# ISSUES RELATING TO TESTING OF SOILS AND PAVEMENTS BY SURFACE WAVE METHODS

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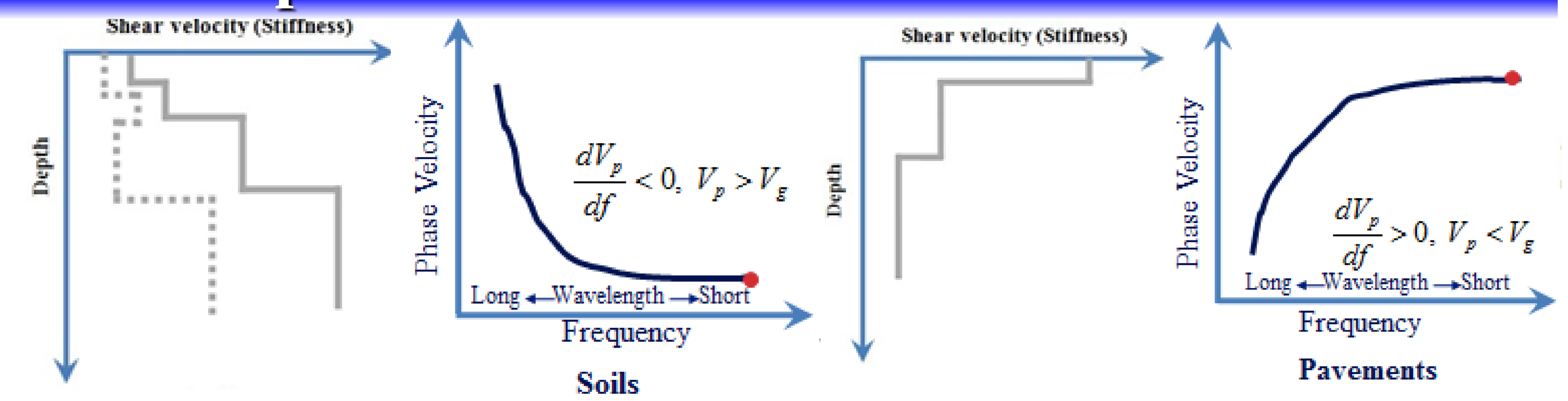
## Abstract

A study on the differences between testing soils and pavements using surface wave methods is presented. The stiffness of soil typically increases with depth while that of pavement decreases with depth, and the resulting wave propagation in the two material types gives rise to significant differences between their dispersion curves. The differences in theoretical dispersion curves are illustrated using the transfer matrix method and the stiffness matrix method for soils and pavements, respectively. The Levenberg-Marquardt and simulated annealing methods are applied for inversion and their relative merits and differences are discussed.

## Dispersion

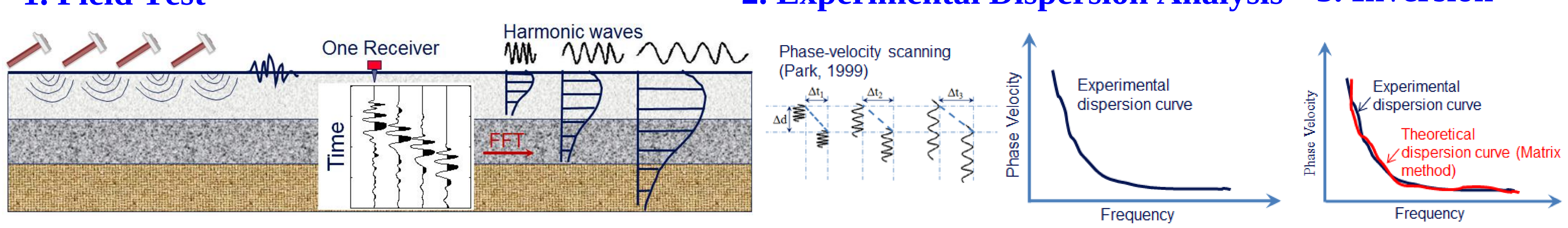
Group velocity and Phase velocity:

$$V_g = V_p\left(1+\frac{\frac{dV_p}{df}}{V_p-\frac{dV_p}{df}}\right)$$



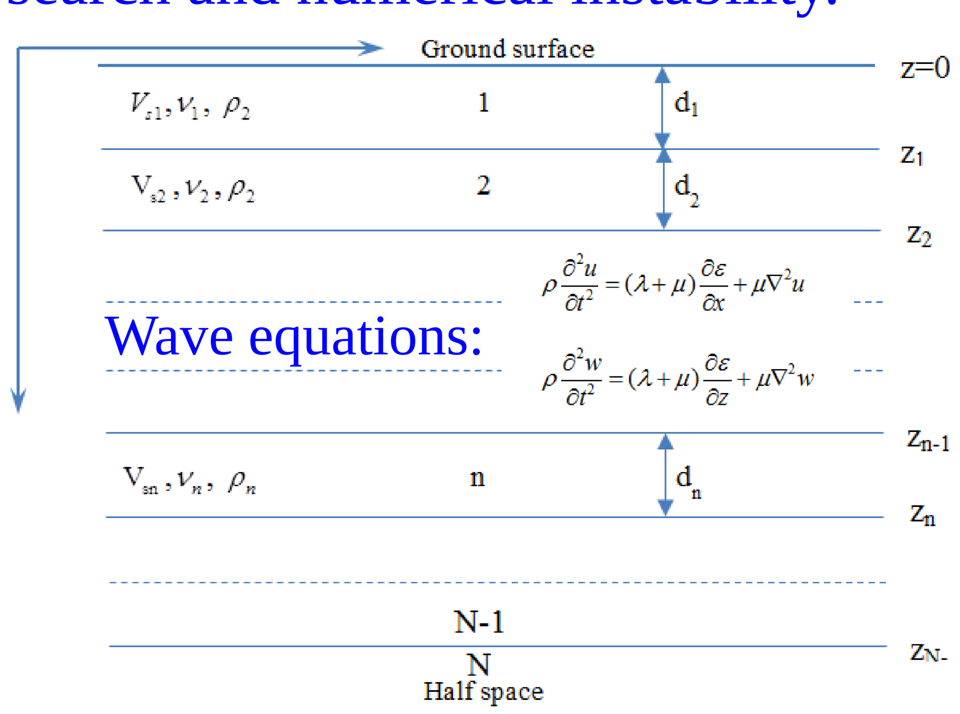

## Surface Wave Method

**1. Field Test** **2. Experimental Dispersion Analysis** **3. Inversion**



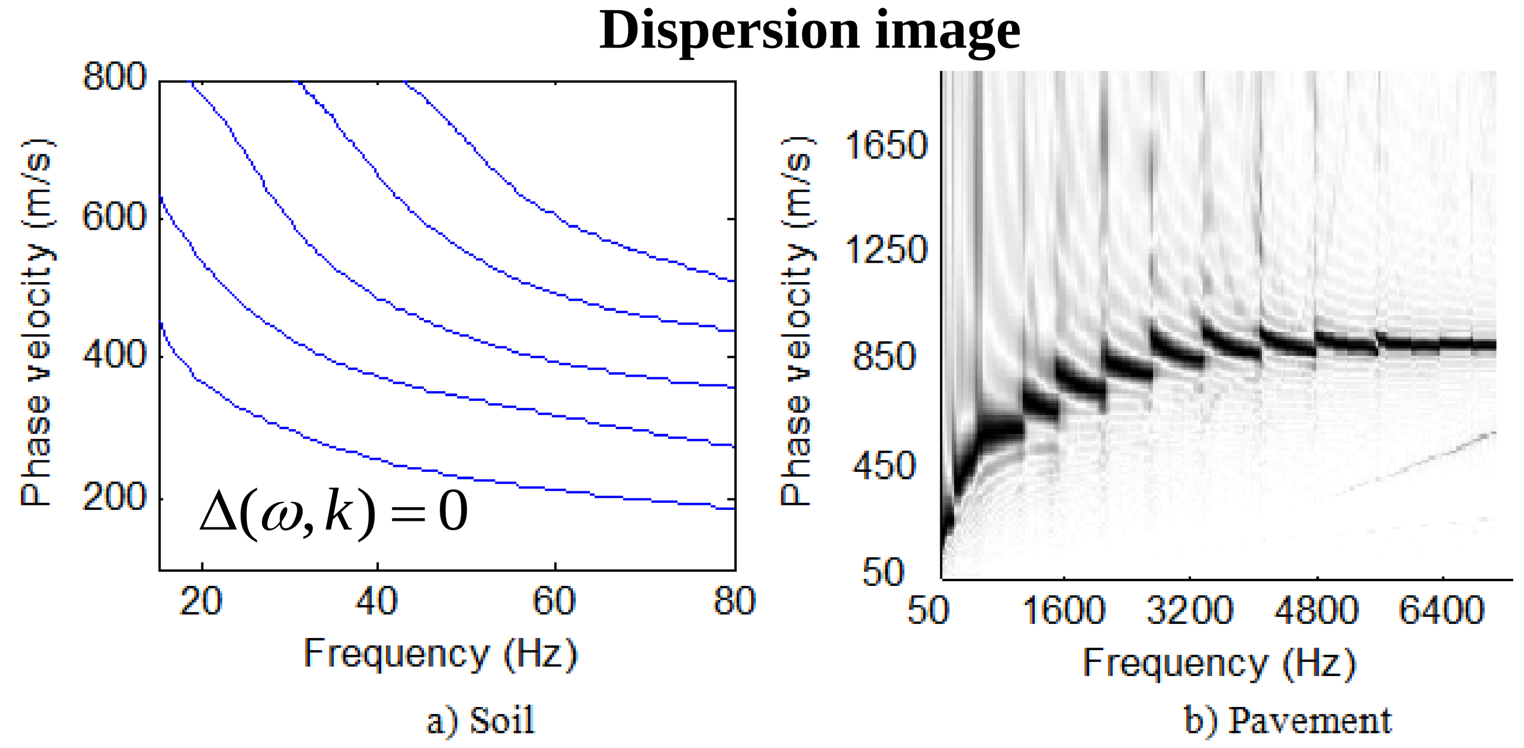

## Transfer Matrix Method vs. Stiffness Matrix Method

Obtaining theoretical dispersion curves with transfer matrix method is to make the dispersion function zero with an appropriate couple of wavenumber (k) and frequency (ω). At high frequencies some large components cause a loss of significant figures in the dispersion function. The stiffness matrix method can combine with phase-scanning method to obtain dispersion image with the consideration of complex wave number and avoiding heavy two-dimension search and numerical instability.




Layered profile

**Dispersion image**




**Transfer Matrix Method** **Stiffness Matrix Method**

## Levenberg-Marquardt vs. Simulated Annealing

Traditional inversion methods usually use L-M method with Jacobian matrix. The component of Jacobian matrix needs partial derivative, and its calculation is time-consuming and may lead to unstable results. This method may trap in local minimum and cannot find the global minimum to minimize the difference between experimental dispersion and theoretical curves. At the same time, it cannot deal with discontinuous dispersion curves with several branches, because the derivative of this kind of dispersion curves dose not exists at the jump points. The SA method, as a global search algorithm without derivative, can be used to overcome all of these shortages.

