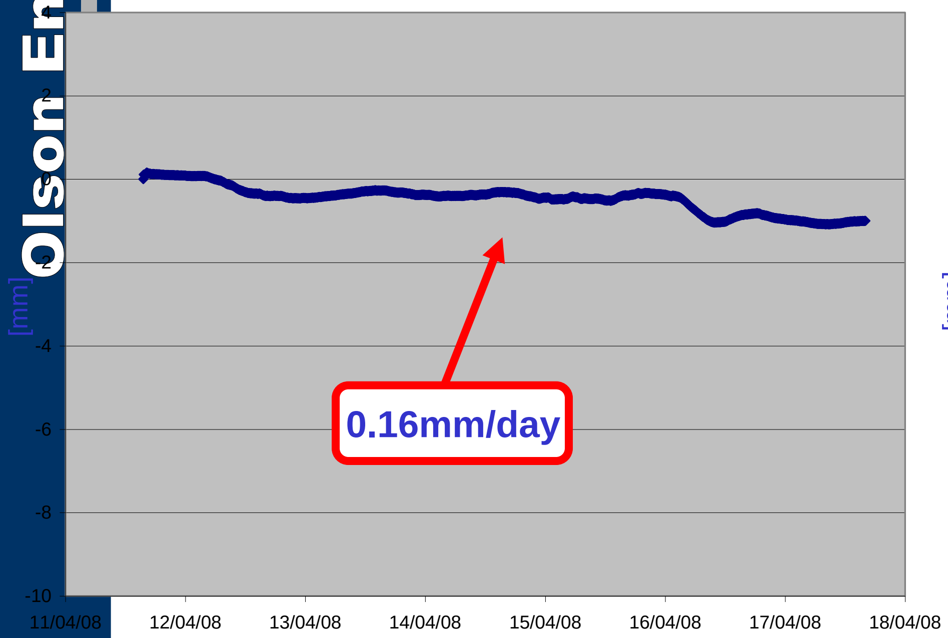
Slope instability monitoring within a quarry

Displacement time series

Temporal period: 11/04/08 – 17/04/08
Measurement time span: 6 days and 30 minutes
Type of filter : 80 samples moving average

