Spectral-Analysis-of-Surface-Waves (SASW) Method

Surface Wave Techniques to Evaluate Subsurface Stiffness Structure

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Principles and Concepts of the SASW Method
Setup for SASW Measurements

Dynamic Signal Analyzer
with anti-aliasing filter
• Frequency Span: 25~52000 Hz
• Real-time FFT
• 2 to 4 input channels

Impact Source
• Assorted Hammers
• 100-kg Drop Weight
• Bulldozer

Geophones
• 4.5 Hz (for D=0.5~1m)
• 1.0 Hz (for D ≥ 2m)
• Shielded Cables

Source-Receiver Distance
• R=D (Conventional SASW)
• R=1, 2, 4, 8, and 16 D
  (for CAP-SASW)

Inter-Receiver Spacings
• 0.5, 1.0, 2.0, 4.0, 8.0 m (for Hammers)
• 16.0, 32.0 m (for 100-kg Drop Weight)
• 64.0, 128.0 m (for Bulldozer)
• FFT Analyzer

• Seismic Sources

• Geophones
Principles of Phase-Velocity Measurement

Frequency = 66.48 Hz
Period = 0.01504 sec

Phase Velocity:

\[ v_{ph} = \frac{2\pi fD}{\Delta\phi} \]

\[ v_{ph} = \frac{D}{\Delta t} = \frac{2.0}{0.01504} = 133.0 \text{ m/sec} \]

\[ \Delta\phi = 360^\circ \]
\[ \Delta t = 0.01504 \text{ sec} \]

Relationship between \( \Delta\phi \) and \( \Delta t \):

\[ \Delta t = \frac{\Delta\phi}{2\pi f} \]
Phase-Velocity Determination in SASW Method

(a) Receiver 1

Receiver 2

FFT

FFT

Phase Difference: \[ \phi_2 - \phi_1 \]

Spectral Amplitude

D=1m

Impact, Swept Sinusoidal Vibration, or Random Noise

(b) Experimental Dispersion Curve

Phase Angle, deg

D=1m

Unwrapped Phase, deg

Unwrapped Phase Unwrapping

(c)
Inversion Analysis in the SASW Method
Inversion Analysis for the SASW Method: Global and Array Inversion Analyses

Dispersion Curve for Global Inversion Analysis

Dispersion Curve for Array Inversion Analysis
Impulse Response Filtration (IRF) Technique

Random Noise Added to the Theoretically Determined Displacements

Impulse Response

Phase Angle, deg

Frequency, Hz

Time, sec

Frequency, Hz

Time, sec
Comparison of the Original and IRF-Enhanced Phase Spectra
WinSASW, Dedicated Software for the SASW Method
Recent Development in the SASW Method

- **Common-Mid-Point (CMP) SASW Method**

  - Far Source: 100 kg
  - Near Source: 5 kg
  - S = D
  - D = (1, 2, 4, 8, 16, 32) m

- **Common-Array-Proﬁling (CAP) SASW Method**

  - Far Source: 100 kg
  - Near Source: 5 kg
  - S = (1, 2, 4, 8, 16) × D
  - D = 2~4 m
• CMP SASW Method vs. CAP SASW Method

![Graphs showing comparisons between CMP SASW and CAP SASW methods for different cases (A, B, C). Each graph includes Shear-Wave Velocity Profile and Phase-Velocity Dispersion Curve.]

Caption: 'Graphs showing comparisons between CMP SASW and CAP SASW methods for different cases (A, B, C). Each graph includes Shear-Wave Velocity Profile and Phase-Velocity Dispersion Curve.'
Evaluation of 2-D Shear-Wave Velocity Profiles

- CAP SASW Method
- **MASW Method**
SASW Method for Deep Profiling

Low-frequency vibroseis, 64,000 lb-heavy Liquidator

Typical time histories of a vibroseis source
Applications of the SASW Method
Applications of the SASW Method

- Geotechnical Sites
  - NDE of asphalt pavements
  - Modulus and thickness of pavement layer, subgrade and grade
  - Evaluation of Compaction Quality
  - Site Investigation of
    - MSW Landfill
    - Road bed or Railroad bed
  - Evaluation of Vacuum Consolidation
- Pavement Systems
- Concrete Structures
  - Structural Integrity test of
    - Tunnel Concrete Lining
    - Concrete Bridge Deck
    - Retaining Wall
  - Shear-Wave Velocity Profile for Seismic Analysis
Quality Assurance of Compaction

- Compaction by Hydraulic Hammer:

  Runway of Inchon International Airport
Comparison of Shear-Wave Velocity before and after Compaction

Shear Wave Velocity, m/sec

Depth, m

Before

After

Shear Wave Velocity, m/sec

Before

After
Site Investigation at Man-Made Island

- Stiffness Profiling of Engineering Fill

Treasure Island in San Francisco
Comparison of Shear-Wave Velocity Profiles from SASW and Crosshole Tests

Shear Wave Velocity, m/sec

Depth, ft

Crosshole (UT)
SASW (Array Inversion)
**Site Investigation of MSW Landfill Site**

- **Vs Profiling of OII Landfill at LA, USA:**

  **Comparison between SASW Results and Results of OYO Suspension Logging**
Stiffness Profiling of Ballast and Railroad Bed

- Vs Profiling of Ballast and Railroad Bed to Investigate Mud Pumping
• Shear-Wave Velocity Profiles from Inversion Analyses
$V_s$ Profiling of Asphalt Pavement System
• $V_s$ Profiles from SASW Tests

Comparison between Results of SASW Tests and CPT
Stiffness Evaluation of Soil Layers under Airport Runway

- JFK Airport, New York

Before Tunneling

After Tunneling
• Experimental Dispersion Curve for Runway of JFK Airport (Expanded for Long Wavelengths)

Before Tunneling

After Tunneling
Investigation for Tunnel Concrete Lining (1)

- NDE for Tunnel Concrete Lining:

Road Tunnel
- 1-D Shear Wave Velocity Profile

![Graph showing Shear Wave Velocity Profile with depth and velocity values.

- Concrete Lining
- Water-Proofing Membrane
- Shotcrete and Original Material

Not much reliable
- **2-D Stiffness Profile**

1-D Phase Velocity profile in Wavelength-Distance Domain

![Graph showing 1-D Phase Velocity profile in Wavelength-Distance Domain]
2-D Shear-Wave Velocity Profile of Tunnel Concrete Lining in Depth-Distance Domain
Investigation for Tunnel Concrete Lining (2)

(a) Generalized Tunnel Cross Section

(b) SASW Testing Arrangement and Planes of Investigation

SASW testing performed inside a concrete-lined tunnel (from Stokoe and Santamarina, 2000)

Examples of $V_s$ profiles measured inside a concrete-lined tunnel (from Stoke and Santamarina, 2000)
Examples of $V_s$ profiles measured inside a concrete-lined tunnel (from Stoke and Santamarina, 2000)
Investigation of Surface Cracks in Concrete Runway

- Defects → Small Modulus
- Good Material → Large Modulus
Investigation of Damaged Area after Explosion
Surface-Wave Vel. m/sec

- 1200
- 1100
- 1000
- 900
- 800
- 700
- 600
- 500
- 400
- 300
- 200
- 100

Wavelength, m

Before Explosion

After Explosion

Distance from Cliff, m
Thank you for your attention!

감사합니다.