## Case Studies

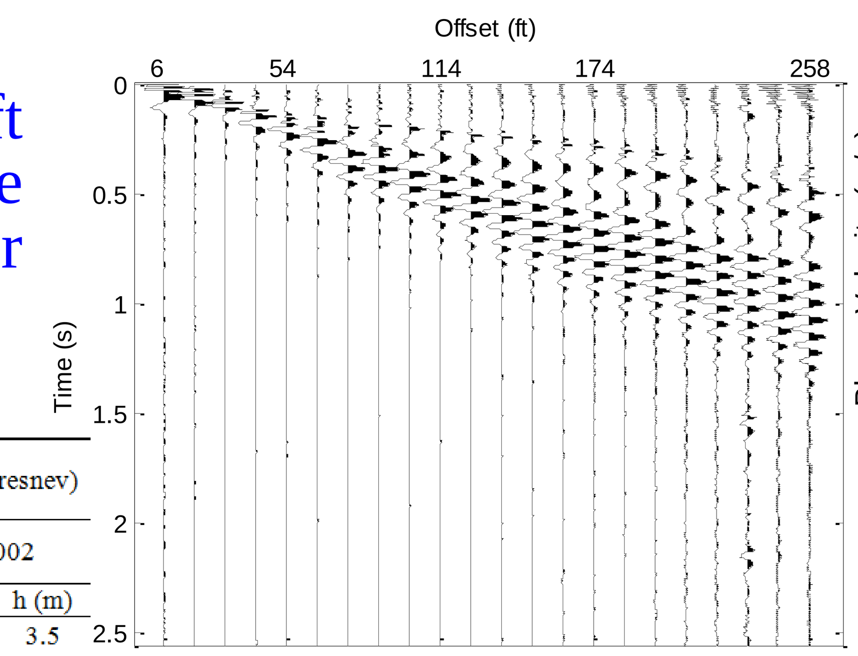
## Testing Results

### *Soil Testing:*

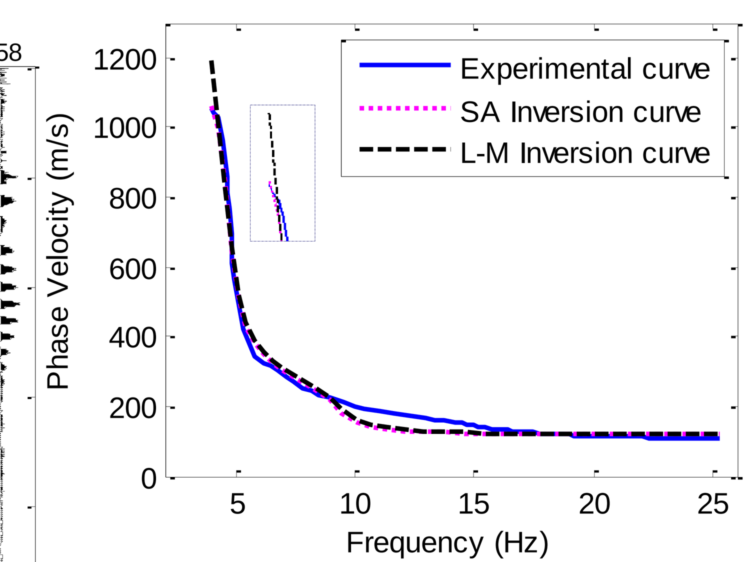
This testing was made with 12 ft station separation over an offset range from 6–258 ft using a sledge hammer source and one geophone.

Table 2. Testing results with surface wave method and P-wave refraction method

| Layer | Surface wave method (May 2011) | | | | P-wave refraction method (Dr. Beresnev) | | | |
|---|---|---|---|---|---|---|---|---|
| | SA method (RMS=27) | | L-M method (RMS=38) | | Oct. 2000 | | Apr. 2002 | |
| | $V_s$ (m/s) | h (m) | $V_s$(m/s) | h (m) | $V_s$ (m/s) | h(m) | $V_s$ (m/s) | h (m) |
| 1 | 124 | 6.6 | 126 | 6.6 | 143 | 7.0 | 85 | 3.5 |
| 2 | 729 | 36.9 | 626 | 36.9 | 511 | 24.0 | 516 | 25.5 |
| 3 | 1264 | ∞ | 1840 | ∞ | 1334 | ∞ | 1186 | ∞ |




