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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

The finalized design of the array is shown in Figures 1 and 2. Testing of the geophone array was attempted at CONSOL Energy's Buchanan coal mine during the week of March 3, 2003. The other industry cooperator, NSA Engineering Inc., made a seismograph available to assist with the testing. The borehole was located in the barrier pillar portion of the 4th Right longwall panel. The borehole was drilled by the degasification drill crew for the sole purpose of testing the geophone array. The borehole was drilled approximately 6 weeks prior to the time of testing.

The first day of the test (March 4) was spent spotting the array at the borehole collar location. During the second day, a 'crawler' unit was placed in the borehole to 'crawl' to the end of the 960-ft long borehole and anchor itself, allowing the array to be pulled in by a cable and pulley. Unfortunately, the crawler did not function as hoped, and was not able to get further than about 20 ft. The problem was due to a combination of factors including the borehole being larger in diameter than expected, the walls of the borehole being wetter (muddier) than expected, and the locking arms on the crawler not extending far enough. The evening of the second day, we purchased 300 ft of 0.75-in diameter PVC pipe and planned to push the array into the hole on the third day. On the third day of testing, the array was pushed into the hole with the PVC pipe. Unfortunately, the hole was blocked at a distance of 60 ft.

Results and Discussion

Consol Energy continues to express a high level of interest in the project and has agreed to drill another borehole for testing. This hole will be located in the barrier panel portion of the 5th Right longwall panel at the Buchanan mine. It is anticipated that this borehole will be completed in July, 2003. This borehole will be different than the prior borehole in that it will be drilled completely through the panel, eliminating the need for a crawler unit. Project personnel will be at the mine during drilling and will attach a vinyl-coated aircraft cable to the drill steel when it punches through the panel. As the steel is retracted, the cable will be pulled through from the headgate to the collar of the borehole in the tailgate. The array will then be attached to the cable and pulled through toward the headgate. A hammer source will be used at multiple locations (approximately 50-ft intervals) around the barrier pillar to test the performance of the array.

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 ninth calendar quarter of the project (January 1, 2003 through March 31, 2003) focused on discussions with project cooperators regarding scheduling of the underground testing. Additionally, an application was approved by the US Department of Labor, Mine Safety and Health Administration for an Experimental Permit to allow the array to be tested in a methane drainage borehole within an underground coal mine. The outcome of the project 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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Figure 1. End view of geophone module.

Figure 2. Side view of geophone module.