(Mar. 27, 2015)

IISEE Lecture on Seismology and Earthquake Engineering Course

Microtremor Observation II

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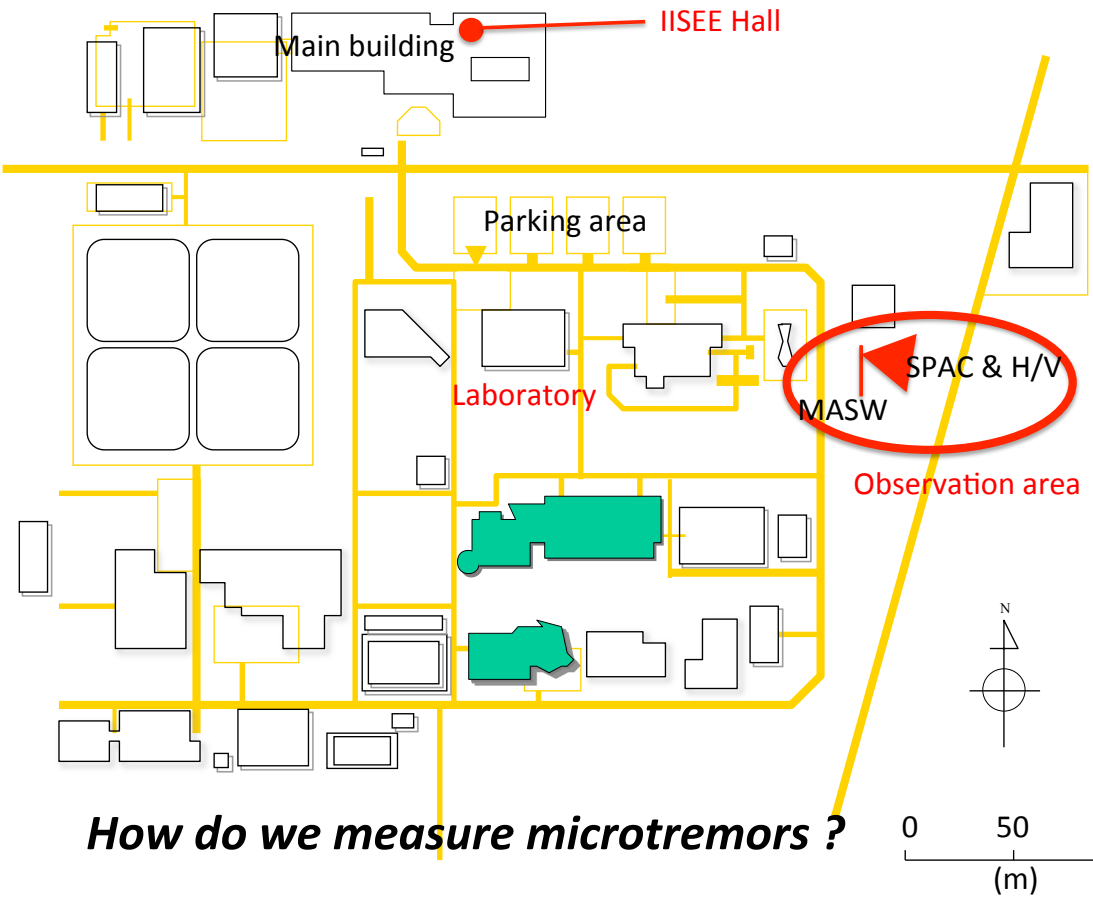
1. CONTENT

Field survey & Data processing

- H/V spectral ratio
- Spatial Autocorrelation (SPAC) method
- Multichannel Analysis of Surface Waves (MASW)

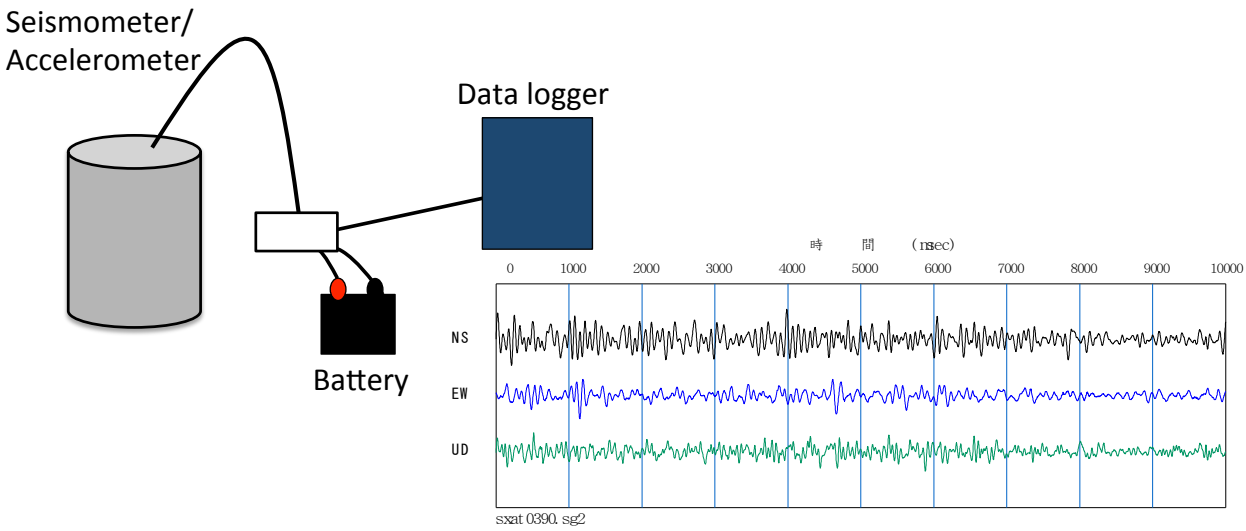
2. FIELD SURVEY



How do we measure microtremors ?

2.1 Single station measurement

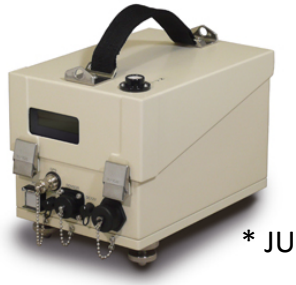
H/V method : Passive method (uses microtremors)



Requirements for H/V method

All-in one accelerometer
- JU-310 (HAKUSAN cooperation)
- Sensor : JA-40GA04 (Japan Aviation Electronics Industry, Ltd.)
- Data logger : LS-8800 (HAKUSAN cooperation)

