DAY 4 SLIDES
Active and Passive Surface Wave Methods

Majority of material provided by Koichi Hayashi – Geometrics

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Overview – Active and Passive Surface Wave Methods

- What? Why? Advantages and Applications
- Surface waves
- Data acquisition
- Case Histories
- Field Investigation
- Data processing
Active and Passive Surface Wave Methods

- MASW = Multichannel Analysis of Surface Waves (active)
- MAM = Microtremor Array Measurement (passive)

These are....
- Surface wave method used to measure shear wave velocity variation with depth
- Developed in order to overcome the limitations of the SASW method

Why MASW and MAM?

- Using surface wave methods to calculate the shear wave velocity is important because shear velocity is related to the shear modulus, which is directly related to a materials stiffness and shear strain (critical geotechnical engineering properties)
- Cheaper than SPT/CPT or downhole geophysical methods (no need to drill and environmentally friendly, i.e. non-invasive)
- Capable of using in areas that may be inaccessible to drill rigs
- Easier to obtain necessary permits for testing if needed
- Can be correlated with borehole data in order to more fully develop a spatial site investigation
Advantages of MASW over other geophysical applications (Miller et al. 1999)

- The relative high-amplitude nature of surface waves (in comparison to body waves) allows surface wave application in locations of elevated noise levels (where body waves may not be able to produce quality results).
  - Ability to produce shear wave velocity profiles in areas where other geophysical methods may be limited
- Surface-wave propagation does not need velocity to increase with depth (seismic refraction does) and/or require a contrast at a boundary.
- Conductivity inherent in soils, structures that are conductive, electrical noise, and buried utilities can create problems for electrical or electromagnetic methods. The latter generally have little to no influence on the generation/propagation and processing of surface-wave data.

Advantages of MASW over SASW (Ólafsdóttir 2016)

- Reduced time of data acquisition and dispersion analysis
  - MASW is a multiple receiver approach (typically 12 or more) that can be sufficient with a single measurement
  - SASW is a two receiver approach that is set up multiple times in order to obtain results to the desired depth range
- MASW method is able to differentiate fundamental-mode Rayleigh waves from other surface and body waves from both a seismic source and ambient site conditions
- MASW generally provides geophysical information to greater depths than SASW given the same impact load for an active source
- Noise sources are more easily identified (thus leading to a more accurate dispersion curve and shear wave velocity profile)
Applications of MASW

- Shear wave velocity profiles
- Site response
- Foundation Engineering (shear wave velocity related to many critical geotechnical properties)
- Depth to bedrock (case history later)
- Levee inspections (locate potentially weak zones)
- Void and sinkhole detection (case history later)
- Landfill investigations
- Liquefaction potential/Probability of liquefaction
- Quality control for fill compaction

Overview of MASW procedure (Park et al. 2007)
Overview of MASW procedure (Park et al. 2007)

Three General Steps:
1) Acquiring the multichannel field records
2) Extracting dispersion curves (one from each record)
3) Inverting these dispersion curves to obtain 1D velocity profiles (one profile for each curve)

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Seismic waves

- Body waves
  - P-wave
  - S-wave

- Surface-waves
  - Rayleigh-wave
  - Love-wave

$S_V$ and $S_H$ waves
P-$S_V$ and $S_H$ waves

P-S$_V$ and Rayleigh waves

OR
Surface-wave dispersion

Heterogeneous medium

Phase velocity differs in the frequency.

⇒ Dispersion

Dispersion

Propagation velocity is function of frequency

=> Analyze waveform data in frequency domain
What is “dispersion”?

The velocity of each frequency is called **Phase velocity**.

The wave of long period (low frequency) transmits fast, and the wave of short period (high frequency) does slowly.

→ Dispersion
**Surface-wave dispersion**

Q: What is “Phase velocity curve (Dispersion curve)”?
A: It is the graph of phase velocity representing frequency and velocity.

