

M040

## Verification of Soil Profiles Obtained from Experimental Rayleigh-wave Dispersion Inversion Using Synthetic Microtremors

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### SUMMARY

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An attempt to discuss and/or verify the suitability of subsoil velocity models estimated from Monte-Carlo inversion using synthetic microtremors is performed. In the last 2 decades, experimental Rayleigh dispersion curve from passive microtremor measurements has been explored as a tool for estimating subsoil velocity profiles. The Monte Carlo inversion is one of the most popular methods to estimate them. However, it is also known that the Monte Carlo method gives non-uniqueness solutions. In this paper, the suitability of one of the solutions (the bad case) of soil profiles estimated from experimental surface wave dispersion curves at one site is discussed using the simulation method proposed by the authors in 2009. The simulation is carried out by controlling the magnitude of input sources at the ground surface, through the parameter: ratio of forces RF. As case study, microtremor measurements from an Alpine site are analyzed and compared with the synthetic ones. The synthetic vertical/horizontal dispersion curves and the synthetic classical/modified H/V spectral ratios for certain values of RF are compared with the experimental one. According to this comparison, the tested subsoil profile should be discarded. The proposed method would be a promising tool to resolve the problem of non-uniqueness.

## Introduction

One of the most popular methods for estimating  $V_s$  subsoil profiles from experimental surface-wave dispersion characteristics, due to its relative simplicity, is the Monte Carlo inversion. However, the disadvantage of this inversion is the non-uniqueness, which produces sometimes diverse  $V_s$  subsoil profiles. To discuss and/or to verify the characteristics of experimental Rayleigh dispersion curves obtained at an Alpine site, Tokeshi and Socco (2009) introduced a parametric study of synthetic microtremors based on the parameter Ratio of forces,  $R_F$ , on a probable suitable subsoil model (called as Model-2).

In the present paper, the experimental Rayleigh dispersion curves and the H/V spectral ratio are compared with the synthetic ones for the non-suitable subsoil model (called as Model-1).

## Microtremor measurements at an Alpine site

Synchronized microtremor measurements recorded at an Alpine site with a sampling frequency of 100 Hz were analyzed and compared with synthetic microtremors both in terms of Rayleigh dispersion curves and the H/V spectral ratio. A circle array of 10 m radius composed by 6 stations (one at the centre) using 3 components sensors in all stations was used.

Two relationships for the H/V ratio are discussed in the present paper; the classical and the modified H/V ratio. Figure 1 shows the classical and the modified average H/V spectral ratios, where the predominant frequency is around 5.5 Hz for the classical one, and around 5.3 - 6.3 Hz for the modified one. According to the relationship reported by Tokimatsu (1995), the value of the predominant frequency of the modified H/V spectral ratio is a better parameter for defining an approximate threshold of the fastest experimental Rayleigh-wave dispersion curve.

Twelve sets of 40 s length records were selected simultaneously from the 6 vertical components of stationary microtremor records. The experimental Rayleigh dispersion curve obtained by the  $f-k$  spectral method (beam-forming) is shown in Figure 2 with 13 red dots. The value of 6.3 Hz for the predominant frequency obtained from modified H/V spectral ratio is shown in Figure 2 with a vertical red dashed line.

The inverse analysis was performed assuming that the 13 points of the experimental Rayleigh dispersion curve would belong to the fundamental mode. The standard deviation of each frequency was calculated and used in the inversion. Also, the value of 6.3 Hz was used for improving the efficiency of the algorithm (Tokeshi *et al.*, 2008).

The Monte Carlo inversion was applied on a subsoil velocity structure composed of 4 horizontal layers overlying a half-space. The global searching was performed on three random parameters: the thickness  $H$  (m), the shear wave velocity  $V_s$  (m/s), and the Poisson's ratio  $\nu$ , which ranges are shown in Table 1. The P-wave velocity  $V_P$  (m/s), and the density  $\rho$  ( $\text{kg/m}^3$ ), were calculated according to Tokeshi *et al.* (2008). The 4 best subsoil velocity structures estimated after 1 million trials are shown in Figure 3, where the subsoil Model-1 (bold black line) shows a lower shear wave velocity and smaller thickness for the 1<sup>st</sup> layer than the others 3 subsoil Model-2. The theoretical Rayleigh fundamental mode for this subsoil Model-1 satisfied 11 points of the experimental dispersion curve (blue bold curve in Figure 2). Also, Figure 3 shows the 3 subsoil Model-2 which theoretical Rayleigh fundamental modes satisfied 10 points of the experimental curve (blue thin curves in Fig. 2).

