GEOPHYSICAL VOID DETECTION DEMONSTRATIONS

By: Kanaan Hanna, Bart Hoekstra, Jim Pfeiffer, & Brandy Uphouse

MSHA: Steve Vamosy George Gardner

6th Biennial ITGAUM Workshop, June 4-16, 2006, Rochester, NY
Presentation Focus

- Engineering Problem
- Program Goals and Objectives
- Geophysical Methodology – Field Investigations
- Void Confirmation
- Geophysical Technologies Performance Evaluations
- Conclusions and Recommendations
Old mine works present major H&S hazards to our nation’s miners...

- Unknown mines,
- Inaccurate historical mine maps, or
- Incomplete historical mine maps

Abandoned mines beneath roadways impact the performance of transportation infrastructure in terms of...

- Cost,
- Public safety
MSHA’s Overall Goals

To...
Advance the current state-of-the-practice geophysical technologies for detecting mine voids

Overall Program Objectives

To...
Accurately & economically detect underground mine voids
Definition: Old mine works vs. Mine voids

- **Old mine works**: Identify the general location/boundary of the UG workings
- **Mine voids**: Identify the location of mine opening/entries, and pillars
Presentation Focus

- Engineering Problem
- Program Goals and Objectives
- Geophysical Methodology – Field Investigations
- Void Confirmation
- Geophysical Technologies Performance Evaluations
- Conclusions and Recommendations
- **Demonstration site:**
  - Known abandoned coal mine adjacent to an active UG room-and-pillar mine, Georgetown, IL

- **Surface and borehole geophysical methods:**
  - 3-D high resolution seismic (HRS) using P-waves (HRPW) and S-waves (HRSW)
  - Crosshole tomography (XHT)
  - Crosshole guided waves
  - Reverse vertical seismic profiling (RVSP)
  - Borehole sonar mapping
Basic Concept of the RVSP and HRS Techniques

RVSP vs. HRS Geometry

Loosely consolidated near surface soils around a surface seismic source undergo non-elastic deformation which decreases the transmission of seismic energy and reduces the effective bandwidth through the medium.

Seismic Energy from surface shot must pass through the high attenuation surface zone twice, resulting in increased attenuation and decreased resolution. The surface shot has a longer travel path which also increases attenuation.

Coal Seam

- Geophone
- Seismic Source
- Reflected Wave Path from Surface Seismic
- Reflected Wave Path from RVSP
### Geologic Setting

<table>
<thead>
<tr>
<th>Subsurface Strata Above and Below the Herrin Coal Seam #6</th>
<th>Thickness of Material in Ft</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Glacial Material</strong></td>
<td>30.00</td>
</tr>
<tr>
<td>Unconsolidated Clay with Gravel Tan or Buff</td>
<td></td>
</tr>
<tr>
<td>Unconsolidated Silt with Gravel Red or Brown</td>
<td></td>
</tr>
<tr>
<td>Unconsolidated Silt with Gravel Med Gray</td>
<td></td>
</tr>
<tr>
<td>Unconsolidated Sand with Gravel - Large</td>
<td></td>
</tr>
<tr>
<td>Sandstone - Med. Gray</td>
<td></td>
</tr>
<tr>
<td>Sandy Shale - Med Gray</td>
<td>110.00</td>
</tr>
<tr>
<td>Shale - Dark Gray</td>
<td></td>
</tr>
<tr>
<td><strong>Danville</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Coal Seam # 7 (No Mining ~ 140 Ft Deep)</strong></td>
<td>3.70</td>
</tr>
<tr>
<td>Sandy Claystone - Med Gray</td>
<td></td>
</tr>
<tr>
<td>Sandstone - Med Gray</td>
<td></td>
</tr>
<tr>
<td>Limestone</td>
<td></td>
</tr>
<tr>
<td>Sandstone - Med Gray</td>
<td></td>
</tr>
<tr>
<td>Sandstone, Limey Med Gray with Nodules</td>
<td></td>
</tr>
<tr>
<td>Sandy Shale - Med Gray</td>
<td></td>
</tr>
<tr>
<td>Shale - Med Gray with Coal Streaks</td>
<td></td>
</tr>
<tr>
<td><strong>Herrin</strong></td>
<td>6.80</td>
</tr>
<tr>
<td><strong>Coal Seam # 6 (Target Zone ~ 233-235 Ft Deep)</strong></td>
<td></td>
</tr>
<tr>
<td>Limey Sandy Claystone</td>
<td></td>
</tr>
<tr>
<td>Sandy Claystone - Med Gray</td>
<td></td>
</tr>
<tr>
<td>Limey Claystone - Med Gray - Nodules</td>
<td>13.20</td>
</tr>
<tr>
<td>Black Shale with Coal Streaks</td>
<td></td>
</tr>
<tr>
<td><strong>Springfield</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Coal Seam # 5 (No Mining ~ 253 Ft Deep)</strong></td>
<td>0.80</td>
</tr>
<tr>
<td>Limey Claystone - Med Gray - Nodules</td>
<td></td>
</tr>
<tr>
<td>Sandy Shale - Med Gray</td>
<td></td>
</tr>
<tr>
<td>Shale - Dark Gray</td>
<td></td>
</tr>
<tr>
<td>Black Limey Shale</td>
<td></td>
</tr>
<tr>
<td>Sandy Shale - Med Gray</td>
<td></td>
</tr>
<tr>
<td><strong>Total Drill Depth</strong></td>
<td>320.00</td>
</tr>
</tbody>
</table>

- **Upper Coal Seam**
- **Target Coal Seam**
- **Lower Coal Seam**
Grid Location of HRSW and HRPW 3-D Reflection Surveys

HRS Data Acquisition
Geophysical Methodology - HRS

Data Analysis and Interpretation
Anomalous Coal Response from P-wave
Conclusions...

