

DOWNWARD EXTRAPOLATION OF DECOMPOSED P AND S WAVE FIELDS

GREG HAIME and C.P.A. WAPENAAR

Delft University of Technology, Laboratory of Seismics and Acoustics, PO Box 5046,
2600 GA Delft, The Netherlands

Introduction

The use of amplitude information in pre-stack seismic data to delineate and characterize reservoirs has shown a considerable growth in recent years. Therefore, in redatuming or prestack migration techniques it is required that the used extrapolation operator contains all the necessary characteristics to treat both the phase and amplitude information in a correct manner, even in cases where the medium is strongly inhomogeneous and/or anisotropic. There are several techniques described in the literature for treating elastic data. We prefer to apply wave field extrapolation on *decomposed* data. Note that in most decomposition techniques there is only a separation of P and S events at the receiver side. Because a seismic source emits both P and S waves into the earth this means that the S to P converted events and the P to S converted events will still be present in respectively the decomposed P -data set and S -data set. As a consequence, by applying elastic extrapolation operators to these data sets each reflector in the imaged result will appear twice because the reflected wave and the converted wave have different traveltimes. To avoid this double image problem it is essential to perform a decomposition for the outgoing source wavefield as well. In this way the elastic data set is *totally* decomposed into four separate data panels, namely PP , PS , SP and SS data. By performing a total decomposition we have not lost *any* information that was previously present in the original data. The elastic propagation and reflection properties are still present and therefore we still need to use *elastic* extrapolation operators to treat these four data panels. A discussion on what kind of elastic operators to be used and the related practical aspects are the subject of this paper.

Elastic extrapolation operator

Ideally one should use elastic operators for decomposed P and S waves (Wapenaar and Haimé, 1990). These opera-

tors are based on the full elastic Kirchhoff integral relation and are adapted for the seismic situation. Amplitude errors in the inverse operators are of second order (for low to moderate contrast media), but if one wishes, *any* higher order accuracy can be reached by applying these operators in an iterative way (in case of high contrast media). A brief discussion about these operators follows next.

From the elastic Kirchhoff integral for inhomogeneous and/or anisotropic solids it can be shown that, after converting the recorded wavefield into up- and downgoing P and S potential fields, extremely simple expressions for elastic (forward and inverse) wave field extrapolation can be derived. These operators are potential operators and operate on the decomposed P and S data panels described in the introduction. Mathematically, the inverse extrapolation operators read,

$$\Phi_A^- = \frac{2}{\omega^2} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \left[\Phi^- \cdot \frac{1}{\rho} \left(\frac{\partial}{\partial z} \Phi_G^- \right)^* \right]_{z_0} dx dy \quad (1)$$

and

$$\Psi_{i,A}^- = \frac{2}{\omega^2} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \left[\tilde{\Psi}^- \cdot \frac{1}{\rho} \left(\frac{\partial}{\partial z} \tilde{\Psi}_{i,G}^- \right)^* \right]_{z_0} dx dy \quad (2)$$

where in equation (1) Φ_A^- represent the upgoing P -wave potential in any point A in the subsurface. On the right hand side Φ^- represents the upgoing P data at the surface (PP -data panel). Φ_G^- represents the Greens function due to a P -wave source in A . In equation (2) $\Psi_{i,A}^-$ represents the i th component of the upgoing S -wave potential in any point A in the subsurface. On the right hand side $\tilde{\Psi}^-$ represents the upgoing S data at the surface (SS -data panel). $\tilde{\Psi}_{i,G}^-$ represents the Greens function due to a S_i -wave source in A (S_i -wave: S wave polarized in the plane perpendicular to the i -axis, i stands for x , y or z). Although these operators are accurate for inverse extrapolation through arbitrarily inhomogeneous and/or anisotropic

media they are not yet applicable from a practical point of view. The main reason for this is that in order to extrapolate several shot records we need to compute all the Greens functions first (covering the whole subsurface) and store these on disk. This requires a huge storage capacity to be available. For a 2D migration experiment this may reach about 500 Mbyte storage capacity for typical 100 shots, 125 frequencies, 50 depth levels and 100 Greens functions (See Fig 1). For 3D depth migration this may reach 5 Tbyte disk space. An alternative way of migrating the data is by reverse time extrapolation (Chang and McMechan, 1987). This way of extrapolating the data is, relatively, not so demanding on disk usage. Moreover, during the presentation it will be shown that reverse time migration can be modified in such a way that the results are identical to those obtained by using the operators described by equations (1) and (2) (see Fig. 2).

