

- Final Conference -
Earthquake engineering
Presentation of the book

“Strategies for reduction of the seismic risk”



EVALUATION OF SOIL STIFFNESS BY IN SITU INNOVATIVE TECHNIQUE

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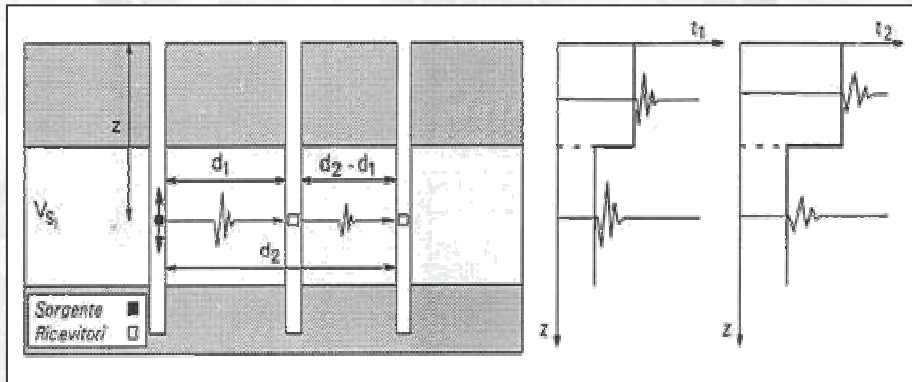
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- Signal processing***
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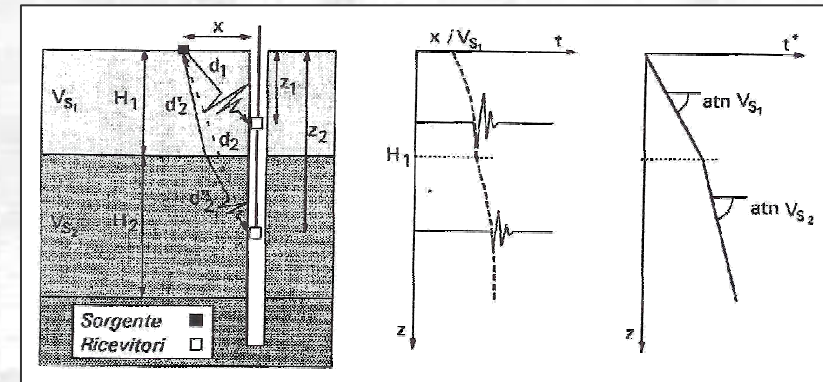
In situ techniques

□ Invasive methods

▪ Cross-Hole

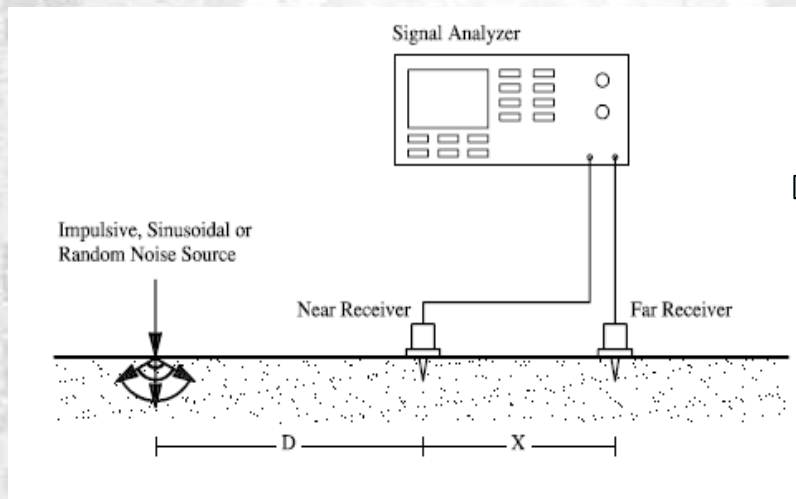


▪ Down-Hole

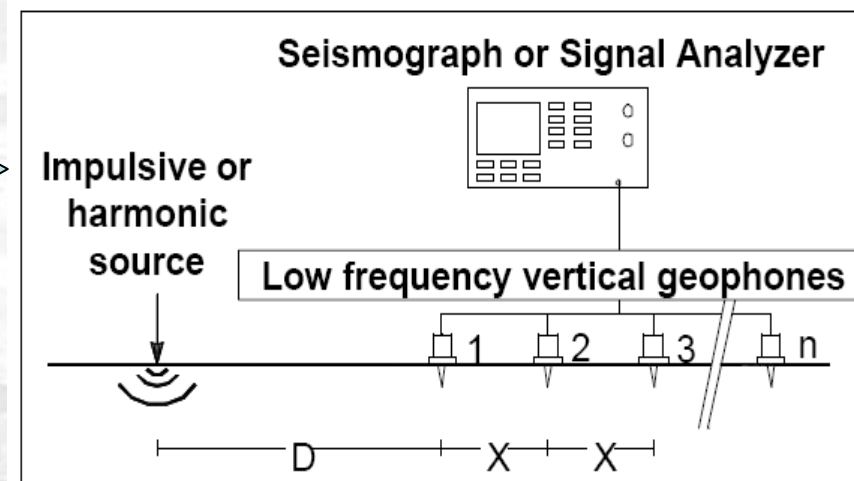


□ Non invasive methods

▪ SASW



▪ MASW



In situ techniques

INVASIVE METHODS

NON INVASIVE METHODS

ADVANTAGES

- *Direct measurements: simple and accurate interpretation*
- *Good resolution also at great depth*
- *Additional information from borehole logging or the penetration of the cone*
- *Costs and flexibility (in time and space)*
- *Non-intrusive (important for waste landfills)*
- *Average properties (dynamic behaviour of the whole soil deposit)*
- *Large volumes are investigated*

DISADVANTAGES

- *Costs and necessity of planning well in advance*
- *Complex interpretation (indirect measurements based on inversion procedures)*



