Update on the WV Miner Location Seismic System

By
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Disclaimer

- There were a lot of people contributing to this work.
- I AM NOT A SEISMOLOGIST
- The results from the field test are very preliminary.
An accident has happened in an underground coal mine that has left some number of miners trapped.

All communications systems have been compromised and there is no way to determine if there are survivors or exactly where they are.

All operations other than ventilation and rescue have ceased at the mine.

The trapped miners have begun signaling on the half-hour by pounding – ten strikes, pause for a count of ten and then ten more strikes, then wait for a half-hour.
Seismic Location System
Seismicity

- The waves consist of 2 types:
  - P waves – primary, compression waves
  - S Waves – secondary, shear waves
    - Larger amplitude
    - Slower (60% of P wave velocity)

- Seismic waves travel through the ground (5000 m/s), water (1450 m/s), and air (330 m/s).
Active Seismics
Passive Seismics

- Seismic sensor
- Elastic-wave propagation
- Vibration source
In 1970, the National Academy of Engineering (NAE) reported that a seismic system might be capable of detecting and locating trapped miners.

- The miners would strike the roof
- The ground vibrations would be recorded by surface geophones
- Difference in arrival times at different geophones would be used to locate the miners
In 1971 and 1972, Westinghouse Electric Co. built and tested such a system.

- Under favorable conditions, the system worked.
- At actual disaster sites, the background noise generated by surface rescue operations masked any miner generated signals.
- Thus a time specifically designated for seismic “listening” must be allocated and enforced.
Detection Distances
Developed in the 70’s
Uses 7 sub-arrays of 7 geophones each.
Capable of detecting miners up to 1500 ft deep
Equipment Truck
Generator Truck & Equipment Trailer
Older electronic technology – 70’s

“There have been some modifications over the years, but it is generally agreed that it is in need of replacement”
Since the 70’s

- Greatly Enhanced Computer Technology
  - Digital transmission and storage of seismic signals
  - Digital filtering and triggering for enhanced resolution.
Seismic Monitoring Systems

- Nickels mines in Sudbury Canada
- Deep Gold mines of South Africa
- Research Tool
  - Australian coal mines
  - US coal mines – NIOSH
  - US limestone mines - NIOSH
Schematic of Seismic System

- Spread Spectrum Radio Telemetry
- Digitalizer
- Digitizer
- Surface Geophones
- Underground Geophones
- Surface Data Acquisition
- Fiber-Optic Network
- Main Data Analysis
- Underground Data Acquisition
Surface Station

Pre-Amplifier

Geophone
Seismic Events at Willow Creek Mine

Top View

Event Scale (Richter)
0
1
2

Side View

Scale (m)
0 200
Present Research
West Virginia Mine Safety Technology Task Force report (May 29th, 2006):

- “The director shall provide portable seismic locating systems at each regional office (4) for use in locating trapped miners.”
- “Each office will maintain a trained staff that shall, upon notification from Homeland Security Office, be capable of delivering the system to the mine site and to deploy the system immediately and without delay.”
- “These persons shall practice with the said systems at least annually at different mine sites.”
Research Objectives

- Determine and Acquire the “best available” seismic location system for trapped miners.
- Conduct field tests to determine the capabilities and limitations of the system:
  - Depths, Distances
  - Geology
  - Multiple seams, gob areas, etc.
- Long Term: Help develop the hardware and software for a practical location system for trapped miners.
Technology Requirements

- Portable
  - Small enough to carry in regular vehicles
  - Require no power beyond portable batteries
- Easily Deployed
  - Can be deployed in 60 minutes
  - Can be moved quickly
  - Can interconnect with additional units
  - Rugged enough to survive repeated use.
Technology Requirements

- Simple to Operate
  - Software should be automated enough for on-site technician
  - Produce accurate results in real-time
  - Ability to produce maps
  - Ability to save and transmit seismic data to consulting seismic experts to assist in interpretation
Successful Location

“Location accuracies to within one or two coal pillars, and even to within dimensions of a working section, when used in conjunction with a good mine map, will be extremely valuable and, in many cases, be more than sufficient to direct the efforts of both in-mine rescue crews and surface drilling crews.”
Field Test Site

- 4 West Mine, Dana Mining Co. of PA, Inc.
- North of Morgantown and the PA border
- Off the Mt Morris Exit (Exit #1) of interstate 79
Field Test Site
Downhole Geophone
Seismic Equipment

- Geospace 32CT geophones
- Terrasciences 24 channel, 24 bit digitizer sampling at 2 kHz
- Portable PC & car battery
Test Protocol

- Signaling devices:
  - Hilti DX76, Hilti DX460, Hilti DX462, 8 lb sledge hammer, and crib block

