Using Ambient Vibration Array Techniques

for Site Characterisation

Monday, April 3^{rd} 2006 to Friday, April 7^{th} 2006
Institute of Geosciences, University of Potsdam, Germany

In recent years, the number of research papers dealing with ambient vibration analysis methods has increased considerably. Clearly, the interest in these methods originates from both the economical attractive cost benefit ratio and the straightforward data acquisition. Being a non-destructive passive technique, these methods also complement geotechnical and/or active geophysical methods within highly populated regions.

Within the SESAME project ("Site EffectS assessment using AMbient Excitation", EU-Project EVG1-CT-2000-00026) detailed research has been accomplished to identify the capabilities and limitations of ambient vibration analysis techniques. Within this context a set of software tools has been developed to ease the processing and interpretation of ambient vibration wave field recordings.

The main findings of the SESAME project however show, that ambient vibration array analysis techniques have to be applied with care. It requires not only a careful measurement, but especially the interpretation and the inversion of analysis results need a (self-)critical review. From these conclusions it has been agreed among SESAME-partners, that it is highly necessary to distribute the software tools together with adequate training.

The main purpose of this course is to achieve the necessary understanding among the course participants for the problems related to these techniques. By doing so, we try to enable a correct usage of the software tools and to avoid misuse of these methods ("black-box usage"). The course fees are intended to support current and future improvements of the software package, distributed under an open source and free license.

Due to the number of registrations we received with the first course in Grenoble 2005, we are organizing this second edition (and, who knows, a third one) to give everybody a chance to participate.

Contributions

organised by	IGUP and LGIT
hosted by	Institute of Geosciences at University of Potsdam
presented by	Cécile Cornou, Matthias Ohrnberger, Marc Wathelet
supported by	SESAME (EU-Project EVG1-CT-2000-00026) and Sismovalp (Interreg IIIB, Alpine Space) and all participants of the first edition.

Course outline

This is program which may be subject to slight changes in the future.

Monday

9:00-9:30 Reception and welcome

- Technical issues and program overview

9:30-10:30 Physical background of ambient vibrations — Lecture

- Overview of the physical background of ambient vibration studies.
- Basic assumptions and state of the art about the nature of the ambient vibration wave field.
- The linkage between subsurface structure and wave field propagation properties.
- The use of ambient vibration array analysis for observation and recovery of site characteristics (site response).

10:30-10:45 Coffee break

10:45-12:15 Single station measurement, H/V — Lecture

- Interpretations for horizontal to vertical spectral ratio technique (H/V).
- Relationships between Rayleigh ellipticity and S_H transfer function.
- Effects of experimental conditions.

12:15-14:00 Lunch break

14:00-15:30 Single station measurement, H/V — Exercises

- A very short introduction to Geopsy database.
- Geopsy tools for H/V interpretation.

15:30-15:45 Coffee break

15:45-18:00 Single station measurement, H/V — Exercises

- Geopsy tools for H/V interpretation (continued).
- Mapping H/V results with Geopsy.

Tuesday

9:00-10:30	Basic array processing concepts (frequency wavenumber, f–k)	Lecture

- Overview array processing methods.
- The intuitive shift-and-sum technique in time domain and its transposition into the frequency wavenumber (f–k) domain.
- Discrete spatial sampling of the continuous seismic wave field (by small groups of seismic stations - arrays) : concepts of resolution and aliasing.
- Resolution and aliasing of simple linear array layouts and generalisation to bi-dimensional array settings.
- Relation between array geometry and resulting estimation capabilities: rules of thumb and the array response function.

10:30-10:45 Coffee break

10:45-12:15	Array geometry and f–k response	Exercice

- Design of array geometry with build_array software: optimum usage and functionalities.
- Building experience on how modifications in array layout affect the theoretical array performances.

12:15-14:00 Lunch break

14:00-15:30	Conventional f-k processing	Exercises

- Data management for array processing with Geopsy.
- Application of the conventional f-k algorithm to estimate the dispersion curves from synthetic signals

15:30-15:45 Coffee break

15.30-18:00	Conventional f–k processing	Exercises

- Building your own experience with f-k input parameters (frequency sampling, time window length, ...)
- From the discussion of the analysis results, new insight into dependencies between the observability of dispersion curves, array geometries and signal spectra (high pass filter effect and H/V).

Wednesday

9:00-10:30 High resolution f–k (Capon's method) Lecture and exercise

- Background of a widely used method, the high resolution f–k method after Capon (1969).
- Application of the method to the synthetic data set, previously mentioned.
- Comparison with the conventional f–k method.

10:30-10:45 Coffee break

10:45-12:15 Spatial autocorrelation method (SPAC) Lecture and exercise

- Background of the spatial autocorrelation technique (SPAC) introduced by Aki (1957).
- Ongoing developments around Aki's original work.
- Application of the method to the synthetic data set, previously mentioned.
- Discussion of differences with f–k techniques.

12:15-14:00 Lunch break

14:00-15:30 Synthetic data sets, high resolution f–k and SPAC Exercise

- Comparison of the three methods used for array processing, advantages and limitations of each approach.