**S-wave velocity model and dispersion curve**

S-wave velocity model

Dispersion curve

H/V and amplification
Passive surface waves
*Microtremor or Ambient noise*

Active and passive surface waves
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Data acquisition

Active method  Passive method

Several important equations in active and passive surface wave methods

\[ \text{Wavelength} = \frac{\text{Phase velocity}}{\text{Frequency}} \]

\[ \text{Depth} = \frac{\text{Wavelength}}{3} \text{ (rule of thumb)} \]

\[ \text{Phase velocity} \approx \text{S-wave velocity} \]
Surface wave sources: Active

Surface wave sources: Passive

Typical dispersion in Structure basin
Active or Passive?

Depth (m)

Usability

Active

Passive

Array size

Active

Passive

Depth = Array size/2

Depth = Array size
Active: Source offset?

Debated: some suggest 0.25*array length (we’ll use this)

Passive: array shape

Circle

Triangle

L shape

Linear
Passive : Data length?

- Depth (m):
  - 100
  - 1000
  - 3000

- Data length (min.):
  - 10
  - 30
  - 100
  - 300
  - 1000

Passive : day or night?

- Source must be outside of array!

- Small array (< 100m):
  - Traffic outside of array can be signal!
  - Can be done day or night.

- Large array (> 100m):
  - Traffic inside of array is noise!

Passive: day or night?

Large array (>100m)

Daytime

Nighttime

< 100 m

> 100 m

Nighttime is better for large array.

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Case History – Mapping Bedrock (Miller et al. 1999)

- MASW can help provide a profile of bedrock depth by itself or incorporated with boreholes.
- The primary objective of this survey was to improve the bedrock surface map and delineate any potential contaminant pathways on or into bedrock.
- MASW geometry selected to optimize the near surface imaging
- We are going to focus on “line 2”

1) Extreme drop in shear wave velocity beneath station 2050 (paleochannel infill of weathered bedrock or a fault zone?)
2) Low Vs zone correlates with a known location of a sewer line (fill around sewer line not compacted?)
3) Wide channel of a drop in shear wave velocity from station number 2140 and eastward (potentially affect fluid movement)
Case History – Mapping Bedrock (Miller et al. 1999)

- Combination of drilling data and surface wave data provide a more representative depth to bedrock

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Case History – Sinkhole (Pusey & Caccese 2014)

- Problem: Sinkhole formed beneath buried petroleum pipeline in unpopulated area with a stream nearby.
- The formation of sinkholes beneath buried pipelines can have the potential of damaging the pipeline and of course causing hazardous environmental incidents (especially with nearby stream).
- Used MASW and microgravity for initial investigation to find sinkholes and then based SPT/rock coring locations to verify sinkholes for grouting.
- Microgravity provided spatial coverage of the area and highlighted voids in the bedrock/weak soil compared to a distinct contrast to dense soil/continuous bedrock
Case History – Sinkhole (Pusey & Caccese 2014)

- MASW investigation performed along the pipeline in order to highlight the subsurface conditions directly beneath the pipeline.

Case History – Sinkhole (Pusey & Caccese 2014)

- SPT/rock coring locations decided by microgravity, MASW, and adjacent to sinkholes observed at the ground surface.
Case History – Sinkhole (Pusey & Caccese 2014)

- Conceptual drawing depicting solution upon geophysical (microgravity and MASW) and geotechnical (SPT/rock coring) investigation

MASW Links

- Link to MASW papers/articles
- Link to geophysical case histories
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Field Investigation

- Head over to Sylvan Grove
- Put the ATOMs in order from smallest to largest (notice there are gaps, e.g. 1, 2, 7, 8)
- Attach the geophones to the ATOMs
- Place the ATOMs (with connected geophones) in the desired geometry/spacing
- Turn on all the ATOMs except one
- Make sure all of the ATOMs are in order from lowest to highest and that all ATOMs are turned on (except one)
- Turn on the last ATOM and the passive test begins
Field Investigation – Key things to prevent unreliable data

- Make sure all of the atoms are turned on and the geophones connected when starting the test
- Geophones are put into the ground straight (they should not be tilted)
- Spacing is maintained in both lateral directions

Linear array of 10 receivers with 2 m spacings

Deploy receivers from smallest to largest in Atom’s ID order.

For active method (MASW), swing a sledge hammer several times at both ends. For passive method (linear array), record ambient noise 10 ~ 20 minutes.
Data acquisition

To distinguish measurements, turn off and on one box at the beginning or ending of the measurements.

