Waveform Analysis of Borehole Acoustic Dipole Data in Transversely Isotropic Medium with a Tilted Axis of Symmetry

*Satoshi Fuse[1], Hitoshi Mikada[1], Junichi Takekawa[1]

1.Kyoto University Graduate School of Engineering

It is important to understand anisotropic property around a borehole for effective production of oil and gas, efficient control of hydraulic fracturing, etc. In the conventional research, Vertical Seismic Profiling (VSP) has been used to estimate the anisotropic properties. However the 3-dimensional anisotropic properties around a borehole may not be well obtained using VSP because seismic waves covers only a low frequency band that degrades the spatial resolution. So this uncertainty causes some problems in practical fields for which some improvements have been waited for. In the present study, we propose a novel approach which uses the waveform of the cross dipole for more accurate measurement of anisotropic properties around a borehole.
We conduct numerical experiments of three-dimensional seismic wave propagation around a borehole using a Hamiltonian particle method (HPM). HPM has advantages in computational efficiency over the conventional lattice based methods. Our numerical model includes an anisotropic layer in a homogeneous medium. We generate seismic waves using the cross dipole placed inside the borehole, and record seismic waves which pass through the anisotropic layer at receivers also placed inside the borehole. We investigate the change of the recorded waveforms induced by the anisotropic layer. Distinctive feature can be observed when shear wave passes through the HTI (Transverse Isotropy with a Horizontal axis of symmetry) medium which is known as shear wave splitting. When shear wave reaches the HTI medium, it splits into two polarized shear waves: fast shear and slow shear. To detect the azimuthal anisotropy, Alford rotation has been applied in the previous studies. The wave excited from dipole source is recorded both the same and orthogonal components. After applying Alford rotation using all 4 waveforms, we could estimate the azimuth from the energy and degree of anisotropy from the phase difference.
We simulate seismic waves pass through an anisotropic layer. We change the anisotropic properties both in the order and the orientation of the symmetry axis. At first, we check the waveforms at receivers. If the anisotropic layer is HTI medium, fast shear and slow shear can be detected explicitly by applying Alford rotation. On the other hand, the symmetric axis of the anisotropic layer becomes tilted from HTI medium, the phase difference between fast shear and slow shear becomes smaller. This result indicates that if anisotropic layer tilts, we cannot estimate correct anisotropic parameters just by using the Alford rotation. On the other hand, we can observe an evident difference between fast and slow shear waveforms. Since this difference stems from the tilted angle of the anisotropic layer, inversion technique utilizing full-waveform (full-waveform inversion) could estimate anisotropic properties around a borehole with high accuracy and resolution.

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