Radial-Transverse (SV-SH) Coordinates for 9-C 3-D Seismic Reflection Data Analysis
James L. Simmons, Jr.* and Milo M. Backus
Bureau of Economic Geology, The University of Texas at Austin

Summary

Nine-component 3-D seismic reflection data are acquired using orthogonal shear-wave sources and orthogonal horizontal geophone components. Shear-wave sources are usually oriented inline and crossline to the receiver lines, as are the horizontal geophones. These coordinates are referred to as the field coordinates.

Field coordinates implicitly mix SH, SV, and P-waves. Shear-wave data processing and interpretation is simplified if the prestack data are azimuthally rotated to a radial-transverse coordinate system. The radial component contains predominantly SV and P-wave modes, while the transverse data are predominantly SH. The SH data are simplified in that SH waves convert only to SH upon reflection and transmission (in a flat layered earth), unlike SV propagation which is coupled with P.

There are distinct differences between SV and SH waves in terms of the surface waves generated (Rayleigh versus Love). SH systems exhibit SH head waves, while SV systems have P head waves followed by P-SV-P head waves, etc., having very different slopes and intercepts than do those for SH. Normal moveout and amplitude-versus-offset are different for SH and SV waves, and the SV data contain P-waves and converted waves.

Field coordinates mix all of these components together in variable proportions, confusing attempts at processing and interpretation.

Introduction

Two-dimensional 9-C data acquisition orients the orthogonal shear-wave sources (S) and horizontal geophones (R) parallel and perpendicular (inline and crossline) to the receiver line. Separation of SV (and P) and SH occurs implicitly for experiments acquired in this manner.

Three-dimensional 9-C acquisition records data at a range of azimuths for each shotpoint. A receiver at an arbitrary azimuth from the source records a mixture of SV, SH, (and P) waves on each horizontal component. The degree of "mixing" is dependent on the location (azimuth and offset) of the receiver from the source. Rotation based on source-receiver azimuth is necessary to obtain separation of SV and SH waves. Rotation of the 3-component receivers to radial and transverse is quite common in VSP, 3-C seismic, and OBC data processing. Rotation of the orthogonal shear-wave sources does not appear to be as common.

Proponents of shear-wave splitting argue that data found on the crossterms (inline source, crossline receiver; crossline source, inline receiver) are indicative vertical cracks. Note that subsurface dip and near-surface heterogeneities will also produce energy on the crossterms and are likely more prevalent causes of crosstern energy than is fracture induced shear-wave splitting. Alford rotation (Alford, 1986) is only strictly valid at normal incidence where there is no distinction between SV and SH waves. The near normal-incidence data reside in the surface wave "noise cone" where extraction of the reflection signal is most difficult. In field coordinates, isolation of the reflection signal is made even more difficult because of the mixing of SV, P, and SH waves.

We illustrate some of the benefits of rotating prestack 3-D four-component shear-wave data into radial-transverse (SV-SH) coordinates on several real 9-C 3-D data sets. Surface waves focus onto their respective components (Rayleigh to SV, Love to SH). Shear-wave statics are more easily estimated, and found to be much smaller than those estimated by commercial processing shops that processed these data sets in field coordinates. The amplitude-versus-offset (AVO) response of SV waves and SH waves are very different and should be examined in SV-SH coordinates. The normal moveout of SV and SH waves is significantly different, leading to a splitting of reflection events (due to vertical transverse isotropy), with the splitting increasing with offset.

Field coordinates versus SV-SH coordinates: Rectangular recording patch

A shot record (one source location, one receiver line) from a 9-C 3-D survey recorded in north Texas is shown in Figure 1. The $S_i; R_j$ data are obtained from the inline source-inline receiver, and the $S_x; R_x$ data are obtained from the crossline source-crossline receiver. The recording patch is rectangular, roughly 15000 ft in the inline (i) direction, and 5500 ft in the crossline (x) direction.

Note the P-waves apparent in both field coordinates. Since the source is offset from the receiver line, the mixing of P, SV, and SH energy occurs most at the near offsets. In the far-offset limit, SV (and P) energy is contained in $S_i; R_j$, and SH energy is contained in $S_x; R_x$.

