Rotational motion and spatial wavefield gradient data in seismic exploration – a review

Cedric Schmelzbach, David Sollberger, Cederic Van Renterghem, Mauro Häusler, Pascal Edme and Johan Robertsson

In exploration seismology, the acquisition and processing of rotational motion and spatial wavefield gradient data have gained increasing attention during the past years. The interest in these 'new' seismic measurement types has primarily been driven by the expectation to find novel solutions to long-standing exploration problems like the attenuation of coherent noise and relaxing spatial sampling requirements. A particularly interesting aspect of gradient and rotation observation is that they allow carrying out data processing with single station recordings that would conventionally be performed with data recorded with (large) arrays.

Emergent application fields of gradient and rotation data acquisition and processing in exploration seismology are, for example, improved wavefield characterization (e.g., through the inherent link of rotational motions to S-waves), local wavefield separation (e.g., by exploiting the fact that gradient and rotation measurements give access to quantities that appear in wave equations), local wave parameter estimation (e.g., extracting the local phase velocity), wavefield reconstruction from data recorded at sparsely located stations, and sensor tilt corrections.

Because small portable rotational-motion sensors are not yet widely available, local arrays of densely-spaced sensors are the most common way to acquire gradient data. As source location and timing can be controlled in exploration work, arrays of (multicomponent) sources can be combined to emulate gradient and rotation sources, which opens up the possibility to joint gradient-based processing on the source and receiver side.

In this contribution, we will review recent developments and the road ahead in the use of gradient and rotation data in seismic exploration. In order to reliably estimate gradient data from receiver arrays for land and sea-bed applications, we have developed workflows to optimize array dimensions and configurations as well as to correct for receiver related issues such as coupling variations. We have conducted a series of field tests to compare array-based gradient estimates with recordings from different prototype rotational-motion sensors to study the performance of these rotational sensors as well as to formulate exploration-specific requirements for rotational sensors. Using synthetic and field data (land and sea-bed), we will discuss different wavefield separation approaches that exploit different properties of combined translational and gradient measurements. These techniques allow us to separate the wavefield into, for example, P- and S-waves, up- and down-going wavefield constituents as well as to isolate surface waves and to split the wavefield by azimuth. These wavefield separation techniques can be extended to source arrays, which allows emulating sources that only 'emit' certain wave types, which is of interest, for example, for borehole surveys. These wavefield separation techniques either require local physical property values as input parameters, or the same techniques can be used to extract estimates of local subsurface properties with single station recordings for near-surface characterization.

Looking ahead, we expect that new seismic sensor types like fiber-optic based distributed acoustic sensing (DAS) for dynamic strain measurements and land divergence sensors will further lead to a rise in the interest in seismic sensing and processing beyond conventional translational measurements, motivated by complementary nature of these different observables. Combinations of strain, rotation, divergence and spatial wavefield gradient observations provide comprehensive seismic data sets recorded at single stations that are of particular interest at sites with limited access such as the ocean bottom or for space exploration.