15:30-15:45 Coffee break

15:45-18:00 Dispersion curve (DC) inversion Lecture

- Short introduction to the fundamentals of inversion theory.
- Direct search methods based on a random sampling, and particularly the Neighbourhood algorithm.
- Specific issues solved for the inversion dispersion curves: robustness of the forward computation, non-uniqueness of the final solution.

20:00-... Workshop Dinner

9:00-10:30	DC inversion	Exercise

- Introduction to dinver software.
- Inversion of theoretical dispersion curve in order to identify critical issues.
- Model parameterisation and parameter range (v_P, v_S, ρ), a natural way to introduce prior information and to reduce the non-uniqueness.

10:30-10:45 Coffee break

10:45-12:15	DC inversion	Exercise

- Inversion of the analysis results which have been obtained from f–k (standard and high-resolution) and SPAC computations the day before.
- Combining the results of arrays with distinct apertures and geometries: decision on the usable frequency range for the inversion target.

12:15-14:00 Lunch break

14:00-15:30	Discussion of inversion results	Moderated discussion

- Comparison of the inversion results obtained by the course participants with the true underlying model.
- Discussion of the causes and the significance of apparent discrepancies between obtained inversion results.

15:30-15:45 Coffee break

15:45-18:00 ...	Array analysis and DC inversion of test data sets I	Exercise

- Blind test experiment performed among the course attendees on a synthetic case.
- Choice of the array layouts, analyse the selected records with f–k and SPAC techniques and finally derive the underlying velocity model.

Friday

9:00-10:30	Discussion of results from data sets	Moderated discussion

- Comparison of the individual results obtained during the blind test.
- General discussion of experience gained during this complete test.

10:30-10:45 Coffee break

10:45-12:15	Course summary	Lecture

- Summary of the various steps involved for the task of ambient vibration array analysis and site characterisation by the inversion of one-dimensional earth models.
- Ongoing developments around ambient vibration techniques and currently open questions.
- Recall of the advantages and limitations of using ambient vibrations to site characterisation.

12:15-14:00 Lunch break

14:00-...	Departure of Participants	Open discussion

Suggested readings

Aki, K. (1957). Space and time spectra of stationary stochastic waves, with special reference to microtremors, *Bull. Earthq. Res. Inst.* **35**, 415–456.

Bard, P.-Y. (1999). Microtremor measurements: a tool for site effect estimation?, State-of-the-art paper, *2nd International Symposium on the Efects of Surface Geology on Seismic Motion*, Yokohama, Balkema, **3**, 1251–1279.

Bettig, B., P.-Y. Bard, F. Scherbaum, J. Riepl, F. Cotton, C. Cornou and D. Hatzfeld (2001). Analysis of dense array noise measurements using the modified spatial auto-correlation method (SPAC). Application to the Grenoble area., *Bolletino di Geofisica Teorica ed Applicata* **42**, 281–304.

Capon, J. (1969). High-resolution frequency-wavenumber spectrum analysis, *Proc. IEEE* **57**, 1408–1418.

Sambridge, M. (1999a). Geophysical inversion with a neighbourhood algorithm: I. Searching a parameter space, *Geophys. J. Int.* **138**, 479–494.

Sambridge, M. (1999b). Geophysical inversion with a neighbourhood algorithm: II. Appraising the ensemble, *Geophys. J. Int.* **138**, 727–746.

Tokimatsu, K. (1997). Geotechnical site characterization using surface waves, *Earthquake Geotech. Eng.*, Ishiliara (ed.), Balkema, Rotterdam, 1333-1368.

All deliverables and reports of the SESAME project are available at (especially, D18.06, D19.06, D24.13 may be of interest): http://sesame-fp5.obs.ujf-grenoble.fr/SES_TechnicalDoc.htm.

Registration and Fees

To offer the best attention to each of the course attendees, the maximum number of participants is fixed to 15. A minimum of 8 registrations is required for the organisation of this cession.

Online registration (http://www.geopsy.org/arraycourse/login.php) is open until Friday March 10^{th} 2006. If the number of applicants is greater than 15, the organisers reserve their rights to select the participants.

The fees include lectures, practical exercises, workshop dinner and coffee breaks. One computer per participant will be made available during the exercises. Profits will be devoted to the development and improvement of the SESARRAY softwares.

Organisation	Number of participants	Price (euros, excluding VAT)
SESAME partners	1	1000
	2	1500
	n > 2	1000+n*500
Sismovalp	1	1000
	2	1500
	n > 2	1000+n*500
Others	1	2500
	2	4000
	n > 2	4000+(n-2)*1000

Special discounts may be offered if really needed, please contact Pierre-Yves Bard (pierre-yves.bard@obs.ujf-grenoble.fr).

Contacts

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Geopsy	http://www.geopsy.org
SESAME	http://sesame-fp5.obs.ujf-grenoble.fr
Sismovalp	http://www-lgit.obs.ujf-grenoble.fr/sismovalp