VELOCITY ESTIMATION BY WAVE FRONT SYNTHESIS

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FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

By

Philip S. Schultz

August, 1976

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

Jon F. Claerbout
(Principal Adviser)

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

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Approved for the University Committee
on Graduate Studies:

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Philip S. Schultz, Ph.D.
Stanford University, 1976

A "wave stack" is any stack over a common shot or geophone gather in which the moveout is independent of time. It synthesizes a particular wave front by an organized superposition of the many spherical wave fronts of raw data. Unlike the common midpoint stack, wave stacks retain the important property of being the sampling of a real possible wave field, and as such permit rigorous wave equation treatment of formerly difficult or impossible problems.

Seismic sections generated by wave stacks which synthesize slanted downgoing plane waves of a fixed ray parameter show a similarity in appearance to the common midpoint stacks. In signal to noise ratio they lie between the single offset section and the midpoint stack. A velocity-dependent coordinate transformation in these slant frames effects the same first order dip correction as common midpoint coordinates on raw data.

Simple velocity estimation in slant frames differs only in detail from standard coordinates. The enhanced signal to noise ratio and angle selectivity of the slanted plane wave stacks permitted an interval velocity measurement to be done on an extremely angle-dependent reflector which was not visible on either the midpoint stack or the raw gathers.

Because of the wave field character of data which has been slant plane wave stacked, wave equation techniques can be used to generalize migration and velocity estimation to regions in which exist a strong lateral velocity inhomogeneity within the distance of a cable spread.

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TABLE OF CONTENTS

Introduction

Migration of reflection seismic data using finite difference approximations to the scalar wave equation is currently of interest in the petroleum industry. Central to the development of wave equation migration has been the assumption that seismic data can be correctly regarded as the sampling in space and time of a passing upcoming wave field. Migration then becomes extrapolation of this wave field back into the earth to the depths of the reflectors.

Difficulties can arise in applying wave equation techniques to data which can no longer be considered as the sampling of a single wave field. Virtually all conventional reflection seismic data processing is oriented around common midpoint gathers and the common midpoint stack. Neither of these data formats can be regarded as the record of a single possible experiment, and as a result wave equation treatment is not rigorously correct. Indeed it seems that it is not even approximately correct when the acoustic velocity varies in the lateral dimension within the distance of a cable spread (Doherty, 1975), or when attempting to predict diffracted multiple reflections (Riley, 1975).

An alternative to the common midpoint stack is a stack which is based on wave front reconstruction. The assumption of linearity of propagating wave fields and Huygens' principle of superposition permits the reconstruction of arbitrarily shaped downward propagating wave fronts from the many spherical wave fronts of the raw data. This thesis will introduce the concept of "wave stacks" to be the result of any wave front reconstruction operation applied to raw data which retains its original wave field character.

In the first chapter we will consider the many opportunities afforded us, by a rigorous wave equation analysis of wave stacks, to address formerly difficult or impossible problems. The remainder of this thesis will investigate the particular problems of migration through, and velocity estimation in, regions of lateral velocity inhomogeneity. In Chapter 2 the basic properties of slanted plane wave stacks are investigated as a necessary preliminary. Chapter 3 develops techniques of simple velocity analysis in these new data displays and coordinate systems. These basic techniques are then extended to more general diffracting earth models in Chapter 4 where strong lateral velocity variations are eventually discussed.