3-D converted wave asymptotic binning

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ABSTRACT

In order to process P-S converted elastic waves from a 3-D multicomponent survey, several geometric transformations must be performed on the recorded data. These include locating traces' common conversion points and rotating their horizontal components into a radial and transverse system. Given these, the data can be binned and standard 3-D P-P processing techniques can be applied. This paper discusses these transformations and demonstrates their application to a dataset derived from a physical model.

INTRODUCTION

Most current seismic datasets contain only the vertical component of ground motion. Techniques to process these datasets are well established and understood. However, by recording ground motion in all three spatial directions, the possibility of extracting new information exists. Even with seismic sources emitting only compressional (P) waves, shear (S) waves may be produced at boundaries and reflected or scattered back to the surface. With horizontally layered media, only vertically polarized S waves, SV, are produced. With straight line recording geometries, there are two corrections which must be made to the recorded SV seismic traces. One is locating traces by common conversion point (CCP) instead of common mid point (CMP). The second is to reverse the polarity of either the trailing or the leading spread (Schafer, 1992, 1993, Tessmer and Behle, 1988)). When collecting 3-D data, these corrections must also be made, but in a more general sense. The following describes the more general 3-D transformations and illustrates their application to physical model data.

COMMON CONVERSION POINTS

Consider the simple case of a horizontally layered Earth. For unconverted elastic waves, the reflection point lies under the midpoint between the source and receiver. However, for P-S converted waves, this is no longer generally true. The conversion point lies inline between the source and receiver, but its location depends on the ratio of the P to the S velocities (V_p and V_s). It also depends on the depth of the conversion point. However, as the depth increases, this depth dependence approaches an asymptotic value (Eaton et al., 1990, Schafer, 1992). We consider this asymptotic location as a first approximation for binning and stacking purposes. The location error will increase as the conversion point depth decreases. The asymptotic location is given by

$$\mathbf{S} + \frac{\mathbf{R} - \mathbf{S}}{1 + \frac{Vs}{Vp}} , \tag{1}$$

where **S** is the vector location of the source and **R** is the vector location of the receiver.

As these locations lie on a straight line connecting the shot to the receiver, in the special case of 2-D surveys, they lie in the plane of the spread.

VECTOR ROTATIONS

In the 2-D P-SV conversion case, there is an apparent polarity reversal from one side of the shot to the other. This is because we usually record with all geophones oriented in the same direction, inline with the spread. Thus a surface motion away from the shot will be recorded as positive on one side of the spread and as negative on the other, and vice versa. In the 3-D case, however, we must mathematically rotate the recorded signals so that one horizontal channel contains the component within the source-receiver plane, and the other contains the component perpendicular to this component (transverse). In the isotropic case the radial component will contain only P-SV data while the transverse component will be null. It should be kept in mind that these are vectors and thus a trace rotated radially from shot to receiver would be polarity reversed relative to the same trace rotated radially from the receiver to the shot. Thus this more general rotation case includes the 2-D polarity reversal implicitly.

Although there is only one geophone rotation required to go from the field to the rotated data, one can consider it as the difference of two rotations. These are the

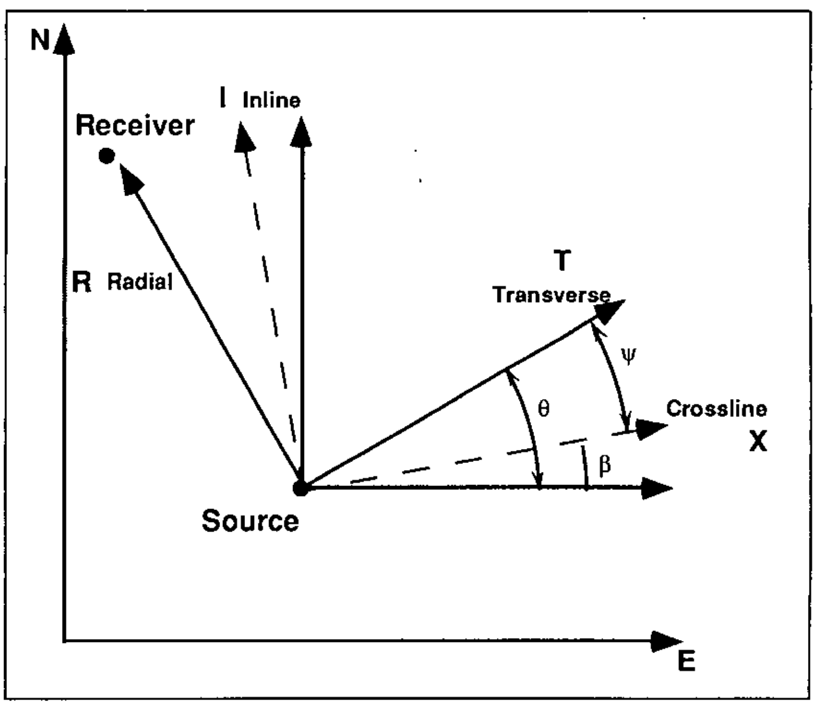

FIG. 1. Data recorded in the (X,I) system are rotated to the (T,R) system to isolate the radial and transverse components. The reference angle β is usually constant for a survey while the source-receiver angle θ varies with each source-receiver pair.

