Stanford Exploration Project, Report 67, January 13, 1998, pages 1–25

Cross-hole seismology at SEP

Francis Muir[1]

keywords: *elastic, velocity, processing, modeling*

INTRODUCTION

Although surface-to-surface geometry is still pre-eminent in seismic exploration, the increasing use of the seismic method in oil field exploitation applications such as reservoir delineation has led to the development of new downhole tools, and with these tools the need for new data processing techniques. To this end, the SEP conducted a weekly seminar/workshop throughout the Summer Quarter on cross-hole data processing.

THE DATA

The idea for the workshop sprang from two datasets that were presented in seminars. The first was a remarkable (reversed) profile of crosshole data that Jon Claerbout had got from Western Geophysical. Both the vertical and inline horizontal components were available, and they both showed very clean compressional and shear direct arrivals.

The second set of data was shown by Reinaldo Michelena who had sufficiently processed the data under an isotropic assumption that it had become clear that it was, in fact, anisotropic. That is, that slanting rays were traveling faster than horizontal rays.

PROCESSING PROCEDURES

The idea was to get a dataset and use it as the basis for a workshop. A single 3-component profile would fit quite easily into anyone's workstation, and yet would contain enough information to end up with an estimate of the elastic moduli (to an unknown density factor) of the earth between the two boreholes.

A benefit of working with crosshole data is that it was expected that we would come across unexpected problems, and that many of our techniques would need to be

[1]**email:** not available

developed from first principles, rather than available processing package solutions.

Preprocessing

The data we chiefly used was a single 3-component reversed profile. That is, there was a single 3-component receiver fixed in one borehole, and a source which was moved and shot every 50 feet over a span of the other borehole.

At first the data was processed without benefit of precise location information, and there were some traces which had gains that were substantially different to others. In the end, we were able to disentangle the headers and come up with a reasonable idea of the borehole geometries.

Rotating the receiver

Since the source is a variable pressure source, it was taken to have a vertical symmetry axis. The same receiver was used throughout the data recording process, so it seemed reasonable to assume that it did not move up and down, or rotate during the experiment. This proved to be a good assumption. There were two rotations involved, one about a vertical axis to point the receiver at the other borehole, and the other in the vertical plane joining the two boreholes. This was likely to be more complicated, since it would depend on both the wave type and the vertical angle between the receiver and the various source locations..

Source waveform estimation

Western were using a source extended both in time and along the borehole for this work. As received, the raw data had been correlated so that the wavelets were somewhat collapsed. Nevertheless, the direct arriving compressional waves had well developed precursive energy, and the normal minimum phase deconvolution was clearly inappropriate.

The compressional waves were quite clean and similar in character, and the first plan called for picking, shifting, and stacking to form the estimate.

Source wavelet deconvolution

Since kinematic inversion based on picked events was to be the heart of the planned processing suite, Dwork's Result (1950) for maximizing signal peak amplitude to rms background noise was chosen as the first thing to try.

Velocities estimation

There are two important qualities that distinguish crosshole from conventional surface datasets.

- Source to receiver distances as well as travel-times are known.
- Both time/distance and NMO velocities are avaiable

Our intention, then, was to estimate these velocity pairs for at least the two plainly visible direct arrivals, P and SV, and, maybe, for the hidden SH arrival.

Velocities to elastic moduli

If these velocity pairs can be established for all three wavetypes of a transverse isotropic model, then the five elastic moduli of the TI model, C11, C33, C13, C44 and C66, can be estimated to an unknown density factor. If the SH event could not be identified, then we would still have four of the five, missing only C66.

A tomographic scheme

Since we had a single profile of data, we would not be able to do more than estimate the mean elastic properties of the material between the two boreholes. However, Reinaldo Michelena had been working on a 1-component, multiple profile dataset, and this would be useful for testing out ideas on anisotropic tomographic inversion methods.

This work is incomplete, but we have developed some ideas for a practical scheme:

- Replace the conventional isotropic scheme with one based on elliptic dispersion relations with vertical symmetry axes. This only doubles the degrees of freedom for each wavetype, but is sufficient to arrive at reasonable estimates of the elastic moduli of the material.
- Begin by estimating the best homogeneous model, and then, by a divide-and-conquer technique, arrive at increasingly finely layered models.
- If it proves necessary, use the final, finely layered output as the input to a vertical divide-and-conquer scheme.

CONCLUDING REMARKS

I have presented the original intentions of the workshop. The actual results are in the papers and short notes that follow. The format of the seminar/workshop seemed to work well, and maybe chiefly because we were doing what SEP does best—we worked with real data.

REFERENCES

Dwork, B. M., 1950, Detection of a pulse superimposed on fluctuation noise: Proc. IRE, **38**, 771–774.