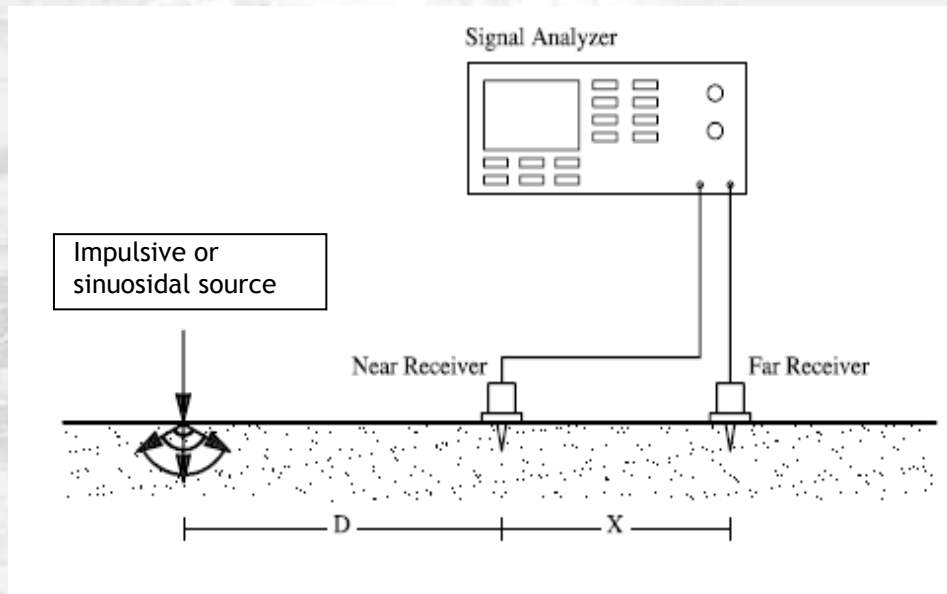
***Application of non invasive test
at study of geotechnical
characterization on large area***

Spectral Analysis of Surface Waves methods

Spectral Analysis of surface waves tests utilizes the dispersive nature of Rayleigh-type surface waves (relation between Rayleigh wave velocity and frequency or wavelength) propagating through a layered material to determine the shear wave velocity profile into the material.

The traditional test setup (SASW) uses two sensors to measure an actively produced Rayleigh surface wavefield at several spatial lags.

The source is an active source: an impulsive or sinusoidal source.



DISADVANTAGES

- time consuming;
- limited soil volume;
- no ability to consider interfering noise;
- no ability to consider near-field effects;
- no ability to consider multiple mode of propagation.

Spectral Analysis of Surface Waves methods

The Multichannel test setup (MASW) uses:

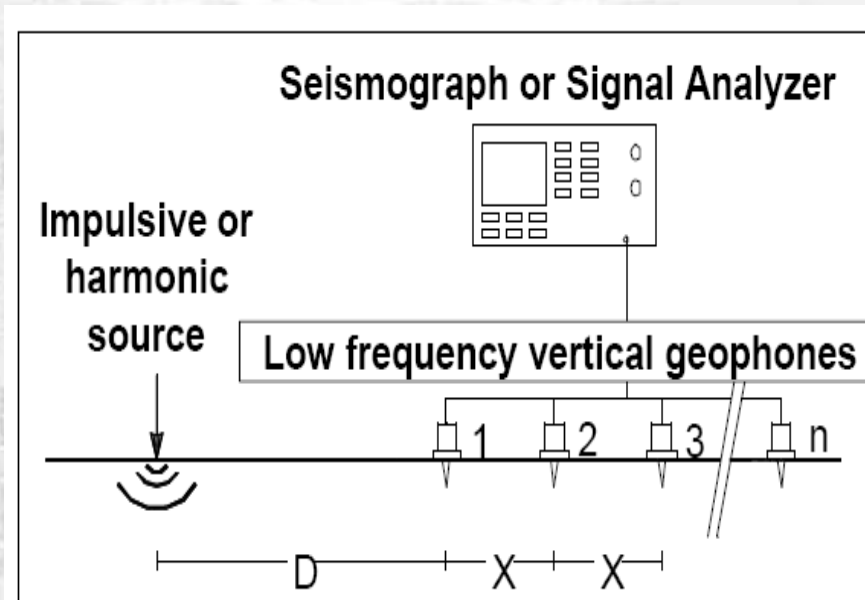
- multiple receivers (>2);
- two types of sources: *Active sources* (impulsive or harmonic)
Passive sources (cultural noise, microtremors and traffic);
- geometry of the array and type of analysis depend on the source type:

Linear array

Two-dimensional array

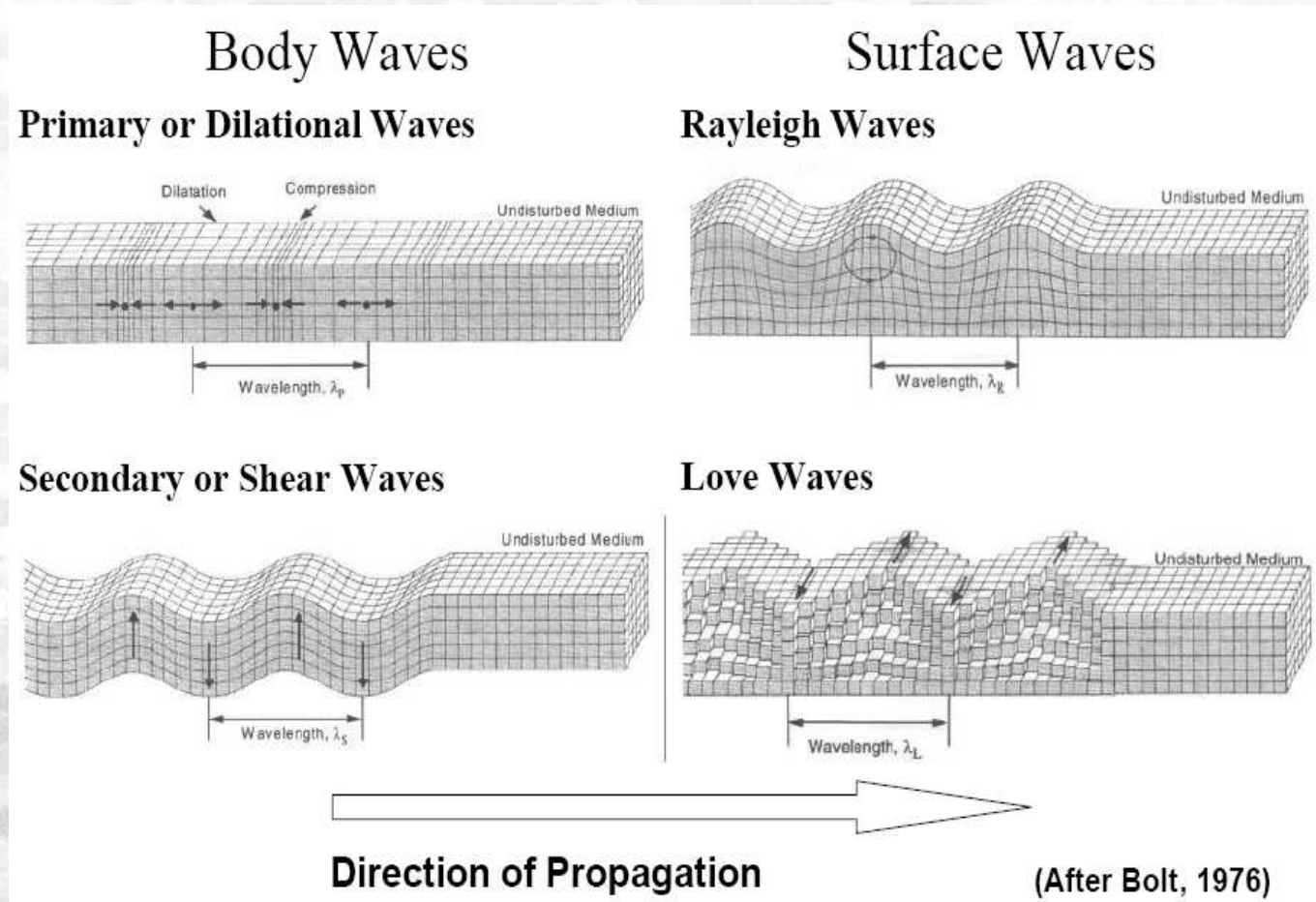
ADVANTAGES

- information at several spatial lag simultaneously
- ability to consider interfering noise;
- mitigation of near-field effects;
- ability to isolate a single mode of propagation;
- ability to isolate multiple modes of propagation.