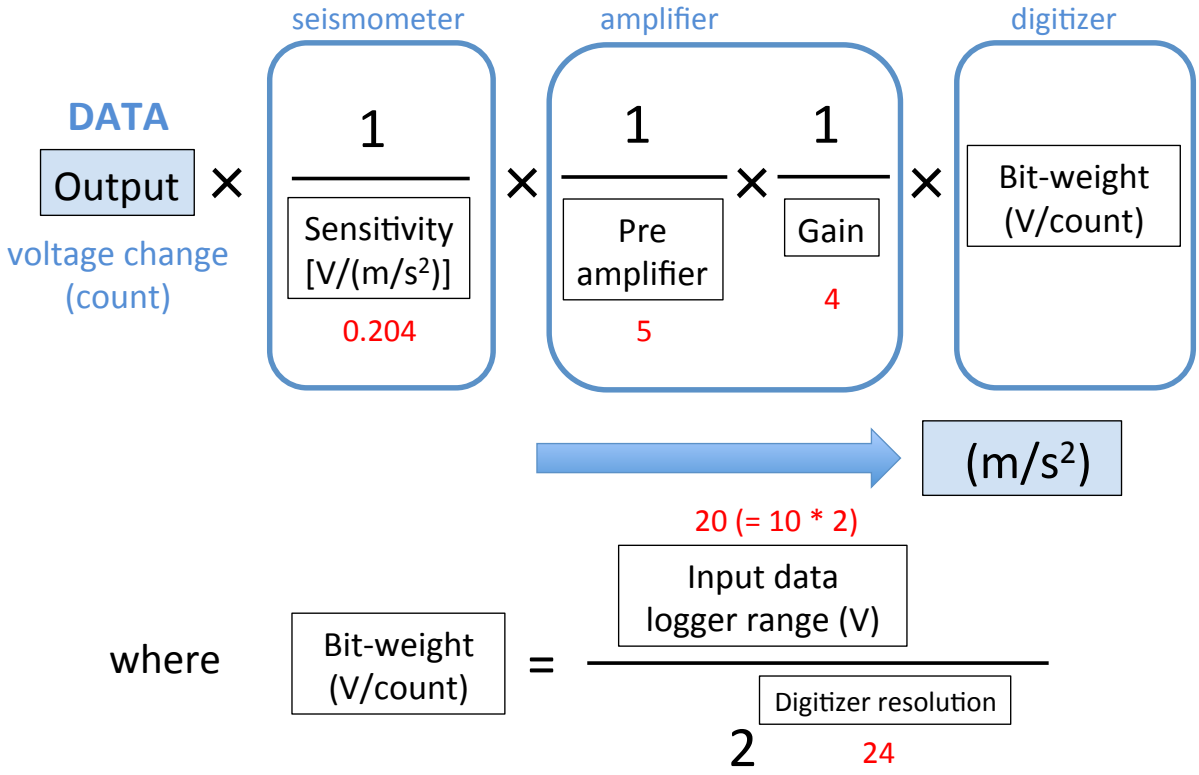
GPS antenna
Compass
SD card



* JU-210 (previous version)

Bandwidth	Resolution	Sensitivity	Preamplifier	Gain	Input data logger range
DC-200 Hz	24-bit	0.204 (V/(m/s^2))	×5	×4	±10V

Supplemental: Unit conversion

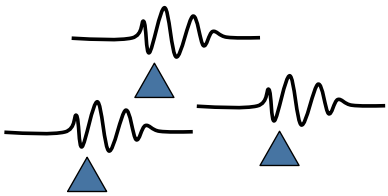


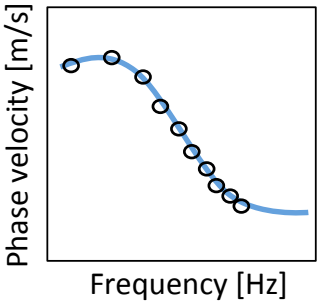
2.2 Array measurement

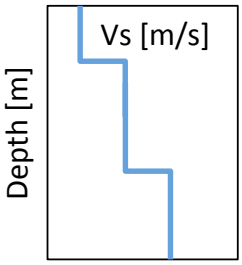
(1) Active method (uses activated source)
- Spectral Analysis of Surface Waves (SASW)
- Multi-channel Analysis of Surface Waves (MASW)
- MASW using Common Midpoint Cross Correlation (CMPCC)

(2) Passive method (uses microtremors)
- Frequency-wavenumber (f-k) method
- SPatial AutoCorrelation (SPAC) method
- Centerless Circular Array (CCA) method
- Fifth (V) method
- Multi-channel Analysis of Surface Waves (MASW)

Brief outline of array analysis for surface waves







1. Data acquisition
-> Observation

↓

2. Data processing
-> surface wave dispersion curve

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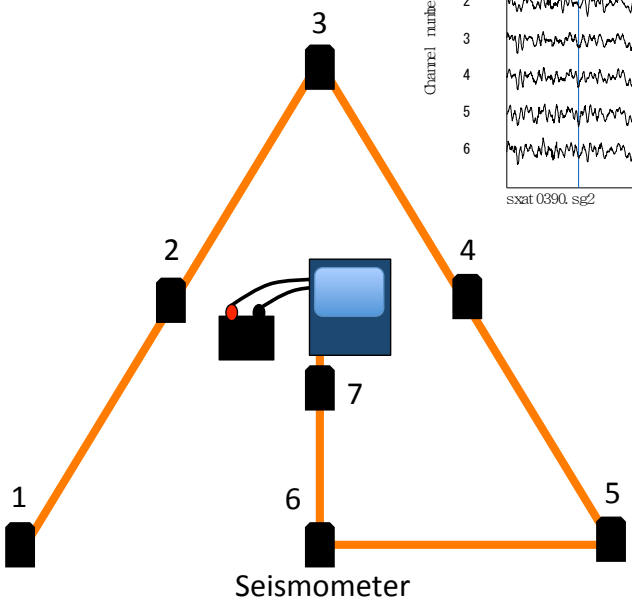
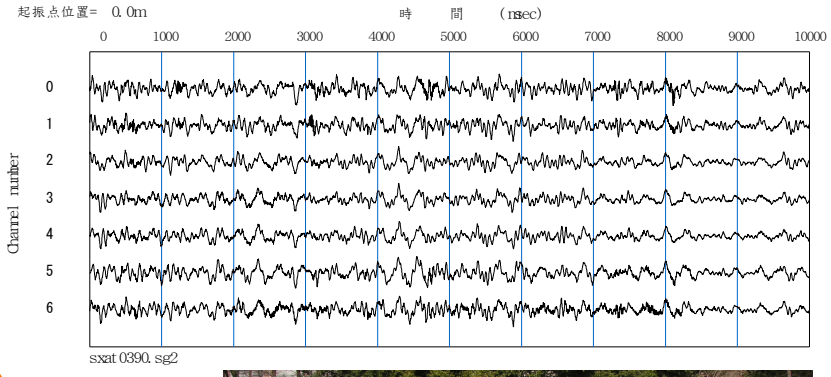
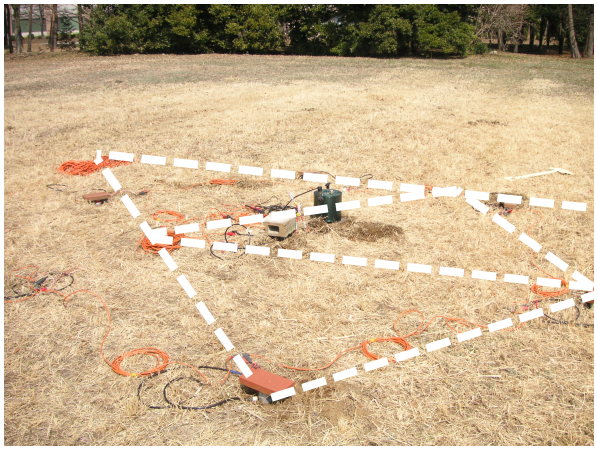
3. Inversion
-> Estimated velocity profile

