STRUCTURE INDEPENDENT SEISMIC VELOCITY ESTIMATION

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

Stephen M. Doherty

March, 1975

Structure Independent Seismic Velocity Estimation

Stephen M. Doherty, Ph.D.
Stanford University, 1975

Many commonly used seismic velocity estimation procedures assume that the reflectors are horizontal. Because of this their performance tends to degrade as the reflectors become curved or discontinuous. Much of this degradation can be traced to the fact that data recorded over non-horizontal reflectors need not resemble in detail the subsurface in the area where they were recorded. Diffraction and scattering are the major complicating factors.

Using general principles of reflector mapping it can be shown that surface recorded seismic reflections which have been downward continued to the depth of their source reflectors must resemble those reflectors in detail. This property of downward continuation can be exploited to improve velocity estimates by using downward continuation as a pre-processor for velocity estimation techniques. The estimates resulting from this kind of approach should not exhibit diffraction effects and should not be dependent on reflector dip.

Since much reflection seismic data are described to a good approximation by the scalar wave equation, this equation is an obvious starting place in deriving a downward continuation operator for seismic data. Beginning with the scalar wave equation and using a small dip assumption, approximate wave equations which quite accurately model both near and wide angle reflections generated by one or more sources can be found. Finite difference formulations of these equations can be used as stable and economic downward continuation operators for reflection data.

These wave equation continuation operators allow the demonstration, with both synthetic and field data examples, that downward continuation represents an economically viable process for removing the effects of reflector geometry from seismic velocity estimates. Additionally, synthetic data examples illustrate the fact that the use of downward continuation allows accurate velocity estimates to be made from no-record data recorded over an earth in which the reflectors are random functions of the horizontal and vertical coordinates. For reasonable data parameters, theoretical considerations indicate that the semblance of properly downward continued random reflector data measured along the true velocity hyperbolic is approximately 50% greater than a similar measure on the corresponding surface data. This semblance increase should make velocity estimates based on downward continued random reflector data less susceptible to noise than estimates based on surface recorded random reflector data.

Approved for publication:

By Jon F. Claerbout
For Geophysics Department

By _____
Dean of Graduate Studies

ACKNOWLEDGEMENTS

This work was funded entirely by the member sponsors of the Stanford Exploration Project. I thank each sponsoring organization for their interest in and financial support of project research in general and my work in particular. Special thanks are due to Digicon Inc. and Western Geophysical Company for the data they provided and to Chevron Oil Field Research Company for the use of its seismic section plotter.

It is a pleasure to express here my gratitude to my advisor, the ever optimistic Jon Claerbout for his guidance, support and enthusiasm throughout my career at Stanford.

I wish also to express my appreciation to Dave Boore and Amos Nur for their suggestions and critical reading of the manuscript. Numerous rambling discussion with and suggestions from my fellow traveler, Don C. Riley, were helpful in coping with the waves.

I would also like to thank Sue Erlin for her great patience and expert typing of the manuscript. Finally, I thank Agoston Haraszthy, without whose vision and foresight this work would have been less endurable.

TABLE OF CONTENTS

Abstract		iii
Acknowledgements		v
Table of Contents		vi
1.	Introduction	1
2.	Basic Concepts from Reflection Seismology	
	Introduction	5
	Velocity Estimation	5
	Recording Geometries and Data Displays	9
3.	Downward Continuation of Profiles	
	Introduction	14
	Downward Continuation and Reflector Mapping	14
	Moveout Correction	17
	Coordinate System and Wave Equation	20
	Continuation Equation	23
4.	Downward Continuation of Sections	
	Introduction	35
	Coordinate Transformation and Wave Equation	36
	Continuation Equation	38
5.	Velocity Estimation	
	Introduction	48
	Effects of Reflector Structure on Velocity Estimates	48
	Preprocessing with Downward Continuation	53
	Downward Continuation with Erroneous Velocities	59
	Velocity Estimation in the Absence of Structural Continuity	70
	Interference in Random Scatterer Data	74
	A Field Data Example	86

6. Summary and Conclusion

Summary 98

Conclusion 100

References 103