Rayleigh Waves

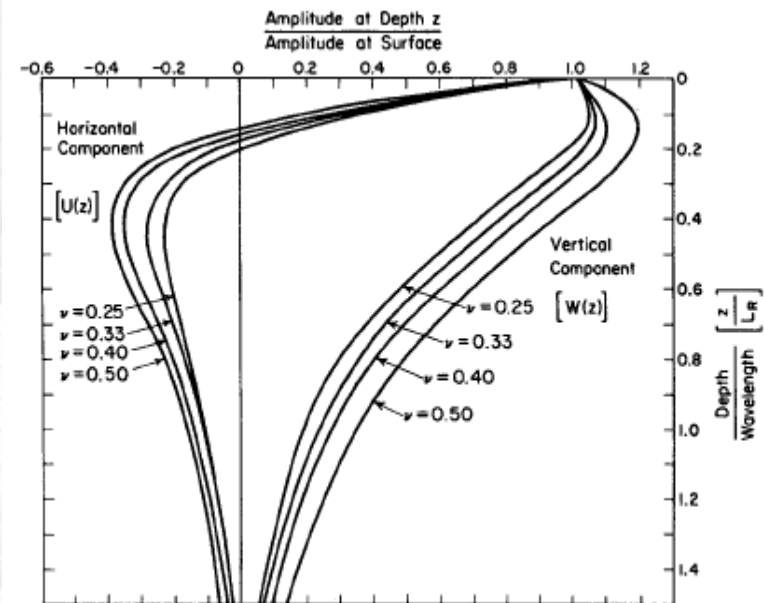
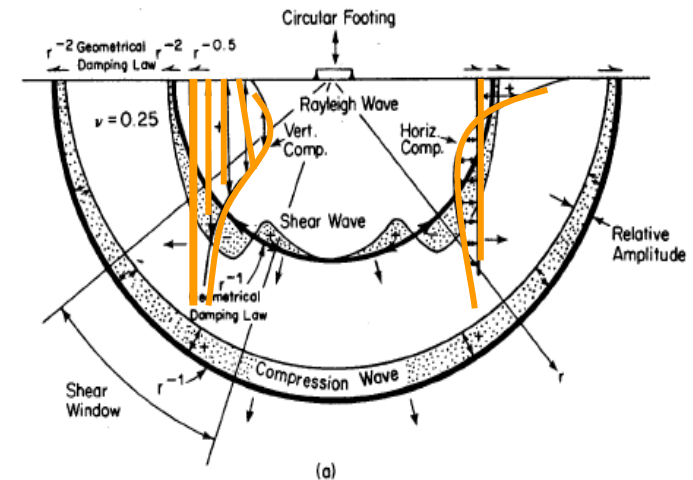
Seismic waves propagating in a medium bounded by a free surface can be categorized into two type: Body waves and Surface waves .



Rayleigh waves are the result of an incident P and SV plane waves interacting at the free surface and traveling parallel to that surface.

Rayleigh Waves

- ❑ Easily generated and detected on the ground surface;
- ❑ Travel along the surface with a retrograde elliptical particle motion and changing to prograde with depth passing through a node where there is no motion at all. Rayleigh wave particle motion is only found in the vertical plane with no tangential motion.
- ❑ 2/3 of the total energy released by a vertical harmonic point source acting on the surface of a homogeneous halfspace;
- ❑ Reduced geometrical attenuation ($1/\sqrt{r}$) compared to other waves;
- ❑ The propagation involves only a limited depth (~ 1 wavelength);
- ❑ *In homogenous linear elastic media: velocity of propagation is almost equal to V_s and it is not frequency dependent;*
- ❑ *In vertically heterogeneous media: dispersive behaviour, i.e. phase velocity is function of frequency.*



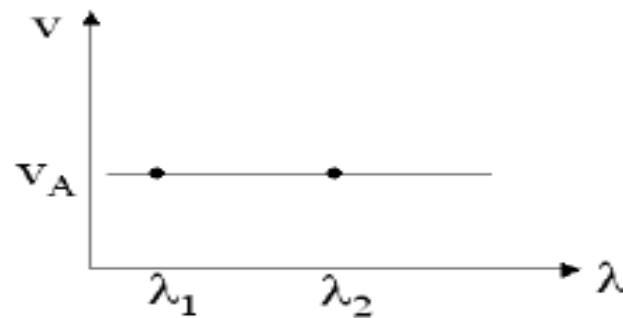
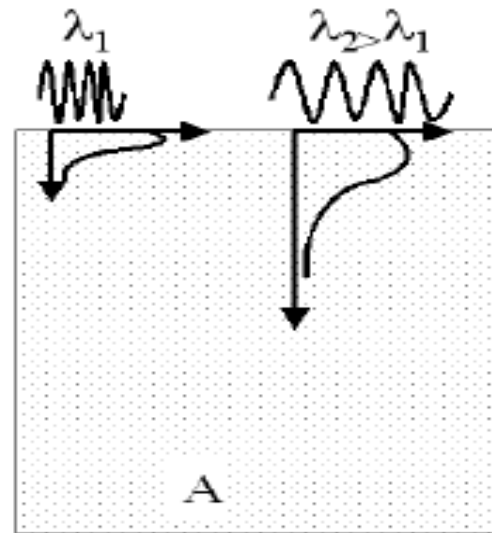
Rayleigh Waves

