Site Characterization using Surface Waves

by

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This talk is about...

- How we can use surface waves to help us to investigate/characterize a site using seismic methods
- Why use surface waves?
- Engineering and Geotechnical Applications
- Looking at surface waves from a non-seismological view
- Multichannel approach – producing continuous shear wave velocity sections – 2D
Types of Waves

A: Air Wave
B: Direct Wave
C: Surface Wave
D: Reflection
E: Refraction
F: Back Scattering of Surface Wave
G: Ambient Cultural Noise
Surface Waves

- Dominant low frequency wave (ground roll)
- Is dispersive – low frequencies (long wavelengths) travel deeper than high frequencies (short wavelengths)
- Velocities of different wavelengths can be analyzed to determine velocities as a function of depth
- Surface wave velocities approximates shear wave velocities
Dispersion

Larger variation of Vs with depth – larger ‘fanning’ effect
Why use Surface Waves?

- Easy to generate
- Can be used in seismically noisy areas
- Substitute other geophysical techniques
- High resolution imaging
- Non-invasive, no boreholes required
- Insensitive to velocity inversions
- Sensitivity to lateral velocity variations
- Can be used on asphalt, industrial areas
- Substitute for down hole shear wave measurements
- It is interesting....
What is MASW?

- MASW = Multichannel Analysis of Surface Waves
- SASW = Spectral Analysis of Surface Waves
- Why the MASW approach?
  - Dispersion properties of all waves are imaged in overtone analysis
  - Allows separation of the fundamental Rayleigh mode
  - Dispersion curve of the fundamental mode is chosen
Passive & Active

- Passive MASW – cultural and ambient noise
- Active MASW – active source

**Passive**
- 1D
- Complex receiver array
- Difficult to move, roll
- Deeper penetration (larger arrays, lower frequency)

**Active**
- 2D
- Linear array
- Easy to move
- Shallower penetration than passive

**Combined Analysis**
Field Geometries

Active MASW

Source Receiver Configuration (SRC)

Receivers

SRC Move = n * dx

Passive Remote MASW

Receivers

N

Iowa St.

Clinton Pkwy

23rd St.

Passive Roadside MASW

Linear Receiver Array

Array Move = n * dx

* : Impact point for trigger recording
Passive Arrays
Passive Circular Array
MASW Applications?

- Shear wave velocity measurements
- Velocity variations
- Bedrock topography
- Fault/Fracture zones
- Voids & Tunnels
- Soil Stiffness & Compaction
Seismic Waves on Shot Record

Body waves – direct, refracted, reflected p and s waves

Air-wave

Surface waves
The Steps

Acquisition

Dispersion Curve Extraction

Inversion

Time-Space

Frequency-Phase Velocity

Depth-Vs
MASW Processing

24 channel shot gather

Overtone Analysis with picked Dispersion Curve

Dispersion Curve
MASW Inversion

Inversion of Dispersion Curve to produce Vs profile
2D Map

Acquire multiple records by moving the same source-receiver configuration after each acquisition.

Prepare multiple number of 1-D Vs profiles by following previous 3-step procedure.

Construct of a 2-D Vs map by using an appropriate interpolation scheme.
Data Acquisition Settings

- Geophone spacing (dx)
- Shot – spread offset (X1)
- Number of geophones
- Record length
- Source
- Shot stacking
- Spread & Source roll – roll & move-along
Survey Geometry

### Survey Geometry Table

<table>
<thead>
<tr>
<th>Material Type*</th>
<th>$x_1$ (m)</th>
<th>$dx$ (m)</th>
<th>$x_M$ (m)</th>
<th>Optimum Geophone (Hz)</th>
<th>Optimum Source* (Kg)</th>
<th>Recording Time (ms)</th>
<th>Sampling Interval (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Soft ($v_s &lt; 100$)</td>
<td>1 – 5</td>
<td>0.25 – 0.5</td>
<td>≤ 20</td>
<td>4.5</td>
<td>≥ 5.0</td>
<td>1000</td>
<td>1.0</td>
</tr>
<tr>
<td>Soft ($100 &lt; v_s &lt; 300$)</td>
<td>5 – 10</td>
<td>0.5 – 1.0</td>
<td>≤ 30</td>
<td>4.5</td>
<td>≥ 5.0</td>
<td>1000</td>
<td>1.0</td>
</tr>
<tr>
<td>Hard ($200 &lt; v_s &lt; 500$)</td>
<td>10 – 20</td>
<td>1.0 – 2.0</td>
<td>≤ 50</td>
<td>4.5 – 10.0</td>
<td>≥ 5.0</td>
<td>500</td>
<td>0.5</td>
</tr>
<tr>
<td>Very Hard ($500 &lt; v_s$)</td>
<td>20 – 40</td>
<td>2.0 – 5.0</td>
<td>≤ 100</td>
<td>4.5 – 40.0</td>
<td>≥ 5.0</td>
<td>500</td>
<td>0.5</td>
</tr>
</tbody>
</table>

* Average properties within about 30-m depth range

+ Weight of sledge hammer

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Spread Length = resolution
Short X1 – near field effect, but better shallow imaging
Long X2 – far-field effect, but better deeper imaging
Near and Far Field Effects

- Near-Field Effects
  - Non-planar surface waves
  - Weak amplitude
  - Wavelength dependent – longer wavelengths need further offsets
  - > 10 m – Rule of Thumb for common soil sites

- Far-Field Effects
  - Effect of higher order modes more pronounced
  - Body waves
  - Low S/N
  - Ambient Noise Domination
  - < 100 m – Rule of Thumb for common soil sites
Recording Parameters

- **Total Recording Time (T)**
  - 1000 ms
  - Increase when using longer than usual spread
  - Increase when very low velocities

- **Sampling Interval (dT)**
  - 1 ms
  - Decrease when also using body waves

- **Acquisition Filters** – not to be used
Equipment

- Sledgehammer – 14 pound
- Frequency content determines penetration
- Weight drop for increased penetration
- 4.5Hz Geophones
- Land streamers – no noticeable decrease in data quality – very efficient
- 24 channel seismography is sufficient
Hammer Source

Image courtesy Kansas Geological Survey
Receivers

Image courtesy Kansas Geological Survey
Land Streamers
Geophone Coupling
Land Streamers versus Spikes
Data Quality

GOOD

BAD

GLOBAL GEOPHYSICAL
Combined Analysis

More accurate modal identification
Combined Analysis

More accurate modal identification

Passive OCT04

Active OCT04

Active OCT04 + Passive OCT04

M1

M2

M0

GLOBAL GEOPHYSICAL
Mapping of Fracture Zone for Groundwater Flow

Electrical methods not feasible due to electrical noise

Survey conducted on road between buildings

Bedrock topography & Fracture zones

Possible fracture zone

Sasol Chemical Industries
Fill Compaction / Small Strain Elastic Moduli

Calculation of soil stiffness and elastic moduli important for modelling response of certain plant components.

Rustenburg Processing Plant
Depth to Bedrock

Data example courtesy of Kansas Geological Survey

Mapping of flow of contaminants along bedrock topography
Future Developments

- Inversion of Higher Order Modes
- Joint Inversion of Surface Waves and Seismic Refraction
Acknowledgements

- Kansas Geological Survey