To discuss and/or to verify the suitability of the subsoil Model-1, synthetic microtremors are calculated in the next section. The 3 models that satisfied 10 points, i.e., subsoil Model-2, were discussed in a previous paper (Tokeshi and Socco, 2009).

## Synthetic microtremors for subsoil Model-1

Synthetic microtremors were calculated according to the technique developed by Tokeshi *et al.* (2000). An infinite surface divided into small squares of 200 m side length was used (Fig. 4). The 3 components of the synthetic microtremors at each station were calculated for 80 s with 100 Hz sampling frequency. Two ratios of forces ( $R_F = 0$  and  $R_F = 1$ ) were used for calculating synthetic microtremors.

The physical parameters of subsoil velocity Model-1 are shown in Table 2. Figure 5 shows several dispersion curves, which descriptions are detailed in captions and legends of Figs. 5(a)–(d). The synthetic vertical (Rayleigh) dispersion curves for both  $R_F = 0$  and  $R_F = 1$  (Figs. 5.a and 5.b) show bad agreement with the experimental one. The synthetic vertical dispersion curves are above the theoretical 1<sup>st</sup> higher Rayleigh mode for most of the frequency band. Also, the synthetic horizontal dispersion curve for  $R_F = 0$  (Fig. 5.c), which is supposed to contain predominantly Rayleigh dispersion characteristics, showed bad agreement when compared with the experimental Rayleigh one. Finally, the synthetic horizontal dispersion curves for  $R_F = 1$  (Fig. 5.d) are closer to the theoretical Love fundamental mode, but they are in bad agreement with the experimental horizontal dispersion curve for most of the frequencies.

In order to get better fitting between these horizontal dispersion curves, additional synthetic microtremors for several values of  $R_F$  were carried out. The experimental horizontal dispersion curve and the synthetic one for  $R_F = 0.5$  are compared in Figure 6, where both horizontal dispersion curves show bad agreement. Also, the classical and the modified H/V ratio for synthetic microtremors ( $R_F = 0.5$ ) were calculated. The value of 5.8 Hz was obtained for the classical H/V predominant frequency (Fig. 7.a), which is in good agreement with the experimental classical H/V predominant frequency of 5.5 Hz (Fig. 1.a). However, the synthetic modified H/V predominant frequency of 10 Hz (Fig. 7.b) is quite different than the value of the experimental one (Fig. 1.b).

In general, the vertical / horizontal dispersion curves and the classical / modified H/V spectral ratios from experimental and synthetic microtremors were in bad agreement, and in consequence, this subsoil velocity model should be discarded.

## Conclusions

The suitability or unsuitability of subsoil velocity models estimated from Monte Carlo inversion using synthetic microtremors was successfully discussed and verified. The synthetic vertical/horizontal dispersion curves and the synthetic classical/modified H/V spectral ratios at certain values of  $R_F$  for one subsoil velocity model were compared with the experimental ones. This subsoil Model-1 should be discarded due to bad agreement between them, considering it as unsuitable solution.

The proposed method is a promising tool to resolve the problem of non-uniqueness of Monte Carlo inversion.

## Acknowledgements

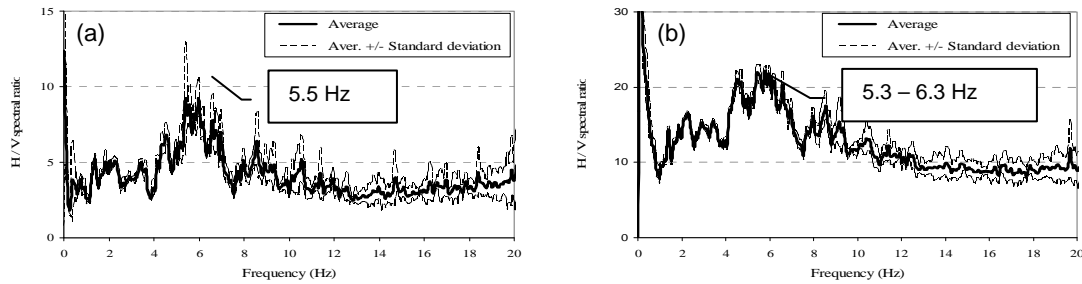
Joseph Fourier University of Grenoble for acquiring the data. The Regione Piemonte Foreigner Researcher Fellowship Program for financing Ken Tokeshi grant.

