CONCEPT PAPER

Development of a Seismic System for Locating Trapped Miners

in response to
NIOSH Broad Agency Announcement:
#2011-N-13046

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Technical Summary

In the last decade, the mining industry has seen a rash of mine accidents. In four of these accidents (Quecreek, Sago, Crandall Canyon and San Jose) miners were trapped underground (or assumed to be trapped underground). In three of these entrapment cases, a seismic system was employed (or considered) to try and detect and/or locate the trapped miners, but the background noise (in particular the rescue drilling) made hearing the miners' pounding impossible. Certainly, a seismic system that could "hear" the miners pounding through the background noise at depths of 2000+ ft would have been extremely useful in these mine accidents and may have saved lives.

In the United States, after the Sago Mine accident, mine wide mine communication and tracking systems were mandated in U.S. coal mines, and if the communication system is working, then a seismic system to locate trapped miners would not be necessary. However, it is still not very certain that these communication systems would withstand the type of major explosions or collapses such as occurred at the Sago, Crandall Canyon, Upper Big Branch or San Jose Mines. If the communications system is not working then the seismic method has considerable promise for locating trapped miners because it inherently has good distance capabilities, can be designed to be simple, fast and easy to use, and is reasonably priced.

Traditional systems require that the seismic signal from the miners' pounding be "larger" than the background seismic noise in order to detect and locate the signal. If there is a lot of ground vibration due to natural environmental noise or due to rescue drilling or other rescue activities, the seismic systems can not distinguish the sound of the miner's pounding above the background noise. Also, signal attenuation from the depth of the miner's pounding can make the signal too weak to hear even with only minimal environmental background noise. In field tests with these original systems performed by this researcher, the signal from miner's pounding was successfully detected (and located) from a coal mine that was 440 ft deep (Heasley et al., 2006), but was not detected at a coal mine that was 780 ft deep (Heasley et al., 2007).

The SureWave Technology Company from the United Kingdom has developed a prototype seismic system that uses an advanced proprietary signal processing system to greatly reduce the background noise and enhance the signal-to-noise ratio for detecting miners' pounding even when the background noise is much greater than the pounding signal. Recently, this system was tested at an operating mine in West Virginia with stellar results. The SureWave system reduced the background noise by a factor of 100 and allowed the miner's pounding to be clearly detected at over 1000 ft of depth. In fact, the strength of the signal detection at 1000 ft of depth strongly suggested that the system could detect a miner pounding at 2000 ft of depth, or greater.

This concept paper proposes to more fully evaluate the capabilities of the SureWave Technology's seismic system for locating trapped miners, and if deemed successfully, to obtain a working system for rapid field deployment in any upcoming emergency entrapment situations. The initial field evaluation/test will determine if the system can successfully detect and locate a miner's pounding signal at 2000+ ft of depth. If this critical test is successful, then a completely functioning system will be obtained for future deployment and further detailed evaluation. Once obtained, the seismic system will be further evaluated for locating trapped miners under various difficult (but not un-common) situations at different field sites such as: thick soil, fill or spoil, multiple-seam mining, active drilling, and other large environmental noises.

Deliverables

The first task in this project is to further evaluate the detection and location capabilities of the SureWave Technologies seismic equipment at a field site with depths up to 2000+ feet of cover. At this "deep" field site, it is also planned to test at an intermediate depths around 1500 ft. Each of these fields test will be very comprehensive. Multiple underground pounding locations at successively greater horizontal distances will be used in order to determine the horizontal offset distance at which the pounding signal becomes undetectable. Also, multiple surface sensors will be used and the ability of the system to accurately locate the pounding source using arrival times and/or source vector analysis will be evaluated. If the SureWave Technology system can successfully detect the miner's pounding signal at 2000 ft of depth through a "normal" amount of background noise, then it will have been proven that the system can be successfully be employed to detect trapped miners at over 95% of the coal mines in the U.S. The deliverable from this first task will be a report on the initial field test.

The second task of the project will be for West Virginia University to obtain a complete functioning SureWave Technology system: 1) for potential use in a future mine entrapment situation and 2) for further evaluation of the detection capabilities under various "difficult" conditions typically found in mining situations. The procured seismic system will be designed for rapid field deployment and will include all of the necessary auxiliary equipment for quickly transporting, locating and installing the equipment in an emergency situation. This acquisition will only be completed if the system is successful at detecting the miner's signal at 2000+ ft of cover with "normal" background noise. The deliverable from this task will be the acquisition of the system.