Active
armonic
source

Dispersion
Relation

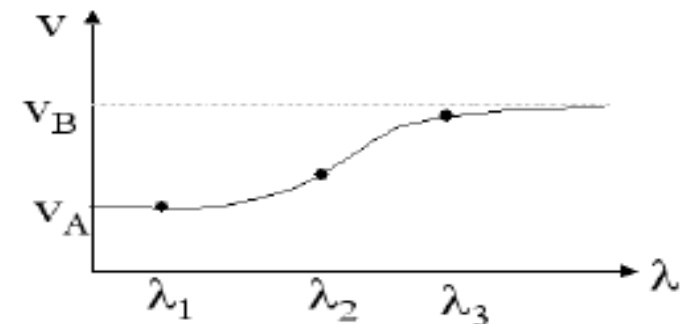
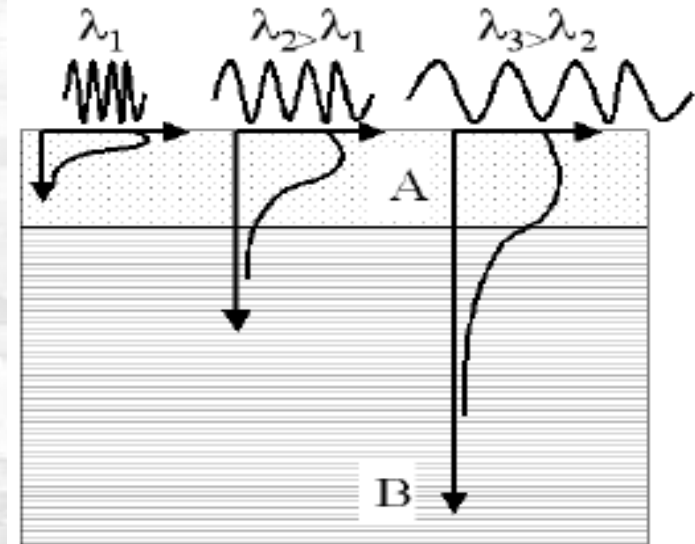
$$V_r = \lambda \cdot f$$

Homogenous medium



waves of different frequency
or wavelength propagate at
same velocities

Eterhomogenous medium



waves of different frequency
or wavelength propagate at
different velocities

Experimental Procedure

:

-Dispersion properties of R-waves :

samples at smaller frequency intervals as frequency decreases.

-Number of point to be used in the frequency domain calculation:

limit to the frequency resolution of the calculations

RESOLUTION

$$\Delta f = f_s / N$$

The chosen test frequencies must all be multiples of Δf resulting in a minimum temporal spacing of Δf .

The upper limit of frequency resolution:

:

ALIASING (N_{quist} frequency)

$$f_{N_{\text{quist}}} = f_s / 2$$

Experimental Procedure

The ability to measure a surface wavefield is directly related to the geometry of the receiver configuration. For actively produced wavefields, the direction of propagation is known, so the problem of determining the wavefield characteristics simplifies to one of scalar wavenumber estimation.

In an ideal case, spatial information would be collected at all spatial distances. However, practical constraints necessitate the use of a limited number of sensors placed in an optimum geometry.

ALIASING (N_{quist} Criterion)

$$k_{N_{\text{quist}}} = \pi / d_{\text{min}}$$

RESOLUTION (Rayleigh Criterion)

$$\Delta k = 2\pi / L$$

Insufficient minimum wavenumber resolution can cause multiple waves with closely spaced wavenumbers to become combined into a single peak, limiting the wavenumber resolution and accuracy of the analysis. This results in a superposition of modal energies and results in the estimate of an effective phase velocity.

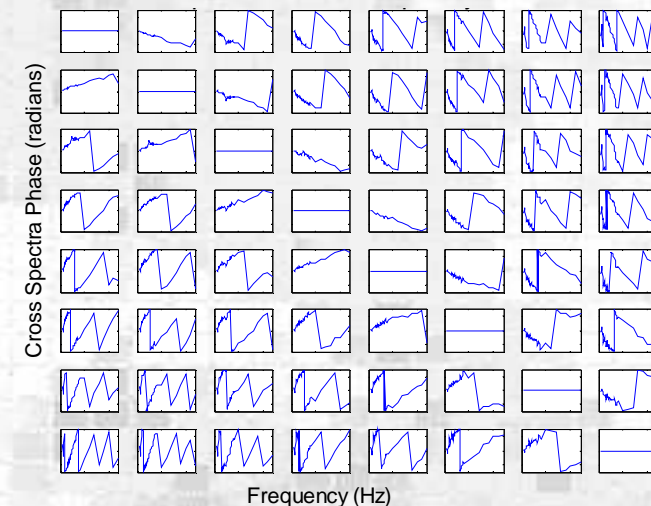
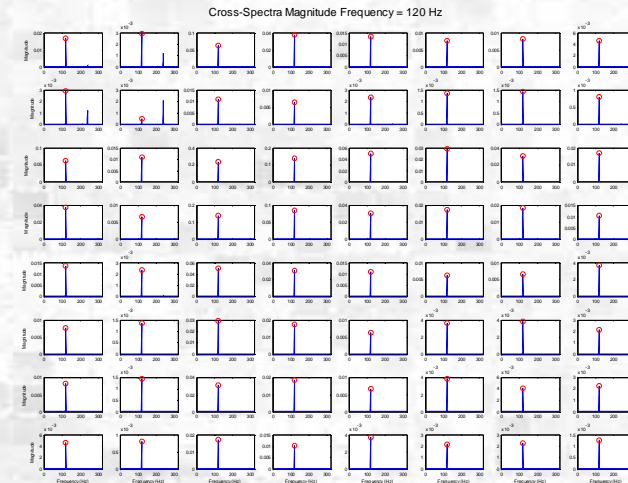
Signal Processing

Frequency-wavenumber spectral techniques are based on the premise of scanning wavenumber space to determine the wavenumber power spectrum for each frequency of interest.

1. CROSS POWER SPECTRUM DENSITY FUNCTION for each frequency of the ave generation

2. SPATIOSPECTRAL CORRALTION MATRIX

$$R(f) = \begin{bmatrix} S_{11}(f) & S_{12}(f) & \cdots & S_{1M}(f) \\ S_{21}(f) & S_{22}(f) & \cdots & S_{2M}(f) \\ \vdots & \vdots & \ddots & \vdots \\ S_{M1}(f) & S_{M2}(f) & \cdots & S_{MM}(f) \end{bmatrix}$$