## References

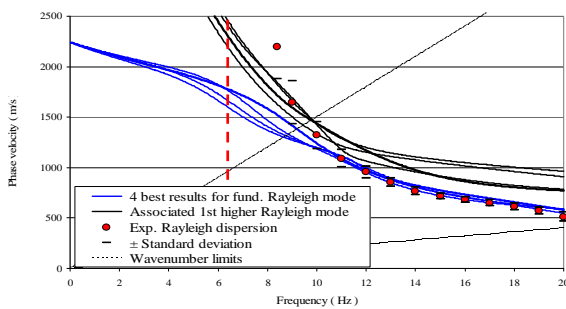
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**Table 1** Ranges used in parameters for random inverse analysis.

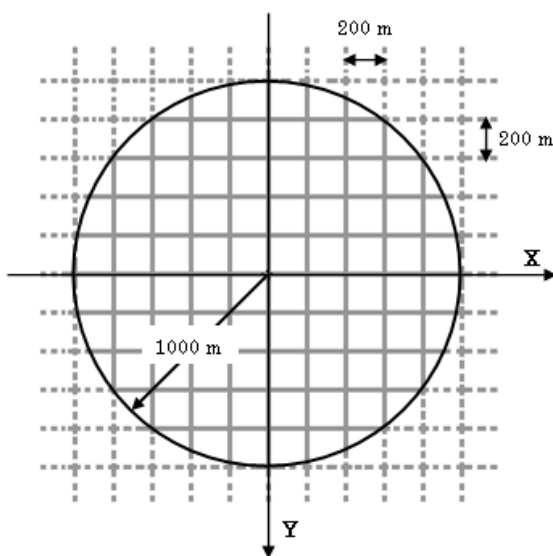
Layer	H <sub>o</sub> (m)	H <sub>r</sub> (m)	V <sub>s o</sub> (m/s)	V <sub>s r</sub> (m/s)	v <sub>o</sub>	v <sub>r</sub>
1	1	6	100	600	0.25	0.49
2		26		1000		
3		34		1500		
4		34		2200		
Half-space	Infinite		V <sub>s</sub> =2500		V <sub>p</sub> =3800	



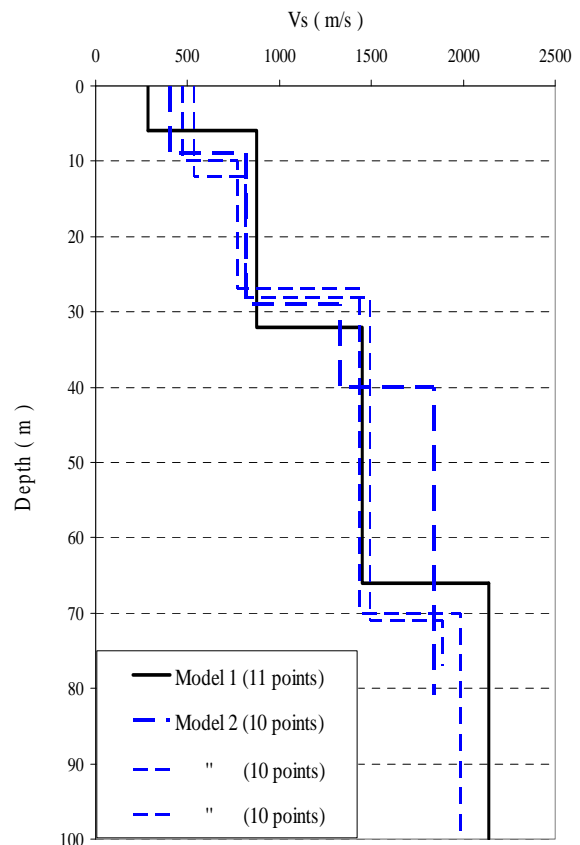
**Figure 1** (a) Classical and (b) modified H/V spectral ratios from microtremors.



