ELASTIC WAVEFIELD INVERSION

A DISSERTATION
SUBMITTED TO THE DEPARTMENT OF GEOPHYSICS
AND THE COMMITTEE ON GRADUATE STUDIES
OF STANFORD UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

By
Peter Mora
July, 1987

I certify that I have read this thesis and that in my opinion
it is fully adequate, in scope and in quality, as a dissertation
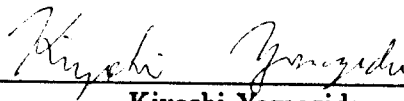for the degree of Doctor of Philosophy.

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Elastic wavefield inversion

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Stanford University, 1987

ABSTRACT

The goal of seismology is to obtain Earth properties from seismic data. I derive formulas based on nonlinear least squares iterations to find the elastic properties of the Earth corresponding to the synthetic wavefield that best matches the seismic observations. Primary P- and S-wave reflections, mode converted waves and Rayleigh waves are all theoretically useful in the inversions. Beginning with a starting guess, the Earth properties are iteratively updated using a preconditioned conjugate-gradient algorithm. The gradient direction is cast in terms of two wave propagations so Frechet matrices are not necessary and the calculations are easily implemented on fine grain parallel computers.

Although the derivation is in three dimensions and commences from the anisotropic elastic wave equation, I have chosen to concentrate on the special case of an isotropic Earth and solve for the compressional and shear wavespeeds. This case is important because the wavespeeds are the properties that have the largest influence on seismic waves. The sudden (high-wavenumber) variations in the wavespeeds at layer boundaries determine the amplitudes of reflected waves while the gross (low-wavenumber) variations in the layers determine the traveltimes of reflected and transmitted waves.

The method is tested by inverting 2D synthetic reflection seismograms (shot profiles), 2D synthetic transmission seismograms (VSP's) and real reflection seismograms (a shot profile). The wave propagations in the tests are done using elastic finite differences to allow for Earth models of realistic complexity. The synthetic data results indicate that low-wavenumber components in wavespeed converge slowly when only reflection data were inverted. This was not expected considering that traveltime curves of reflections should rapidly resolve the low wavenumbers. However, by analyzing an acoustic equivalent of the algorithm in detail, I have identified reflection-tomography-like terms and migration-like terms in the inversion formulas. I prove that the low wavenumbers are resolved by the tomography-like terms and suggest how to get an even rate of convergence of the high and low wavenumbers. I conclude that my iterative elastic inversion formulas obtain all

wavenumbers of the compressional and shear wavespeeds that are resolvable separately by migration and tomography.

I propose that the main topics for future research in seismic wavefield inversion are: how to eliminate the need for an initial model, how to model seismic waves more accurately, how to resolve additional Earth properties, and how to allow for non-Gaussian distributed noise and Earth properties.

Preface

Finally, both the theory and computer power make it feasible to throw away ad hoc methods and partial solutions. Seismic observations can be fed into computers and Earth models will pop out. This goal is on the verge of being realized! Read on.

Acknowledgements

I'd like to express my gratitude to Jon Claerbout for creating the perfect research environment. He nurtures the concept of academic freedom. I have never met anyone with higher scientific morals and he has my utmost admiration and respect.

Next, I would like to thank Albert Tarantola who has been the source of many ideas and who has had a great impact on my Ph.D. research. Without his encouragement and support I doubt any of this research would have come to fruition. His energy level and idealistic approaches, undaunted by excessive pragmatism, have been a constant source of inspiration.

I also want to acknowledge the help of my many fellow students at Stanford. When I arrived at Stanford, the older students acted like patrons, patiently teaching and providing guidance. In particular, Jeff Thorson helped me build a firm foundation for seismic research. Younger students and peers, especially Kamal Al-Yahya, John Toldi, Dan Rothman and Jos Van Trier, were a constant source of interesting discussion, useful comments and suggestions, Others who have contributed in various ways are Chuck Sword, Paul Fowler and Clement Kostov.

During a learning and collaborative period with Albert Tarantola in France, I was aided by many people including Alexandre Nercessian, Jean Virieux, Valerie Lebouc, Manuela Mendes, Antonio Pica, Odille Gauthier, Ligor Nikolla, and Luc Ikelle.

Finally, I want to thank the people who are most important in my life, for without them, I would never have persevered. They provided support and love throughout. They are my parents and close friends, especially, Evelyne Meier.

Contents

List of Figures