a. SPAC method







Requirements for measurement

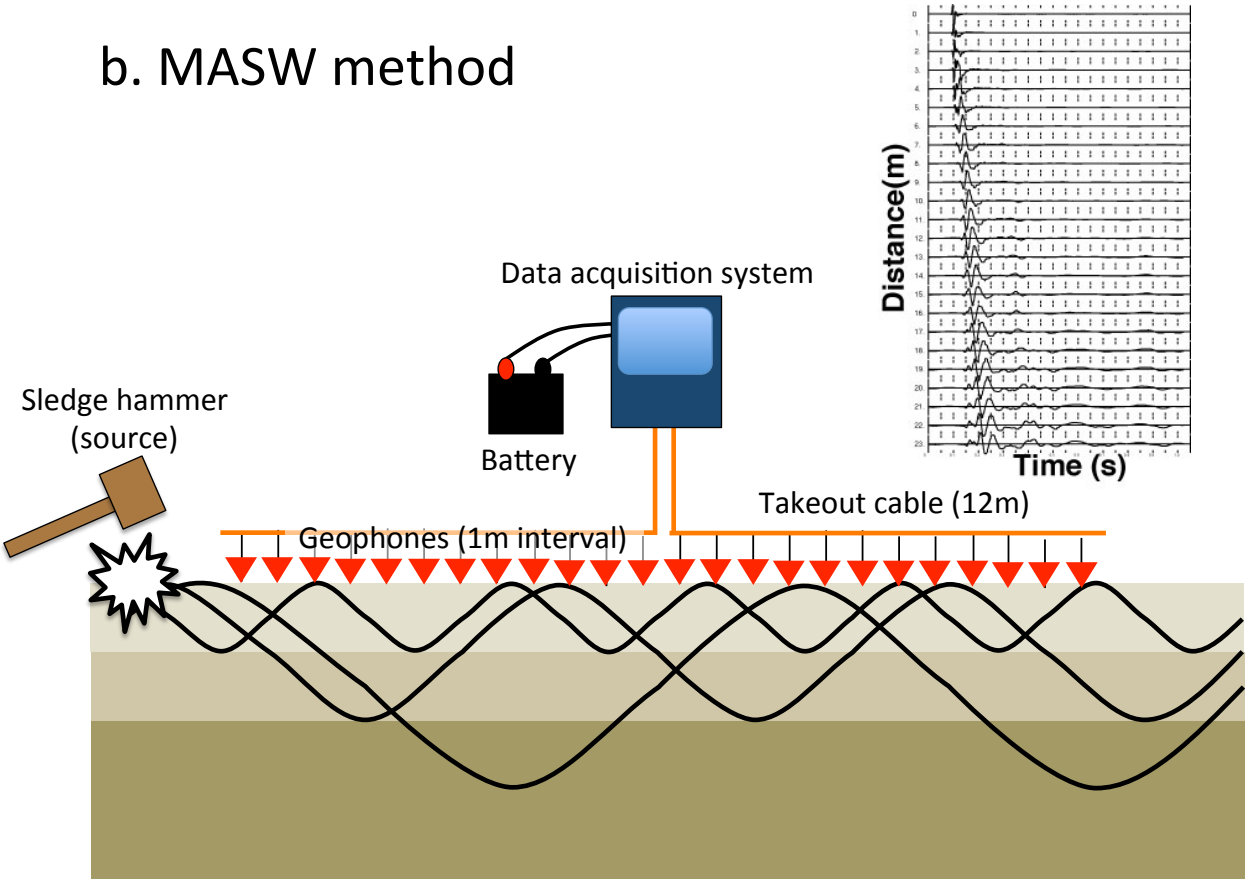
Data acquisition system
(McSEIS-SXW by OYO corp.)

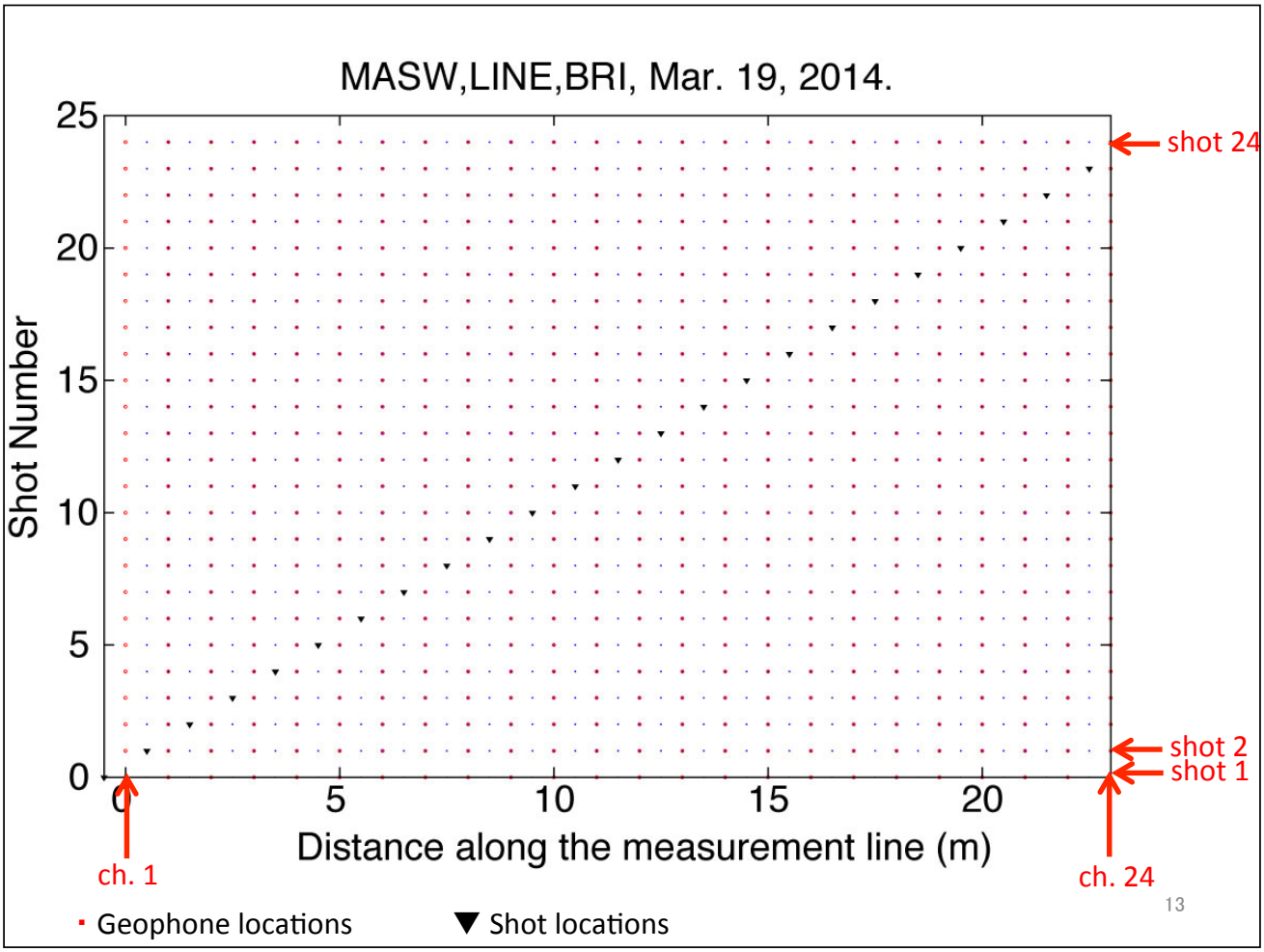
Seismometer × 7
- Natural frequency : 2.0 Hz
- Vertical component

12 channel takeout cables × 2

Concrete bricks × 7
Battery × 1
MO disk
Tape measure

b. MASW method





Requirements for measurement

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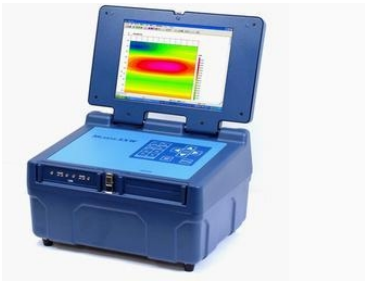
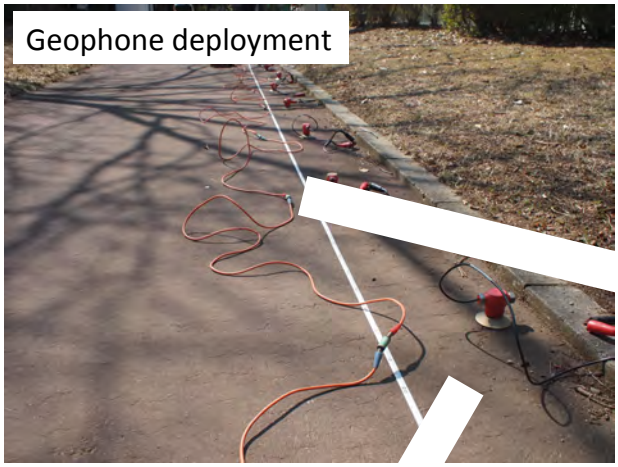
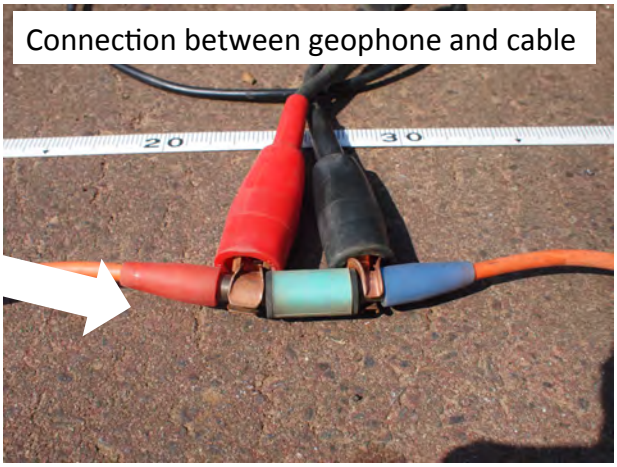