Signal Processing

3. FREQUENCY DOMAIN BEAMFORMER ANALYSIS

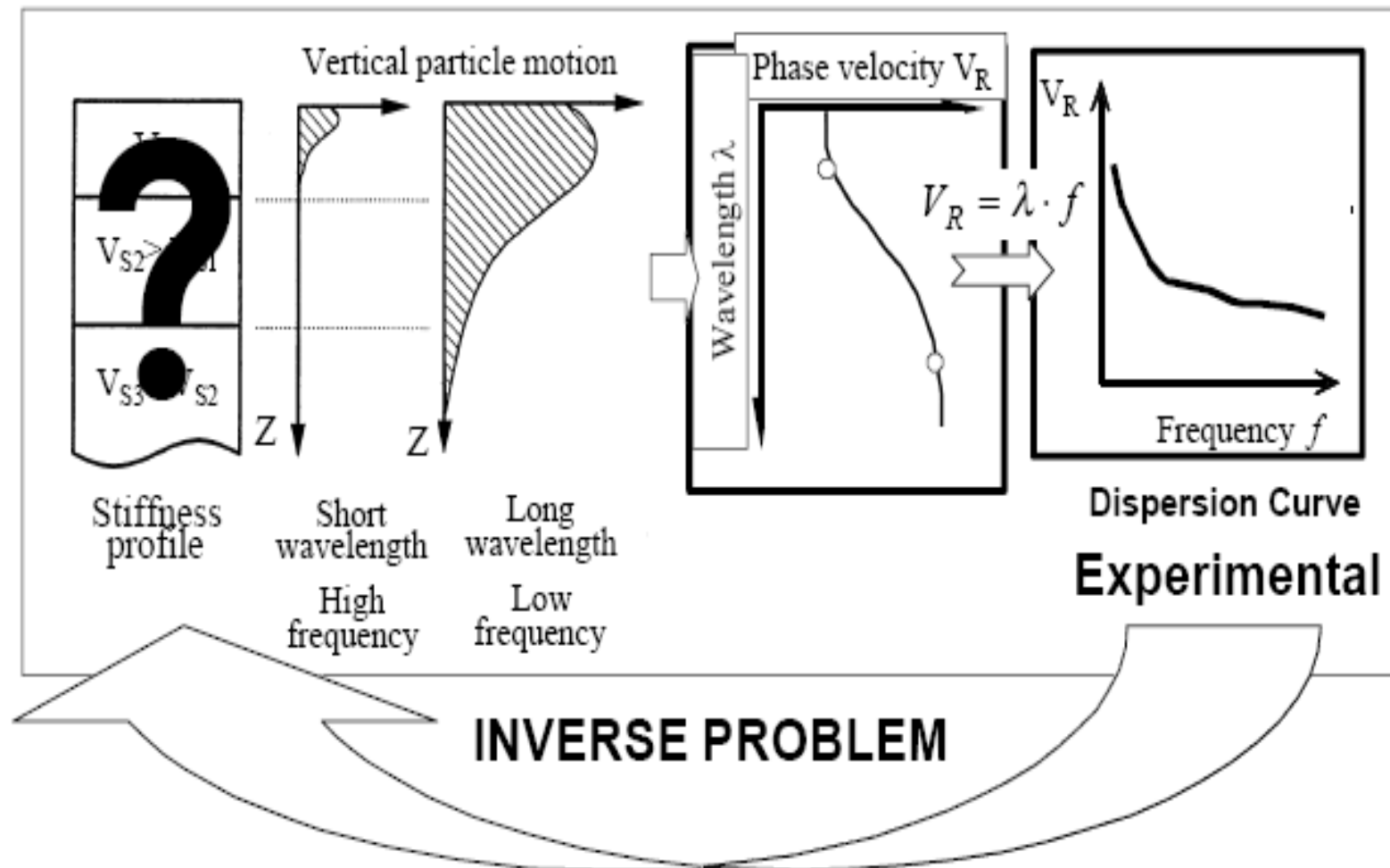
$$\mathbf{e}(\mathbf{k}) = \left[e^{-ikx_1}, \dots, e^{-ikx_M} \right]^T$$

Steering vector: phase shift
vector associated with a trial \mathbf{k}

$$Z(k, f_0) = \sum_{m=1}^M w_m S_m(f_0) e^{-ikx_m}$$

By peaks in the f - k Power Spectrum is
obtained the dispersion curve.