The third and final task of the project will be to further evaluate the capabilities of the SureWave Technology seismic system for locating trapped miners under various difficult (but not un-common) situations for seismic systems such as: thick soil, fill or spoil, multiple-seam mining, active drilling, and other large environmental noises. In this task, it is expected to perform testing at a couple of additional field sites where one or more of the common difficulties mentioned above are present (or can be simulated). At these two "difficult" field sites, the capabilities of the system for detecting and locating the miner's pounding and minimizing the background noise in relation to the respective difficult situation will be thoroughly evaluated. The deliverables from this third task will be reports from each of the field test sites.

Throughout the project, quarterly reports which briefly detail the technical and budgetary progress of the project will be completed and delivered to the Technical Project Officer (TPO). Also, after the first year, a detailed technical and management report will be completed, and at the end of the project after year two, a final technical report will be completed and forwarded to the TPO.

Deliverables

1) Quarterly Reports
2) Field Test #1 Report – Deep Cover – 2000+ ft
3) Acquisition of Seismic System for Locating Trapped Miners
4) Annual Report
5) Field Test #2 Report – fill, multiple-seams and/or active noise.
6) Field Test #3 Report – fill, multiple-seams and/or active noise.

7) Final Written Report

Schedule, Personnel Time, and Costs

The total project is estimated to require 2 full years (see table below). The Principal Investigator (PI) will direct and administer the project with 15% of his time and a half-time Graduate Research Assistants (GRAs) will assist with the various tasks. Also, the Project Manager from SureWave Technology will be assisting with the initial field test. In the first 6 months of the project, all effort will be directed towards obtaining a suitable field site (with 2000+ ft of cover) and testing the seismic system at that site. It is expected that the actual field site will require a full week to survey, install and perform multiple tests with the system.

If the field test at depth is successful, then the project will continue, and in the second 6 months of the first year, a fully operational SureWave Technology system (≈$150,000) will be procured. The procured seismic system will be designed for rapid field deployment and will include all of the necessary auxiliary equipment for quickly transporting, locating and installing the equipment in an emergency situation. At the end of the first year, a yearly report will be produced.

In the second year of the project, two additional field sites that will test the seismic equipment in difficult conditions will be performed. It is expected that each of these sites will take 6 months to organize and complete the field testing with the PI on 15% of his time and a half-time graduate assistant.

The primary costs for the project will be the acquisition of the seismic system (if it proves successful) at approximately $150,000. Also, a significant cost is for the time of the principal investigator (15% effort) and the Graduate Research Assistants (50% effort) for a labor cost (with fringe and overhead) of about $50,000 per year. In the first year, the project will contract with SureWave Technology to provide the equipment and technical assistance to perform the first field test ($19,000). Also, travel to the deep field site in the first year is assumed to be out west and require about $5000, while the last two field sites should be in the east and only require about $2500 each. Overall, with acquisition of the equipment in the first year, it is estimated to cost $236,000 in year 1 and $58,000 in year 2 for a total project cost of $294,000.

Project Schedule

	Year 1				Year 2			
	Qtr1	Qtr 2	Qtr3	Qtr4	Qtr1	Qtr2	Qtr3	Qtr4
Field Test #1 – Deep Cover	XXX	XXX						
Acquisition of Seismic System			XXX	XXX				
Annual Report				XXX				
Field Test #2 – Difficult Conditions				XXX	XXX	XXX		
Field Test #3 – Difficult Conditions						XXX	XXX	XXX
Final Report								XXX

Personnel

Principal Investigator (15% time):

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Graduate Research Assistant (50% time):

SureWave Technology, Managing Director (2 weeks):

Philip Shaw
Managing Director
SureWave Technology, Ltd.
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Personnel Qualifications

Principal Investigator: Keith A. Heasley – 15% effort

Education:

Ph.D., 1998, Mining and Earth Syst. Eng. (Minor-Computer Science), Colorado School of Mines, Thesis: "Numerical Modeling of Coal Mines with a Laminated Displacement-Discontinuity Code."

M.S., 1988, Mining Engineering, Pennsylvania State University, Thesis: "Computer Modeling of Subsidence and Subsidence-Control Methods."

B.S., 1981, Mining Engineering, Pennsylvania State University.

Career Experience:

Professor - West Virginia University, Morgantown, WV, May, 2007 to present.

Associate Professor - West Virginia University, Morgantown, WV, Aug., 2001 to May, 2007.

