Elastic Wavefield Decomposition

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SUMMARY

Surface multi-component seismic land data are presented in terms of particle velocities measured on a stress free surface due to multi-component sources. We show that it is possible for any inhomogeneous subsurface to decompose the wave fields both at the source and receiver side. This enables us to represent the seismic data in terms of upgoing P or S waves reaching the surface due to a pure P or S wave source. In case of a homogeneous near surface layer the decomposition can be done in the frequency-wavenumber domain (ω,k_x,k_y). Like in the migration process, in case of lateral velocity variations it is preferable to work in the frequency-space domain (ω,x,y); in this domain decomposition can be described in terms of lateral convolution. To do a correct wave field decomposition we have to know the P and S wave velocity in the near surface layer. If this information is not available, it is possible to estimate them in an iterative way from the wave field decomposition results. The birefringence study, usually done on the horizontal particle displacements, should preferably be done on the decomposed S_x and S_y wave fields.

INTRODUCTION

In order to have a better knowledge about the elastic properties of the subsurface, seismic acquisition must be achieved with multi-component sources and receivers over large offsets. By using multi-component receivers it is possible to record P and S wave energy at any offset. Similarly the use of multi-component sources, that radiate both longitudinal and transversal waves, makes it possible to "illuminate" any point of the subsurface by P or S wave energy. In case of surface land seismics, the data measured are of the type $V_{i,j}$; $i,j = x,y,z$ corresponding to the particle velocities measured at the surface along the i axis due to a stress source applied at the same surface along the j axis.

Berkhout and Wapenaar (1988) proposed in their inversion of multi-component data to transform the nine original data type panels $V_{i,j}$ into nine other data type panels (P^--P^+: upgoing P waves measured at the surface due to a pure downgoing P wave source and similarly P^--S_x^+, P^--S_y^+, S_x^--P^+, ... , S_y^--S_y^+). This data transformation consists of two decomposition procedures (Herrmann et al. 1989): a decomposition at the receiver side, which separates the upgoing P and S waves reaching the acquisition surface from the measured particle velocities, and a decomposition at the source side which simulates a pure P or S wave source by combining the multicomponent sources used.

Until now the decomposition procedure has been described in the frequency wavenumber domain (ω,k_x,k_y) with the underlying assumption of a homogeneous near surface layer. During this presentation the following topics will be discussed:

- Wavefield decomposition in the case of lateral velocity variations.
- Birefringence detection on the decomposed S panels.
- Wavefield decomposition as a tool to estimate the near surface velocities.

DECOMPOSITION OF MULTICOMPONENT DATA

Homogeneous near surface layer, an example

The raw seismic sections contain a mixture of P and S wave energy for two main reasons: the particle velocity detectors are both sensitive to P and S waves and seismic sources emit both longitudinal and transversal waves. The goal of full wavefield decomposition is to reorganize the data in such a way that we obtain new seismic sections that contain pure upgoing P or S waves reaching the surface due to pure P or S wave sources. During this process there is no loss of information, just a reorganisation that makes the seismic sections significantly clearer. This is illustrated on simulated data. Considering the 2-D inhomogeneous elastic subsurface, shown in Figure 1, the multicomponent vibrators and geophones are situated at the free surface $z_0 = 0$ m. We modeled 128 multi-component shot records for this configuration (finite difference elastic modeling). In Figure 2 one multi-component shot record is shown, the source position is indicated by the arrow in Figure 1. In Figure 3 the same multi-component shot record is depicted but now after ground roll removal. We clearly see that both P and S wave energy is present in all the sections. In Figure 4 we see the same multi-component shot record after full wave field decomposition at the receiver side as well as at the source side (bear in mind that we used all 128 shot records to achieve the decomposition at the source side). In the next step we eliminated the surface related multiples contained in those four panels. Following Verschuur et al.(1988), we obtain the multiple free decomposed data, as shown in Figure 5. Compared with the original data (Figure 2) the improvement may be referred as dramatic.