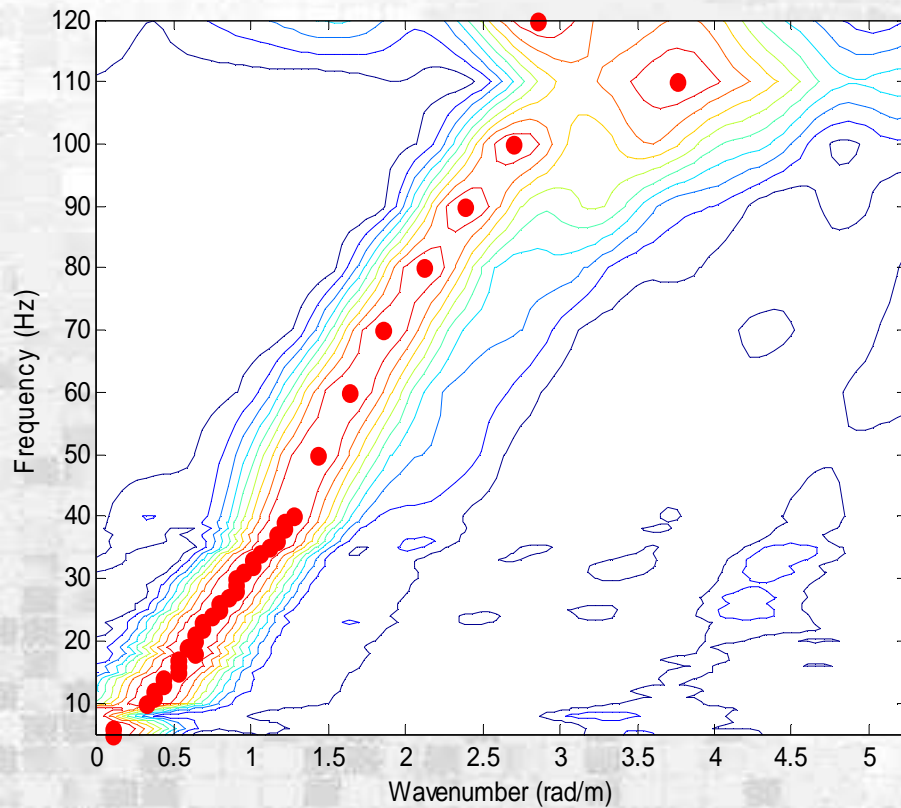
Signal Processing



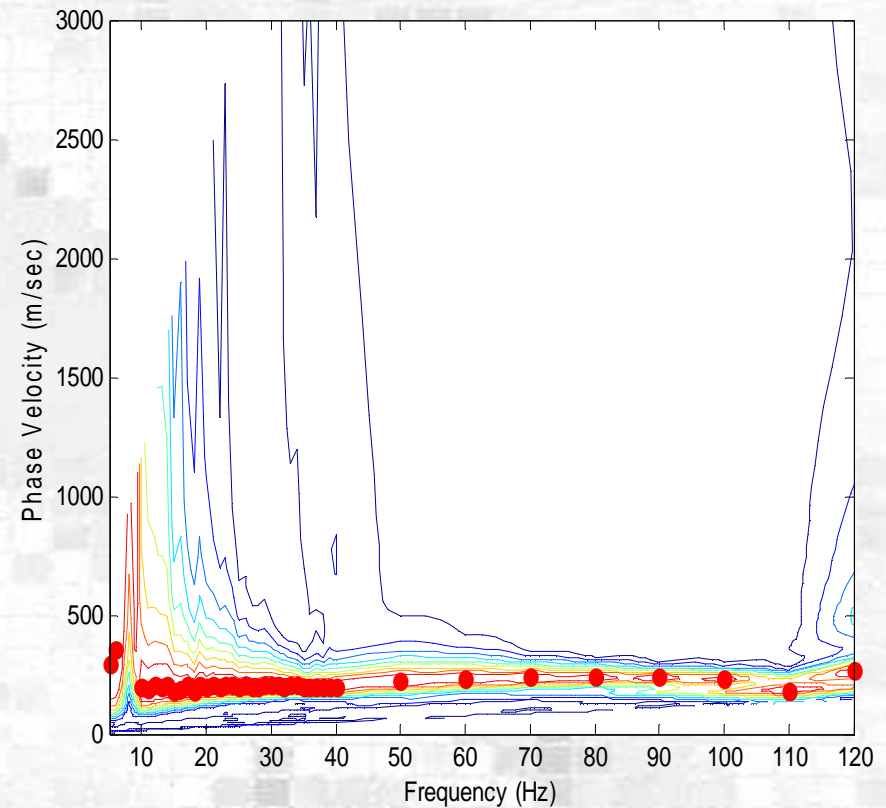
Signal Processing

Frequency-wavenumber spectral techniques are based on the premise of scanning wavenumber space to determine the wavenumber power spectrum for each frequency of interest.

f-k POWER SPECTRUM



DISPERSION CURVE



Signal Processing

INVERSION

M
O
D
E
L

Parameterisation of the subsoil:

Horizontal stratification, homogeneous layers

Constraints:

- *Density*
- *Poisson ratio*
- *Layer thickness*
- *Uncertainty*

$u_1; \rho_1; z_1; G$

$u_2; \rho_2; z_2; G$

⋮

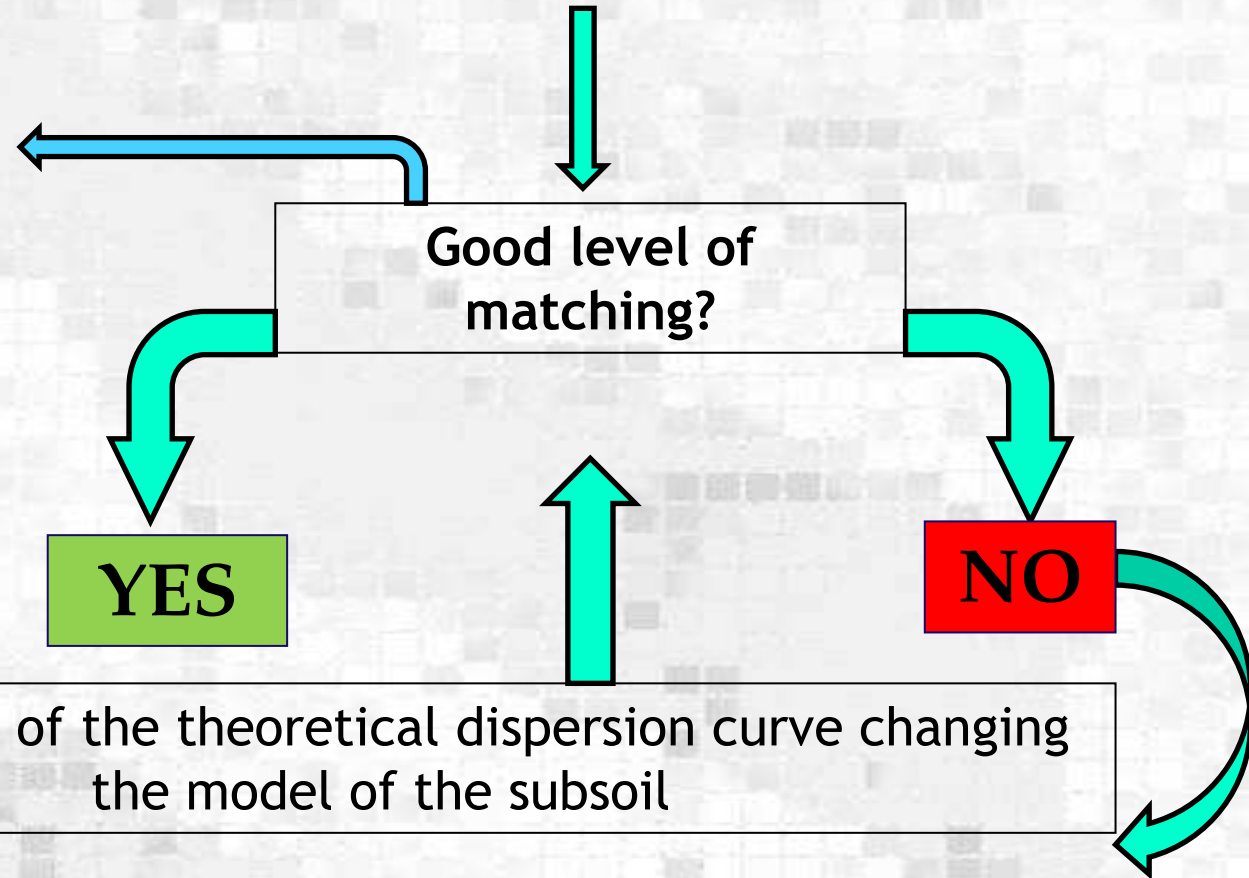
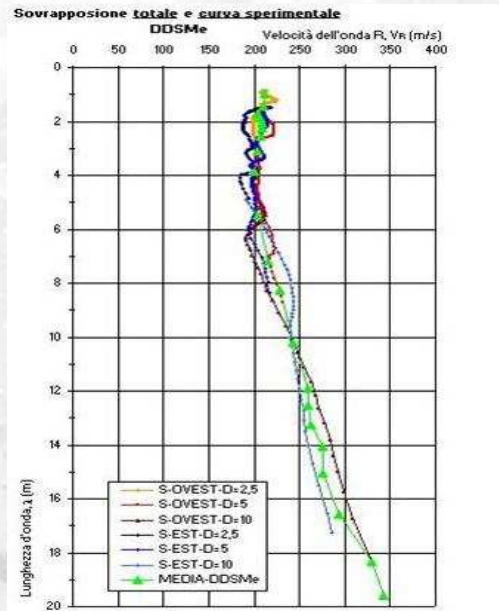
$u_n; \rho_n; z_n; G$

