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Principal Author: Erik C. Westman

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Name and Address of Submitting Organization:

Virginia Polytechnic Institute and State University
Office of Sponsored Programs
Collegiate Square
460 Turner Street, Suite 306
Blacksburg, VA 24060

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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 clamping the sensor once it is emplaced in the borehole. If the sensors (geophones) are not adequately coupled to the surrounding rock mass, the resulting data will be of very poor quality. 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

Project personnel conducted laboratory tests to determine whether resonant frequencies from the geophone housing and locking arm were being added to the true signal. The tests were conducted by comparing the signal from a light hammer tap on top of the block as recorded by two sensors. One sensor was located in the geophone array, emplaced in the borehole. The other sensor was embedded within the block, representing the true signal, unaffected by the borehole or the array.

A concrete test block was built to aid with this study. Figures 1 through 3 show the construction of the test block. In Figure 1 it can be seen that the bottom of the block was textured to reduce the reflected signal. Figure 2 shows the emplacement of the 'control' geophone within the block, adjacent to the borehole. Figure 3 shows the block after the concrete had been poured. Prior to testing, the concrete was allowed to cure for several days, and the white PVC pipe was removed from the 'borehole.'

Figure 1. Bottom of block textured to reduce reflected signals.

Figure 2. Location of 'control' geophone within block, adjacent to borehole.

Figure 3. Completed test block. Block was allowed to cure and white PVC pipe was removed from 'borehole' prior to testing.

Results and Discussion

Results of the testing were encouraging and can be seen in Figures 4 and 5. Figure 4 shows a typical signal recorded in the time domain. The signal recorded by the geophone embedded in the block is shown in yellow while that recorded by the geophone in the hole is shown in maroon. Figure 5 shows the same signal in the frequency domain.

Figure 4. Comparison of signals recorded by geophone in borehole array and by geophone embedded in test block.

Figure 5. Comparison of frequencies recorded by geophone in borehole array and by geophone embedded in test block.

The results show that, while there is an expected reduction in signal amplitude, when comparing the geophone in the block to the geophone in the borehole array, there are no added resonant frequencies. Additionally, it can be seen that there is no reflected signal off the bottom of the block. This block will be used in future stages of the project to test further design modifications.

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 fifth calendar quarter of the project (January 1, 2002 through March 31, 2002) focused on testing whether the geophone array added resonant frequencies to the recorded signal. By determining that no resonant frequencies were added to the signal, it can be stated that the recorded signal accurately represents the signal propagating through the rock mass. The outcome will be an enhanced ability to locate anomalies in advance of mining, thereby increasing the safety and efficiency of the mining process.

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