A Processing Technique for Three Component Seismic Data: Use of Polarisation Characteristics

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Summary

This paper presents a method that uses polarisation characteristics of three component seismic data (recorded by surface reflection profiling, VSP, etc.) for discrimination and filtering of waves.

Discrimination of waves in single (e.g., vertical) component data is based on frequency characteristics and apparent velocities, obtained from line-up observations. When three component records are used, discrimination based on polarisation characteristics is also possible.

In this paper, we first describe the method by which polarisation characteristics are determined from three component records, and how these characteristics are used in polarisation filtering. Polarisation characteristics are estimated by eigenvector analysis of covariance matrices, which are obtained from three component data. The parameters thus obtained are then used in polarisation filtering.

Following this is a discussion of the method. In this discussion, three component data, synthesized from waves having various polarisation characteristics, are used.

Finally, we present an actual application of this method to data obtained in a surface observation. This example demonstrates that by the use of polarisation characteristics, it is possible to (1) discriminate linearly polarised waves (P or S waves) from elliptically polarised waves (Rayleigh type surface waves); and (2) distinguish between P waves and S waves, on the basis of differences in particle motion direction.

Estimation of polarisation characteristics and polarisation filtering

Polarisation characteristics are quantitative expressions of trajectories of particle motions. For three component records, it is assumed that particles follow triaxial ellipsoidal trajectories. Polarisation characteristics are represented as geometrical parameters of the ellipsoid. These parameters can be estimated by eigenvector analysis of covariance matrices, which are obtained from three component records in given time intervals (Esmersoy, 1984).

If $\lambda_1, \lambda_2, \lambda_3 (\lambda_1 > \lambda_2 > \lambda_3)$ are eigenvalues for a seismic wave, and $\underline{u}_1, \underline{u}_2, \underline{u}_3$ their corresponding eigenvectors, the λ's represent the lengths of each of the three axes of the ellipsoid, and the $\underline{u}$'s represent their orientations. The dominant direction of particle motion (θ, ϕ) is then expressed:

$$\theta = \tan^{-1}(u_{1X}/u_{1Y}), \ \phi = \tan^{-1}(-u_{1X}/\cos\theta/u_{1Z}) \quad (1)$$

where $\underline{u}_1 = (u_{1X}\ u_{1Y}\ u_{1Z})^T$ and θ and ϕ are azimuthal angles with respect to the X axis, and vertical angles with respect to the Z axis.

The following parameter defines a triaxial ellipsoid:

$$P = 2\,\lambda_1/(\lambda_2 + \lambda_3) \quad (2)$$

This parameter can be used as a measure of linearity of polarisation. For example, if there is no polarisation, $\lambda_1 = \lambda_2 = \lambda_3$. Therefore, P has a value of 1. P increases with linearity of polarisation.

The polarisation filter presented here is similar to the REMODE (Rectilinear Motion Detection) filter used in the field of seismology (Gal'perin, 1984). It distinguishes different types of waves on the basis of linearity of polarisation and directions of particle motion.

The results obtained after filtering are expressed by the following formula:

$$S(t) = g \cdot \underline{u}_{max}{}^T \cdot \underline{r}(t) \quad (3)$$

where $\underline{r}(t) = (x(t)\ y(t)\ z(t))^T$ is the vector representing three component records; $\underline{u}_{max}$ is the unit vector indicating the dominant direction of motion of wave particles that we want to extract; and g is a weight determined by amount of linear polarisation. The latter is defined as follows:

$$g = [1+(P_o/P)^{2N}]^{-1/2} \quad (4)$$

where P_o and N are constants which control the filtering operation.

Test on synthetic data

To demonstrate how the method works in practice, we conducted a test, using synthetic three component data.

To generate the synthetic data, we used sinusoidal wave A sin $(2\pi t/T+\beta)$, changing amplitude A and phase delay β with time, as shown in Table 1. Sampling time was 1 ms, and data length was 500 ms. Period T was a constant of 25 ms for all time intervals.

t ms / comp	0 - 100	100 - 200	200 - 300	300 - 400	400 - 500
X	$A=\sqrt{3}$ $\beta=0$	$A=\sqrt{3}$ $\beta=0$	$A=\sqrt{3}$ $\beta=0$	$A=1$ $\beta=0$	$A=1$ $\beta=0$
Y	$A=\sqrt{3}$ $\beta=0$	$A=1$ $\beta=0$	$A=-1$ $\beta=0$	$A=1$ $\beta=\frac{\pi}{4}$	$A=1$ $\beta=\frac{\pi}{4}$
Z	$A=\sqrt{3}$ $\beta=0$	$A=1$ $\beta=0$	$A=1$ $\beta=0$	$A=1$ $\beta=0$	$A=1$ $\beta=-\frac{\pi}{4}$

Table 1. Amplitude A and phase delay β in sinusoidal wave $A \sin(2\pi t/T+\beta)$, changed with time.