HR primary P-wave 3-D (HRPW):

• Provided consistent data quality throughout the survey
• Obtained clear reflections from the Herrin #6 coal seam
• Imaged the general location of the old mine works
• Inadequate to identify mine voids (rooms/entries, pillar)
Conclusions

HR shear S-wave 3-D (HRSW):

- Obtained some reflections from Herrin #6 coal seam
- The deployment of two vibrator sources were still insufficient to compensate for energy loss
- Provided limited information on the old mine works
Geophysical Methodology – XHT/ GW and RVSP

Borehole Location Overlaid HRS Image
Geophysical Methodology – Boreholes Drilling
Geophysical Methodology - RVSP

RVSP Data Analysis and Interpretation
Seismic Amplitudes from RVSP Profiles along the Target Zone
Geophysical Methodology - RVSP

Peak Seismic Amplitudes at Target Zone Overlain on Historical Mine Map
Geophysical Methodology - RVSP

Peak Seismic Amplitudes at Target Zone from NS #6 to NS #4
Presentation Focus

- Engineering Problem
- Program Goals and Objectives
- Geophysical Methodology – Field Investigations
- Void Confirmation
- Geophysical Technologies Performance Evaluations
- Conclusions and Recommendations
Boreholes Layout Based on RVSP Results and Historical Mine Map
Void Confirmation

Drilling along NS Mains and Sonar Mapping
Void Confirmation – Sonar Mapping Field Results
Void Confirmation - Sonar Interpretations

Sonar Void Models Overlay Historical Mine Map
Presentation Focus

- Engineering Problem
- Program Goals and Objectives
- Geophysical Methodology – Field Investigations
- Void Confirmation
- Geophysical Technologies Performance Evaluations
- Conclusions and Recommendations
Performance Evaluation of Geophysical Methods

<table>
<thead>
<tr>
<th>Criterion</th>
<th>HRPW</th>
<th>HRSW</th>
<th>XHT</th>
<th>Guided Waves</th>
<th>RVSP</th>
<th>Sonar Mapping*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to Locate Mine Works/Voids</td>
<td>Fair</td>
<td>Fair</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
<td>n/a</td>
</tr>
<tr>
<td>Resolution</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Very Poor</td>
<td>Very Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Depth of Investigation</td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Very Good</td>
</tr>
<tr>
<td>Anticipated Repeatability</td>
<td>Good</td>
<td>Fair</td>
<td>Good</td>
<td>Fair</td>
<td>Good</td>
<td>Very Good</td>
</tr>
<tr>
<td>Robustness under Various Geologic/Surface Conditions</td>
<td>Fair</td>
<td>Poor</td>
<td>Fair</td>
<td>Fair</td>
<td>Good</td>
<td>Very Good</td>
</tr>
<tr>
<td>Cost</td>
<td>High</td>
<td>Very High</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Void Contents</td>
<td>Poor</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
<td>Very Good</td>
</tr>
</tbody>
</table>

*Sonar mapping can only be used in a borehole that has intersected a water-filled void in the mine.
Have these geophysical technologies met the overall project objective...
Performance Evaluation

Objective: Select the most accurate and cost-effective method…!

- NO ............... XHT and guided waves
- Partially ......... HRPW/HRSW
- YES ............... RVSP
Presentation Focus

- Engineering Problem
- Program Goals and Objectives
- Geophysical Methodology – Field Investigations
- Void Confirmation
- Geophysical Technologies Performance Evaluations
- Conclusions and Recommendations
The geophysical technologies demonstration at the site has verified the effectiveness of the....

RVSP

When Complemented by Sonar or Laser Mapping
Combined with Engineering Practices – the most viable geophysical method to...

Accurately and Economically Detect Mine Voids
Where to go from here

Proposed RVSP Geophysical/Geotechnical Investigations for Commercial and Residential Development
A systematic approach – integrating 2-D and/or 3-D RVSP geophysical investigations with subsidence engineering evaluation for optimum foundation design...

**Geophysics**

- RVSP Subsurface Investigation:
  - Identify old mine works
  - Identify mine voids

- Subsurface Characterization in terms of:
  - Subsidence evaluation
  - Void detection evaluation

**Engineering Geophysics**

**Engineering Evaluation**

- Engineering Analysis:
  - Geotechnical evaluation
  - Foundation system evaluation and risk assessment
  - Engineering decision
RVSP Proposed Methodology

Schematic of Recommended RVSP Survey for Mine Void Detection

**RVSP Concept**

**Survey Acquisition Parameters:**
- Boreholes spacing one to two times of target depth.
- Borehole depth approximately 80% to 95% of the target depth.
- Geophone spacing 2 to 10 ft depending on target depth.
- Source interval 1 to 5 ft depending on resolution required.
RVSP Investigation
Questions