Geophone (sensor) × 24
- 4.5 Hz
- Vertical component

12 channel geophone cables × 2

Battery × 1
MO disk
Sledge hammer × 1
Tape measure





3. BASIC THEORY

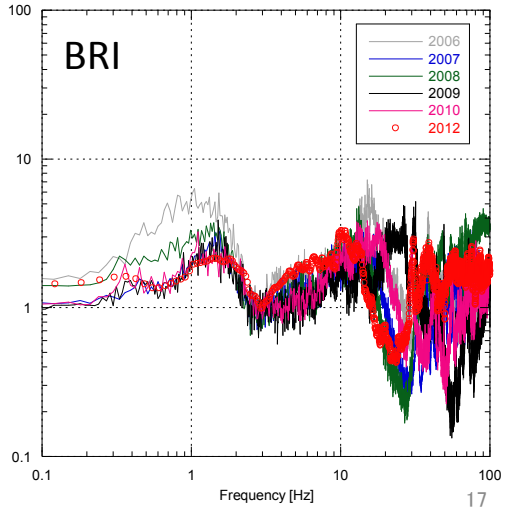
3.1 H/V method

Ratio of horizontal spectrum to vertical spectrum at single site:

$$H/V(\omega) = \frac{\sqrt{F_{NS}(\omega)^2 + F_{EW}(\omega)^2}}{F_{UD}(\omega)}$$

- Easily reduce source effects
- Stable
- corresponds to transfer function for horizontal motion of surface layers (depends only on subsurface soil parameters)

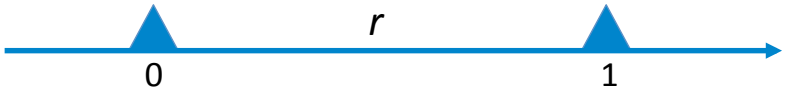
-> H/V can be used to deduce subsurface structure.



3.2 SPAC method

Fourier spectrum at station 0 : $F(0,\omega)$

Fourier spectrum at station 1 : $F(r,\omega)$



Cross-correlation

$$C(0,r,\omega) = F(0,\omega)\cdot\overline{F(r,\omega)}$$
$$= |F(0,\omega)||F(r,\omega)|\exp\{i\Delta\phi(\omega)\}$$

$$\because \Delta\phi = \frac{\omega r}{c} \qquad \exp\left\{i\omega\left(t+\frac{r}{c}\right)\right\} = \exp\left\{i\left(\omega t + \boxed{\frac{\omega r}{c}}\right)\right\}$$

phase shift

$$= |F(0,\omega)||F(r,\omega)|\exp\left(i\frac{\omega r}{c}\right)$$

Coherence

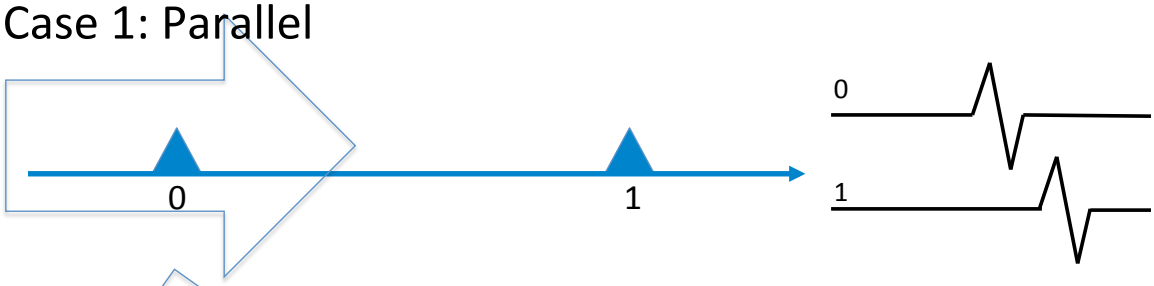
$$Coh(0,r,\omega) = \mathrm{Re}\left[\frac{C(0,r,\omega)}{|F(0,\omega)||F(r,\omega)|}\right]$$

$$= \mathrm{Re}\left[\exp\left(i\frac{\omega r}{c}\right)\right]$$

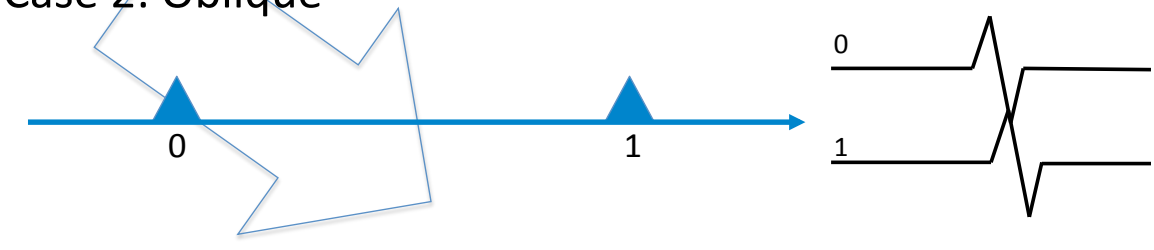
$$= \cos\left(\frac{\omega r}{c}\right)$$

c: Phase velocity received along the measurement line (apparent velocity)

