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Multimodal Rayleigh Wave Dispersion Curve Picking and Inversion to Build Near Surface Shear Wave Velocity Models

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SUMMARY

The use of Rayleigh waves to invert for a near surface shear wave velocity model is attractive in converted wave processing, such as the application of receiver side statics correction and PS PSDM. We propose a differential evolution inversion scheme to invert Rayleigh wave dispersion curves, and we apply it on a field dataset with high density acquisition to obtain the underlying shear wave velocity structure. The joint use of a new misfit function, which allows multimodal inversion and reduces the risk of mode misinterpretations, combined with differential evolution inversion is highly likely to converge to the real shallow shear wave velocity structure. A semi-automatic picking method based on the quick thinning algorithm is introduced to extract the dispersion curves from frequency-phase velocity spectra. This greatly reduces the demand on manual labor and improves productivity.

Introduction

Although usually treated as low-velocity coherent linear noise needing to be attenuated, Rayleigh waves are attracting more attention due to their possible applications in extracting the shallow shear wave velocity structure (Xia et al., 1999; Socco et al., 2010; Strobbia et al., 2011). The lack of an accurate and reliable near surface S wave velocity model is an obstacle for further improving the quality of receiver side statics and pre-stack depth migration in converted wave processing. The widely used P wave first breaks tomography fails for S waves because their first arrivals are hidden in earlier and mostly PS arrivals. Owing to the sensitivity of Rayleigh wave dispersion on shear wave velocity structure, Rayleigh wave inversion provides a promising way to solve this problem.

Rayleigh wave inversion is the numerical search for a model $\boldsymbol{m}$ such that the difference between the observed dispersion curve and the synthetic one associated with model $\boldsymbol{m}$ is minimal. Usually a dispersion curve consists of several branches and each branch is called a dispersion mode. Compared to fundamental mode inversion, multimodal inversion provides higher resolution and can reach larger inversion depth. In order to employ multimodal inversion, Maraschini et al. (2010) propose a new misfit function based on the eigen-determinant of Rayleigh wave equation of motion, which can help avoid mode misinterpretations.

Even though dispersion curves play a central role in surface wave inversion, their picking remains a challenging problem. Pure manual picking is not feasible for commercial scale projects. Consequently, an accurate and automatic dispersion curve picking method is imperative.

Method and Theory

The inversion of Rayleigh waves is a minimization of the misfit function, and we use the differential evolution (DE) method as a global optimization engine. DE maintains a population of individuals ($\boldsymbol{m}$), perturbs each individual according to differential variation and accepts the move if fitness, which is a measure of optimization and can be set to the inverse of the misfit function, increases. Instead of using binary coding as in genetic algorithm, DE intrinsically deals with continuous real number optimization problems, which makes it extremely suitable for searching in a multi-dimensional velocity space. In the inversion process, we use a generalized reflection/transmission coefficient method to evaluate the misfit function (Chen, 1993).

A method based on binarization and thinning is introduced to semi-automatically pick the dispersion curve from frequency-velocity domain dispersion spectra, which are obtained from an input time-offset gather through a variable substitute *f*-*k* transform (Park et al., 1999). In general, the dispersion curve should be picked in strong amplitude regions in the *f*-*v* plane. Any pixel with an amplitude value larger than a threshold is set to 1, otherwise it is set to 0. After this binarization, a thinning method is used to shrink each connected region to a dispersion mode. In practical application, a mask can be introduced to exclude some unwanted strong noisy regions.

Application on real data

Fig. 1(a) shows a shot gather of ground roll from a high density acquisition, the body waves and other noise have been previously removed. The transformed dispersion spectra are illustrated in Fig. 1(b), indicating many dispersion branches. The binarization of the lowest three branches are depicted in Fig. 1(c), and the picked dispersion curves after thinning are marked as brown dots in Fig. 1(b).

Using the picked lowest three dispersion modes, the inverted 1D layered Vs model is plotted in Fig. 1(d). The near surface V_P mode needed by the inversion was obtained from first arrival tomography and the density was estimated according to Gardner's equation. As verification, we plot all the dispersion branches corresponding to the inverted V_S model in Fig. 1(b). We can see the dispersion branches match well with the spectra, even the ones we do not use in the inversion.

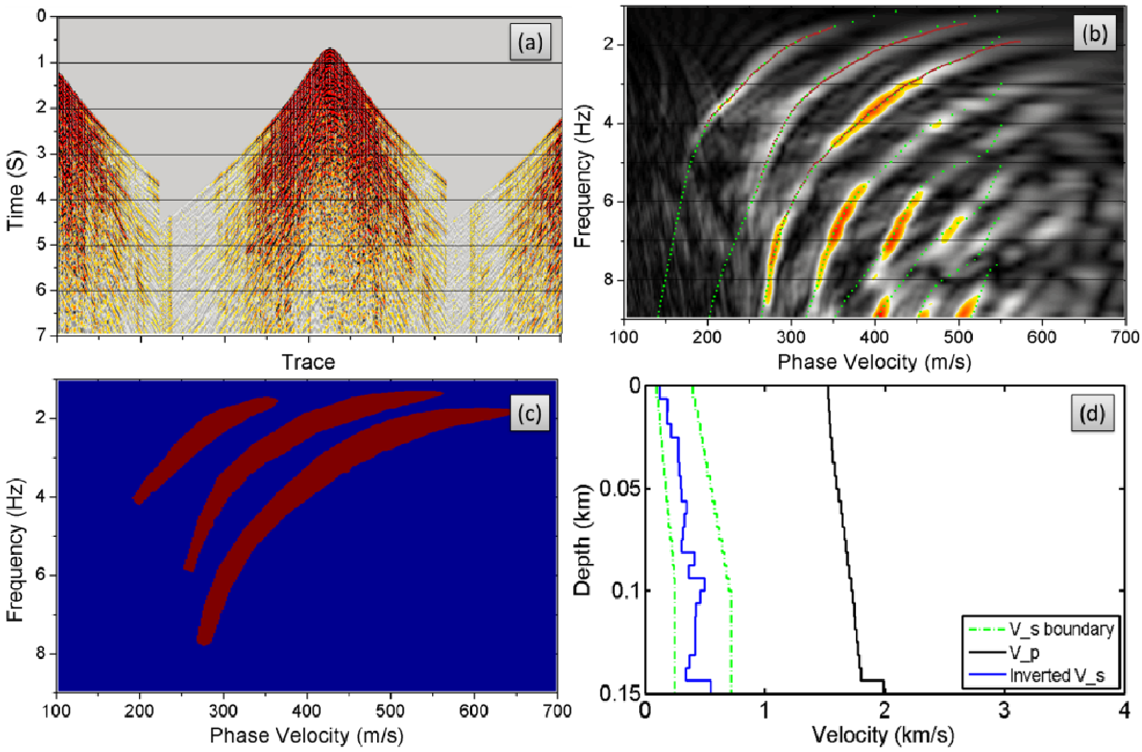

***Figure 1** (a) Input shot gather of ground roll; (b) Dispersion spectra, picked dispersion curves (brown dots) and synthetic dispersion curves (green dots); (c) Binarization; (d) Inverted 1D layered Vs model.*

Conclusions

Through the application of the proposed multimodal DE inversion scheme on real data, we verified its feasibility in building near surface shear wave velocity models. The semi-automatic dispersion curve picking method can extract dispersion curves accurately and effectively, even in regions with strong amplitude noise.

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