CROSSHOLE RESISTIVITY AND ACOUSTIC VELOCITY IMAGING: 2.5-D HELMHOLTZ EQUATION MODELING AND INVERSION

by

Zhou Bing

B.Sc., M.Sc. (China)

Department of Geology and Geophysics

The University of Adelaide

SA 5005, Australia

Submitted in fulfillment of the requirements for
the degree of Doctor of Philosophy

September 1998

Contents

Abstract

Crosshole resistivity and seismic velocity imaging (diffraction tomography or waveform inversion with the acoustic approximation) are two very useful techniques in geophysical exploration, because they may be employed to map conductivity or velocity inhomogeneities (geological anomalies) between boreholes. Such imaging techniques, when considered in mathematical terms, both reduce to 2.5-D Helmholtz equation modeling and inversion. This thesis presents (1) new finite element solutions for two specified forms of this kind of equation, which define 2.5-D resistivity and 2.5-D acoustic wave problems, as well as an extension to 2.5-D elastic waves solution; (2) iterative algorithms for tackling inversion problems, including Tikhonov regularisation, the smoothest model solution and the subspace solution, in which the generalised algorithms and their inter-relations are formulated, and new approximations for the Fréchet and second derivatives are developed; (3) numerical and physical model experiments for crosshole resistivity imaging with different electrode arrays (or configurations) and synthetic simulations for crosshole acoustic velocity imaging with different full-waveform spectral data (real and imaginary components, amplitude and phase, and the Hartley spectra).

The modeling examples for resistivity and acoustic wavefield show that the presented methods are effective and flexible to compute the 3-D physical response for 2-D arbitrary media. Furthermore, it is shown that the accuracy of the modeling mainly depends upon the wavenumber range and the number of wavenumber samples, both of which can be evaluated in terms of the typical shape of the transformed potential in the resistivity case and the critical values of the wavenumber of the media around the seismic source in the acoustic wave case, respectively. The constant-point approximation based on the explicit expressions for the Fréchet and second derivatives has been shown to be a robust and efficient algorithm for inversion. The numerical and physical imaging experiments show that some specified three- and four-electrode arrays are more suitable for crosshole resistivity imaging than the pole-pole array. For acoustic imaging with spectral data, the real and imaginary components, the Fourier amplitude

and the Hartley spectra are suitable for full-waveform inversion with a known source wavelet, but the phase data do not permit satisfactory object field reconstruction. It is shown in the thesis that the normalised Fourier/Hartley spectral data can be used for imaging when the seismic source wavelet is unknown.