Signal Processing

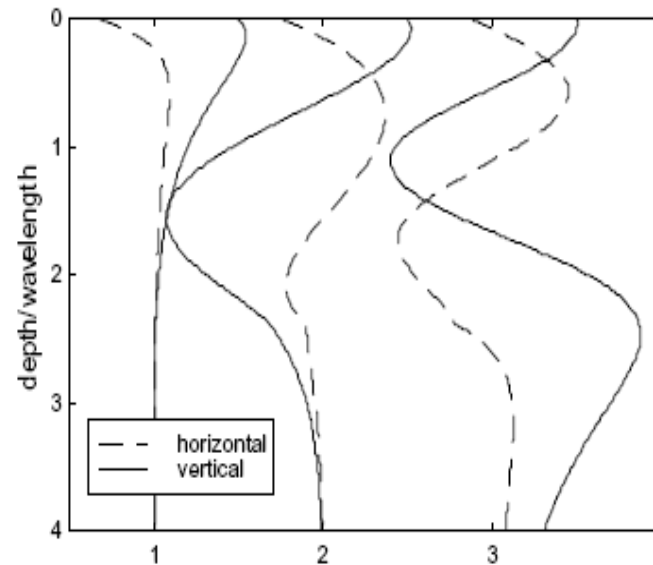
Experimental Dispersion Curve

VS

Theoretical Dispersion Curve



Signal Processing

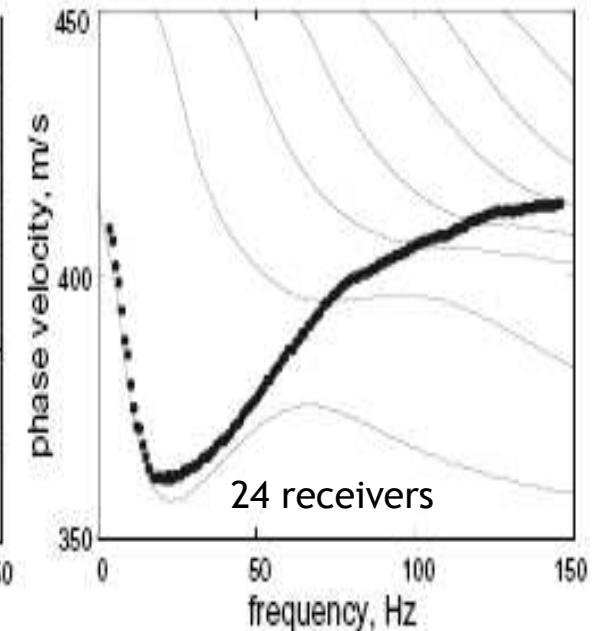
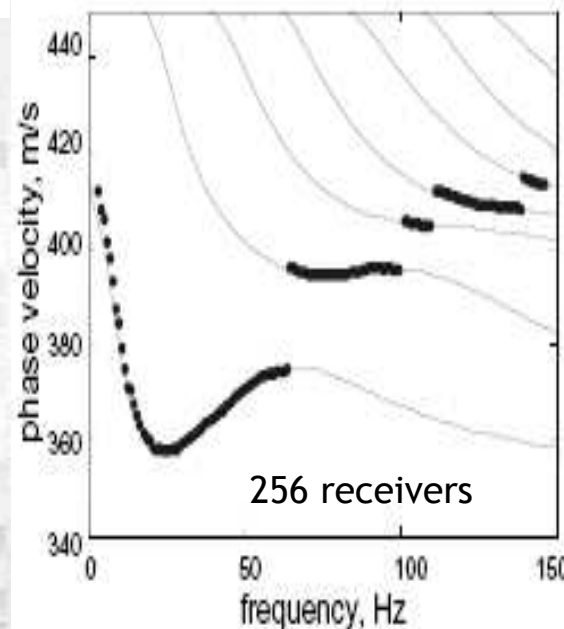


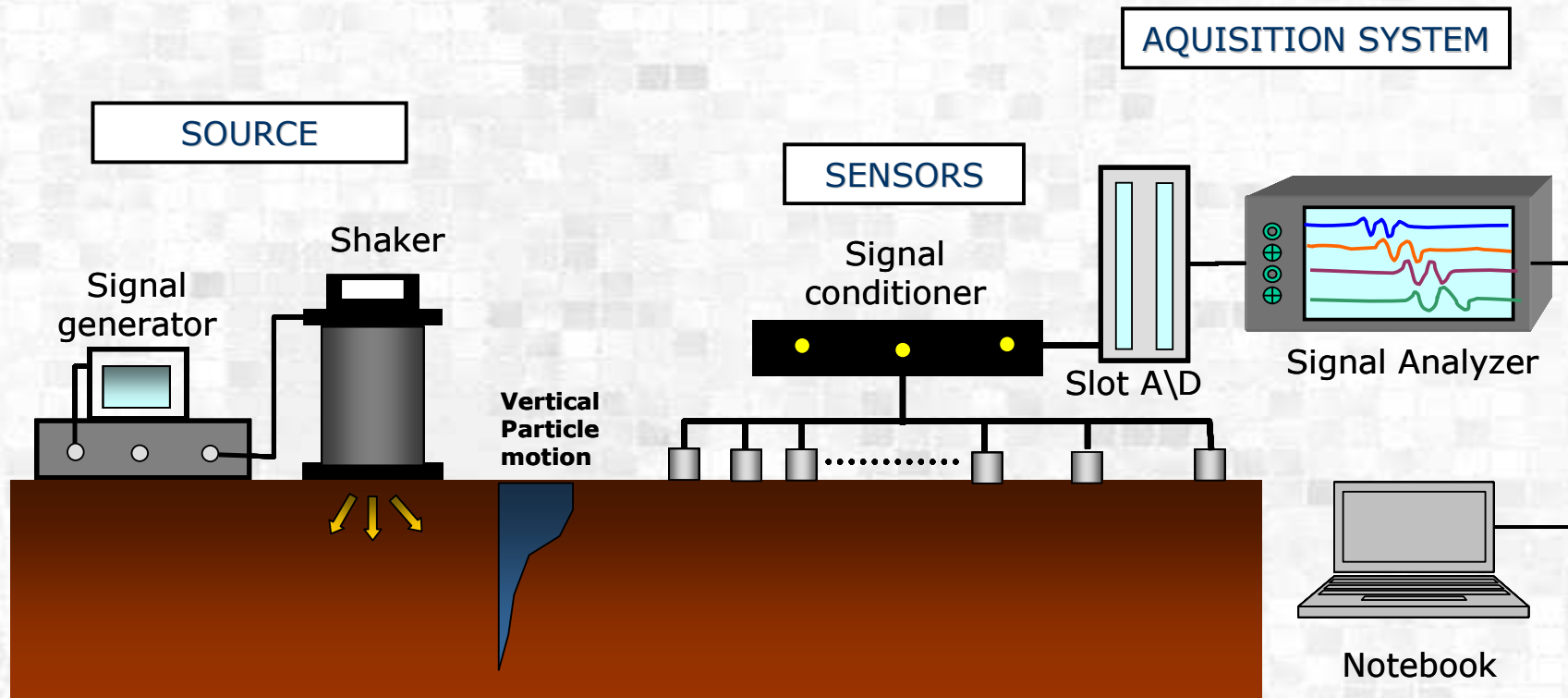
The Rayleigh wave propagation in a vertically heterogeneous media is a multimodal phenomenon.

