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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.

Table of Contents

Disclaimer	i
Abstract	ii
Table of Contents	iii
Introduction.....	1
Experimental.....	2
Results and Discussion	3
Conclusion	4
References	5

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 field tests to determine the ability of the array to record seismic signals in the field. The experiment was conducted by dropping an array of four geophones down a vertical borehole at a quarry located near the Virginia Tech campus. Blastholes were being drilled near the highwall. Figure 1 shows the quarry test site, including the drill rig and the highwall. The hole depths were approximately 80 feet and the experimental design included locating sensors at 20, 40, 60, and 80 feet. One geophone was inadvertently disconnected, and unwittingly acted as a control sensor. The array is shown laid out on the ground in Figure 2. Data were recorded as the drilling progressed in a nearby hole (typically 30 to 50 feet distant), with the drill bit acting as the seismic source.

Figure 1. Location of tests at quarry, showing drill rig location and quarry highwall.

Figure 2. 4-Channel Prototype used at Quarry Test Site
(Array laid on ground following tests in borehole)

Results and Discussion

Results of tests at the quarry showed a clear signal being recorded. A comparison of frequency distributions, shown in Figures 3 and 4, shows that Channel 1, which was not plugged in, has no significant signal from the drill as compared to Channel 2 which shows energy between 40 and 100 Hz. The signal shown in Figure 3 is likely from electrical noise within the data acquisition system. Analysis will be conducted to determine whether this noise can be reduced or if the desired signal must be amplified to increase the ratio between signal and noise.

Figure 3. Recorded signal, in frequency domain, of control channel which was not connected. Energy shown is from electrical noise within the data acquisition system.

Figure 4. Recorded signal, in frequency domain, of channel which was connected. Energy shown between 40 and 100 Hz is from drilling in nearby blasthole.

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 sixth calendar quarter of the project (April 1, 2002 through June 30, 2002) focused on testing a four-channel prototype in vertical, dry blastholes at a local quarry. In addition to being successfully deployed and retrieved, the system was successful in recording the signals generated by the drilling of a nearby blasthole. 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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