P024

Full-wavefield Seismic Tomography of Vibrator Data on Land

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SUMMARY

Application of full wavefield tomography has been proved to work well on marine seismic data. However, it still suffers some problems when applied to land seismic data. Few examples of land application have been shown for explosive sources and very low vibrator data. We present an application of the method on vibrator data acquired with normal frequency bandwidth.

Introduction

Full wavefield tomography (FWT) uses the two-way wave equation to compute the cross-correlation of the forward and backward-propagated wavefields by minimising the misfit function in a least-square sense. Due to the non-linearity of the inverse problem, success in waveform inversion is dependent upon both acquiring low-frequency data and obtaining the initial low-wavenumber information present in the model space. An accurate starting model can provide the latter and mitigate lack of the former. The starting model should predict the traveltime picks to within a half cycle to avoid 'cycle skipping' (Beydoun and Tarantola, 1988), otherwise a deficiency in the starting model may produce an inaccurate result, and thus the wavefield tomography may fail (Warner et al., 2010).

FWT in field data still suffers some impediments that limit the range of its applications (Warner et al., 2008). In addition to the need for a good starting model and very low frequencies, those impediments include the necessity for long offsets and an intense pre-conditioning process in order to mitigate the inverse problem (Virieux and Operto, 2009). This implies that FWT of land data is highly challenging due to the increase in the non-linearity in the inversion of such data. The non-linearity here is introduced by the free surface, which is often ignored on grounds of computational efficiency (Bleibinhaus et al., 2009). Such a non-linearity happens because the acoustic wave equation attempts to explain the propagation of waves in the elastic media (Brenders et al., 2010). Moreover, the problem becomes even bigger with severe variations in geology and topography, statics, and near-surface conditions as well as source and receiver coupling (Mulder et al., 2010). Therefore, data pre-processing would be an essential step for land data prior to inversion, in order to remove surface waves and account for topographic changes. This means the wavefield tomography of land data is even more expensive (Pratt et al., 2010).

Although many studies have shown the effectiveness of the FWT method in synthetic and marine seismic data, very limited examples using land data have been demonstrated. Such examples were shown for explosive sources (Mulder et al., 2010) and very low vibrator data purposely acquired for FWT application (Plesix et al., 2010).
In this paper, we present an example of the acoustic FWT in 2D vibroseis land seismic data with normal frequency bandwidth. Vibroseis data usually have an extended zero wavelet that makes it difficult to pick the first arrivals in order to build a traveltime tomography model.

Background

The data used in this study were acquired over an onshore field in north-west part of the Sultanate of Oman in 1991. A 2D line was extracted from a multi-component 3D survey. The line contains 50 sources spaced at 100m and 72 receivers per source spaced at 25m, and with a maximum source-receiver offset of about 2.2km. The data were acquired using vibroseis sources and geophone receivers. The sweep frequency ranges from 5 to 60 Hz. The aim of this paper is to apply the acoustic FWT to this 2D line of P-P data (P-source and P-receiver) in order to recover the velocities of the top shallow layers of the field. For a typical vibroseis source on land, the seismic energy travels through the top layer, and hence a good compensation of wave propagation through the shallow subsurface allows for a better resolution of the deeper reflections (Smithyman and Clowes, 2010). Part of the objective of this inversion is to validate and investigate the problems that might arise from applying the FWT technique to a set of normal bandwidth vibroseis land seismic data. The other part is to produce an interpretable section of the shallow subsurface.

Pre-processing

Due to the use of the acoustic wave equation method, extra care must be taken to mitigate the elastic effects on land data. On land, statics can cause severe problems to the subsurface image if there are large surface elevations variations or the weathering layer velocity changes laterally (Cox, 1999). However, for this 2D example, elevation static effects were very mild and have been accounted for by placing the sources and receivers at their correct positions in the initial model relative to a datum. An absorbing boundary was then assumed to mitigate the effect of the top surface.

Most of the applications of full wavefield inversion have assumed an absorbing boundary to remove surface-related multiples from the data. Although this might cause a loss of resolution (Bleibinhaus et al., 2009), this assumption is mainly taken to avoid the instability and high computation overburden caused by free surface effects (Hicks and Pratt 2001). In addition, for the 2D acoustic method, shear modes were not modelled and thus were removed prior to the inversion in this case. Therefore, a top and bottom mute was applied to the raw P-P data in order to minimise any effects of the shear waves and the airwaves, as well as any precursor arrivals. Bad traces from each source gather were also removed (Figure 1).
First arrivals from the raw data were handpicked, and a first arrival seismic tomography "FAST" program (Zelt and Barton, 1998) was used to produce an initial model.

