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Automated Dispersion Mapping of Surface Waves

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SUMMARY

With the increasing amount of innovative geophysical sensors and sensor networks there is a need for faster and more controlled data processing and interpretation in order to cope with the abundance of data coming from monitoring systems. In this article, we are presenting a possible method to deal with automated processing of multi-station Rayleigh wave data. We use the strong points of the visualization process of the MASW method (Park et al. 1999) and combine them with an automated dispersion curve mapping procedure. By doing this, we are presenting a possible alternative for fast and repeatable real-time processing of surface wave data. By presenting a case study on a dike the operational speed of the method and the potential for use in monitoring studies is demonstrated. There is a short evaluation of alternative inversion methods that are able to perform the calculation to a subsurface layer model.

Introduction

In near surface exploration geophysics, a certain shift is taking place the last few years. With the increased amount of innovative geophysical sensors and sensor networks there is a need for faster and more controlled data processing and interpretation in order to cope with the abundance of data coming from monitoring systems.

For the use of dike or levee monitoring, we foresee resistivity, electromagnetic and surface wave methods to play an important role, for they are able to measure important dike parameters as lithology, groundwater and shear stiffness. From a geotechnical point of view, there is a need to have better control on the results of geophysical measurements in order to use it in risk analysis, as repeatability and uncertainty analysis is stressed upon by e.g. Uzielli (2008). Surface wave exploration methods are suitable for geotechnical purposes, mainly because Rayleigh wave velocity has a relation with the geotechnical parameter G_0, also known as the shear modulus. Surface wave research took major steps by the introduction of SASW by Gucunski and Woods (1991) and Stokoe et al (1994), the introduction of MASW by Park et al. (1999) and the passive method ReMi by Louie (2001). In future years, we expect more spin-off products of multi-station surface wave methods, also for the use of surface wave methods for monitoring purposes.

Strengths and weaknesses in current methods

We are building further upon the MASW data processing as proposed by Park et al. (*1999*). After data-acquisition in the field, the processing of Rayleigh wave data can be explained in four stages:

A. **FFT transformation from the x-t domain to the f-k domain.** The field-data, in the space-time (x-t) domain, is transformed to the frequency-wavenumber (f-k) domain using a double Fast Fourier Transformation (FFT). The data in the f-k domain is a very pure representation of the data: when we do not use resolution-enhancement like zero-padding before the FFT, the resolution of the data can still be deduced.

B. **Projection on the frequency – phase velocity (f-v) domain or frequency – phase slowness (f-p) domain.** The double FFT is followed by a projection on the so called frequency-velocity (f-v) domain. The main advantage of this procedure is that dispersion curves can be distinctly defined visually and manually picked in the f-v domain. Other people prefer visualization where phase slowness instead of velocity is imaged (f-p domain), because the data shows less ‘smearing’ at lower frequencies (i.e. O’Neill, 2003). In fact both projections on the f-v and f-p grid skews the data. Interpolating the f-k data to f-v or f-p axes, we lose information about the resolution of the data and we cannot guarantee that interpolation of data to the f-v grid is correct.

C. **Manual picking of the dispersion curve.** Picking the fundamental mode and possible higher modes manually is a subjective and time consuming task. Mainly because individual modes can be difficult to recognize/separate in real data.

D. **Inversion of the dispersion curve to a subsurface model.** In the MASW method, this is done as described in Xia et al (2003). The inversion process assumes that from every picked mode it is known which mode it is, i.e. fundamental, second, third, etc. The subjective manual picking procedure therefore becomes more important.

Automated Dispersion Mapping

When we look at the Nyquist values of the power spectrum of the f-k array that is calculated by the double FFT, the result is an m-by-n array of k and f values where m is half of the number of recording channels and n is equal to the Nyquist frequency.

We run a procedure of picking 15 maxima in the f-k spectrum. We correlate the data along the frequency axes by a Gaussian wavelet with a width that is a few times smaller than the length of the frequency axis. We do this to prevent picking too many neighboring cells in this procedure. An example of this correlation for one k-value is shown in Figure 1.

By doing this, we create two major advantages. First of all, we do not have to convert data to the f-v domain, in which we bypass the weaknesses as already mentioned in stages B and C of the MASW method. Secondly, as can be seen in Figure 2, when we do plot the f-k maxima in the f-v or f-p domain, a clear line-up of multi-modal energy can be seen, which could easily be overlooked by picking dispersion data manually.

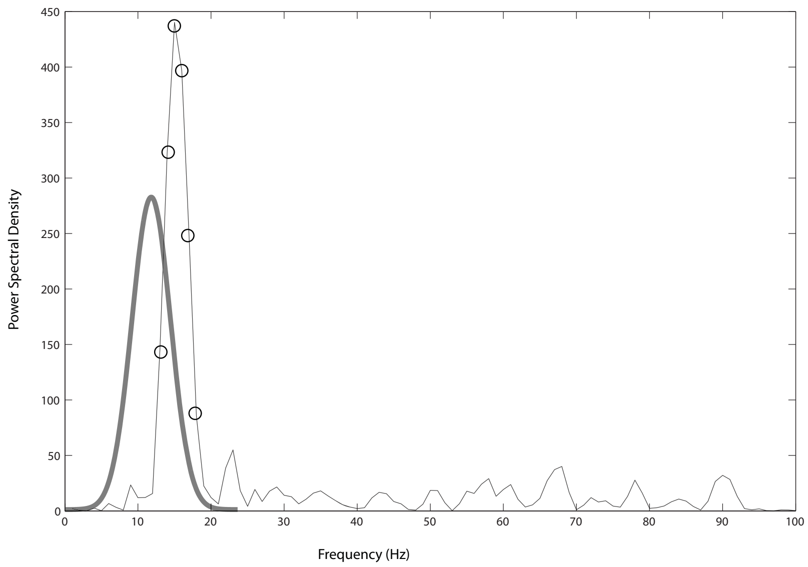

Figure 1 - Data for one k-value as seen on the frequency axis. In this example, all six values in the peak of the power spectrum are higher than all other values. To pick only the maximum value of this peak and thus to prevent the picking of neighboring maximum cell, data is correlated with a Gaussian before picking the maximum values.