**Field data**



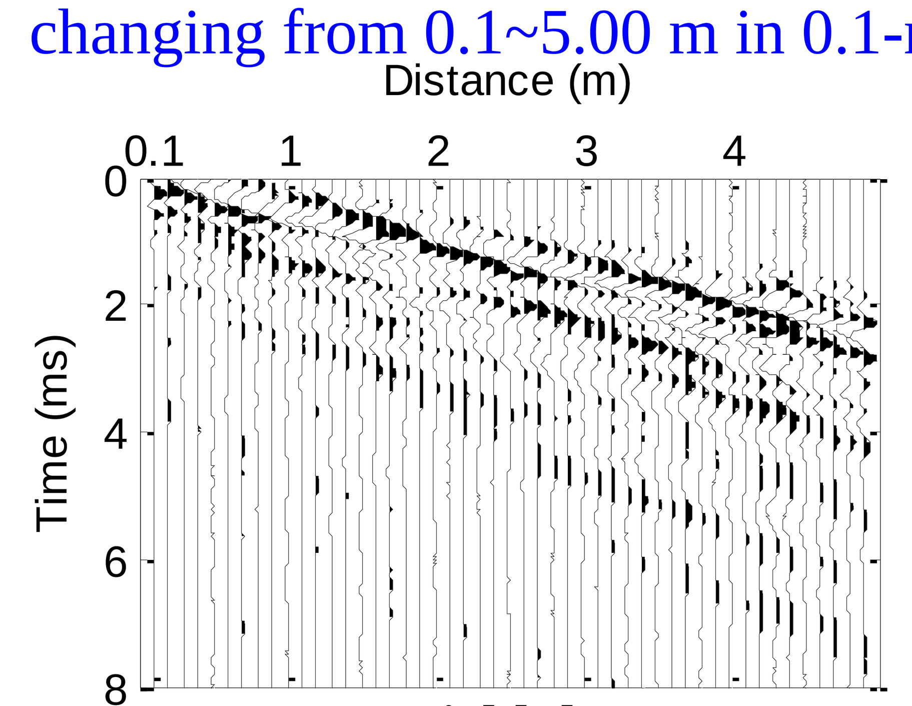

**Comparison of dispersion curves**

### *Basement Floor Testing:*

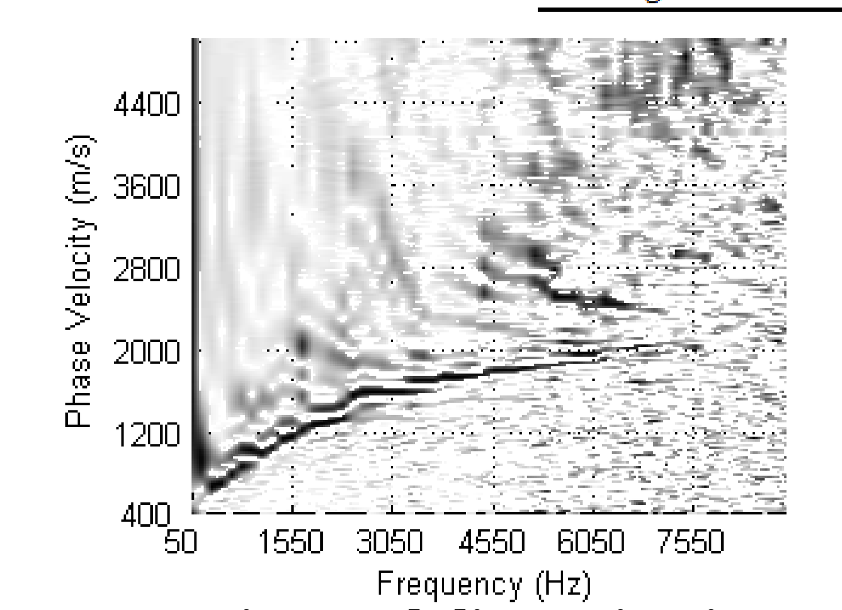
Field data were acquired with only one accelerometer and a small hammer with offsets changing from 0.1~5.00 m in 0.1-m increments.

Table 3. Three inversion results with three-layer model

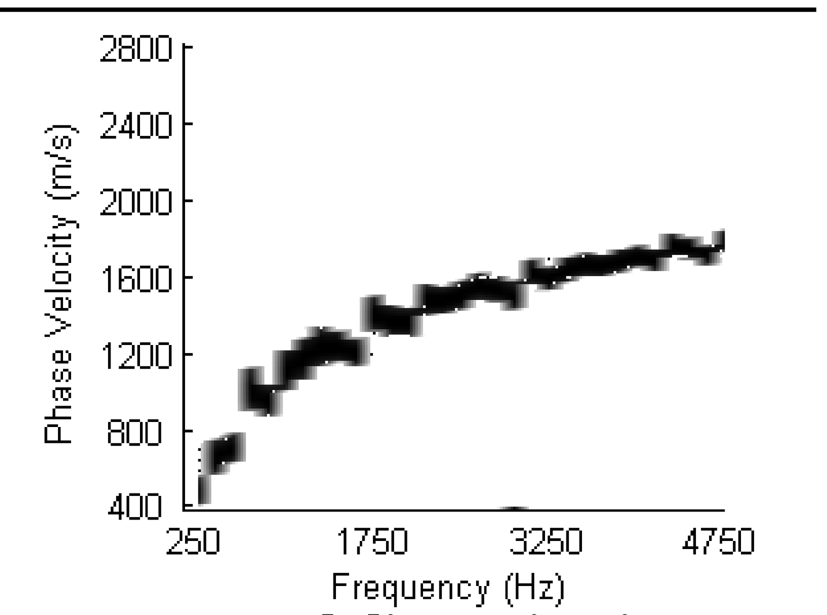
| Layer | h (m) | | | $V_s$ (m/s) | | | ν | ρ (kg/m³) |
|---|---|---|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 1st | 2nd | 3rd | | |
| 1. Concrete | 0.28 | 0.33 | 0.25 | 1996 | 2031 | 2119 | 0.2 | 2400 |
| 2. Base | 0.66 | 0.53 | 0.66 | 278 | 382 | 435 | 0.3 | 2300 |
| 3. Subgrade | ∞ | ∞ | ∞ | 269 | 257 | 333 | 0.4 | 2100 |




**Field data**




**Experimental dispersion image**




**Inverted dispersion image**

## Conclusions

i. When we use surface wave method for testing layered media, we should pay attention to differences between soils and pavements, including wave propagation, frequency range and shape of dispersion curves.

ii. Dispersion curves are continuous, multimode for soils and discontinuous, multibranch for pavements.

iii. Transfer matrix method can be used to obtain theoretical dispersion curves of soils without the need of any improvement about the instability at high frequencies, and stiffness matrix method can be used to obtain the curves without the unstable problem at high frequencies and heavy search.

iv. Levenberg-Marquardt method can be used for inversion of soils with continuous dispersion curves, and however may be trapped in local minimum. Simulated annealing method can be used for inversion with the capacity to find the global minimum.