1 Abstract
The near-surface shear-velocity profile can be determined from the inversion of surface-wave dispersion data. Several methods of analysis have been developed in the past mostly using the phase information of seismic signals observed on linear arrays of sensors. A better technique is a possible misidentification between modes and secondly lowes resulting from the limited aperture of the array. Another limitation comes from the contamination and/or signal generating noise since the whole waveform is taken into account. In this work, we propose to overcome these limitation by adding a group delay time information in the analysis. The waveform is mapped into the group-velocity/phase-velocity (U-c) domain which enables us to improve the dispersion measurements. The observed multidispersion data are then inferred in terms of a 1-D velocity profile. We show that on synthetics and field data that the U-c diagrams greatly facilitates the identification of each modes and that our inversion procedure quickly converge to the expected models.

2 Dispersion measurements - U-c Diagrams
Multi mode signals recorded by an array of sensors are stacked in order to reinforce the individual modes by constructive interference:

\[ u(x, t) = \sum_{k=0}^{N} \left[ A_k \sin \left( k \frac{2\pi}{x} t - \phi_k \right) \right] \]

where \( u(x, t) \) is the time Fourier transform of a record obtained after distances \( x \), and filtered around the circular frequency \( \omega \). The last term in this expression is the phase-shift filter with \( k \) defined so: \( \sin(k \omega t) = \sin(\omega t) \). In particular, the first harmonic of the multi-mode wave packet.

We call "U-c diagram" the modulus of the inverse Fourier transform \( u(x, t) \) of \( u(x, t) \). It will exhibit peaks at group velocity \( v_g \) and phase velocity \( v_p \) related to each surface-wave mode - (Cara 1976, Duputel et al. 2009).

The series of diagrams plotted at different frequencies \( \omega \), then allows the analyst to retrieve the fundamental and the higher-mode dispersion curves.

3 Inversion for 1-D velocity profile
We consider a first layered model of the subsurface where we invert for \( v_g \) only since \( v_p \) and \( v_g \) have a small influence on the phase-velocities (Figure 1). This is a non-linear problem which solved using a two-inversion scheme (Duputel et al. 2009). The first step is a pre-inversion step providing the a priori model which is necessary to cut the second step based on a quasi-Newton algorithm. Two alternative approaches were tested: (a) Choosing the a priori model according to the expected shear-velocity profile \( v_p \), and (b) extraction of an optimum a priori phase from a model-library made of 5000 models.

4 Synthetic tests
The fundamental mode and the first higher mode are clearly visible on the U-c diagrams (Figure 3). On Figure 4, the fundamental mode phase-modes measurements fit well with the theoretical values, even for frequencies lower than 15 Hz. Finally, Figure 5b) we note a phase-velocity which is greater for the first overtake than for the fundamental mode. This is probably due to the low amplitude of the first overtone which is clearly visible on the U-c diagram (Figure 5b)), but merely detectable on the U-c diagram (Figure 5a)).

Figure 6 depicts the inversion results corresponding to the dispersion data measured on U-c Diagrams.

5 Application to field data
Dispersion curves related to the records displayed in Figure 6 are estimated by using the U-c diagram technique. Note on Figure 7 that only the fundamental mode and the first overtone are well excited. Even if the two initial models, the final inverted models are remarkably similar (Figure 6) and a good fit is observed between, solutions and data (Figure 9). This emphasizes the robustness of this solution that is confirmed by the resolution matrix. These three layers can clearly be distinguished on Figure 8. They correspond to the local soil structure which is well known from previous seismic reflection investigations (e.g. Ban et al. 2002). A geological interpretation is given in Table 1.

6 Conclusions
We show that the discrimination between the fundamental and the first higher mode is clearly made easier by using U-c diagrams instead of classical f-k analysis. The high quality data dispersion thus obtained can be processed to infer the main surface shear-velocity structure with a better depth resolution than when using fundamental mode dispersion only.

Our simple inversion procedure converges rapidly to acceptable solutions both for synthetic and actual data. The fact that the inverted \( v_g \) profiles depend weakly on the a priori model gives us confidence in the robustness of the solutions.

The source-receiver configuration and the test area which we consider in this paper corresponds to a cheap, classical experiment in near surface prospecting. This limits the higher-mode content in the observed surface-waves signals. A simple but more expensive configuration to increase the resolution of the method at depth could, for example, consist of using a buried instead of a surface source.

Acknowledgement
We thank Jean-Quentin Lieveaux and Alessia Maggi for helpful comments and the students of the EOST survey engineers for the data acquisition. We wish to acknowledge Robert Herrmann to provide models for the propagation of surface waves. We are also grateful to Jean-Claude Gess, Stéphanie Guetet, Julien Bois, Olivier Leffler and Philippe Gorny who initiated this project.

References
Dutuit, A., Cara, L. Rivero, and G. Herpin. Improving the resolution of inversion of multi-mode Rayleigh wave dispersion by using group delay time information observed on arrays of high frequency sensors. Accepted in Geophysics, 2009.