reference direction, aligned to one of the horizontal channels, and the direction from the shot to the receiver. The reference is usually a constant, as geophones are laid in the same orientation, while the second varies for each shot-receiver pair (Figure 1). We call the reference direction the *inline*, as it is common to orient geophones in the line of receivers, and the angle 90 degrees clockwise the *crossline* direction. Thus the rotation is from the (crossline,inline) system to the (transverse,radial) system. Figure 1 illustrates the coordinate systems and angles used for the rotation. In order to perform the rotations, we do not need the rotation angle, but rather its sine and cosine. In practice we know the angle of the geophone, β, as it is fixed in the field, and can calculate its sine and cosine. The angle θ, from the shot to the receiver, is not known, but we can calculate its sine and cosine directly from the source and receiver's relative positions. Let $\phi = 90^\circ + \theta$. Then $\sin(\phi)$ is the receiver northing minus shot northing, divided by the shot-receiver distance. $\cos(\phi)$ is the receiver easting minus shot easting, divided by the shot-receiver distance. These relate to θ through the formulas $\sin(\theta) = -\cos(\phi)$ and $\cos(\theta) = \sin(\phi)$. Then, as we want to rotate the traces by the negative of ψ, or $\beta-\theta$, we can use the difference angle formulas giving $\sin(-\psi) = \sin(\beta-\theta) = \sin\beta\cos\theta - \cos\beta\sin\theta$ and $\cos(-\psi) = \cos(\beta-\theta) = \cos\beta\cos\theta + \sin\beta\sin\theta$. Substituting the 90° formulas yields $\sin(-\psi) = \sin\beta\sin\phi + \cos\beta\cos\phi$ and $\cos(\psi) = \cos\beta\sin\phi - \sin\beta\cos\phi$. Thus the rotation matrix from the $\begin{bmatrix}\text{Crossline}\\ \text{Inline}\end{bmatrix}$ to the $\begin{bmatrix}\text{Transverse}\\ \text{Radial}\end{bmatrix}$ system is

$$\mathbf{R} = \begin{bmatrix} \cos\beta\sin\phi - \sin\beta\cos\phi & -(\sin\beta\sin\phi + \cos\beta\cos\phi) \\ \sin\beta\sin\phi + \cos\beta\cos\phi & \cos\beta\sin\phi - \sin\beta\cos\phi \end{bmatrix}.$$

We can rotate in the horizontal plane because, with real data, the low velocity near the surface causes the wave direction to be nearly vertical when it strikes the receivers. If this was not the case, we would need to know the impinging wave angle and rotate in a 3-D space. With model data this may present a complication. Any P component on the horizontal channels will be oriented in the radial direction. Then, after rotation, it will be distributed into the other two channels. In order to have a correct rotation there must also be identical coupling in both directions and identical geophone outputs. For model data, as we used, where different shots are used for each component at a given receiver location, the shots must have the same coupling.

EXAMPLES

In order to illustrate the effect of the rotations on seismic data, we acquired a small 3-D survey using the University of Calgary elastic physical modelling system (Gallant and Bertram, 1992). The portion of the survey shown here was over a horizontally layered structure. Thus the reflections are dependent only on angles and not on location, assuming uniform layer bonding. This means that we can demonstrate rotations with waves not having a common CCP. We wrote a computer program which bins according to asymptotic CCP and rotates the data to radial and transverse components. The acquisition geometry is shown in Figure 2. Figure 3 shows the input inline and crossline data and the rotated transverse and radial components. Note the apparent polarity reversal on the inline channels between the first two and the next two traces. Note also that there are some deviations from symmetry apparent on the crossline channels. These are likely due to transducer coupling differences and lack of uniformity in the medium's layer bonding. After rotation, essentially all the energy is now on the radial (SV) channels with the same polarity, suitable for stacking. The residual energy on the transverse channel energy is due to the model imperfections mentioned above.

CONCLUSIONS

We have demonstrated the successful rotation of physical P-S data into radial and transverse components, containing SV and SH components respectively. We have also shown the mathematical transformation required to extend 2-D CCP asymptotic binning to the 3-D case.

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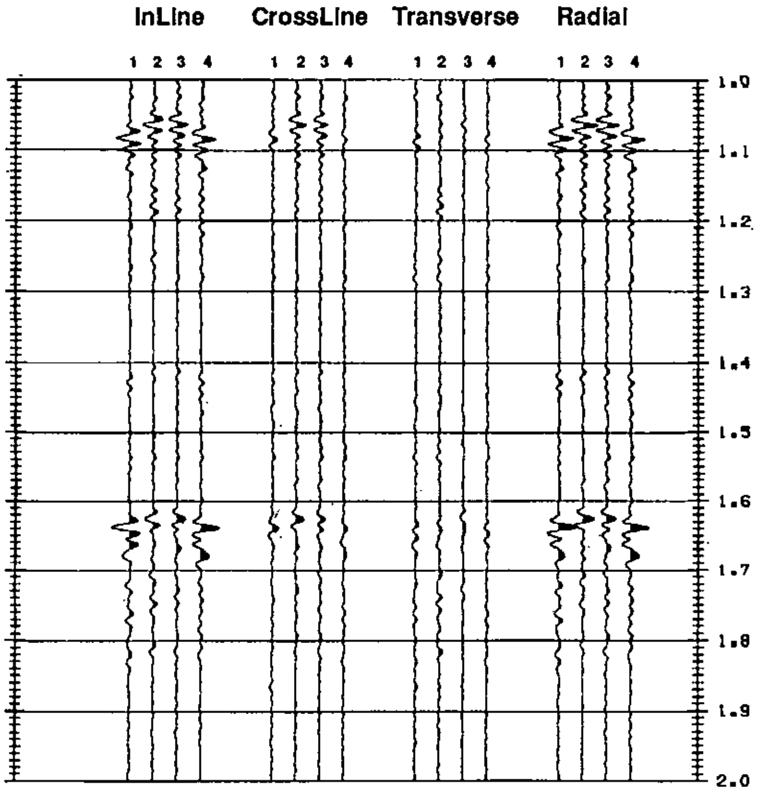

FIG. 3. Model data. The inline, crossline data have been rotated to the radial, transverse system. Note that essentially all the energy is in the shot-receiver (radial) direction.