Decomposition in the frequency-space domain

Originally the operators used for the wavefield decomposition are described in the frequency-wavenumber domain (ω, k_x, k_y). It is possible to take a band limited version of the operators and use Fourier transformation routines to express them in the frequency space domain (ω,x,y). In the space domain the decomposition process is expressed in terms of convolutional operations. During the decomposition it is possible to change the operator each time a change occurs in the elastic parameters of the near surface layer. This offers the possibility to take into account lateral variations in the elastic parameters of the near surface layer. This possibility will be illustrated on simulated data.

Birefringence study

In the case of 3 component detectors it is possible to decompose the S wavefield into two kinds of S waves, the S_x waves polarized in the (y,z) plane and the S_y waves polarized in the (x,z) plane. By applying a rotation around the z axis it is possible to detect the direction along which the S waves are optimumly separated. In practice this procedure is already applied on the horizontal particle velocity detectors to detect S wave birefringence. Here we will illustrate it on decomposed data.

Estimation of the near surface velocities

In the case of particle velocity detectors on a stress free surface, the S waves can be well separated from the total elastic wavefield if we know the correct S wave velocity in the near surface layer (the P wave velocity is not involved). In case we use the wrong velocity P events appear in the decomposed S panel. Based on this property, we can determine the correct S wave velocity in an iterative way. Once it has been determined, a similar procedure can be used to determine the P wave velocity of the near surface layer by minimizing the S events that appear in the decomposed P panel.

CONCLUSIONS

The elastic wavefield decomposition procedure not only simplifies considerably the character of the seismic sections, but it may also constitute the starting point of a new type of multicomponent inversion procedure, see Berkhout and Wapenaar (1988). In order to do the wavefield decomposition correctly, we have to know the P and S wave velocity in the near surface layer. We have illustrated that the decomposition itself can be used to determine the required velocities (compare with pre-stack migration based velocity analysis). In case of lateral variations in the elastic parameters of the near surface layer it is still possible to decompose the wavefield by means of lateral convolution in the frequency-space domain.

ACKNOWLEDMENTS

These investigations were supported by the Compagnie Générale de Géophysique (first author), the sponsors of the DELPHI consortium (second author) and the Royal dutch Academy of Sciences (third author).

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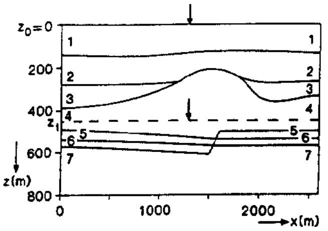

Layer	Cp(m/s)	Cs(m/s)	ρ(kg/m³)
1	2400	1400	1000
2	3000	2000	1600
3	3000	2000	2100
4	4100	2200	2200
5	3700	2000	2300
6	4200	2400	2000
7	3500	2100	1800

Figure 1 2D inhomogeneous elastic subsurface. The multi-component vibrators and geophones are situated at the free surface z0= 0 m.

