Seismic Processing 1: Multicomponent Processing and Wavelet Transforms

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Off-line imaging using 3-component seismic data

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SUMMARY

Off-line seismic energy or side-swipe may degrade conventional records and lead to erroneous interpretation. But, we can take advantage of this off-line energy to construct a partial 3-D image from a 2-D line, if 3-component seismic data are available. Different arrival angles of energy from below the seismic line and off-line, sometimes allows us to distinguish in-line and off-line energies by their polarization directions. The polarization direction of a P wave is generally in the propagation direction of the wave. Most previous polarization analysis relies on the eigenvalue method of analysing the covariance matrix of the observed data. This is an effective method, but requires considerable computation. We use a similar but faster direct least-squares method. This time-domain method finds the direction in which the sum of the projections of the seismic data is maximum. We can set a direction window to pass the waves coming from a certain direction range. The main procedures for making an off-line picture are: 1) apply conventional processing (statics, NMO, deconvolution, and stacking) to both vertical and transverse components, 2) apply the directional filter to the vertical and transverse stacked sections, 3) migrate (if necessary), and output the off-line section. We tested this processing flow on physical modeling data. The physical model consists of a plexiglas plate with an embedded "reef". Ultrasonic transducers in vertical and horizontal directions surveyed the reef from an offset of 200 m scaled distance. A reasonable off-line image was reconstructed.

INTRODUCTION

Seismic recordings contain not only the reflections from points directly beneath the line, but also from areas away from the line. The existence of off-line energy (French, 1974; Hospers, 1985) may result in the misinterpretation of conventionally processed 2-D seismic data. We are interested then in developing an algorithm to determine the direction of incoming waves and to pass waves from a specific direction: say, enhancing in-line energy and rejecting off-line energy. This should improve the quality of a conventional section. Using 3-C seismic recordings allows full analysis of the impinging seismic energy. Furthermore, we would like to take advantage of the recorded off-line energy to make an image of off-line reflectors (Ebrom et al, 1989; Stewart and Marchisio, 1991). This paper describes a procedure to develop a partial 3-D image from a 2-D seismic line. A physical model, which consists of a Plexiglas plate and a hollowed out “reef” is used to test the procedure. Ultrasonic sources in vertical and receivers in both vertical and horizontal directions are used to acquire the data. The seismic line is a scaled distance of 200 m from the reef.

METHODS

There are a number of techniques to determine the polarization direction of a seismic signal from multicomponent data (Flinn, 1965; Montalbetti and Kanasewich, 1970; Kanasewich, 1981; Samson and Olson, 1980; Jurkevics, 1988; Bataille and Chiu, 1991). Most of them are based on eigenvalue analysis. The direct least-squares method (DiSiena et al, 1984) is similar but somewhat faster than eigenvalue methods. We define a seismic data set $\overrightarrow{V(t)} = (V,(t), V_2(t))^T$ which contains signal as well as noise. Within a time window, we extract some data from $\overrightarrow{V(t)}$ as $\overrightarrow{u(t)} = (u_1(t), u_2(t))^T$, t=j-L, j+L, where j is the midpoint of the selected window and 2L+l is the length of the window. A schematic particle trajectory hodogram is shown:

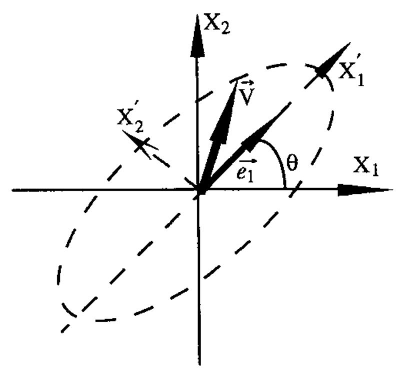

Figure 1: The trajectory ellipse of the seismic wave.