Supervisory Mining Engineer - National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Laboratory, Oct., 1997 to Aug, 2001.

Mining Engineer - U.S. Bureau of Mines, Pittsburgh Research Center, Aug., 1986 to Oct., 1997.

Graduate Research Assistant - The Pennsylvania State University, Jan., 1984 to May, 1987.

Project Engineer - Consolidation Coal Company, Cadiz, Ohio, Jun., 1981 to Aug., 1983.

Selected Research Projects:

Calibrating the LaModel Program for Deep Cover Pillar Retreat, NIOSH, 04/08-12/10,	$400K
Modeling Rock and Drill Cutter Behavior under HTHP Conditions, DOE, 06/06-11/09,	$441K
Mine Stiffness Calculation for the LaModel Program, CERB, 07/09-06/11,	$60K
Energy Release Rate Calculations for LaModel, NIOSH, 03/08-02/09,	$24K
Incorporating the Roof Fall Risk Index (RFRI) into StabMap, NIOSH, 07/06-11/07,	$23K
Development a Seismic Location System for Trapped Coal Miners, CERB,07/06-06/08,	$35K
Integration of the AMSS Computer program with LaModel, NIOSH, 07/06-09/06,	$10K
Integrated Stability Mapping System for Mines, (StabMap),NIOSH, 09/02 - 05/06,	$255K
Development of 2-D, Multi–Seam Stress Program (Lam2D), CERB, 07/02 - 06/03,	$33K

Statement of Qualifications:

Dr. Heasley has a long history of successfully performing mining research, organizing and successfully completing field projects, and publishing results. From 1986 to 2001, Dr. Heasley performed numerous ground control projects including many field investigations for the U.S. Bureau of Mines and then NIOSH. In particular, he was the lead investigator on a major 3 year project investigating coal bumps which installed and maintained a 3-D seismic system at the Willow Creek Mine in Utah. This seismic system successfully located a 4.1 Richter event within the mining overburden and provided a wealth of understanding of the strata failure around this deep longwall mine. More recently, Dr. Heasley was the principal investigator on a project investigating seismic systems for locating trapped miners that was a result of the Sago Mine Explosion. This project tested 2 different seismic systems at two field sites in the Morgantown area

Managing Director, SureWave Technology: Philip Shaw – 2 weeks effort

Education:
HND, North Staffs Polytechnic (Staffordshire University), Electronics and Control Systems.
HNC, North Staffs Polytechnic (Staffordshire University), Electrical/Electronic Engineering.
TT4, Newcastle College of F E, Telecommunications Technician Course in Electronics, Level 4.

Career Experience:
Managing Director – SureWave Technology, Ltd., UK, 2011 to present.
Principal – Magus Electronics, Cheshire, UK, 1985 to present.
Design Manager – Environmental Equipments (Northern) Ltd., UK, 1985 to 1985
Senior Development Engineer – ICL Kidsgrove, UK, 1975 to 1985

Selected Development Projects:
SP2 Mine Demonstration - full production unit tested to 1040 feet in WV working mine, 2011
SP2 Mine Demonstration - successfully tested to over 200 feet, 2010
SP1 Development - successfully proved that SP1 could be automated for live event picking and displaying of real time data, 2006
Security Monitoring – Demonstrated monitoring for security and runway incursion at Gatwick Airport, 2004
SP1 Development – Produced a micro-seismic system for monitoring strata stress in a working mine, 1996
Developed world's first vibration and type 1 (Leq) unit, 1988
Developed vibration / AOP digital system

Statement of Qualifications:

Mr. Philip Shaw has spent the last 35 years in the business of developing electronic equipment and the software to run it. Since 1985, he has been developing the hardware and software for micro-seismic systems for mine and incursion monitoring. His first full scale system (SP1) was successfully implemented at a working coal mine in the UK in 1996. Since that time, he has been continually upgrading the hardware and software to ultimately produce the SP2 system that was successfully demonstrated at a coal mine in West Virginian earlier this year.

Technical Rationale and Approach

Background

Unfortunately, in the last decade, the mining industry seems to have had a rash of mine accidents: the Quecreek Mine Inundation, 07/24/02; the Sago Mine Explosion, 01/02/06; the Aracoma Alma Mine Fire, 01/19/2006; The Crandall Canyon Mine Collapse, 08/06/06; the Upper Big Branch Explosion, 04/05/10; and the Chilean San Jose Mine Collapse, 08/05/10 (MSHA, 2003, 2007a, 2007b, 2007c and Fiscor, 2011). In four of these accidents (Quecreek, Sago, Crandall Canyon and San Jose) miners were trapped underground (or assumed to be trapped underground). In the United States, an established rescue method for trapped miners is for surface rescuers to produce three small explosions on the surface and then for the trapped miners to respond by pounding on the roof. Therefore, in two of these entrapment cases a seismic system was employed to try and detect and/or locate the trapped miners.