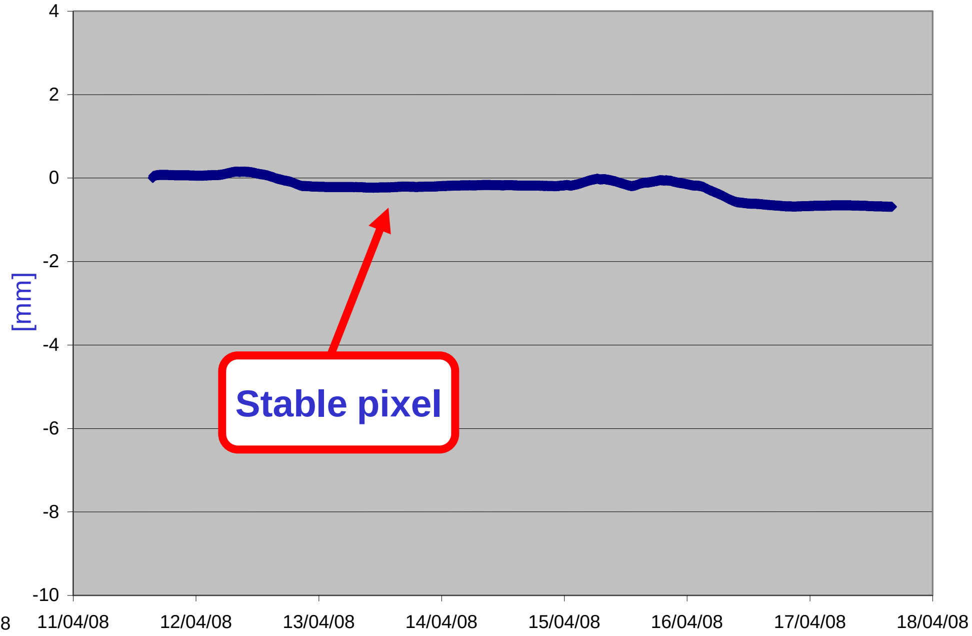


Pixel D displacement



0.16mm/day

Pixel E displacement

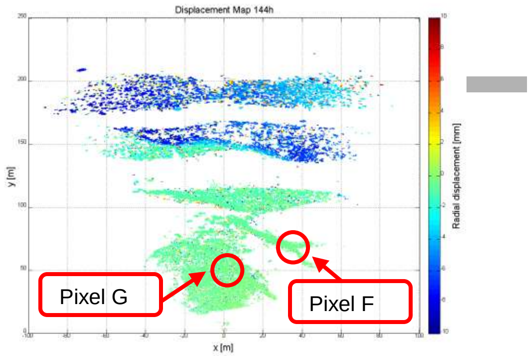


Stable pixel

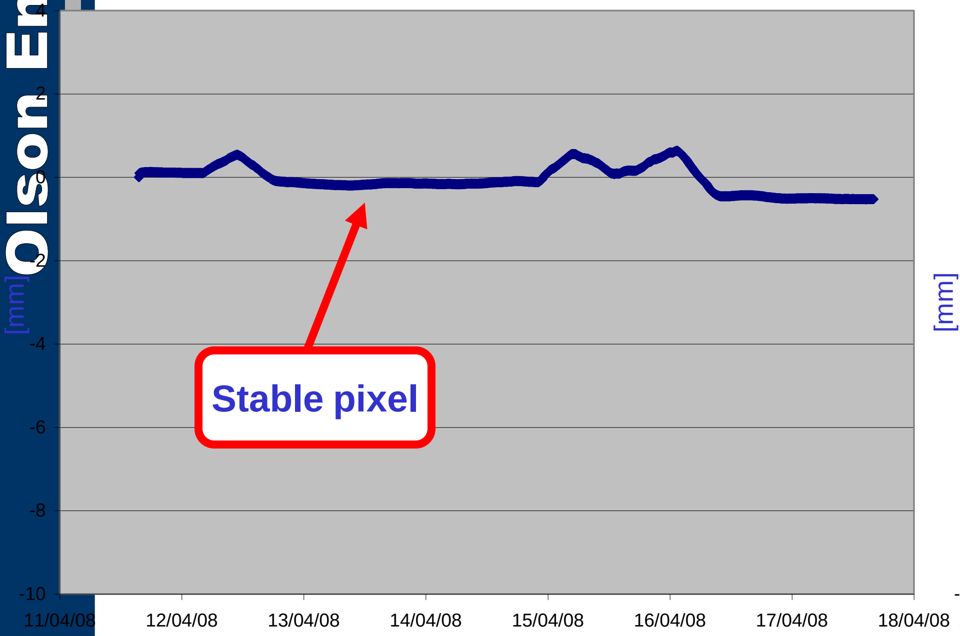
Slope instability Monitoring within a quarry

Displacement time series

Temporal period: 11/04/08 – 17/04/08
Measurement time span: 6 days and 30 minutes
Type of filter : 80 samples moving average