Assuming that there is a line through the centre of the hodogram (x_0, y_o) (Figure 1) with the direction cosine (cos 0, sin 0), we can project the displacement vector to the line and sum up the squares of the projection.

$$A(e)=\sum_{t=j-1}^{j+1}\left((u_1(t)-x_0)\cos\theta + (u_2(t)-y_0)\sin\theta\right)^2. \qquad (1)$$

If the line has the same direction as the major axis of the polarization ellipse, A(0) receives its maximum value. If the line has the same direction of the minor axis of the ellipse, A(0) receives its minimum value. We find the extreme values of A(0).

Assuming A_1 is the maximum and A_2 is the minimum of the A(0), we define the first filter factor as:

$$G_1 = 1 - A_2/A_l. \qquad (2)$$

G_1 varies between 0 and 1. For a rectilinear wave, the hodogram should be a line. Therefore the projection of the displacement vector on the line perpendicular to the hodogram line is 0. A_2 is 0 and G_1 is 1. For circularly polarized wave, the projection of the displacement vector on the line of any direction will be the same. Therefore, A_1 equals A_2 and G_1 is 0.

The direction vector of the major axis of the ellipse is $\vec{e_1} = (\cos 0, \sin 0)^T$, so the second filter factor is:

$$\vec{G_2} = \left|\overrightarrow{u(j)}\cdot \vec{e_1}\right| \cdot \vec{e_1} = g\left(\cos\theta, \sin\theta\right)^T. \qquad (3)$$

Where, $g = \left|u_1(j)\cos\theta + u_2(j)\sin\theta\right|$.

If we want to pass the waves within a certain range of directions, the directional filter factor is defined as following:

$$G_3 = \begin{cases} 1, \text{ if } \theta_0-\varphi \le \theta \le \theta_0+\varphi \\ 0, \text{ if } \theta \le \theta_0-\varphi \text{ or } \theta \ge \theta_0+\varphi \end{cases} \quad (4)$$

Where, θ_0 is the midpoint of the direction window. φ is the half-length of the window.

The output of the filter for passing the waves of the direction within the window of $\theta_0-\varphi \le \theta \le \theta_0+\varphi$ is:

$$\vec{u} = G_1\vec{G_2}G_3 = (1-A_2/A_1)\ g\ G_3\ (\cos\theta, \sin\theta)^T. \quad (5)$$

For rejecting the waves of the direction within the window, we simply use $1-G_3$ instead of G_3 in equation (5). Some smoothing functions could also be applied to the filter factors.

Directional filtering can be applied both pre- and post-stack. For post-stack processing, it is important to use same procedure and parameters of conventional processing for both vertical and horizontal components. The stacked sections of vertical and horizontal (transverse) components are directionally filtered trace by trace. After directional filtering, other post-stack processing, e.g. migration, can be used to improve the image.

APPLICATIONS OF THE DIRECTIONAL FILTER

Physical modeling data are used to test the algorithm discussed above. The Plexiglas model is shown in Figure 2. The "reef" anomaly in the Plexiglas plate is a milled-out hole. The plate is supported by a jig apparatus. A scale factor between the actual dimension of the model and field size, based on the ultrasonic and seismic frequency difference, is 10 000. The seismic line is then a scaled distance of 200 meters away from the reef. An end-on spread is used in the survey. The near offset is 200 m and the far offset is 650 m. The station interval is 50 m and the shot interval is 100 m. The raw data are shown in Figure 3. After NMO, the stacked sections of the vertical and transverse components are shown in Figure 4. There is an anomaly apparent above the plate bottom. We applied the directional filter to the stacked sections. From the model, we know that the incident angle of the reflection from the reef is 13º from the vertical direction. Figure 5 is the stacked section of the in-line energy enhanced data. We can see the reflection from plate bottom at 0.7 s as expected (1960m/2750m/s). In contrast, Figure 6 is the stacked section of the energy from 100º - 110º incident angles. We can see a clear reflection from the reef at about 0.62 s as expected (1750/2750m/s). The anomaly width, measured from the section is about 800 m compared to the actual reef width of 800 m. And the location of the reef can be estimated from the direction window and the travel time (refer to Figure 2).