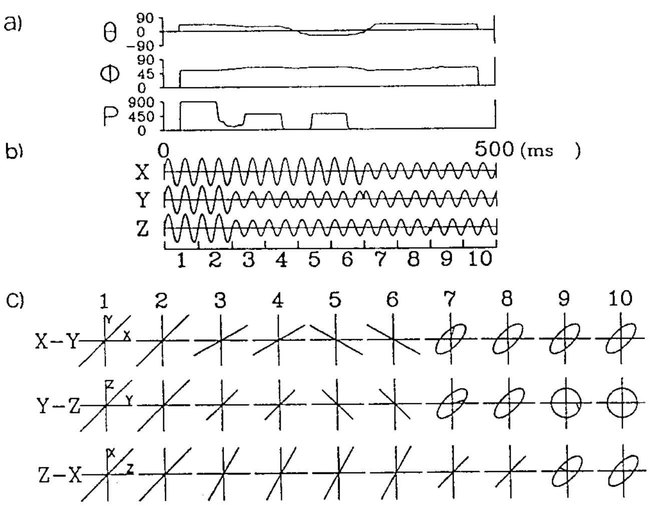

FIGURE 1
Time variations of polarisation characteristics for synthetic three component data
a Polarisation characteristics:
θ Azimuthal angle with respect to X axis
ϕ Vertical angle with respect to Z axis
P Linear polarisation measure
b Synthetic three component data
c Particle motions of the data in each time window indicated in b

We calculated time variations of polarisation characteristics for the synthetic data by moving the 50 ms long time window 1 ms at a time. The result, shown in Fig. 1, reveals the changes in polarisation characteristics, that is, the changes from linear to elliptical polarisation at 300 ms and of azimuthal angle in the time interval, 200–300 ms.

Figure 2a shows the synthetic data after applying a polarisation filter having the same polarisation characteristics as data within the window shown in Fig. 2b. From this figure, we can see that this filter completely eliminates elliptically polarised oscillations and greatly suppresses amplitude of the data having other azimuthal angles than those within the window.

Application to field data

The method was applied to field data obtained in a surface observation.

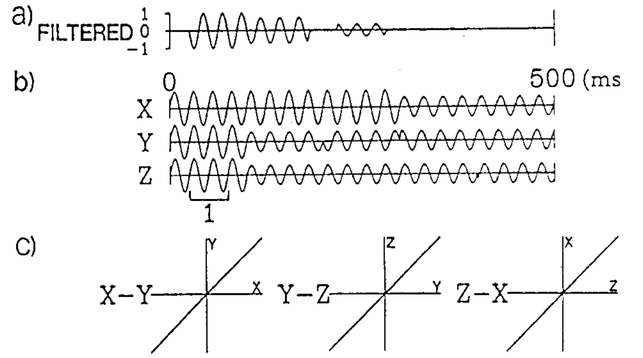

FIGURE 2
Application of polarisation filter
a Filtered data
b Synthetic three component data
c Particle motions of data within the window indicated in b

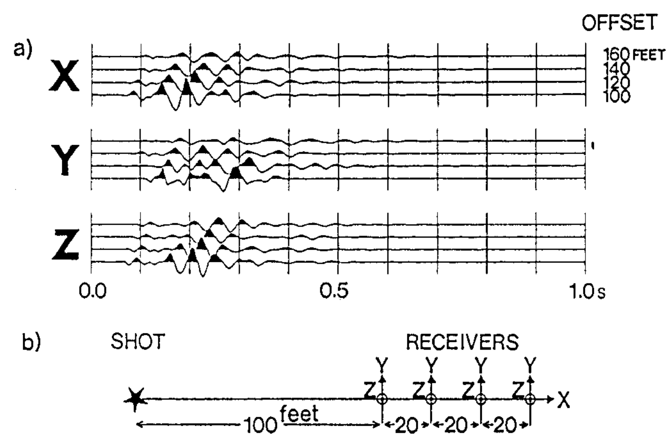

FIGURE 3
An example of field data used in this analysis
a Observed three component records. These are common shot gathers with four different offsets.
b Shot and geophone locations. Geophone orientations (X, Y and Z directions) are also indicated.

Figure 3 shows the locations of shot points and receivers and the three component data that was recorded. Each receiver consisted of three single type geophones, oriented to the X, Y and Z directions, as shown. Seismic waves were produced by vertical shooting, using a Bolt land air gun.

