Report Title: Technical Progress on Project Entitled: "24-Channel Geophone Array for Horizontal or Vertical Boreholes"

Type of Report: Quarterly Technical Report

Reporting Period Start Date: July 1, 2002

Reporting Period End Date: September 30, 2002

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Date Report was Issued: January 2003

DOE Award Number: DE-FC26-01NT41063

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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 meetings with industry cooperators to discuss the prototype and the planned testing at an underground coal mine. Personnel also held a meeting with the US Department of Labor, Mine Safety and Health Administration regarding the application procedure to obtain an Experimental Permit allowing testing of the geophone array in an underground coal mine.

Results and Discussion

Based on the discussions with industry, an improved method of emplacing the array in a long (greater than 50 ft), horizontal borehole was developed. The equipment designed for this purpose is believed to be novel enough for a patent. Additionally, an application to MSHA was submitted during the reporting period for the Experimental Permit.

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 seventh calendar quarter of the project (July 1, 2002 through September 30, 2002) focused on discussions with project cooperators regarding improvements to the prototype. Additionally, an application was submitted to 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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