CONCLUSION

Side-swipe seismic energy can be used to build a partial 3-D image from a 2-D seismic line, if 3-component seismic recordings are available. Directional filtering for 3-component seismic data is possible. We have successfully applied the filter to process physical modeling data. Off-line energy is extracted from the data and separated from the in-line energy. The off-line energy is highlighted on the filtered section. The location of the off-line reflector could be estimated.

ACKNOWLEDGEMENTS

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REFERENCES

Bataille, IS. and Chiu, J.M., 1991, Polarization analysis of high-frequency, three-component seismic data: Bull. Seis. Soc. Am., 81,622-642.

DiSiena, J.P., Gaiser, J.E., and Corrigan, D., 1984, Horizontal components and shear wave analysis of three-component VSP data: In Toksoz, M.N. and Stewart, R.R., Eds., Vertical Seismic Profiling: Advanced concepts: Geophysical Press.

Ebrom, D.A., Tatham, R.H., Sekheren, K.K., McDonald, J.A. and Gardner, G.H.F., 1989, Nine-component data collection over a reflection dome: A physical modeling study: presented at the 59th Ann. Intemat. Mtg., Soc. Expl. Geophys.

Flinn, E.A., 1965, Signal analysis using rectilinearity and direction of article motion: Proc. I.E.E.E., 53, 1874-1876.

French, W.S., 1974, Two-dimensional and three-dimensional migration of model-experiment reflection profiles: Geophysics, 39,265-277.

Hospers, J., 1985, Sideswipe reflections and other external and internal reflections from salt plugs in the Norweigian-Danish basin: Geophys. Prosp., 33, 52-71.

Jurkevics, A., 1988, Polarization analysis of three-component array data: Bull. Seis. Soc. Am., 78, 1725-1743.

Kanasewich, E.R., 1981, Time sequence analysis in geophysics: The University of Alberta Press.

Montalbetti, J.F. and Kanasewich, E.R., 1970, Enhancement of teleseismic body phases with a polarization filter: Geophys. J.R. Astro. Soc., 21,119-129.

Samson, J.C. and Olson, J.V., 1980, Some comments on the descriptions of the polarization state of waves: Geophys. J.R. Astro.., 61,115-130.

Stewart, R.R. and Marchisio, G., 1991, Side-scanning seismic: Analysis and a physical modeling study: Presented at the 1991 Ann. Nat. Mtg., Can. Soc. Expl. Geophys., Calgary.

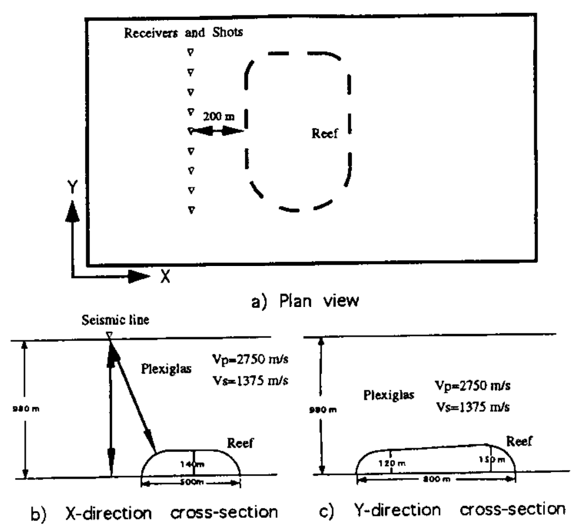
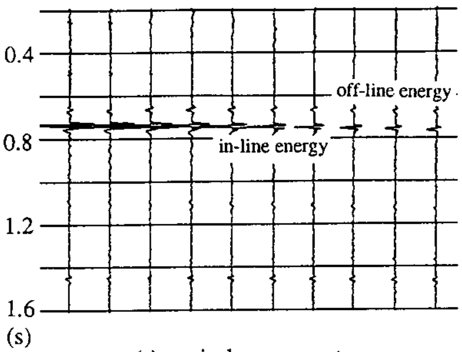
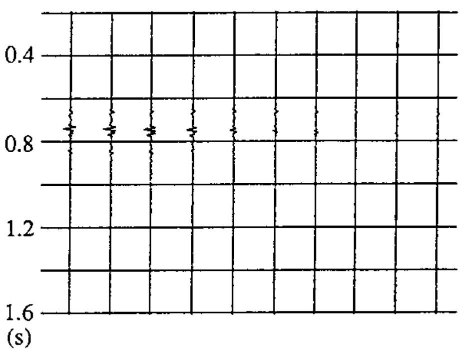