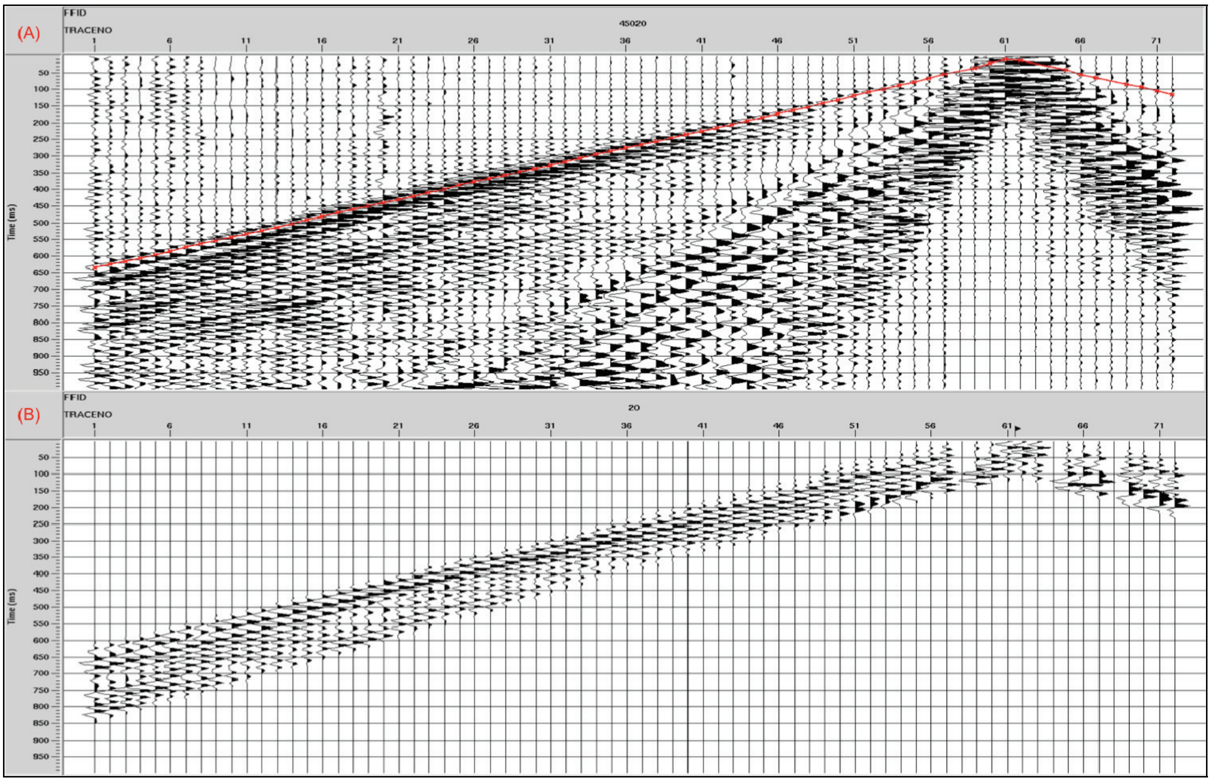

Figure 1. An example shot no. 20 of the 2D line. *A) Raw data prior to pre-processing. The red line indicates the first arrival picks used to obtain the FAST model. B) Pre-processed data used for the inversion, with top and bottom mutes applied and bad traces removed.*

Inversion process

The input elements for the inversion are preconditioned data, a source signature extracted from the data, and a starting velocity model. The inversion was run using the frequency domain method developed by Pratt and Worthington (1990).
The model size of the inversion is 901x201 with 5m nodal spacing corresponding to about 4.5x1.0 km. The inversion was run with six frequencies (5, 6, 8, 10 and 12 Hz) proceeding sequentially from low to high numbers, with 10 iterations at each frequency.

Results

The result (Figure 2) suggests that there is a high velocity near surface layer that extends to about 100 m below the surface. The top layer was resolved using FWT technique and might give a high potential to better recover the deeper overburden part of the model. The slightly high velocity zones at the bottom of both sides of the inversion model (Figure 2.b) are regarded as edge effects, and the high velocity below about 400m is also an artefact. Thus only 300m of the model is shown here.