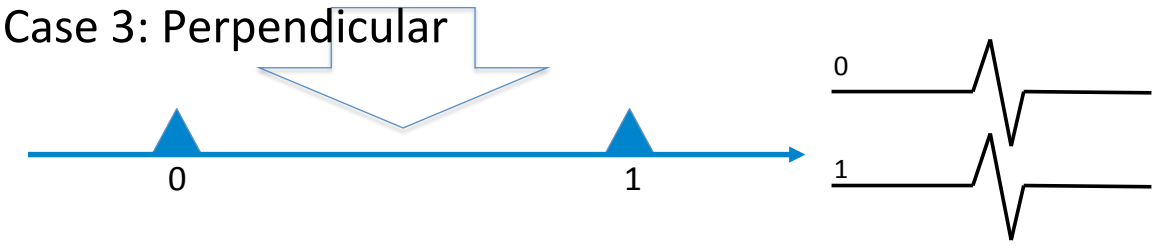
Case 1: Parallel

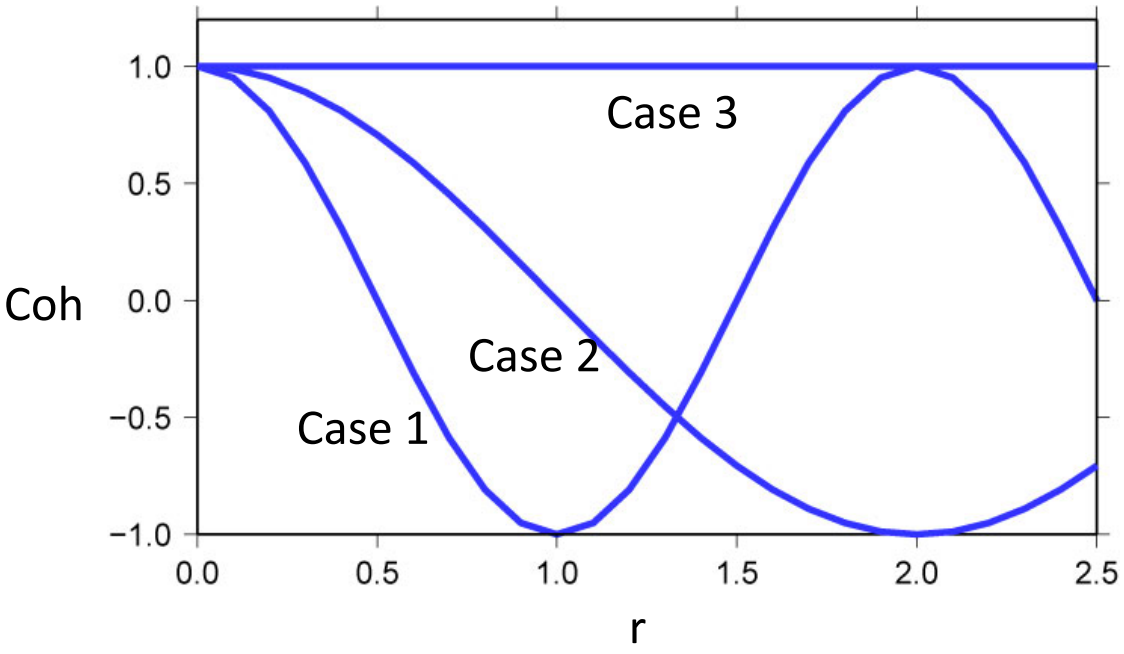


Case 2: Oblique



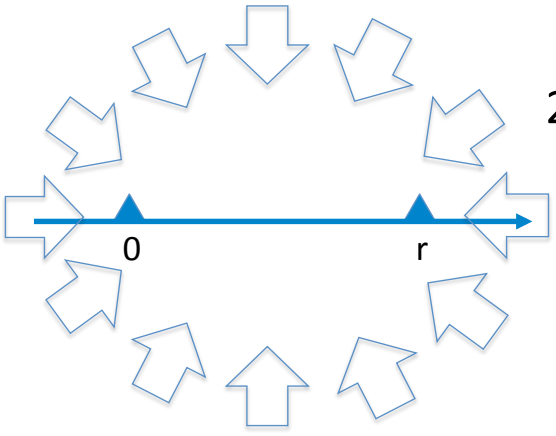
Case 3: Perpendicular





$$\rho(r,\omega) \equiv \mathrm{Re}\left[\frac{C(r,\omega)}{C(0,\omega)}\right] = \frac{|F(r,\omega)|}{|F(0,\omega)|}\mathrm{Re}\left[\exp\left(i\frac{\omega r}{c}\right)\right] \approx \cos\left\{\frac{\omega r}{c(\omega)}\right\}$$

SPAC coefficient



2D wave propagation

Cross correlation between two sites

$$\rho(r,\omega) = \frac{1}{2\pi}\int_0^{2\pi}\left(\frac{C(r,\theta,\omega)}{C(0,\theta,\omega)}\right)d\theta$$

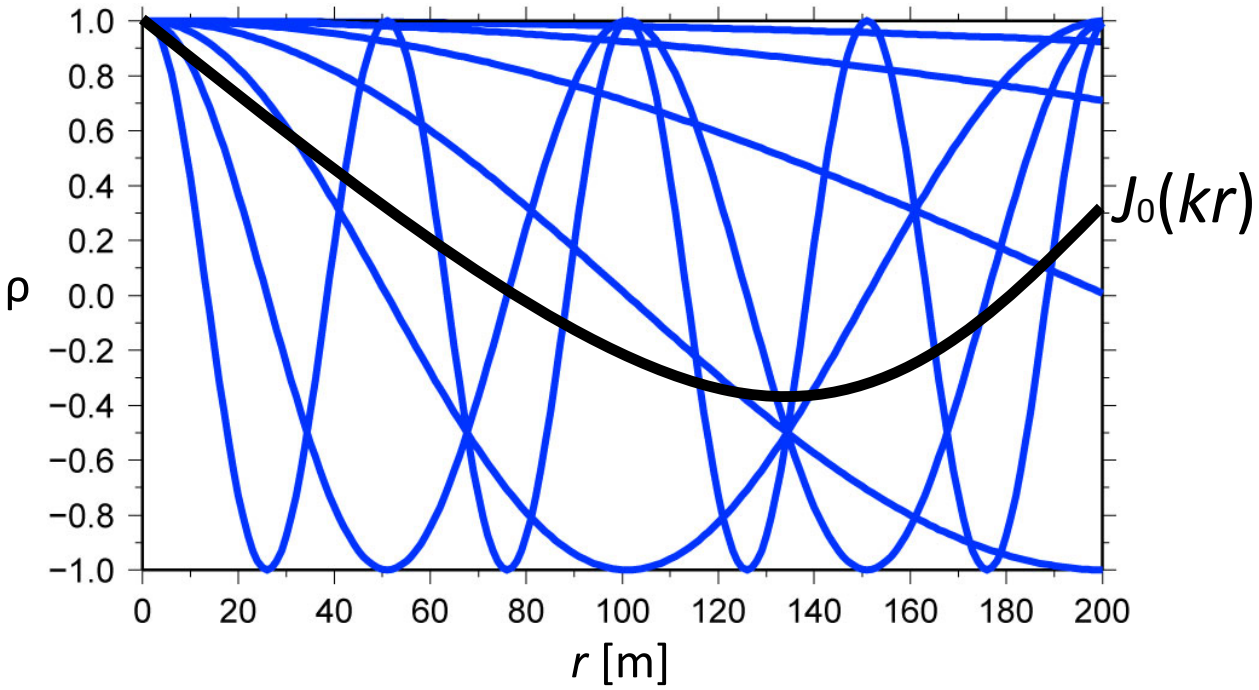
Auto correlation at reference site

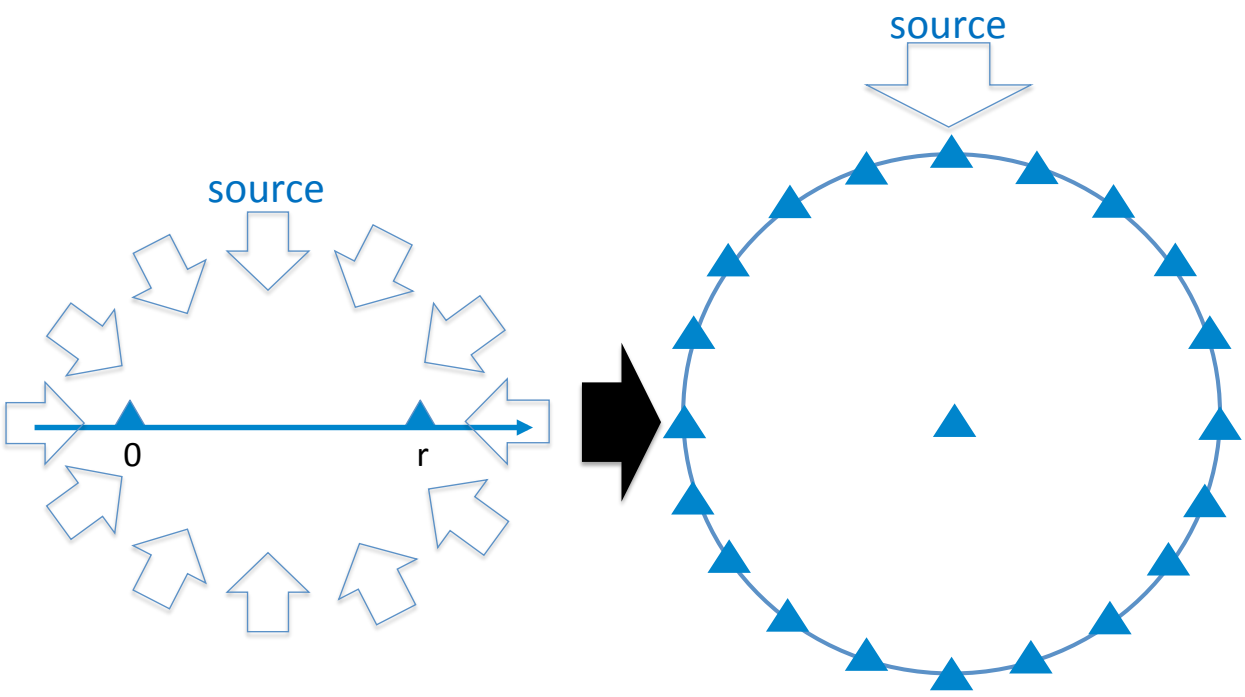
$$\cong J_0\left\{\frac{\omega r}{c(\omega)}\right\}$$