- Signaling Locations:
  - Roof bolt, roof rock, and rib

- 5 impacts, wait 30 seconds, next device
## Test Results

<table>
<thead>
<tr>
<th>Device</th>
<th>Location</th>
<th>PPV (μm/s)</th>
<th>Offset (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hammer</td>
<td>Roof Rock</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>Hammer</td>
<td>Roof Bolt</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>Crib Block</td>
<td>Roof Rock</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Crib Block</td>
<td>Roof Bolt</td>
<td>80</td>
<td>0</td>
</tr>
<tr>
<td>Hammer</td>
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<td>45</td>
<td>70</td>
</tr>
<tr>
<td>Crib Block</td>
<td>Roof Rock</td>
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</tr>
<tr>
<td>Hammer</td>
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<td>140</td>
</tr>
<tr>
<td>Block</td>
<td>Roof Rock</td>
<td>45</td>
<td>140</td>
</tr>
</tbody>
</table>
Seismic Signal

Geophone #6, Z-Axis - Crib Block on Roof Rock - 0 Feet Offset

velocity (m/sec)

Time (secs)

11.00 12.00 13.00 14.00 15.00 16.00 17.00 18.00 19.00 20.00 21.00

15.70 15.75 15.80 15.85 15.90 15.95 16.00 16.05 16.10
Z-Axis – X-Axis

Geophone #6, Z-Axis - Crib Block on Roof Rock - 0 Feet Offset

Geophone #6, X-Axis - Crib Block on Roof Rock - 0 Feet Offset
Buried - Surface

Geophone #6, Z-Axis - Crib Block on Roof Rock - 0 Feet Offset

Geophone #2, Z-Axis - Crib Block on Roof Rock - 0 Feet Offset
UnFiltered - Filtered

Geophone #6, Z-Axis - Crib Block on Roof Rock - 0 Feet Offset

Time (secs)
velocity (m/sec)
Test Results

- Crib Block on the Roof Rock appeared to be the strongest
  - -> Crib on Roof Bolt
  - -> Hammer on Roof Rock
  - -> Hammer on Roof Bolt

- Hilti tools were not very detectable?
  - Higher Frequencies?

- Good detection out to 140 ft
  - Not at 210 ft
Test Results

- Mostly Vertical Ground vibration
- Buried geophones provided about twice the peak particle velocity
  - Better connection?
  - Less soil?
- Increase in distance not totally responsible for signal attenuation
  - Polarized source?
  - Horizontal bedding?
Conclusions

- Use a crib block on the roof rock
- An effective trapped miner, seismic location system is achievable.
Future Work

- Thoroughly analyze data
  - Quantify detection strength
  - Apply filtering

- Test at “deep” mine
  - Multiple-seam
  - Gob areas

- Acquire “state-of-the-art” system
Seismic Signaling

WHEN ESCAPE IS CUT OFF

1. BARRICADE
2. LISTEN for
   3 shots, then …
3. SIGNAL by
   pounding hard
   10 times
4. REST 15 minutes,
   then REPEAT signal until…
5. YOU HEAR 5 shots, which
   means you are located
   and help is on the way.
Supporting Literature


- WV Mine Safety Roundtable on Seismic Miner Location, June 28th, 2006

Ground Rules

- System hardware suitable for rapid field deployment
- System use present state-of-the-art equipment
- System operates from the surface.
- System is self-contained
- System is compatible with overall rescue effort
- Readily available signal sources
- Likely area of trapped miners is known
- Surface team will have mine maps.
Field Test Site

- Near the top of a ridge for maximum overburden (441 ft)
- Over the supply entry in an 11 entry main.
Test Layout

- 4 geophone sites in a “T”
- A “surface” geophone at each site
- A “downhole” geophone at site 1 & 2
Successful Location

- Within 100 ft
  - Favorable, Controlled Situations
  - Arrival times can be estimated within 1-5 ms
  - Layering and seismic velocities can be specified within 5%
Signal Improvement

- Bandpass Filtering
- Burial of Sensors
- Subarrays
  - Size Optimization
  - Delayed or Direct Sum
  - Weighted Sum
Consists of 3 trucks
- Equipment truck – recorders and filters
- Generator truck
- Trailer – geophone, cables & supplies
Areas for Development

- Pre-deployed systems
- Data format standardization
- Improved signaling methods
- Signaling from within shelters
- Ideal set of available of geologic information
- Options for remote analysis
- Preloaded mine maps
- Options for use in other emergencies.
Background

- Outcomes, Westinghouse Electric System tests.

- System was all underground
- Signals could be detected up to 1000 ft, but not 1500 ft, away.
- Point-anchor bolts caused a 100 Hz resonance.
- A band-pass filter range of 20-200 Hz worked best.
- Velocities of 4,200-5,000 m/s were observed (with second arrivals at 1,700 m/s).
- An array of 6 geophones did not work any better than a single phone.