Consequence of higher modes:

- Soil involved in surface waves propagation;
- Ability to identifying deeper layer.

(Foti, 2000)





ACTIVE SOURCE:

- **Continuos** (harmonic waveforms) with which each frequency (wavelength) is tested individually;
- Transient (hammer o large dropped weigths) with which an entire range of frequencies to measure simultaneosly.

RECEIVERS:

- **Accelerometers;**
- **Geophones.**

Experimental Results

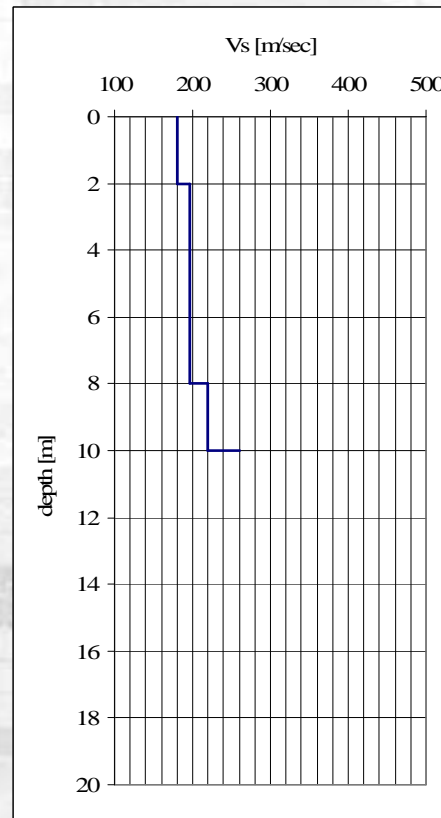
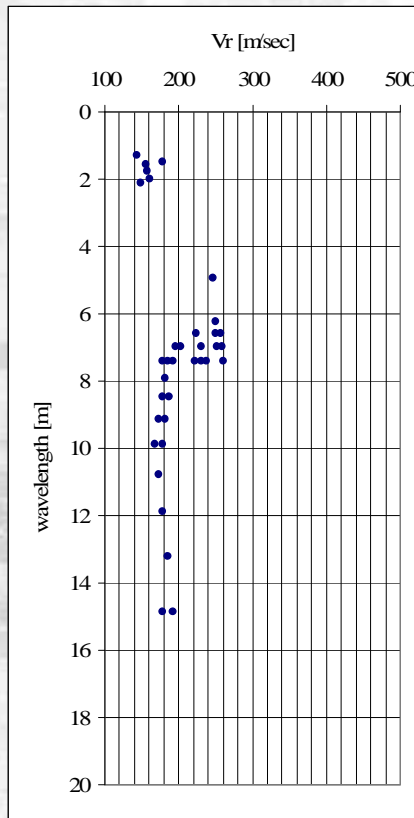


- ❑ Morphology is extremely regular and flat.
- ❑ Geologic context, dominated mainly from the presence of pyroclastic soil.
- ❑ Thick pyroclastic soils (pozzolana, pumices and lapilli) are sometime mixed with organic materials.

Experimental Results

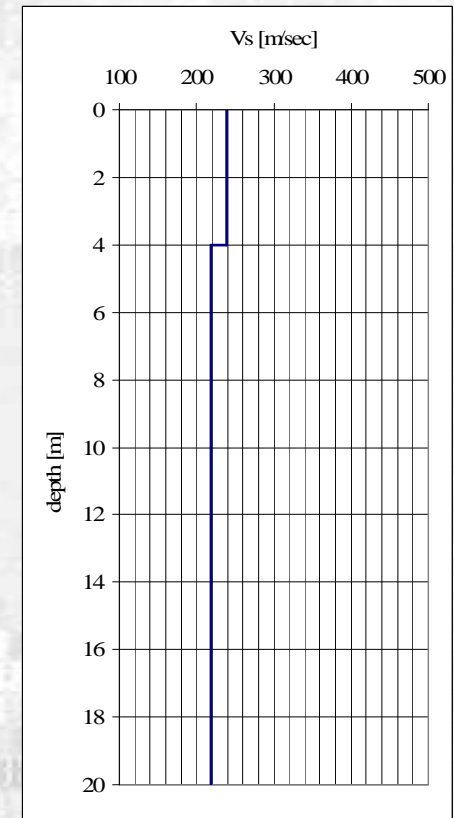
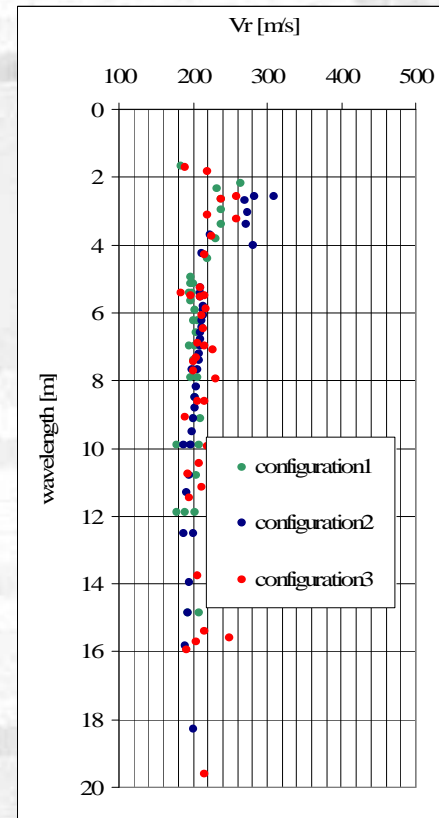
SITE A

- distance array receivers: (2.4, 3, 3.6, 4.5, 5.4, 6.6, 8.4, 10.2 m)
- source frequencies spaced at $\Delta f = 1$ over ranges of 5-30 Hz, and 10 over ranges of 50-120 Hz.



SITE B

- distance array receivers1: (2.4, 3, 3.6, 4.5, 5.4, 6.6, 8.4, 10.2 m)
- distance array receivers2: (5.4, 6.6, 8.4, 10.2, 12.4, 15, 18, 21 m)
- source frequencies spaced at $\Delta f = 1$ over ranges of 5-30 Hz, and 10 over ranges of 50-120 Hz.



Final Remarks

- ❑ Surface waves methods are cost and time effective and allow for accurate characterization;
- ❑ Non-invasive method (hard-to-sample soils);
- ❑ Multistation methods show several advantages (near field effect, low frequencies, automation, stability, noise influence) with respect to SASW two-station approach;
- ❑ Higher modes are important in some sites (the interpretation of the test becomes more complex);
- ❑ Multistation acquisition gives a chance to get an estimate of damping.

Thanks for the Attention