Figure 2: The physical model

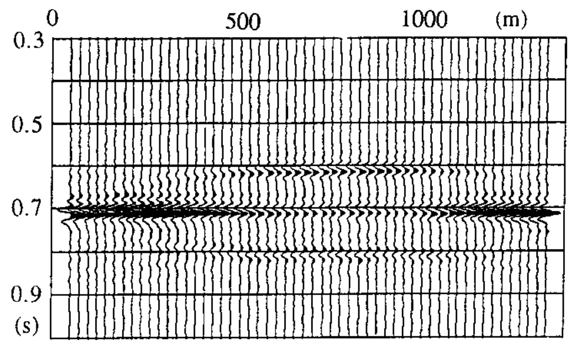


(a) vertical component.

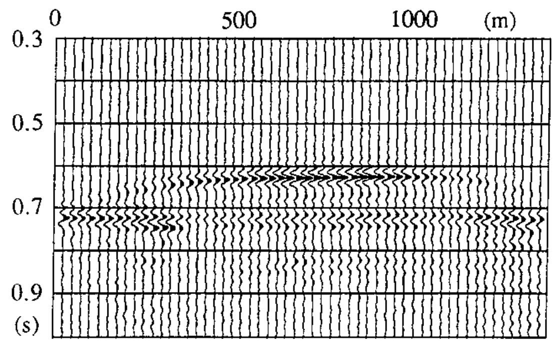


(b) transverse component.

Figure 3: A shot gather of the physical modeling data.



(a) vertical component.



(b) transverse component.

Figure 4: The stacked sections.

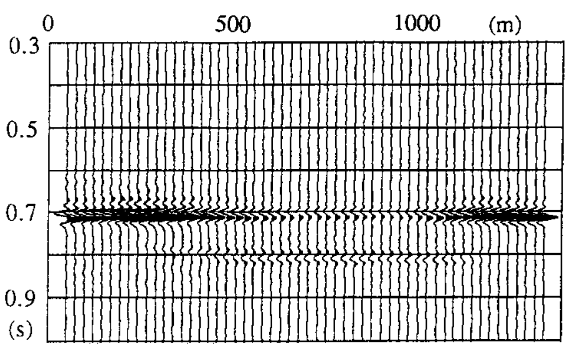


Figure 5: In-line energy (85° - 95°) enhanced stacked section of the vertical component.

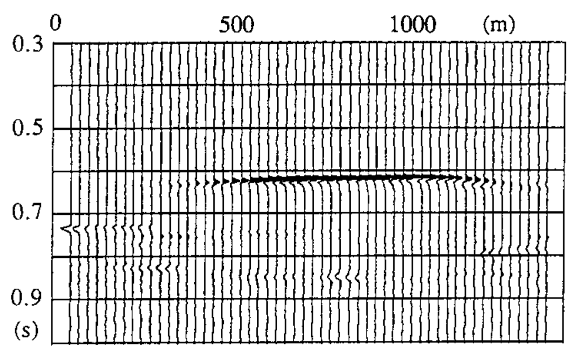


Figure 6: Off-line energy (100° - 110°) enhanced stacked section of the vertical component.