Azimuthal rotation produces the SV and SH gathers. The coupling of P-waves and SV waves is obvious. Estimation of shear-wave statics from the shear-wave first arrivals would be much easier on the SH data than on the SV data.

A second 9-C 3-D seismic survey shot in Clark County, Kansas is available. The Kansas survey was recorded with the same rectangular recording patch.

Field coordinate super gathers are shown in Figure 2. Traces are grouped by offset and stacked over 100 ft offset bins. The maximum source-receiver offset is 18500 ft. The target zone is just below 2.0 s. Given the rectangular recording patch, $S_i; R_j$ is essentially SV at the far offsets, while $S_x; R_x$ is essentially SH at the far offsets. P-wave energy is apparent on $S_i; R_j$ preceding the shear-wave first arrival.

Azimuthal rotation to SV-SH coordinates produces the gathers seen in Figure 3. The effect of the azimuthal rotation is emphasized in the difference between $S_i; R_j$ and SV, and between $S_x; R_x$ and SH, respectively. The reflection signal is enhanced by the rotation. Data at the near offsets are affected most by the rotation.

The fact that reflection signal is apparent in the super gathers suggests that geologic structure is minimal in the area, as are drastic
shear-wave statics and lateral velocity variations. This data set is analyzed in detail in Simmons et al. (1999).

**Square recording patch**

Prestack super gathers from a 9-C 3-D data set acquired in southeast Colorado is shown in Figure 4. One hundred foot offset bins are used. The recording patch is nearly square (approximately 8000 ft in the inline direction, and 6000 ft in the crossline direction).

P-wave energy is apparent on both the $S_1; R_i$ and $S_x; R_x$ components preceding the shear-wave first arrival, although the P-wave energy is somewhat stronger on the $S_1; R_i$ data. Since the recording patch is not exactly square nor uniformly sampled with source stations, the $S_1; R_i$ data contains more SV energy, and the $S_x; R_x$ data contains more SH energy. Note the drastic difference in the behavior of the surface waves. Meanwhile the crossterms $S_1; R_i$ and $S_x; R_x$ are very similar. All components are a mixture of P, SV, SH, Rayleigh, and Love wave energy. Note the travel times of the shear-wave first arrivals at the far offset on $S_1; R_i$ and $S_x; R_x$.

Super gathers in radial-transverse (SV-SH) coordinates are shown in Figure 5. The P-wave wave energy has been rotated onto the radial data. The signal-to-noise ratio on the shear-wave first arrivals is much higher on the SH data. The surface waves are now much more coherent; Rayleigh waves on SV, Love waves on SH, than they are in field coordinates.

Note the difference in the head wave first-arrival times. This is an indication that vertical transverse isotropy (VTI) is important in this area. The SV wave speed is 25% slower than the SH wave speed. The SV intercept time is about 0.1 s versus 0.4 s for the SH head wave. The SV head wave is actually the P-SV-P head wave (refracts as SV).

The four field-coordinate records (Figure 4) show P, SV, and SH head waves mixed together. Each of the three head wave types occurs in each component of Figure 4. The 25% difference in SV and SH refractor velocities is a much larger effect than any azimuthally dependent anisotropy, and is not detected in the near-offset VSP data.

**Conclusions**

Processing and interpretation of 9-C 3-D shear-wave data in radial-transverse coordinates isolates SV (and P) from SH waves. We feel that the distinctions between SH and SV waves are very important and cannot be resolved when processing 9-C 3-D data in field coordinates.

**References**


Figure 1: Shot record from north Texas. Data shown are field coordinates $S_1; R_i$ and $S_x; R_x$, and radial–transverse (SV and SH) coordinates.
Figure 2: Super gathers, field coordinates, Kansas 9–C 3–D survey.

Figure 3: Super gathers, SV–SH coordinates and difference gathers.
Figure 4: Super gathers, field coordinates, Colorado 9–C 3–D survey.

Figure 5: Super gathers, radial–transverse coordinates, Colorado 9–C 3–D survey.