More reliable shear-wave data from VSP by using CIPHER-technique

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It has been recognized for a long time that fracture systems in rocks can significantly influence the flow of fluids in the subsurface. Geophysical fracture characterization techniques based on seismic anisotropy and related shear-wave splitting have been under investigation for many years. It is now established as an observable effect. To keep rig time costs low, a 3-C multilevel downhole sonde has been introduced many years ago. Additional horizontal vibrators and additional survey time and processing costs for shear-wave data, however, are still important constraints. The CIPHER-method (Edelmann, 1992) described below aims both at the reduction of costs and at an improvement of VSP shear-wave data.

Fig. 1 shows schematically the basic concept of shear-wave splitting of a circularly polarized shear-wave in a fractured medium. The incident wave illustrated by a spiral is split into a fast component polarized parallel to the fracture direction and a slow component perpendicular to this direction when travelling through the medium. Circularly polarized shear-waves can only be generated by using controlled sources, such as horizontal vibrators. Fig. 2 shows two vibrators, positioned orthogonally radiating two sweep signals differing in phase by 90 degrees. The resulting signal is recorded by a 3-C sonde in the KTB pilot hole over a depth range between 2800 and 3400 m. An upsweep signal of 30 s length and a frequency range between 9 and 43 Hz was used. The hole was drilled in crystalline rocks (gneisses, amphibolites) of the Bohemian Massif. The CIPHER-experiment (Circularly Polarized Horizontal Extension Radiation) was part of a more comprehensive P- and S-wave survey (Lueschen et al., 1991).

Fig. 3 shows the two horizontal components of the wavefield after being rotated into the natural coordinate system, which was determined from the polarization analysis described below. This coordinate system is assumed to coincide with the preferred strike direction of fractures. In this way the fast and the slow shear-wave events as marked in the figure can clearly be separated. The average shear-wave anisotropy (ratio of time delay to travel time of the first arrival) for the overburden is about 10% (Lueschen et al., 1991).

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The horizontal polarization of shear-waves at different depths is determined by calculating the direction of the main axis of the polarization ellipse within a moving window. Fig. 4 shows the result of this analysis for eight different recording depths. The azimuth of the first arrival (fast event) is approximately N 140° E. After about 100 ms the azimuth switches over to about N 50° E the orientation of the second arrival (slow component) as can be seen from the curves.

The advantages of the CIPHER technique compared to the conventional technique are:

- No a-priori knowledge about optimum vibrator orientation needed,
- Only half the number of shear-wave recordings at the well necessary,
- Better quality of data so that less expensive processing is needed to achieve more reliable results.

References:


Figure 1: Schematic illustration of shear-wave splitting using circularly polarized shear-waves
CIPHER field configuration

3 component VSP recording
spacing 25 m,
depth 2800 - 3400 m

Figure 2: Vibrator arrangement for CIPHER VSP at the KTB pilot hole (CIPHER = Circularly Polarized Horizontal Extension Radiation, KTB = Kontinentales Tiefbohrprogramm)
Figure 3: Horizontal component recording after being rotated into a natural coordinate system
Figure 4: Results of azimuth angle determination as a function of recording time