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Broadband Acoustic Impedance Reconstruction from Band-Limited Seismic Reflection Data: A Feasibility Study from First Principles

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Abstract

In exploration seismic, estimation of acoustic impedance is an essential step for quantitative interpretation of seismic data. However, the seismic reflection data are band-limited and thus, the acoustic impedance profiles derived from them suffer from nonuniqueness. This hinders the direct interpretation of observed seismic data in terms of rock properties. The existing methods tackle the nonuniqueness either by stabilizing the answer with respect to an initial model or by assuming certain criterion such as sparsity of the reflection coefficients. Considering a homogeneous and horizontal layered earth model, we formulate a set of linear equations where the recursively integrated seismic trace constitutes the data and the reflection coefficients are the unknowns. The approach makes a frontal assault on the problem of reconstructing reflection coefficients from band-limited data and stems from first principles, i.e., Zoeppritz's equation in this case. Nonuniqueness is countered in part by the layer cake assumption, and in part by the adoption of the singular value decomposition (SVD) method of finding an optimal solution to the set of formulated linear equations, provided the objective is to reconstruct a smoothed version of the impedance profile retaining only its coarser structures. The efficacy of the method has been tested with synthetic data added with significant noise and generated from rudimentary earth models as well as from measured logs of acoustic impedance. Emergence of consistent estimates of impedance from synthetic data generated for several frequency bands increases the confidence in the method. The study also demonstrates the successfulness of the method for (a) an accurate estimate of the impedance mean, (b) an accurate reconstruction of the direct current (dc) frequency component of the reflectivity, and (c) an acceptable reconstruction of the broad trend of the original impedance profile. All these outputs can serve as important constraints for more refined inversions and geological interpretations. Thus, the approach provides an effective solution to the restriction of band-limited seismic reflection data without any initial input or mathematical constraints on earth reflectivity.
(Keywords: Reflection data, Acoustic impedance, Broadband, Linear equations, Singular Value Decomposition, First principles, Inversion)