

Evaluation of Roof Bolting Requirements Based on In-Mine Roof Bolter Drilling

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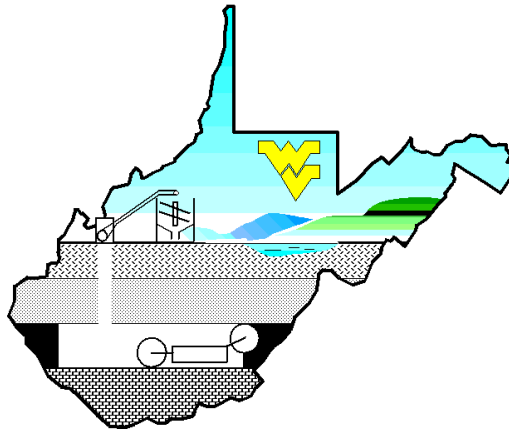
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ABSTRACT

A one-year non-cost extension has been granted for this project. In this quarter, the field, theoretical and programming works have been performed toward achieving the research goals set in the proposal. The main accomplishments in this quarter included: (1) laboratory tests have been conducted, (2) with the added trendline analysis method, the accuracy of the data interpretation methodology will be improved and the interfaces and voids can be more reliably detected, (3) method to use torque to thrust ratio as indicator of rock relative hardness has also been explored, and (3) about 80% of the development work for the roof geology mapping program, MRGIS, has completed and a special version of the program is in the field testing stage.

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Research Objectives

Roof bolting is the most popular method for underground openings in the mining industry, especially in the bedded deposits such as coal, potash, salt etc. In fact, all U.S. underground coal mine entries are roof-bolted as required by law.

However, roof falls still occur frequently in the roof bolted entries. The two possible reasons are: the lack of knowledge of and technology to detect the roof geological conditions in advance of mining, and lack of roof bolting design criteria for modern roof bolting systems.

This research is to develop a method for predicting the roof geology and stability condition in real time during roof bolting operation. Based on such information, roof bolting design criteria for modern roof bolting systems will be developed for implementation in real time.

For the prediction of roof geology and stability condition in real time, a micro-processor will be used and a program (ROOFSTAB) developed to monitor the drilling parameters. These parameters include thrust, penetration rate, rotation torque, rotation rate, drill position, and vacuum condition. At the same time, rock cores will be obtained a borehole drilled immediate next to bolt hole for the determination of the mechanical properties and structure of the rock strata within the bolting horizon. A relationship or relationships will be established between these drilling parameters and the mechanical and structural data of the roof strata. A roof bolter control system will be developed to monitor these drill parameters. For the development of ROOFSTAB drilling parameters will be obtained from four different coal seams in four mine sites. With this information, a computer program will be developed for use in conjunction with the roof bolter for real-time prediction of strata mechanical properties and structures in roof strata within the bolting horizon.

For the development of roof bolting design criteria, numerical simulations will be performed to investigate the mechanisms of modern roof bolting systems including both the tension and non-tensioned (or fully grouted) bolts. Parameters to be studied are: bolt size/strength, bolt length, bolt spacing, grout annulus and length, and roof geology (massive strata, fractured, and laminated or thinly-bedded). The results of these experiments will be analyzed to develop a roof bolting criterion or criteria program (ROOFBOLT) that will be combined with the ROOFSTAB for use in conjunction with roof bolt installation.

The following main tasks are to be performed for achieving the proposed research objectives:

- A.** Development of Operator Control Technology for Monitoring Roof Bolter Drill Operations Parameters.
- B.** Laboratory and Underground Testing.
- C.** Drill Parameters Data Analysis and Correlation with Roof Stability Conditions Software Development for Mapping of Roof Geological Conditions
- D.** Laboratory Tests to Investigate the Mechanisms of Roof Bolting Using Simulated Materials
- E.** Development of Roof Bolting Design Criteria for Implementation in Primary Roof Bolting Cycle

Experimental

In this quarter, plan and preparation have been made to conduct more laboratory and field tests. The justifications for and objectives of these planned tests are:

- Most of the laboratory tests were conducted in 2001. Since then, many important changes, both in hardware (e.g., sensors) and software (e.g., conversion formulae and data handling), have been made on the roof bolter. New tests are needed for us to count these changes on the bolter and to compare the old and the new testing results.
- It has been found from the previous tests that higher pre-set penetration rate, such as 1.1 inch/sec, is better for the data interpretation. However, it is believed that such pre-set penetration rate should be site-specific and should be optimized. In order to optimize the drilling control parameters, such as pre-set penetration rate, thrust cap, and rotation rate. The following criteria should be considered in the optimization process: production rate, operation safety, hardness of the rock layers to be drilled into, data/noise ratio and lengths of the transition zones when the drill bit enters from one type of rock to another. The last two items are most important because the data/noise ratio serves as the measure of strength contrast while the length of transition zone is an indicator for the minimum thickness of the rock layer that can be detected. The laboratory tests are the only means for us to control and vary the testing conditions.
- **Laboratory Tests**
 - **Simulation Blocks.** Since there are no more drilling areas in most of the roof simulation blocks. A number of simulation blocks are to be made. The approach of building the last fracture block will be used here for the new test blocks. We can arrange the blocks in various combinations to simulate various roof strata sequences.
 - Four small concrete blocks (each is 3 ft wide, 4 ft long and 15 inch thick) are made at *a specified compressive strength*. The concrete mix is made up with cement and fine sand without gravel so that is more homogeneous in structure.
 - The suggested compressive strengths are 4,000 psi and 11,000 psi (eight small blocks needed). If possible another four blocks are made at 8,000 psi strength level.
 - Methods for tie these blocks are to be designed. The methods should be able not only to tie four small blocks tightly together to form one simulation block but also to easily disassembly the simulation block after the tests.
 - **Testing Plans.** Tests are to perform on various simulation blocks with various pre-set drilling control parameters (i.e., penetration rate, thrust cap, and rotation rate). The objectives for the tests are to obtain the highest data/noise ratio and the shortest transition zones under the allowable production conditions.

- **Field Tests.** More field tests are also to be conducted.
 - **Site Selection Criteria**
 - If possible, a site with hard to soft rock strata sequence should be chosen. Field tests on soft strata only (CONSOL, Big Mountain, Marrowbone), hard strata only (Marrowbone, Black Knight II), soft to hard strata (Big Mountain, Marrowbone), and fractured strata (Black Knight II) have been conducted. A site with hard to soft strata sequence will be ideal for studying the possible strata sequences.
 - The number of rock layers within the drilling horizon should be small and increase as time goes on.
 - **Testing Plans.** Similar to those in laboratory tests.
- **Optimization of Drilling Control Parameters Studies**
 - Optimization of the drilling control parameters for the purposes of
 - Improving the drilling productivity under safe operation
 - Improving the accuracy and resolution of the geology interpretation using the data.

Results and Discussion

1. Development of Data Interpretation Methodologies

The development of data interpretation methodology is still continuing in this quarter. Development of the systematic and mechanics-based approach for interpreting the drilling parameters is continuing. A new trendline analysis method to filter out the extreme points that are results of data noises and errors has been developed. The derived trendlines for thrust, torques, penetration and rotational rates are used in the determination process for rock strengths to improve the accuracy. It shows that incorporating this trendline method with the original mechanical approach to make the data interpretation more reliable. Another benefit of using the trendline method is that it is capable of more positively identify the fractures/voids in the strata.

A method to use torque to thrust ratio as indicator of relative rock hardness and to identify the fractures and voids has also been developed and tested. It seems that torque/thrust ratio is a good indicator for relative rock hardness based on the testing results.

Two technical papers on the developed methodologies for data interpretation have been presented at 2004 SME Annual Meeting held at Denver, CO on Feb. 23-25, 2004.

2. Exploring the Roof Bolting Mechanisms

Most of the work in this stage has been completed.

3. Development of On-Board Data Visualization and Database Program

The development of a computer program, Mine Roof Geological Information System (MRGIS), to display the original and derived drilling parameters, the estimated rock strengths and geological structures in the bolting horizon in 2-D and 3-D is continuing in this quarter. The program is a Windows-based stand-alone database PC program. It provides an engineer-friendly working environment for importing AutoCAD mine map into this program and to display the interpretation results for easy comprehension. It also provides a platform for incorporating the developed data interpretation methods for nearly real-time geological visualization of the strata drilled during the roof bolting operation. Using the roof geology information, the suitability of the current roof bolting design will be assessed. A technical paper about MRGIS has been presented in 2004 SME Annual Meeting held at Denver, CO on Feb. 23-25, 2004.

The commercialization of the research results is also under way. A special version of the geology mapping program for roof bolters in limestone mine has been developed with the sponsorship of the J.H. Fletcher, Co. and currently is in the testing stage. The following photo shows the special version of the program in testing site in an underground limestone mine.



Fig. 1 Testing of the Special Version of MRGIS Program
in an Underground Limestone Mine

CONCLUSIONS

The project proceeds well as proposed. The status of various tasks is listed in Table 1. The main accomplishments in this quarter included: (1) laboratory tests have been conducted, (2) with the added trendline analysis method, the accuracy of the data interpretation methodology will be improved and the interfaces and voids can be more reliably detected, (3) method to use torque to thrust ratio as indicator of rock relative hardness has also been explored, and (3) about 80% of the development work for the roof geology mapping program, MRGIS, has completed.

Table 1. Progress on Planned Tasks

<i>Planned Milestone</i>	<i>Scheduled</i>	<i>Completed</i>
Development of operator control technology	09/01/01	completed
Laboratory and underground testing	12/31/01	95% completed
Drilling parameter data analysis and correlation	10/01/03	85% completed
Software development for mapping of roof conditions.	10/01/03	90% Completed
Computer modeling to investigate the mechanisms	10/01/03	100% completed
Development of computerized bolting design system	10/01/03	80% completed

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