Bessel Function of the of first kind of zero order

Details : Aki (1957), Okada (2003)

Expression of SPAC coefficient

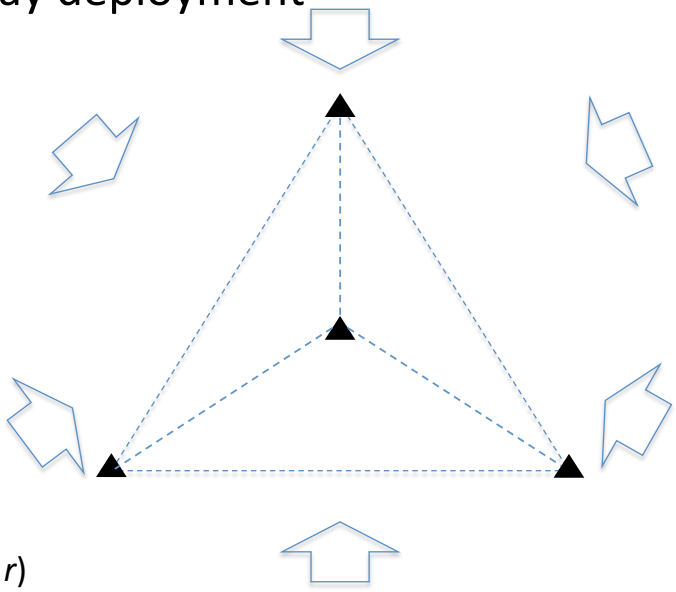




Stations: two station
Source: spatially uniform

Stations: circular array
Source: nonuniform

Practical array deployment

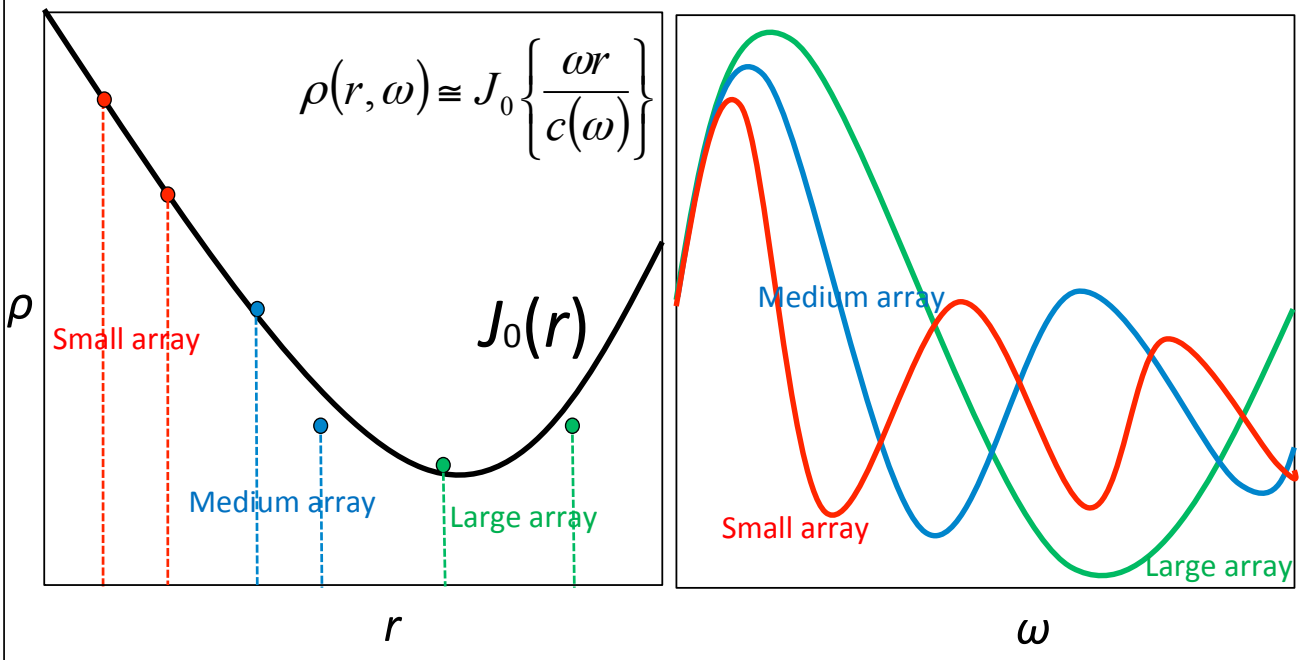


Small array (small *r*)
-> provides information on short wavelength surface wave propagation characteristics
Large array (large *r*)
-> provides information on long wavelength surface wave propagation characteristics

Combination use of small and large array observations provides surface wave phase velocities in a broader frequency range.

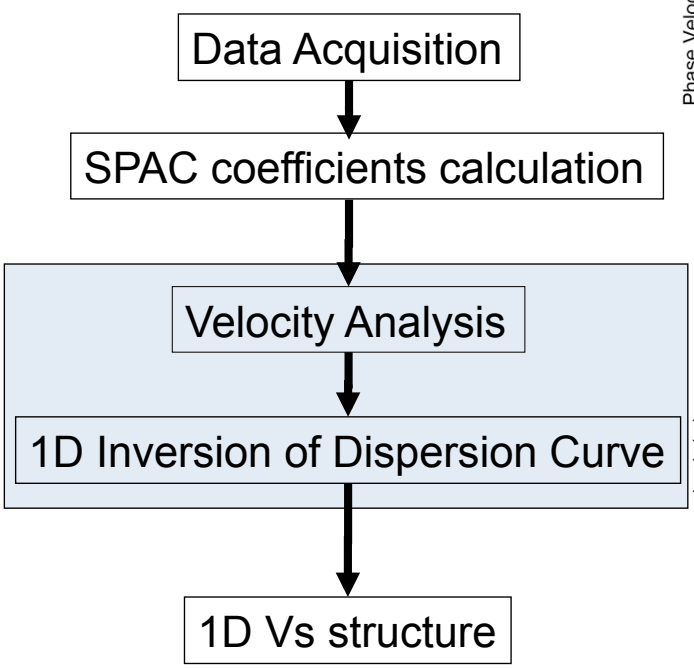
For fixed ω

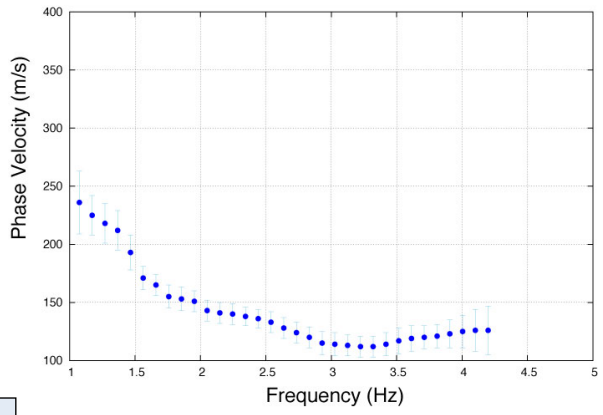
For fixed r

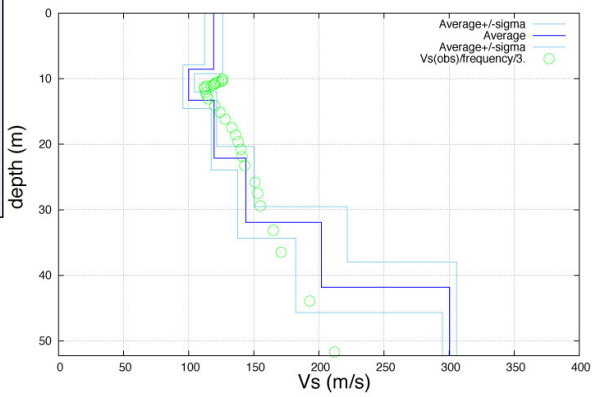


Phase velocity dispersion is estimated by fitting derived SPAC coefficients for target *r* and ω and the Bessel functions $J_0(r)$.

