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Surface Wave Dispersion Analysis - From Local 1D Models to Tomography

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SUMMARY

The analysis of surface wave dispersion represents an important exploration method at different scales. The basic scheme of the method is mainly based on 1D assumption, but laterally varying sites can be resolved if an opportune processing and inversion strategy is applied. Spatially constrained inversion (SCI), joint inversion with P-wave travel times and tomography represent possible techniques to apply to retrieve 2D models.

Introduction

Inversion of surface wave dispersion curves is an established investigation method for building near surface S-wave velocity models. It finds application both in geo-hazard and engineering problems, where S-wave velocity is a primary parameter for seismic site response and for geotechnical characterization, and in hydrocarbon exploration, where near surface velocity models are required for corrections and ground roll modelling and removal.

Traditionally, dispersion curves are extracted from multichannel seismic gathers by wavefield transforms and inverted for a layered system in which V_S is the main unknown variable. Both dispersion curve extraction and inversion assume a 1D system, but the method is often applied to smoothly laterally varying sites which are described with a series of close 1D models. Many modification of this basic approach must be applied to improve the reliability of surface wave analysis in complex sites. Here we describe the different steps that can be applied on seismic multi fold data to obtain a final 2D model.

Processing and inversion techniques

For large multi-fold datasets several dispersion curves can be extracted and then inverted to get a pseudo-2D (3D) VS model. To improve the quality of final results also in case of significant lateral variations several strategies can be implemented.

Before dispersion curve extraction the dataset is analysed in offset domain to detect abrupt lateral variations by estimating the energy decay exponent trend along the line for positive and negative offset shots (Bergamo, 2012). After locating the main sub-vertical discontinuities, the dataset is windowed to extract a dense series of dispersion curves. The window shape is optimized according to considerations about lateral and spectral resolution (Bergamo et. al. 2012) and the position of the moving window is defined also considering the position of lateral discontinuities. The dispersion curves are then picked in f-k domain.

The inversion is performed with a multistep process based on preliminary Monte Carlo inversion to define a consistent initial model and then on a spatially constrained least squares inversion in which all the curves are inverted simultaneously with a single objective function. The spatial regularization along the line is defined considering the position of lateral discontinuities: the spatial constraints are opportunely weakened in correspondence of the expected lateral variations to allow abrupt changes between neighbouring 1D models on the two sides of the discontinuity. In the case higher modes are retrieved a further refinement of spatially constrained inversion with a multimodal misfit function is applied (Maraschini et al., 2010). The next step consists on the application of a joint inversion algorithm that includes also P-wave first arrivals (Boiero et al., 2011; Garofalo, 2014). The inversion scheme is the same applied in spatially constrained inversion of surface wave only but, contrary to surface waves which are inverted using a 1D forward operator, the P-wave travel times are inverted with a 2D forward mapping and linked with the surface waves in the locations of the dispersion curves. Constraints on Poisson's ratio can be included to improve the consistency of the results.

An alternative approach to surface wave dataset in laterally varying sites is to apply a tomographic inversion. Surface wave tomography is routinely applied at crustal scale in earthquake seismology and can be also used for exploration scale active data, also along 2D lines. The method consists in selecting a series of receiver couples and a source in line with them and extracting the average slowness dispersion curve using the two-station method (Bloch and Ales, 1968). After extracting a dense coverage set of average slowness dispersion curves, they are inverted with a tomographic algorithm that implements a spatial regularization based on the same scheme of the spatially constrained inversion previously described (Boiero, 2009). Checkerboard test is used to assess for spatial resolution of the adopted parameterization (Léveque et al., 1993).

Results and conclusion

The application of the previously described methods will be shown on a high resolution seismic reflection dataset acquired over the Alpine Fault in New Zealand (Carpentier et al, 2013; Konstantaki et al., 2013). In Figure 1 we show two examples of results: the spatially constrained inversion of surface wave dispersion curves and the surface wave tomography. To compare the results the position of the high velocity halfspace obtained by SCI is reported on the tomography results. Different resolution and processing efforts for the different techniques will be compared.

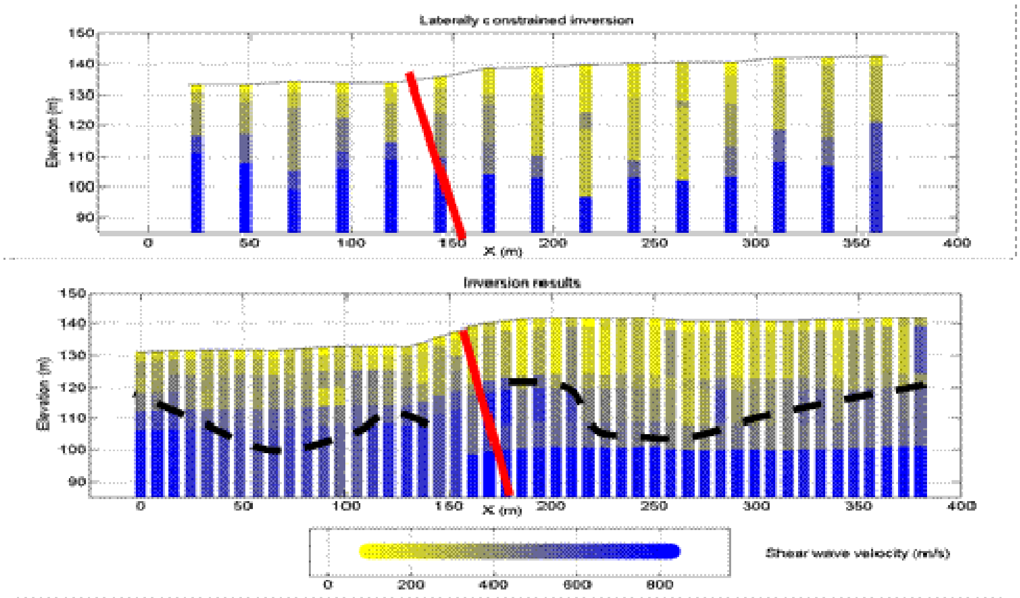

Figure 1 *Examples of different inversion results for the Alpine Fault dataset (new Zealand). Top)* V_S *models obtained from spatially constrained inversion; bottom) results of surface wave tomography. The red line refers to the main lateral discontinuity that corresponds to the Alpine Fault.*

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