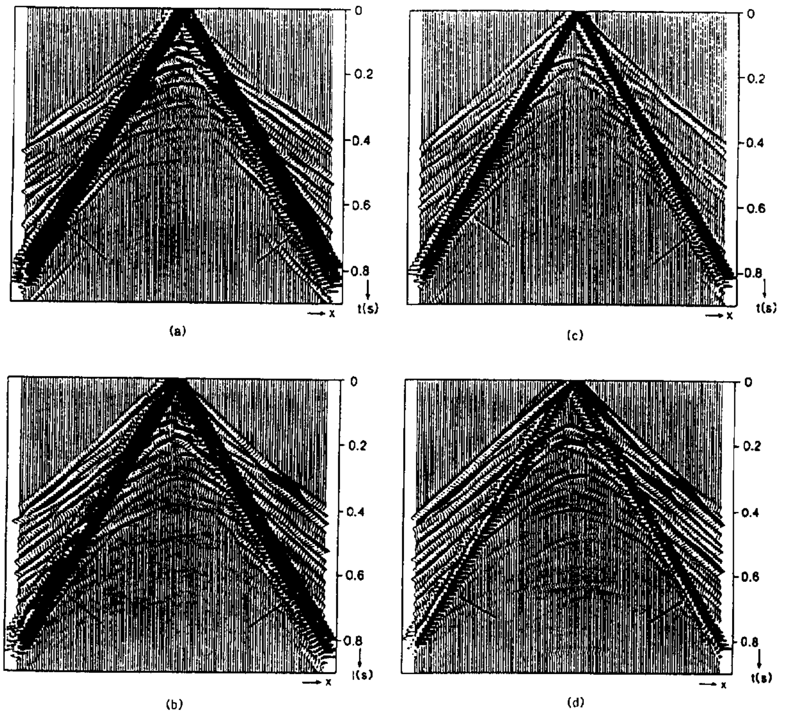

Figure 2 Multi-component shot record. The source position is indicated by the arrow in Figure 1.

a. Pseudo P^--P^+ data ($V_{z,z}$) *.c. Pseudo P^--SV^+ data ($V_{z,x}$)*

b. Pseudo SV^--P^+ data ($V_{x,z}$) *.d. Pseudo SV^--SV^+ data ($V_{x,x}$)*

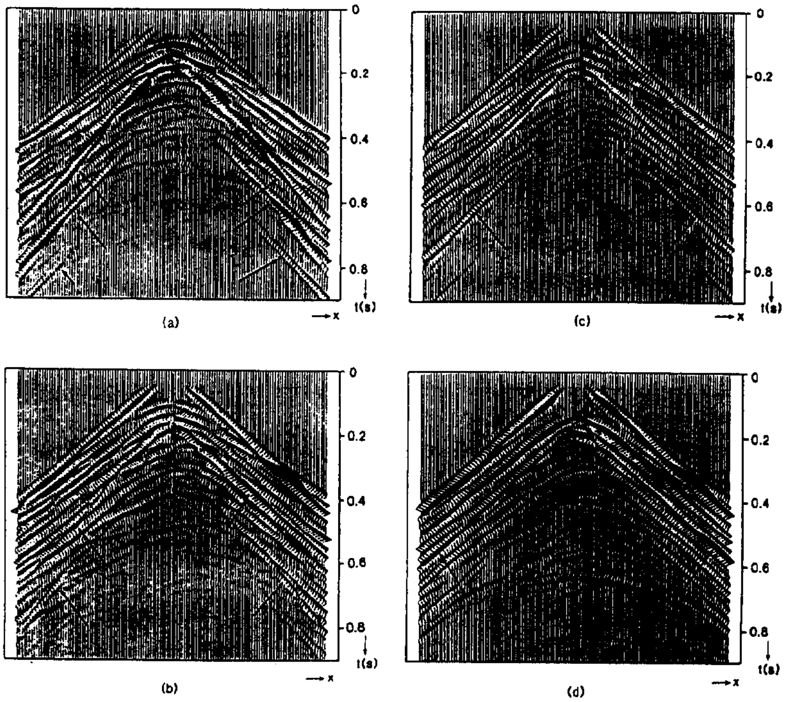

Figure 3 Multi-component shot record of Figure 2 after removal of the ground-roll.

a. Pseudo P^--P^+ data *c. Pseudo P^--SV^+ data*

b. Pseudo SV^--P^+ data *d. Pseudo SV^--SV^+ data*

The arrows indicate spurious events.