Task Flow of SPAC method



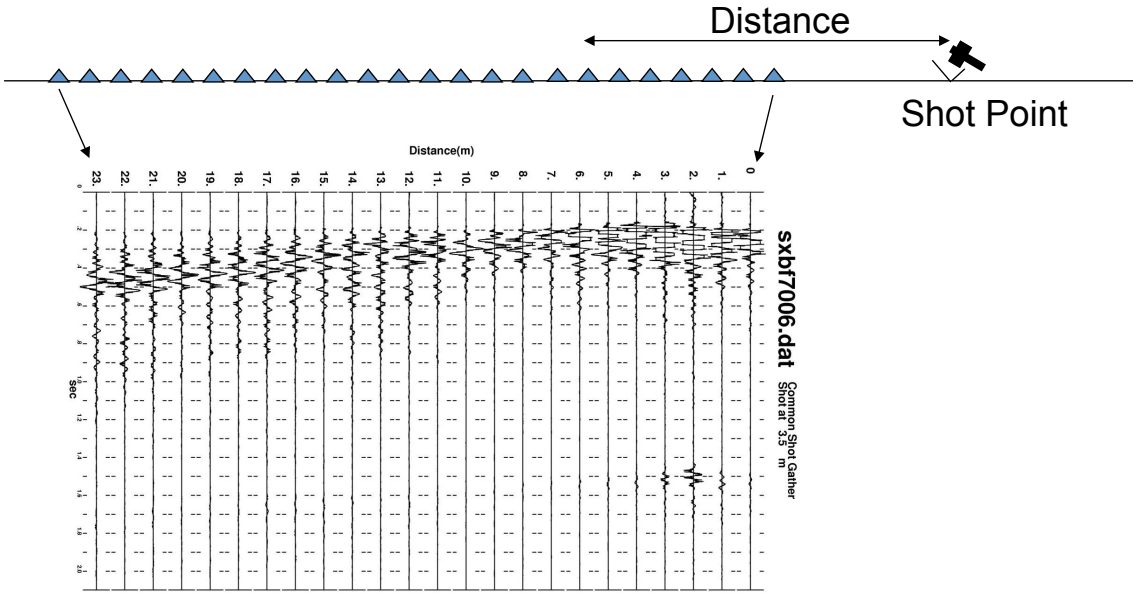




3.3 MASW method

Common Shot Gather

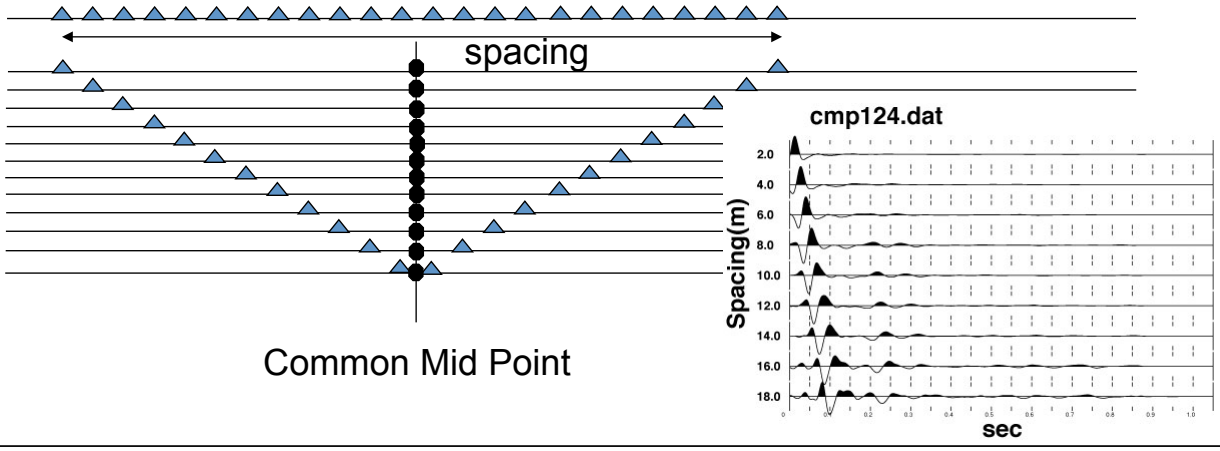
A group of seismic traces having the same shot point



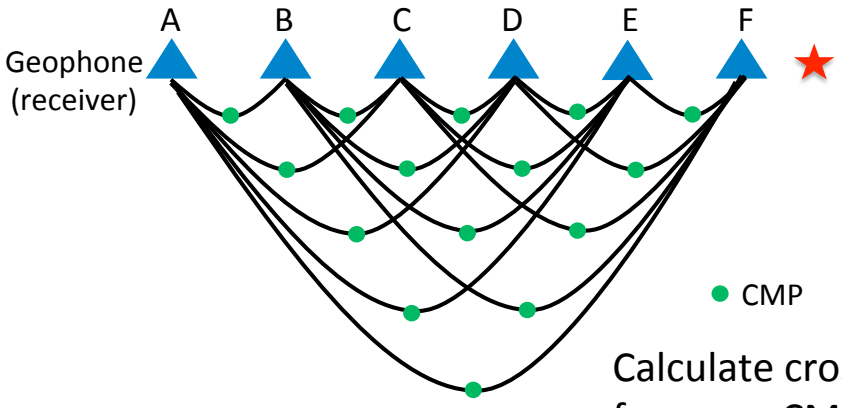
Common Mid Point (CMP) Gather

Usual definition: A group of seismic traces having the same mid point between shot and detector (geophone)

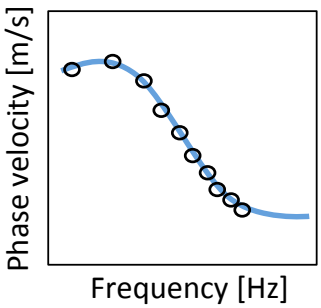
For MASW: A group of correlograms having the same mid point between a pair of detectors (geophone).
A CMP gather includes correlograms of various spacing.



Conventional MASW (Park et al., 1999)



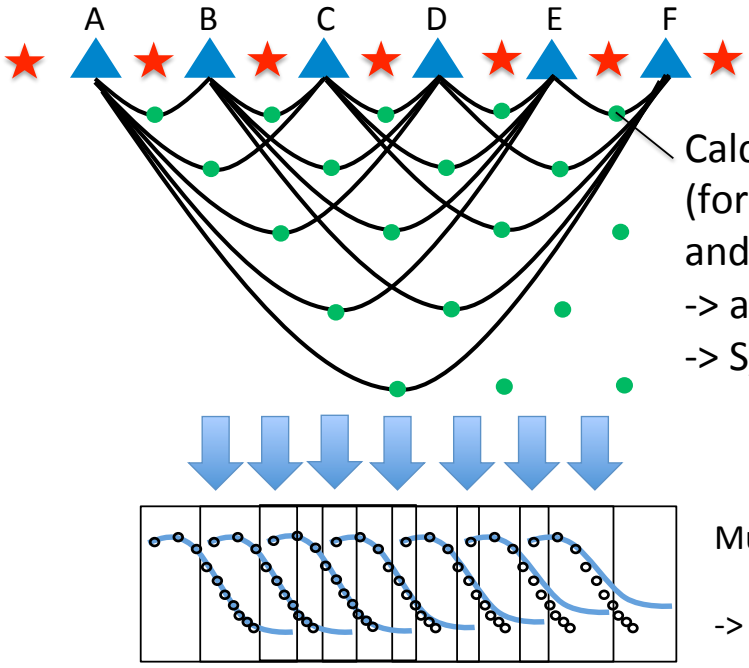
Calculate cross-correlograms for every CMP, one shot



One dispersion curve

-> averaged 1D (layered) structure

Basic concept of MASW using CMP Cross Correlation (Hayashi and Suzuki, 2004)