**Figure 2** Comparison of experimental Rayleigh dispersion curve and theoretical Rayleigh modes.



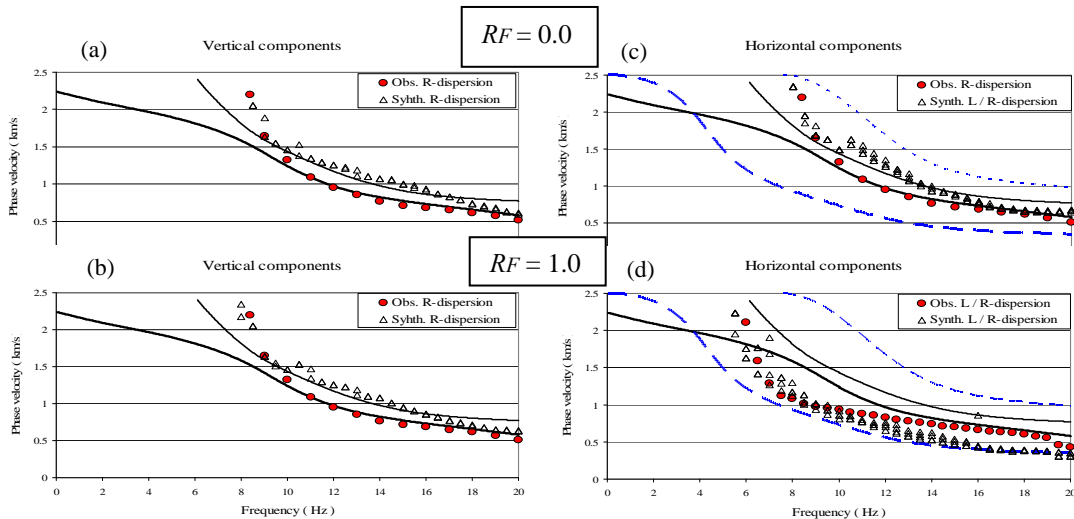
**Figure 4** Model used for calculating synthetic microtremors.



**Figure 3** Subsoil velocity models estimated under the assumption that the experimental Rayleigh curve is the fundamental Rayleigh mode.

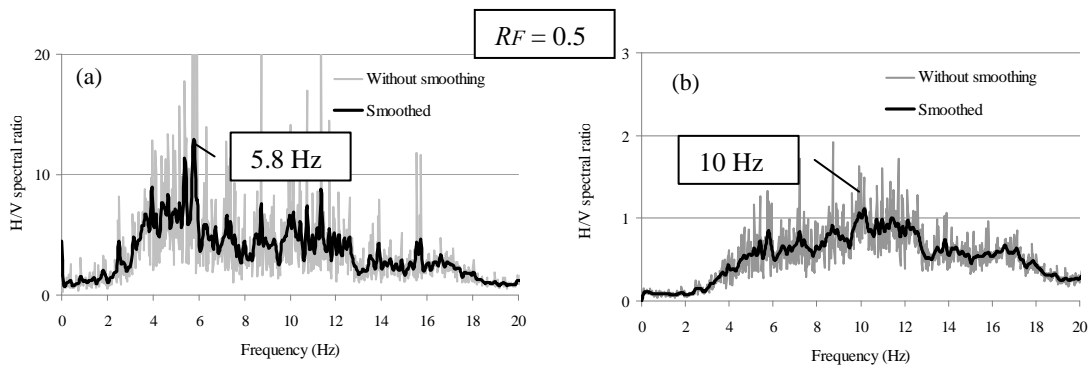
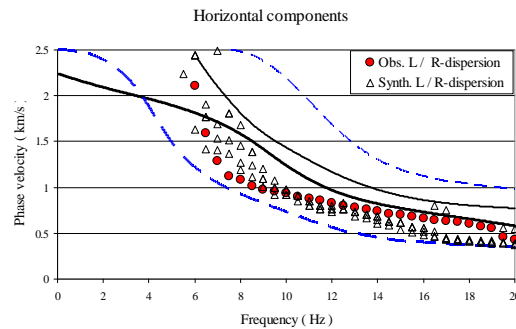
**Table 2** Physical parameters of subsoil Model-1 used for synthetic microtremors.

Layer	Thickness (m)	Density (kg/m <sup>3</sup> )	V <sub>P</sub> (m/s)	V <sub>S</sub> (m/s)	Q <sub>P</sub> & Q <sub>S</sub>
1	6	2000	1730	285	15
2	26	2200	2660	875	45
3	34	2300	2840	1450	75
4	34	2400	3800	2140	100
Half-space	Infinite	2500	3800	2500	125



**Figure 5** (a) (b) Vertical and (c) (d) horizontal experimental and synthetic dispersion curves for  $RF = 0$  (at the top) and  $RF = 1$  (at the bottom), and their corresponding comparison with the theoretical curves.

**Figure 6** Comparison between experimental and synthetic horizontal dispersion curves obtained for  $RF = 0.5$ .



**Figure 7** (a) Classical and (b) modified H/V spectral ratios obtained from synthetic microtremor for  $RF = 0.5$ .