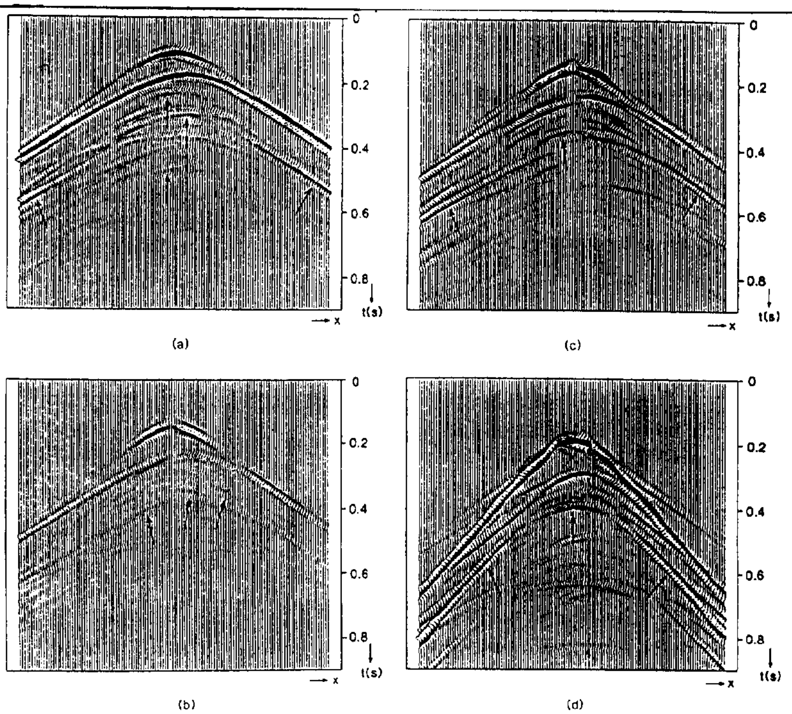

Figure 4 Multi-component shot record, after decomposition into one way P- and SV-wave responses. The source position is indicated by the arrow in Figure 1.

a. True P^{-}-P^{+} data. *c. True P^{-}-SV^{+} data*

b. True SV^{-}-P^{+} data.. *d. True SV^{-}-SV^{+} data.*

The arrows indicate surface related multiple reflections and conversions.

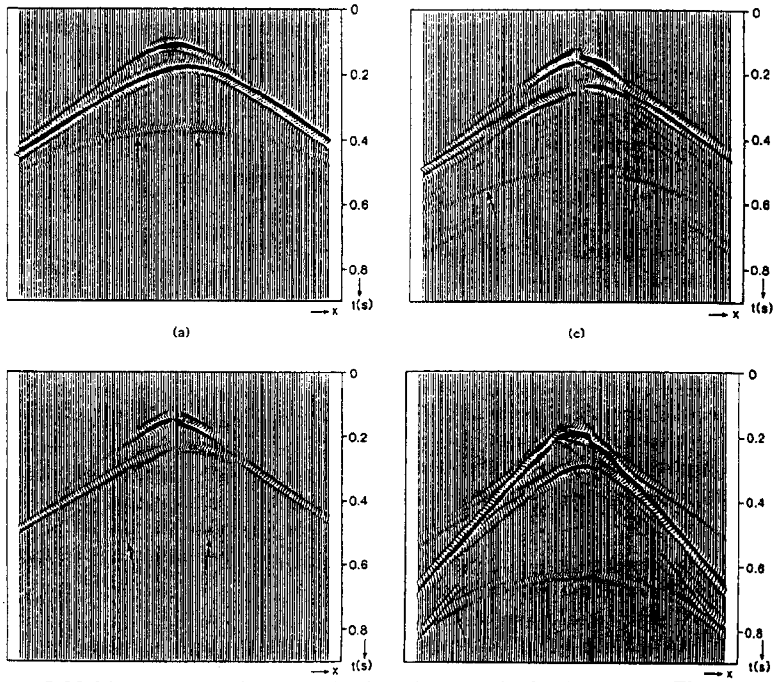

Figure 5 Multi-component shot record, after elastic multiple elimination. The source position is indicated by the arrow in Figure 1.

a. True P^{-}-P^{+} data. *c. True P^{-}-SV^{+} data*

b. True SV^{-}-P^{+} data.. *d. True SV^{-}-SV^{+} data.*

The arrows indicate the response of the target reflectors below zt=450 m.