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Processing flow

**Passive**
- Raw data
- Ambient noise
- Set geometry
- Spatial autocorrelation
- Phase velocity image in frequency domain
- Dispersion curve
- .rst file (passive)

**Active**
- Shot records
- Event detection
- SEG2 files
- Phase velocity image in frequency domain
- Dispersion curve
- .rst file (active)

**SPACPlus**

**Pickwin**

**WaveEq**

**RAPID**

Raw data

In SPACPlus, waveform traces appear in order from lower to higher Atom ID numbers. An area surrounded by a red rectangle is a “Common Time Block (CTB)” during which all Atom units were recording data (this is why you leave one atom off until you’re ready to start the test.}

![Raw data graph](image-url)
Select a common time block to be processed

Select a common time block (CTB) to be processed, using left and right arrows if several tables are shown.

1st common time block is selected.

2nd common time block is selected.

Processing ambient noise data

Click or select [Window] >> [Processing window] and the selected 1st CTB data (in a red rectangle) will appear in another window. The red rectangle as shown below is for a single atom (note the atom numbers on the far right, e.g. 100003)
Set up geometry

Click for select [Analysis] >> [SPAC analysis] to process passive surface wave data in terms of Spatial Auto Correlation (SPAC). A dialog appears for setting the shape and size of the array. Select “Triangle 10” and put “50” for “Array size”. Click “OK” to proceed.

If your geometry is not listed in default arrays, click “Advanced menu” and “Open array file” and select array file. The array file is a simple ASCII file that mentions X and Y coordinate of geophones.

Example of array file.

Spatial autocorrelations by frequencies

Spatial auto correlations appear. When number of receiver separation is more than three, use buttons to scroll receiver separations to be shown. Click or select [Phase velocity analysis] >> [Phase velocity window] and all spatial auto-correlations and a frequency domain phase velocity image appear in another window.
All spatial autocorrelations and phase velocity image in frequency domain

To set the minimum phase velocity to be picked, adjust a red horizontal line in a phase velocity image in frequency domain by a mouse. Click or select [Surface wave analysis]>>[Show phase velocity curve(s)] >>[Launch WaveEq].

Editing a dispersion curve in WaveEq

Delete noises or unnecessary frequency range.

Use or to select phase velocities.
Hit delete key to delete the selected phase velocities.

Select [File]>>[Save 1D phase velocity curve or H/V curve (.rst)] to save a dispersion curve to data file.
Processing active data (MASW)

Click or select [Window]>>[Processing window] and the selected 2nd CTB data (in a red rectangle) will appear in another window.

Detect shots by event detection

Select [Edit]>>[Event (shot) detection]>>[Detect events] and set event detection parameters.

Click "OK" to detect events (shots).
Detect shots by event detection

Number of detected events appears.

Detected events (shots) are shown. Adjust the settings and repeat the detection until appropriate detections were obtained (i.e. if you know you should have 6 events and the event detection returns 8 then you know something is incorrect).

Edit detected shots

- Change horizontal (time) scale.
- Change amplitude.
- Add new event by clicking a left button of a mouse.

Select a detected event. Selected event is shown as a red bold line.

Hit delete key to delete the detected event.

Use a mouse to move the event (left button down).
Show detected shots by Pickwin

Select [Edit] >> [Event (shot) detection] >> [Cut out shot record as SEG2 files based on detect events].

Enter data length.

Shot records are saved as SEG2 files

Number of saved files appears.

Shot records were saved as SEG2 files (.sg2) in a folder being selected.

A shot and file list was saved in an XML file.
Set up geometry

A list of shot records appear in a dialog box. Set up source location, receiver interval etc.

Individual shot record shown by Pickwin

- Change horizontal (time) scale.
- Change distance scale.
- Change amplitude.
- Scroll shot records.
Transform to phase velocity image in frequency domain

Select [Surface wave analysis] >> [Phase velocity frequency transformation] or press "Ctrl+D" to transform data to a phase velocity image in frequency domain.

Set up max. phase velocity and max. frequency. A phase velocity image in frequency domain appears.