Case study on existing data

To test the feasibility of the method, we test it on existing field records. In December 2007, 351 shot records were recorded along a dike in Groningen, The Netherlands, with a sledge hammer of 10 kg, 24 Gimbal geophones on a towed cable with a sample interval of 1 ms and a record length of 1024 ms. For the Automated Dispersion Mapping procedure, we chose dispersive data of the field data to be between k-value 0.0417 and 0.5 and frequencies between 0 – 100 Hz. Dispersion of all 351 records was automatically mapped using a MATLAB script on a Pentium 4 PC. The procedure took 14 minutes, including the creation of dispersion output files in ASCII format. The dispersion curves from two days of field work can thus in practice be delivered from the field in real time, which makes it theoretically possible to use for purposes in a monitoring or early warning system. As the inversion of multi-modal surface wave data requires a quality control, the creation of f-v or f-p images as shown in Figure 2 is also required. By doing this, we see that the method plots the energy maped in the f-k domain in higher modes that would probably have been missed in a manual picking procedure in the f-v or f-p domain. When incorporating this plotting into the method, the calculation time takes approximately 27 minutes, including the creation of image files (in .emf format).

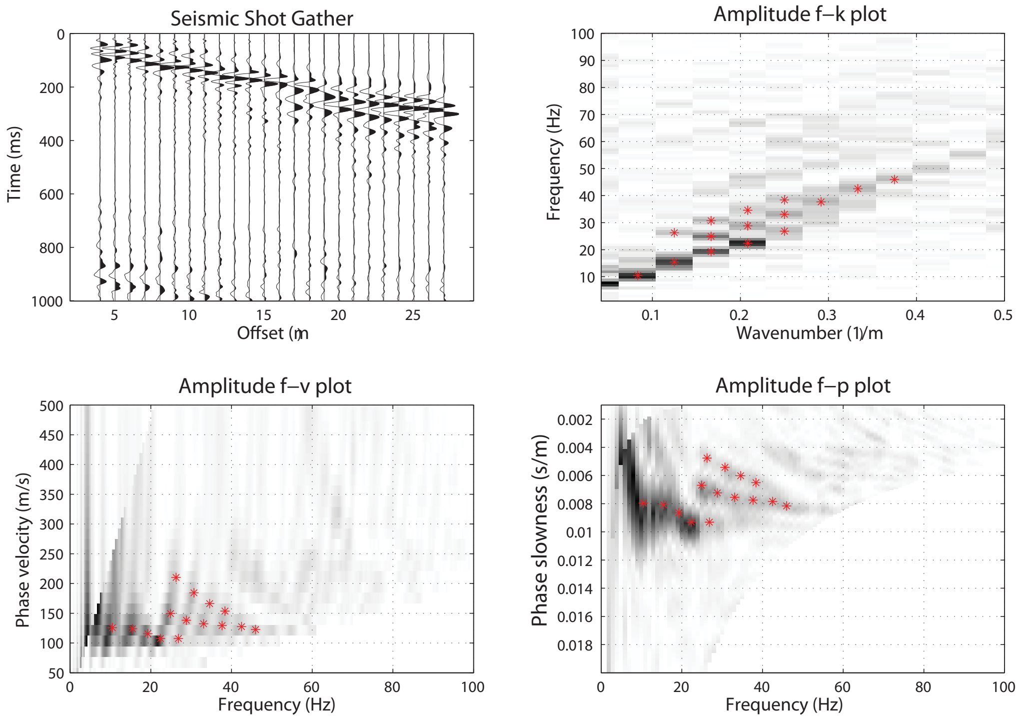

Figure 2 - Automated Dispersion Mapping of the dispersion curve takes place in the f-k domain. Only for visualizing purposes and quality control, the data is also plotted in the f-v and f-p domain.

Evaluation of possible inversion methods

Automated Dispersion Maps do not know whether a fundamental, higher modes, other wave types, or data artifacts have been mapped. When using automated dispersion maps for inversion to a subsurface shear wave velocity layer model, we have to take into account that this data can consist of more than only fundamental mode data without knowing which is which. Thus, we have to look for other methods than the general MASW inversion method (*Xia et al, 2003*). We foresee neural network inversion by i.e. Williams and Gucunski (*1995*), and a Neighborhood Algorithm (Sambridge, 1999) as possible methods for the inversion of multimodal dispersion data.

Conclusion

We have presented an automated dispersion mapping method that can be used for Rayleigh wave data. When operationally incorporated, the method is suited for fast, repeatable, and reliable data processing in the field and also for monitoring purposes to detect temporal changes. The method maps fundamental and higher Rayleigh modes very clearly. In practice, a monitoring network of geophones might measure on regular time bases (e.g. weekly) and changes in dike or levee strength can be analyzed very quickly. Suitable inversion methods are also pointed out briefly and these are incorporated in the present research program of Deltares.

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