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Abstract

This report describes the technical progress on a project to design and construct a multi-channel geophone array that improves tomographic imaging capabilities in both surface and underground mines. Especially important in the design of the array is sensor placement. One issue related to sensor placement is addressed in this report: the method for orienting the sensor once it is emplaced in the borehole. If the sensors (geophones) do not have the same orientation, the data will be essentially worthless. Improved imaging capabilities will produce energy, environmental, and economic benefits by increasing exploration accuracy and reducing operating costs.

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Introduction

The ability to accurately image conditions within a rockmass permits superior resource characterization resulting in more efficient extraction. This ability relates directly to industry goals to:

1) sense, visualize, and predict geological anomalies in front of mining equipment,
2) reduce operational downtime,
3) detect difficult mining conditions,
4) minimize waste, and
5) precisely characterize ore bodies.

Achieving these goals will have the benefits of reducing the amount of energy consumed by mining operations and minimizing the environmental impact of extraction.

Seismic tomography has been used successfully to monitor and evaluate geologic conditions ahead of a mining face. A review of the history and theory of tomographic imaging itself will be presented to properly illustrate the advances introduced by the multi-channel borehole geophone array.

Seismic tomography produces a map of an object's internal properties in a non-invasive fashion (Radon, 1917). By measuring the travel times of a seismic wave between source and receiver points around a rock mass, it is possible to calculate a map of the distribution of physical properties influencing seismic wave velocity within a rock mass. Tomography was first adapted to the field of medicine (Hounsfield, 1973; Cormack, 1973) and subsequently to the geosciences (Dines and Lytle, 1979). For at least 20 years, tomography has been used in the mining industry to create images of geologic features as well as stress-related features (Buchanan et al., 1981, Mason 1981, Kormendi et al., 1986). A more recent mining-specific application of tomography is an adaptation which can image stress concentrations ahead of the longwall face by using the longwall shearer itself as the seismic source (Westman et al., 1996).

Velocity tomography creates a velocity map from signal time-travel data. In this specific type of tomography, the raypath and the velocity variations along the raypath are unknown variables. By representing the medium as a grid, a forward velocity model is constructed to estimate the travel-time and the refraction path of each ray. Refraction paths are estimated by back-projection across the grid from each receiver to the source. By propagating a finite difference wavefront across the grid from a known source location, the travel-times can be estimated. Differences between the estimates and the measured travel times are used to iteratively update the velocity grid from each receiver to the source. The process is repeated a specific number of times, or until no noticeable changes occur.

Tomographic methods usually involve some sort of iterative algorithm to invert the traveltimes (Dines and Lytle, 1979; Peterson et al., 1985). A problem with these techniques is a tradeoff between resolution and stability of the solution. At some point, as one attempts to see smaller features, the inversion becomes unstable and velocity artifacts appear. Velocity artifacts are seen as fluctuations of values between adjacent points and the smearing of anomalous zones. Therefore, too few iterations will produce an image which lacks detail, and too many will overfit the data, and produce an image with an abundance of artifacts. A cross-validation method can determine the number of iterations needed (Peterson and Davey, 1990). Also, this method can give a way to determine several solutions to a non-unique problem, which can be then averaged to produce an image that may be an improvement over a single solution obtained using all the data at once.

To complete a tomographic survey, a seismic source must be selected. Several factors must be considered, including cooperation with mining operations, regularity of signal and amount of energy. Sources, including mining-induced seismic activity (Young, 1992), mining equipment and manually input energy (Westman and Haramy, 1996) are all possible considerations. For surveys at a quarry, a drill excavating blast holes can be used as the source. The longwall shearer has been used as the source for underground coal as it provides a relatively high amplitude signal.

A primary limitation to existing seismic tomography, however, is the placement of sensors. The goal of this ongoing project is to develop an array of 24 seismic sensors capable of being mounted in either a vertical or horizontal borehole. This array will significantly improve the ability of seismic tomography to accurately image conditions within a rock mass.

Experimental

The proposed design uses single geophones at each location, as opposed to three-component geophones. To obtain meaningful measurements, therefore, the geophones must all be oriented in the same direction. Prior research has accomplished this by suspending the geophone in oil, allowing it to rotate as needed to remain vertical. Others have used gimbal mounts to allow the geophone full rotation. We propose to mount the geophone within a module which is contained in the housing but coupled with a viscous material. The viscous material (e.g. honey or a heavy grease) should transfer the stress waves with little attenuation, while still allowing the module to rotate. The module will be weighted so that it will be self-orienting.

Results and Discussion

This design will be tested by comparing signals from three different configurations in a laboratory setting. A concrete block will be poured. Emplaced in the block will be a control geophone with known orientation. Two holes will be drilled in the block near the control geophone. In one hole a geophone using the clamping mechanism will be placed, but with the geophone rigidly attached to the PVC tube. In the other hole will be a geophone within the module coupled with the viscous material. Seismic signals will propagate through the block and the signal quality will be analyzed for each of the three sensors. This experiment will quantify any resonant frequencies due to the clamping mechanism as well as the amount of signal degradation due to the viscous material.

Conclusion

Seismic tomography is a promising technique for imaging conditions ahead of surface or underground mining, thereby increasing efficiency and reducing energy consumption during the mining operation. A principle difficulty in using seismic tomography is the placement of multiple sensors around the mining face. Progress during the third calendar quarter of the project (July 1, 2001 through September 30, 2001) focused on developing a method to orient the geophone vertically once it is emplaced in the borehole.

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