Wavefield Inversion Methods For Refraction and Reflection Data

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Abstract

Two inversion methods are presented: one for refraction (post-critical angle) data, and one for reflection (pre-critical angle) data. Both methods utilize the recorded data in the form of a sampled wavefield, and consequently are applicable to data that is well-sampled spatially.

For refraction data, the process of wavefield continuation (migration) is used to produce velocity-depth models directly from the recorded data. The procedure consists of two linear transformations: a slant stack of the data produces a wavefield in the $p-\tau$ plane which is then downward continued. The result is that the data wavefield is linearly transformed from the time-distance domain into the slowness-depth domain, where the velocity profile can be picked directly. No traveltime picking is involved, and all the data are present throughout the inversion. The method is iterative because it is necessary to specify a velocity function for the continuation. Convergence is determined when the output wavefield images the same velocity-depth function as was input to the continuation. The inversion scheme is easily extendable to free-surface multiples. The method is illustrated with refraction lines from the Imperial Valley and Mojave Desert in California, and with data recorded with a marine streamer cable.

For reflection data, a method is presented for determining density and bulk-modulus variations in the earth from standard reflection surveys. Explicit formulas are given which utilize the amplitude-versus-offset information present in the observed wave fields. The method automatically accounts for dipping reflectors, but since it is based on a Born approximation of the scattering equation, it is restricted to subcritical reflections. For the inversion, the medium is considered to be composed of a known low-spatial frequency variation (the background) plus an unknown high-spatial frequency variation in

bulk modulus and density (the reflectivity). The division between the background and the reflectivity depends on the frequency content of the source. Solutions are obtained for a constant background variation, a depth variable variation, and a smoothly varying background. The Born approach is also extended to two-dimensional elastic reflection data. The observations in this case are a linear combination of the scattering potential evaluated along four different shells, which may be interpreted as P → P, P → S, S → P, and S → S scattering. If the source is either purely compressional or purely shear, then one experiment will suffice to invert the forward equation. If the source is a (known) mixture of P and S components, then two experiments with different combinations of P and S components are necessary for the inversion.

To extrapolate the wavefields, a formulation for one-way wave equations is given that is both accurate and stable. The scalar equations are generated from the full wave equation by a continued fraction square root recursion. The solutions are WKBJ-accurate in the extrapolation direction. The resulting operators are unconditionally stable. Scalar extrapolation is illustrated with the problem of computing Love wave modes in a laterally varying medium. For elastic problems, the choice of variables determines the form of the one-way extrapolation equations. Three sets of variables are considered: displacements, potentials, and a mixed set of variables. None of these three sets appear to satisfy the requirements of being both stable and accurate.

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