Pick phase velocities

Select [Surface wave analysis] >> [Pick phase velocity (1D)] and set up parameters. Click "Advanced menu" to set up detailed parameters.

Picked phase velocities appear on a phase velocity image in frequency domain. Click left mouse button to move one pick or drag to move a range of picks.

Select [Surface wave analysis] >> [Show phase velocity curve (1D) <Launch WaveEq>].
**Editing a dispersion curve in WaveEq**

Delete noise or unnecessary frequency range.

Use \[ \text{ or } \] to select phase velocities. Hit delete key to delete the selected phase velocities.

Select [File] >> [Save 1D phase velocity curve or H/V curve (.rst)] to save a dispersion curve to data file.

**Combine active and passive dispersion curves**

Select [File] >> [Open 1D phase velocity curve or H/V curve (.rst)]. Select a passive data file (.rst) and choose "Append to present data".

Active and passive phase velocities are shown together.

Data will be automatically averaged if "Yes" is chosen. Choose "No" if you want do not want to average automatically.
Editing active and passive dispersion curves in WaveEq

Delete noise or unnecessary frequency range.

Crick to evaluate approximate depth of penetration.
Green circles indicates 1/3 wave length.

Maximum 1/3 wavelength (70 m in this example) implies approximate depth of penetration.

Remember: Depth = Wavelength/3

Initial model

Select [Surface wave analysis] >> [MASW (1D)] >> [Initial model] to build an initial model.
Set “Depth” based on a penetration depth implied by 1/3 wavelength for example.

Refer “SeisImager/SMW™ Manual” and “SeisImager/SMW-Pro™ Manual” for the inversion of dispersion curves from this point.
Summary: Characteristics of the Surface-wave Methods

- Phase velocity of surface-waves is sensitive to the S-wave velocity
- Both active and passive surface waves can be used
- You can obtain S-wave velocity of the ground easily with surface-wave methods
- You don’t need dynamite or special vibrators
- Shallow (<1m) to deep (>2km) structure can be investigated
References

- Koichi Hayashi – Geometrics
Outline of the Module

- What is Applied Streetview?
- Reconnaissance research applications
- What's in the case
- Installation video
- Preparing the route and app
- Installation and data collection activity
- Creating panoramas and viewing interactive street views in Creator
- HazMapper for viewing panoramas on DesignSafe
- Next-steps for RAPID and DesignSafe: hosting a player
- Discussion of:
  - Ideas for Streetview reconnaissance research
  - Limitations
  - Priorities for development in the near term
What is Applied Streetview

- After-market camera system mountable to a vehicle
- Takes photos with five synchronized cameras
- Uses GPS positioning and the vehicle’s computer to geolocate the photos
- Manufacturer software then:
  - Builds panorama images
  - Compiles panoramas into a web player viewable and with interaction through a browser
  - Player requires a web server that can compile a .php website with SQL database
  - Player is similar in operation to Google Street View

Streetview Processing

- Pictures acquired in the field
- Images are aligned, preliminary coordinates are assigned to each based on GNSS, vehicle velocity, etc.
- Panoramas created by stitching images together through a series of algorithms that produce smooth transitions
- Panoramas are draped on 3D models to create the realistic 3D scenes
- No information on the deformations of the individual photos is provided
Reconnaissance Research Review: Katrina Recovery

- Used repeat photography of several locations over 3 years


Reconnaissance Research Review: Katrina Recovery

- Established recovery scores developed and assigned to observed buildings

Reconnaissance Research Review: Katrina Recovery

- Developed and mapped recovery surfaces using interpolations


Findings:

- Recovery advances in a differential manner, geographically and through time
- Initial recovery (i.e., early in time after event and to Stage 1) is negatively correlated with damage
- Relationship decreases over time, indicating that other factors (i.e., pre-existing social or economic vulnerability) become more important with time.
- Overlaying such data with social and economic layers could provide hints as to what communities need to be recoverable.

