High Resolution Wave-equation Traveltime Inversion Utilizing The First Arriving Signals

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Summary

This abstract describes the theory and the application of wave-equation traveltime inversion using multi-frequency bands for gradually producing highly resolved underground structures. The ground truths, the proposed zero-offset gathers and surface wave inversion results validate the effectiveness of this method.

Introduction

The famous cycle skipping problem of FWI can be partly solved by multiscale frequency strategy [1]. In a similar way, we now propose a multiscale wave-equation traveltime (WT) method [2-3] in which the low-to-high wavenumber parts of the velocity model are inverted by taking full advantage of the first arrivals. This is accomplished by using a low-pass wavelet for the computation of the predicted traveltimes. As the iterations proceed, the higher frequencies in the wavelet are gradually incorporated and are used to estimate the finer details of the velocity model. Our results suggest that multiscale transmission WT (MWT) is less susceptible to cycle-skipping problems associated with the transmission FWI. To validate the WT tomogram, we compared it with the zero-offset (ZO) reflection section. Remarkably, the lateral variation of the ZO reflections from a strongly reflecting interface is almost identical to the velocity variations seen in the WT tomogram.

Theory and/or Method

Let J denotes the misfit function:

$$J = \frac{1}{2} \sum_{s,g} \left(\Delta\tau(s,g) \right)^2, \quad (1)$$

where $\Delta\tau_{\text{trans}}(s,g) = \tau_{\text{obs}}(s,g) - \tau_{\text{pred}}(s,g)$ represents the traveltime difference between the observed and the calculated traveltimes recorded at g from the source at s . Note that the first arriving traveltime differences between two receivers, i.e. g_1 and g_2 , should be identical regardless of the main frequencies in the recorded/calculated seismic data (Fig. 1). Therefore, this simple observation facilitate the development of our proposed MWT inversion for gradually higher resolved tomograms. For convenience, we calculate transmission traveltimes with visco-acoustic equations, but this method can also be used for reflection traveltimes. The conjugate gradient method is used to iteratively optimize the velocity model $c(x)$. The Fréchet derivative $\partial\Delta\tau_{\text{trans}}/\partial c$ can be derived using the implicit functional theorem in [2]:

$$\frac{\partial\Delta\tau_{\text{trans}}}{\partial c} = -\frac{\partial\dot{F}/\partial c}{\partial\dot{F}/\partial\Delta\tau_{\text{trans}}}, \quad (2)$$

where $\dot{F}$ represents the temporal derivative of the correlation between the predicted and the observed data, which connects the traveltime and the velocity variations.

Examples (Land Data)

Figure1: Two first arriving events for two receivers.

Figure 2: The (a) 50 Hz WT, and (b) 100 Hz WT tomograms. (c) and (d) are zoom views of (a) and (b), respectively.

Figure 3: (a) The location of the seismic survey, (b) the outcrop viewed from a drone, (c) panorama front view of the outcrop, and the (d) geology of the outcrop. The white arrows in (b) and (c) mark the cracks or vugs that are seen above the ground, and they extend into the subsurface.

Figure 4: (a) ZOG, (b) the black dots mark the velocity curve at $v=750$ m/s in the magnified view of Fig. 2d.

Figure 5: The S-velocity near-surface tomogram.

Conclusions

MWT is robust and effective for first arrivals. We also further explore this method with AI plus envelope inversion.

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