Figure 4 shows time variations of polarisation characteristics, calculated from data having an offset distance 160 feet. This calculation was conducted by moving a window having a width of 100 ms. From this figure, we can identify four different polarisation characteristics: (1) P waves having small ϕ values of about 100 ms; (2) S waves that follow these P waves, having larger ϕ values; (3) surface (Rayleigh) waves having elliptical particle motion, which appear 200 ms later on; and (4) other types of waves having quite different θ and ϕ values.

Figure 5 shows the result of applying the polarisation filter to the data shown in Fig. 4b. This filter, designed from the data within the S wave window indicated in Fig. 5b, emphasizes S wave and suppresses waves having other types of polarisation characteristics.

Figure 6 shows the results of polarisation filtering of data having the offset distances shown in Fig. 3a. Here, the filters were designed to separate P, S and surface waves.

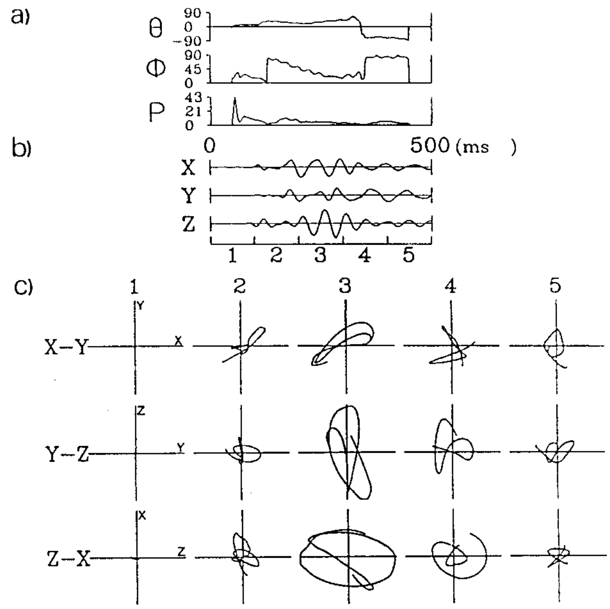

FIGURE 4

Time variations of polarisation characteristics, calculated from data having an offset distance 160 feet.

a Polarisation characteristics
b Original three component records
c Particle motions of the records in each window indicated in b

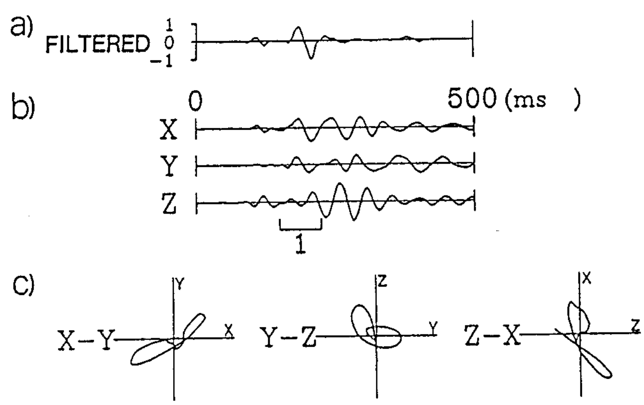

FIGURE 5

Application of polarisation filter to records having an offset distance of 160 feet.

a Filtered record
b Original three component records
c Particle motions of records within the window in b

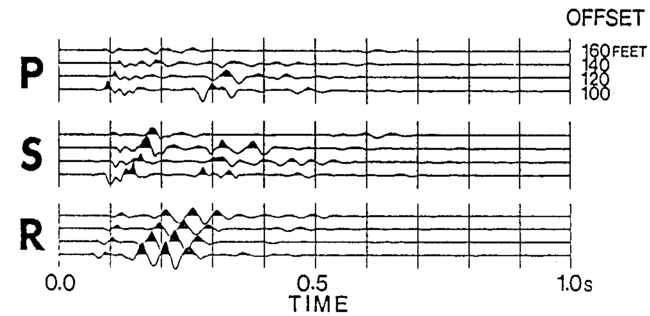

FIGURE 6

Common shot gathers after application of polarisation filter. The gather with symbol P represents the records after application of a filter that passes only waves having P wave polarisation. The gathers marked S and R similarly represent records after S and surface wave (Rayleigh wave) pass filtering.

Conclusion

In the above, we have described a method that uses polarisation characteristics of three component seismic data for discrimination and filtering of waves. This method enables us to (1) discriminate linearly polarised waves (P or S waves) from elliptically polarised waves (Rayleigh type surface waves); and (2) distinguish between P waves and S waves, on the basis of differences in particle motion direction.

References

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