The Quecreek Mine was relatively shallow at 231 ft deep and fairly accessible. At this mine, the inundation occurred at 9:00 pm on Wed., July 24th, 2002, and a small borehole reached the mine by 5:06 am the next day, and located the miners. Three days later the nine trapped miners were successfully hoisted to the surface. At the Quecreek, no surface shots were fired, but the trapped miners did pound on the roof; however, their signaling was not detected by the seismic system due to the high levels of background noise (in particular the drilling) (MSHA, 2003).

The Sago Mine was also relatively shallow at 258 ft deep and fairly accessible. At this mine, the explosion occurred at 6:26 am on Mon., Jan. 2nd, 2006, and a borehole reached the mine level at 5:35 am the next day. No miners were located with the borehole since they were determined to have been incapacitated by carbon monoxide at that time and unable to respond. Ultimately, one trapped miner was rescued while 11 of his colleagues perished due to the bad air. At the Sago Mine, the trapped miners were also pounding on the roof, although no surface shots had been fired. In this instance, the surface seismic system was not deployed because: 1) the approximate location of the trapped miners was already known, 2) it would have taken 8 hours to install the system, and 3) the drilling background noise was deemed too high. (One has to wonder that if the system could have heard the miners pounding through the background noise, that the rescue effort may have then proceeded more quickly and lives may have been saved.)

The Crandall Canyon Mine was much deeper (1800 ft) and more remote. It took a full three days to get the first borehole into the mine. During this time, a surface seismic system was installed, but could only effectively listen when the drilling was stopped due to the drilling noise. Nothing was heard from the mine, since it was ultimately determined that the miners had probably perished in the initial collapse event. The San Jose Mine was also relatively deep, at 2200 ft, and remote. At the San Jose Mine, it took 17 days to get the first borehole into the mine and to determine that the miners were indeed alive and trapped. Ultimately, all 33 of these miners were rescued after being trapped for 69 days. Certainly, a seismic system that could have heard the miners pounding through the background drilling noise at 2200 ft at this mine would have eliminated considerable anxiety and possibly speeded up the rescue operation.

Statement of the Problem

The mine accidents recounted above all demonstrate how useful a seismic system that can detect/locate trapped miners would be. In the United States, after the Sago Mine accident, mine wide mine communication and tracking systems were mandated in U.S. coal mines, and if the communications system is working, then a seismic system to locate trapped miners will not be necessary. However, it is still not very certain that these communication systems would withstand the type of major explosions or collapses such as occurred at the Sago, Crandall Canyon, Upper Big Branch or San Jose Mines. If the communication/tracking system of an underground mine is severely damaged in a mine accident or explosion, the seismic method is one of the most promising practical tool for locating trapped miners since it inherently has good distance capabilities, can be designed to be simple, fast and easy to use, and is reasonably priced. In fact, the WV Mine Safety Technology Task Force (OMHS&T, 2006) recommended that four mine rescue seismic systems be positioned throughout the state for rapid deployment in case of an emergency.

However, as seen in the previous application of seismic systems at the mine accidents, these systems can have great difficulty in "hearing" the miner's pounding above the background noise. Traditional seismic systems for locating trapped miners use geophones to detect ground vibrations from the miners pounding on the roof of the mine. These traditional systems required that the seismic signal from the miners' pounding be "larger" than the background seismic noise in order to detect and locate the signal. If there was a lot of ground vibration due to natural environmental noise or due to rescue drilling or other rescue activities, the seismic systems could not distinguish the sound of the miner's pounding above the background noise. Also, even the depth of the miner's pounding can make the signal too weak to hear above the minimal environmental background noise. In field tests with these original systems performed by this researcher, the signal from the miner's pounding was successfully detected from a coal mine that was 440 ft deep (Heasley et al., 2006), but was not detected at a coal mine that was 780 ft deep (Heasley et al., 2007), apparently because the pounding signal was not above the background noise.