Reconnaissance Research Review: Tohoku Tsunami

- Used GSV images to study damage relative to distance from shore, building usage, building frame and cladding, location relative to other buildings


Reconnaissance Research Review: Tohoku Tsunami

- Manually evaluated GSV images to categorize building type and damage

Reconnaissance Research Review: Tohoku Tsunami

- Found concrete buildings had smallest percentage of buildings in D3 or D4
- Clear trends between distance to shore and damage level
- Evidence of sheltering in photos
- Made recommendations for locations and types of vertical evacuation facilities


Reconnaissance Research Review: Computer Vision Concepts

- Developed algorithms to compute a “Streetscore” from GSV images
- Computed “Streetchange” from streetscore at different years
- Combined with census and GIS available data

Reconnaissance Research Review: Computer Vision Concepts

- Found positive correlation: Better initial conditions lead to better urban change

![Graph showing correlation between Streetscore 2007 and Streetchange 2007-2014]


Reconnaissance Research Review: Computer Vision Concepts

- Positive urban change occurs in areas with dense and highly educated populations

![Maps showing population density, share college education, streetscore, and streetchange 2007-2014]

Reconnaissance Research Review: Survey of Rock Slope Failures

- Used GSV images from web to generate point clouds to study the movement of rock slopes.

Reconnaissance Research Review: Survey of Rock Slope Failures

- Compared resulting point cloud for one site to 2010 lidar obtained DEM


Reconnaissance Research Review: Survey of Rock Slope Failures

- Possible to detect and characterise small landslides and rockfalls (< 0.5m³) for study areas relatively close to the road (from 0 to 10 m)
- Possible to detect large-scale landslides or rock collapses (> 1000m³) over areas located far away from the road (100m or more)
- Challenges:
  - Inconsistent image deformations
  - Impossible to extract original images from Google (but not ours!)
  - Large distances between camera and target
  - Obstacles
  - Image quality
  - Meteorological conditions
  - Shadows

Applied Streetview Parts

- Camera
- Primer cable
- Data cable
- Quick-release (mounted)
- Six lens protectors (mounted)
- 120GB SSD

7Ah Battery with battery cable

Battery Monitor

Charger for 7Ah battery with plugs for:
- USA
- UK
- Germany

Navigation device

Snap-in holder for navigation device

GNSS antenna

Programming cable for navigation device

Remote Control tablet with cable and charger

Mini SD card for tablet with adapter

SSD case

SSD to USB cable
For copying data to the PC in the office.
Applied Streetview Parts

Camera Specs

Number of sensors  6
Sensor resolution  5 MP
Sensor size  2560 x 1920 pixel
Image format  jpg
Frame rate  7 fps
Field of view  360 x 160 degree. All but the car’s rooftop.
Release modes  Distance, interval, manually, POI (Point of Interest)
Safety, Limitations, and Concerns

- Adds 2 ft to height of vehicle
- Can’t shoot in rain….wipers on, camera off roof
- Don’t use windshield washer when camera is mounted
- Roof mount can fit around a roof rack, which provides stability and security
- Max speed is 100 km/hr but you should really be slower than that
- Rigging/installation video

Preparing the route and app

- Preparing the route and app:
  - Downloading map tiles
  - Route planning
  - Transfer to tablet
  - Tablet controls
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Where to go from here?

• We will send a link to workshop slides and data via a google drive link early next week; we will also set up a Designsafe folder.
• We will place workshop photos on the Designsafe folder (if you have any others you wish to contribute, please load them to the folder).
• We will send you expense submission instructions via e-mail.
• If you are interested in reconnaissance research, join GEER, SSEER, or other organizations that lead and participate in field missions—but know too that you may organize your own reconnaissance missions and access RAPID instrumentation.
• Think about how reconnaissance can help answer your research questions, and how reconnaissance can be used to address the challenges and methods outlined in the science plans.
• Be in touch with us about with any questions or suggestions (we are here to support your science). Become familiar with our web resources. (Contact NSF with rapid mechanism specific questions).
• Stay in touch with each other. We need a robust natural hazards and disaster research reconnaissance community.
• Use and re-use the open data developed by past, current, and future reconnaissance missions.
• Please….complete our workshop assessment form (you will receive this by e-mail, or at http://bit.ly/rapid-4day-eval). How can we improve the workshop in future years?
• Spread the word about the RAPID facility! (and our workshop program)
• Thank you Jake, leadership team and staff, REUs, vendors, Designsafe, and … you.