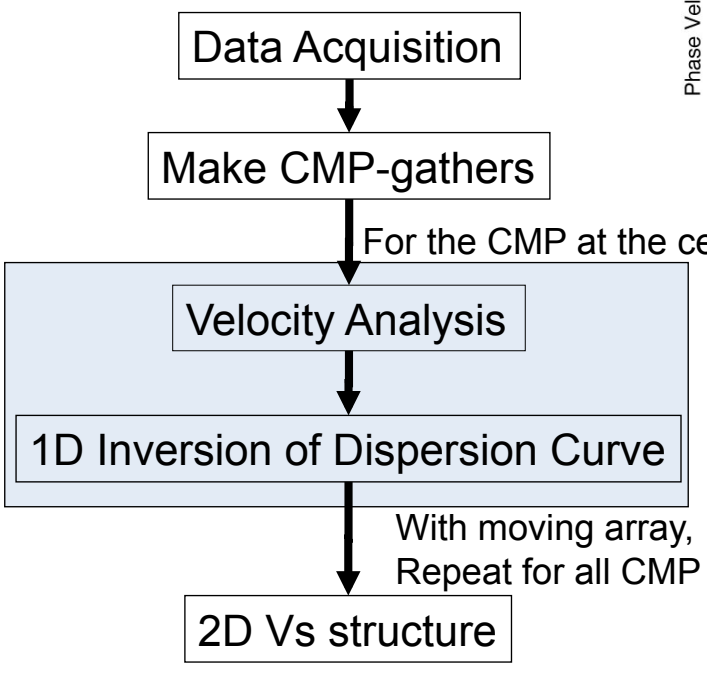


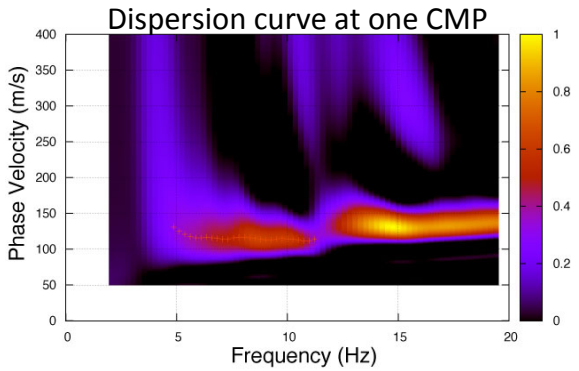
Calculate cross-correlograms (for each CMP, every shot) and stack it.
-> accuracy is improved
-> S/N is increased

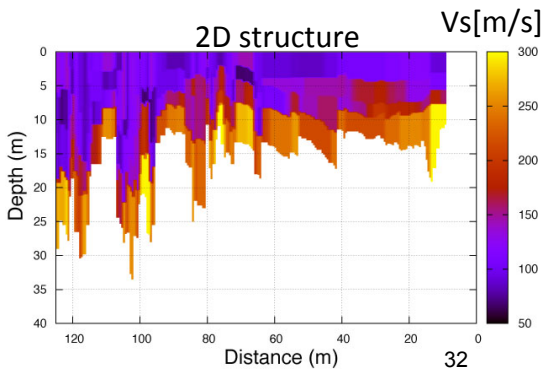
Multi-dispersion curves

-> Detailed 2D structure

Task Flow of MASW







3.4 Calculation code: SPAC and MASW methods

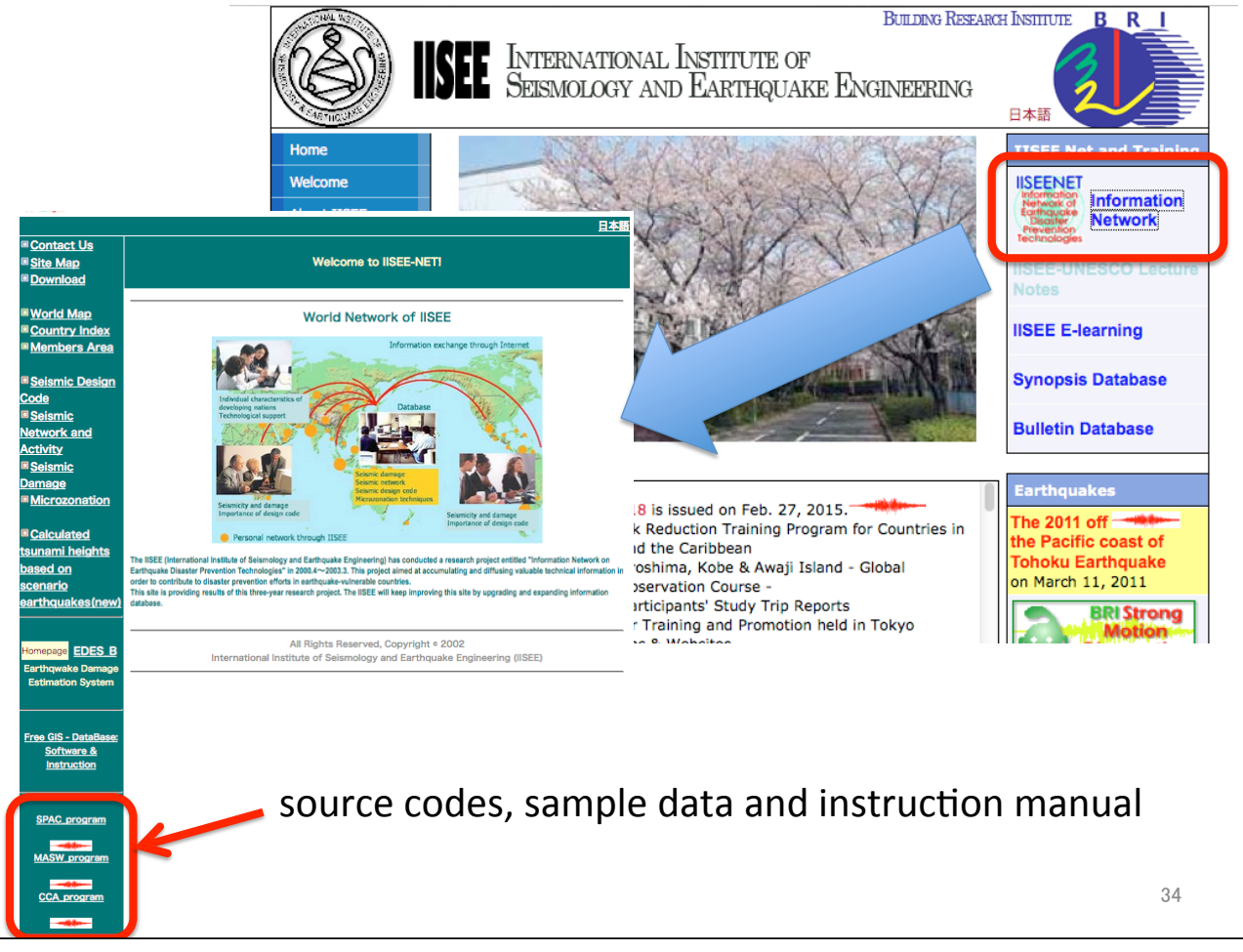
Developed by Dr. Yokoi

- used for individual study (IISEE regular course)
- used for practical purposes
- developed using FORTRAN77 (g77) programming code
- tested on Windows (Cygwin) and Linux (Ubuntu 12.04)
- provided free of charge

Manners

*please let the developer know when you use

*please describe the software/developer names when you write a paper or make presentations



source codes, sample data and instruction manual

4. REFERENCES

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Okada, H. (2003), *The microseismic survey method: Society of Exploration Geophysicists of Japan* (translated by Koya Suto), Geophysical Monograph Series **12**, Society of Exploration Geophysicists.

Park C.B., Miller R.D., and Xia J. (1999), *Multichannel analysis of surface waves*, Geophysics, **64**, 800–808.

5. TODAY'S DATA AND RESULTS

file:\\CATFISH\share\lecture\MicrotremorObservation

will be uploaded within a few days …(weeks?)