Solution

Recently, the SureWave Technology Company from the United Kingdom developed a prototype seismic system that uses an advanced proprietary signal processing system to greatly reduce the background noise and enhance the signal-to-noise ratio for detecting miners' pounding even when the background noise is much greater than the pounding signal. To test the capabilities of this system, the Mining Engineering Department at West Virginia University performed a quick field test in February, 2011. This test was located at the same operating mine in West Virginia where the miner's pounding signals were not able to be detected with a traditional seismic system at 780 ft of depth (Heasley, 2011).

With the SureWave system at this site, the un-processed background noise is shown in Figure 1. Please note that the magnitude of the background noise in this plot is about 2×10^5. After the system was configured into its normal mode of removing and 'seeing through' the site generated background noise, the signal from the miners pounding was clearly recognizable as shown in Figure 2. Notice that the background noise is now about 2×10^3 and has been reduced by a factor of about 100, and the resulting processed signal-to-noise ratio is about 4 to 1. The SureWave equipment clearly detected all of the miner's pounding at this site, including a secondary test that was performed at over 1000 ft of overburden. Also, it should be noted that the mine was fully operating at the time of the testing. A bulldozer working on the coal stockpile less than 2000 ft away, and the mine's coal car bunker system was operating within 2000 ft underground. This was certainly a "noisy" test site.

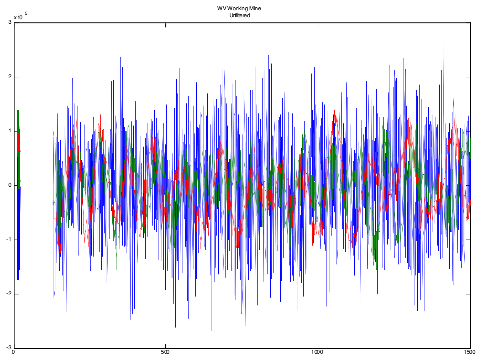

Figure 1. Unprocessed background noise.

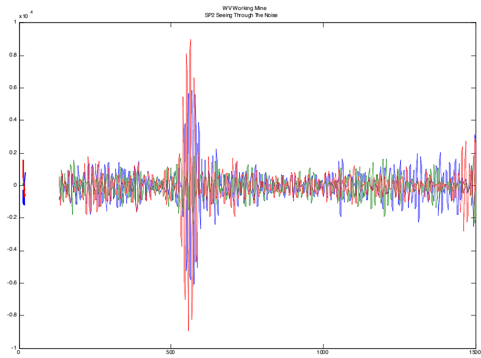

Figure 2. Processed signal showing the miner pounding.

Development Approach

In the initial field test, the SureWave Technology equipment performed significantly better than previous traditional micro-seismic equipment at detecting the miner's pounding signal. In fact, the strength of the signal detection at 1000 ft of depth certainly suggests that the system can detect a miner pounding at 2000 ft of depth, or greater. In order to fully evaluate the capabilities of the seismic system, a three step/task approach is proposed.

First, it is proposed to further evaluate the detection and location capabilities of the SureWave Technologies seismic equipment at another field site with depths up to 2000+ feet of cover. Each of these fields test will also be much more comprehensive than the preliminary testing. Multiple underground pounding locations at successively greater horizontal distances will be used in order to determine the horizontal offset distance at which the pounding signal becomes undetectable. Also, multiple surface sensors will be used and the ability of the system to accurately locate the pounding source using source vector analysis will be evaluated. If the SureWave system can successfully detect the miner's pounding signal at 2000 ft of depth through a "normal" amount of background noise, then it will have been proven that the system can be successfully employed to detect trapped miners at over 95% of the U.S. coal mines.

Therefore, after successful testing of the system at 2000 ft of cover, the second task in the development process will be for WVU to obtain a complete functioning SureWave Technology system: 1) for potential use in a future mine entrapment situation and 2) for further evaluation of the detection capabilities under various difficult conditions. The procured seismic system will be designed for rapid field deployment and will include all of the necessary auxiliary equipment for quickly transporting, locating and installing the equipment in an emergency situation.

The third task in the development process will then be to further evaluate the capabilities of the seismic system for locating trapped miners under various difficult (but not un-common) situations for seismic systems such as: thick soil, fill or spoil, multiple-seam mining, active drilling, and other large environmental noises. In this step, it is expected to perform testing at a couple of additional field sites where one or more of the common difficulties mentioned above are present. At these "difficult" field sites the capabilities of the system for detecting and locating the miner's pounding and minimizing the background noise in relation to the respective difficult situation will be thoroughly evaluated.