Conclusions

Migration of elastic data is preferably applied after decomposition into *PP*, *PS*, *SP* and *SS* data. From a theoretical point of view it should be based on the modified Kirchhoff integrals (1) and (2). From a practical point of view, however, reverse time migration is preferred.

The latter can be modified in such a way that the results of both approaches are identical. Hence, modified reverse time migration of decomposed elastic data provides an accurate and efficient means of imaging the angle-dependent elastic reflectivity properties of the earth. Amplitude errors can be shown to be of second order.

References

- Aki, K. and Richards, P. G., "Quantitative seismology", W.H. Freeman and Co.
- Chang, W. F. and McMechan, G. A., "Elastic reverse time migration", *Geophysics*, 52, No. 10 (October 1987).
- Kuo, J. T. and Dai, T. F., "Kirchhoff elastic wave migration for the case of noncoincident source and receiver", *Geophysics*, 49, 1223-1238, (October 1987).
- Wapenaar, C. P. A. and Berkhout, A. J., "Elastic wave field extrapolation. Redatuming of Single- and Multi-component Seismic data.", Elsevier Science Publishing Co.
- Wapenaar, C. P. A. and Haimé, G. C., "Elastic extrapolation of primary seismic *P* and *S* waves", *Geophysical Prospecting*, 38, No. 1 (January 1990)

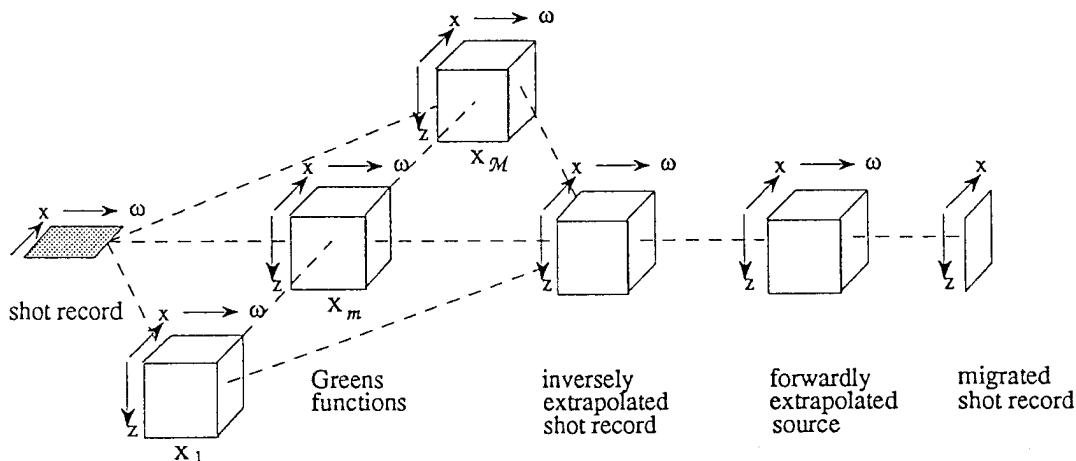


Figure 1. Data flow for true amplitude depth migration using Greens functions

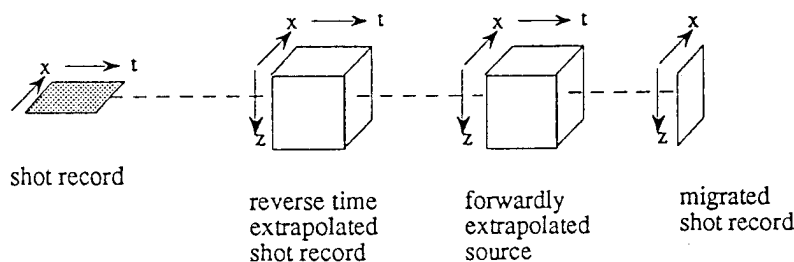


Figure 2. Data flow in case of modified reverse time migration