Condition Assessment of Unknown Foundations

Presented by Larry D. Olson, P.E.
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National Cooperative Highway Research Program
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
Fig. 1 - Variables of an Unknown Bridge Foundation
Unknown Foundation Surface NDE Methods

- Sonic Echo/Impulse Response
- Bending Wave
- Ultraseismic
- Spectral Analysis of Surface Waves
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
Sonic Echo/Impulse Response Testing on Timber Pile with 3-lb Impulse Hammer
Sonic Echo (SE)/ Impulse Response (IR)
Bent 4, Pile 1 (Timber Pile)

Pilecap

Source

Receiver

8.4 ft
Bent 4, Wake County Bridge #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 = ($V \times t/2$) = 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 $= \left( \frac{V}{f^2} \right) = 22.6$ ft (reference is top of pile)
Bending Waves Method

Source

Receiver 1

Receiver 2

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
Triaxial Accelerometer for Ultraseismic Tests
Bridge No. 5188, Minnesota Highway 58, Zumbrota, Minnesota
Ultraseismic Source
Receiver Layout

Footing Top and Bottom Depths?
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
Unknown Foundation Borehole NDE Methods

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

$ \text{Determination of Foundation Depths, Typically with Superstructure on Top of Foundation}$

$ \text{Requires Drilling a Hole Next to the Foundation}$

$ \text{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.
Choose tapping to maximize current A

Oscillator
Detector

Input

Search Coil

Shielded Cables

Transformer

Output

Pile of interest (steel)

Return Electrode

PVC cased hole

Induction Field Method for Steel H- and Pipe Piles
Source/Receiver Layout for US 287 over Little Thomson River, Longmont, Colorado
Triaxial Magnetic Field Coil for Induction Field NDE
H-Pile at 27 ft

Induction Field

Pile tip at 27 ft

Depth (ft)

Amplitude (mV)

millivolts
Borehole Radar Method

Signal Analyzer

Radar Antenna

Reflected Radar Signals

Unreflected Radar Signals

Abutment
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
BOREHOLE ANTENNA FEATURES

- 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

Borehole Application for Piles investigation in Caracas – Venezuela:

- Pile Depth Evaluation
- Pile Integrity

- Used Configuration: RIS One with 300 MHz BoreHole Antenna

Sketch of GPR Bore Hole Technique
Bore Hole Investigation for Geotechnical Application

Hole for GPR investigation
Edificio Royal

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
CPT/PARALLEL SEISMIC METHODS FOR UNKNOWN FOUNDATION DETERMINATION

Hammer Source

Freedom Data PC

Depth of Foundation

Arrival time (ms)

Depth (ft)

Seismic Piezocone

Emission from foundation

Transmission from foundation tip

Compressional, Shear or Flesural Waves

10 ft. max

Emission from foundation

CPT/PARALLEL SEISMIC METHODS FOR UNKNOWN FOUNDATION DETERMINATION

Seismic Piezocone

Transmission from foundation tip

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Freedom Data PC

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Arrival time (ms)

Depth (ft)

Emission from foundation

Transmission from foundation tip

Compressional, Shear or Flesural Waves

10 ft. max
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.

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

<table>
<thead>
<tr>
<th>Foundation</th>
<th>Figure Nos.</th>
<th>Known Depth (m)</th>
<th>PS Predicted Pile Depth (m)</th>
<th>PS Compressional Wave Velocity of Foundation Material (m/s)</th>
<th>Velocity of Soils below Foundation (m/s)</th>
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<tbody>
<tr>
<td>ACIP 4 West</td>
<td>A-1</td>
<td>15-18</td>
<td>17.3</td>
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<tr>
<td>ACIP 4 East</td>
<td>A-2</td>
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<td>4442</td>
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<td>PSPC 4 South</td>
<td>A-3</td>
<td>14</td>
<td>14.6</td>
<td>4865</td>
<td>2467</td>
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<tr>
<td>PSPC 5</td>
<td>A-4</td>
<td>14</td>
<td>14.1</td>
<td>4271</td>
<td>1797</td>
</tr>
<tr>
<td>Telephone Pole</td>
<td>A-5</td>
<td>3</td>
<td>3.6</td>
<td>4290</td>
<td>1908</td>
</tr>
</tbody>
</table>
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
Damage
PS Testing
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
PS Results Showing Diffraction Event from 21.8 ft deep tip of Sheet Pile
More PS Results – Sheet Pile 22.6 ft
More PS Results – Sheet Pile at 21.9 ft depth
Hawaii Renovation Project at Pearl Harbor
PS Testing
PS Results for Concrete Piles
More PS Results
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.
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
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.)

\[
d = -\frac{\lambda}{4\pi}(\varphi_2 - \varphi_1)
\]
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.

\[
R_{dd} \cos \alpha = \frac{h}{R} \sin \alpha = \frac{d_p}{
\frac{R}{h} = d = d_p \cdot \frac{R}{h}
\]

The distance \( R \) is measured by IBIS-S.
### Manhattan Bridge

**Bridge Engineering Association**
**2005 New York City Bridge Conference**
**September 12 - 13, 2005**

**Bridge Top View**
- **Manhattan Bridge**

**Bridge Side View**
- **IBIS-S**

**Technical Information**

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<tr>
<th><strong>Materials</strong></th>
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<td>cables</td>
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<td>deck</td>
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<td>anchorages</td>
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<th><strong>Dimensions</strong></th>
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<td>wires per strand</td>
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<td>height above water</td>
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<td>span lengths of main bridge</td>
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<td>deck width</td>
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<tr>
<td>pylon height</td>
<td>102.4 m</td>
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Manhattan Bridge IBIS-S System Configuration and Survey Geometry

SIDE VIEW

TOP VIEW

INSTALLATION OVERVIEW

SYSTEM PARAMETERS

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<tr>
<td>RANGE RESOLUTION</td>
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<tr>
<td>HALF POWER BEAM WIDTH</td>
<td>[deg]</td>
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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.
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

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<th>Parameter</th>
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<td>Cross-range resolution</td>
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<td>Antenna Aperture (-3 dB)</td>
<td>30°</td>
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<tr>
<td>Acquisition length</td>
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</tr>
</tbody>
</table>

Power image

IBIS-L System set-up
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

- 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

- 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

1.2mm/day

0.7mm/day
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

Pixel G displacement
Slope instability Monitoring within a quarry

Velocity map geo-located and imported into Google Earth