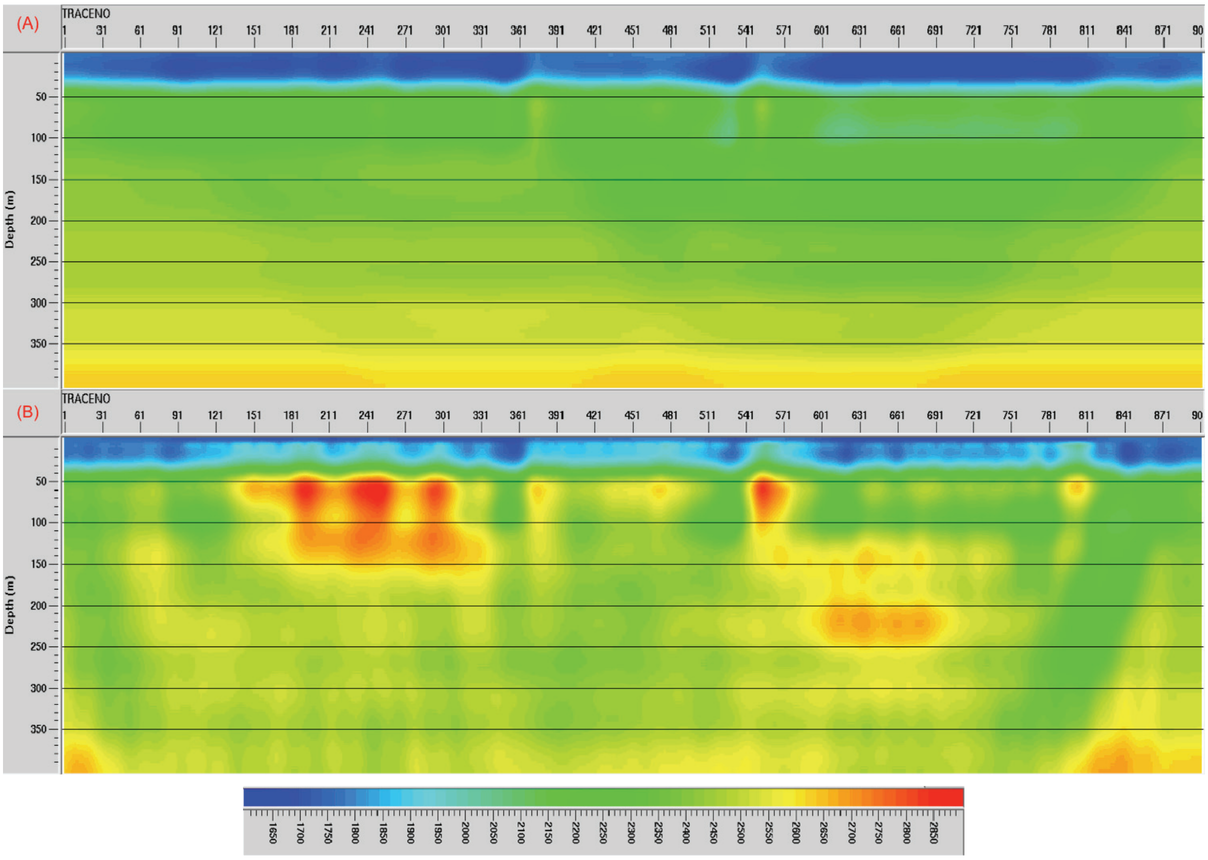

Figure 2. *A) Starting model. B) Inversion result after 6 frequencies with 10 iterations at each frequency. The edge effect of the inversion is noticed at the bottom of the model. Only 400m of the model is shown. Colour bar shows the velocity range.*

Conclusion

A 2D land dataset from an onshore field in Oman was studied in order to examine the effectiveness of the full wavefield inversion technique on land data. The chosen line is a subset from a 3D multi-component dataset that contains compressional and shear waves, but only the acoustic form of the inversion is shown in this paper. There are no significant variations in topography, and thus for the 2D example the elevation statics were minor. The result suggests that there is a high velocity near surface layer that extends to about 100 m below the surface. This feature is absent in the conventional first break tomography model. We are currently investigating the validity of this result. Resolution of such lateral velocity variations may significantly improve the imaging of the deeper part of the model. Despite the many challenges, wavefield tomography of land data can still produce good velocity models and recover the near surface layer.

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