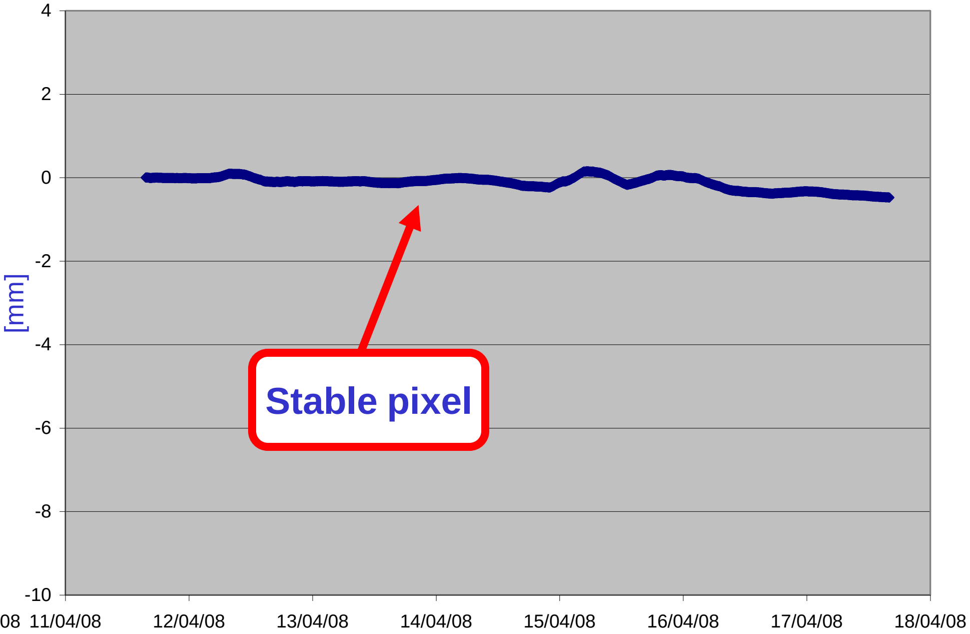


Pixel F displacement



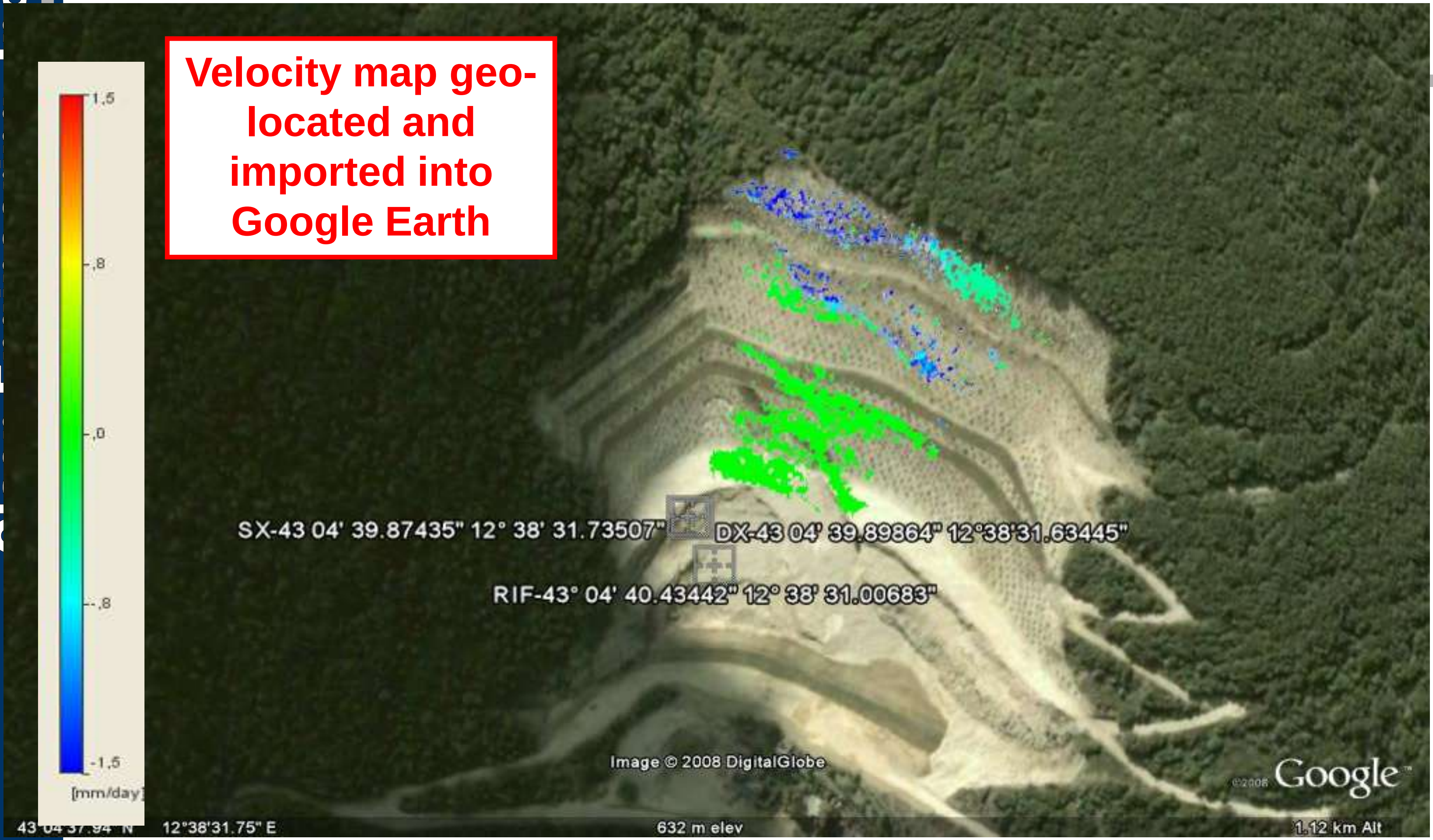
Stable pixel

Pixel G displacement



Stable pixel

Slope instability Monitoring within a quarry



Velocity map geo-located and imported into Google Earth