Pseudo-elastic Wave Equation and its Application in Modeling and Waveform Inversion

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Abstract

Elastic Full-waveform inversion is an effective tool for retrieving earth rock properties for velocity model building and reservoir characterization. One major obstacle for applying elastic FWI is the high computational cost for elastic modeling (Chapman et al., 2014). Finer grids are required to avoid dispersion of the S-waves in elastic modeling and for 3D simulation, such increase in computation is proportional to the ratio of the minimum P-and S-wave velocity. For Poisson medium, the ratio is about nine, while for models with low shear velocity sediments, like near the sea-floor and in the reservoir, the number can be considerably higher. Considering that the majority of the seismic application utilizes the P-waves only, an ideal solution for mitigating the pre-mentioned computation overburden is to develop a pseudo-elastic scalar wave equation, which maintains the following features: 1) **It is expressed as a single wave equation** that can accurately describe a pure-P wave propagating in isotropic heterogeneous elastic medium. It should rely on the same number of elastic parameters as the original vector elastic wave equation, such as density, P-and S- wave velocity. 2) **It does not produce S-waves**, as such a wave equation propagates only a single mode of pressure wavefield. Thus, no requirement for finer grids is needed to guarantee a dispersion-free S-wave propagation. 3) **It shares the same radiation patterns for any the elastic parameters** combinations as that of the PP reflections computed using the vector elastic wave equation. In other words, it produces reflections with the same amplitude variation with offset (AVO) as the PP reflections in an elastic medium, regardless of how large the contract of the elastic parameters.

To address those issues, we present a pseudo-elastic wave equation, describing a pure pressure wavefield propagating in elastic media. The new scalar wave equation utilizes all the elastic parameters (such as density, P- and S-wave velocity). It is free of S-waves and results in the same amplitude variation with offsets (AVO) as the PP reflections computed by the vector elastic wave equation. We show that the proposed new wave equation is actually composed of the conventional acoustic wave equation plus an elastic correction term. As the new scalar wave equation is free of S-waves, it does not require the extra-fine grid for simulation, leading to a computational gain about 50x when the Vp/Vs ratio is about 3. The accurate scattering behavior and computational advantage make the proposed scalar wave equation a good candidate as a physical model engine for performing elastic modeling and waveform inversion. The separate elastic correction term can also be utilized for compensating the elastic effect missing in the anisotropic acoustic wave equation.