U.S. Department of Labor

Mine Safety and Health Administration
Pittsburgh Safety & Health Technology Center
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Mine Waste and Geotechnical Engineering Division

May 14, 2007

MEMORANDUM FOR IRVING McCRAE
Contracting Officer, Acquisition Management Division
MSHA Headquarters, Arlington

THROUGH: DONALD T. KIRKWOOD
Acting Chief, Mine Waste and Geotechnical Engineering Division

GEORGE H. GARDNER
Senior Civil Engineer, Mine Waste and Geotechnical Engineering Division

FROM: J. JARROD DURIG
Civil Engineer, Mine Waste and Geotechnical Engineering Division

SUBJECT: Summary of the Geophysical Void Detection Demonstration Project by Wright State University, MSHA Contract Number B2532536, Conducted at the Riola Mine Complex, Black Beauty Coal Company, Mine I.D. No. 11-03060, Vermillion County, Illinois

Wright State University (WSU) has recently fulfilled a contract to demonstrate a "Forward Looking Seismic Methodology" for detecting underground mine voids. The demonstration was conducted at Black Beauty Coal Company's (BBCC) Riola Mine Complex. I am the Contract Officer's Technical Representative (COTR) for this project. The purpose of this memo is to provide a general summary of the completed project and discuss the successes and failures of the geophysical results.

BACKGROUND

Wright State University was the prime contractor for this void detection demonstration project. Assistance in collecting and processing the field data was provided by Xenon Geosciences.

The primary geophysical method described here was used by WSU in an attempt to measure the margin of poorly mapped old mines using the seismic waves generated by active mining in the same coal seam and by measuring the seismic energy scattered to the ground surface when a disruption in the coal seam was encountered. As an ancillary test, the researchers placed a borehole seismometer into the coal seam ahead of mining, and attempted to characterize the in-seam seismic energy released as the mining operation moved forward and beyond the instrument. A secondary method was attempted in which waves emerging from deeper refracting layers were measured to determine the extent in which they are attenuated by the old mine works and the adjacent intact coal seam.

After WSU was awarded the contract, a project kick-off meeting was held on October 29, 2004, to introduce the team members and to develop a process for reporting project milestones and invoicing for progress payments. Field work required by the contract was carried out as follows:

Wet (flooded) mine demonstration conducted from November 22 – November 25, 2004;

Dry mine demonstration conducted from March 7 – March 11, 2005; Secondary;

"Refraction attenuation" testing with a weight drop system conducted from February 20 – February 24, 2006;

Confirmation drilling conducted from February 27 – March 3, 2006.

The processing of all of the field data collected was completed and a draft report was submitted April 14, 2006. Following a technical/peer review of the report, WSU revised the draft and submitted what they considered to be the final project report on July 31, 2006. However, several comments pertaining to the review of the draft report were not adequately addressed in the document and typographical errors were found. Comments pertaining to the review of this report were forwarded to WSU in an e-mail dated September 15, 2006. Items contained in this transmittal were addressed in the revised final project report dated February 2, 2007. A hard and electronic copy of this report was mailed to your attention on February 12, 2007.

DEMONSTRATION OF "FORWARD LOOKING" SURFACE SEISMIC METHOD

The wet void demonstration was conducted at the Riola mine which was developing in a northwest direction along 7 parallel entries and at the time of testing was approaching the abandoned Bunsen mine (figure 1). The target voids (Bunsen mine) were 2 main entries running north-south at the edge of the abandoned workings. The entries were 10 feet in width and separated by pillars 20 foot wide and 60 foot long. Beyond these entries were a row of barrier pillars (50 feet x 200 feet) and a large area of small (second-mined) pillars. The associated coal seam (Herrin #6) is located at an average depth of 210 feet below the ground surface and has an average thickness of approximately 8 feet.

The surface setup consisted of 120 individual 4.5 Hz geophones placed vertically at 15-foot centers (1800 feet total length). The recording system at the site consisted of two, 60-channel StataVisor seismic recorders which were triggered simultaneously for an effective 120-channel recording. Thirty-two second data records were collected at a sample rate of 0.5 milliseconds. At this rate, the ambient seismic signal could be viewed on the display screens in real time, and periods of mining activity could be easily recognized for manually triggering the recorders. To remove any ambiguity about where mining was occurring underground in relation to the passive recordings at the surface, an observer with a synchronized watch wrote down the details of the mining operations underground while data was being recorded on the surface.

Inspection of the raw data confirmed what was clear on the StrataVisor displays in the field, that a strong mining-generated signal is present in the data. These impulses clearly represent rapid episodic direct-wave arrivals traveling in the rock overlying the coal seam. In a few instances, a series of rhythmic and repetitive seismic waves can be observed in the raw data, and define a distinctive oscillatory concave downward pattern. This pattern, when it occurs, is typically evident just following a period of strong direct wave arrivals and occurs spatially in the immediate vicinity of the likely margin of the abandoned mine. The location and arrival time variation of this oscillatory seismic signal is like that expected from waves radiating from a particular location beneath the surface.

The dry void demonstration was similar in setup, but took place at the Riola mine which was developing in a southeast direction approximately 500 feet from an abandoned part of the same mine (figure 2). The target voids were 6 main entries running northwest to southeast in an area that was abandoned in April of 2002. The associated coal seam (Herrin #6) is located at an average depth of 210 feet below the ground surface and has an average thickness of approximately 8 feet.

The surface setup consisted of 60 individual 4.5 Hz geophones placed vertically at 10-foot centers (600 feet total length). The recording system was a single, 60-channel StataVisor seismic recorder. Thirty-two second data records were collected at a sample rate of 0.5 milliseconds. At this rate, the ambient seismic signal could be viewed on the display screens in real-time, and periods of mining activity could be easily recognized for triggering the recorder. As in the wet demonstration, an underground observer kept details of the underground mining operations.

As was the case during the wet void demonstration, a strong mining generated signal is present in the data. The direct-wave arrivals were present in both the raw field records and the correlated data. However, this data notably lacked the distinctive oscillatory concave downward patterns that were so clear in the wet void data. The researcher presented some theories within the report as to why the oscillatory waves would be present in the wet void data, but not the dry void data.

The ancillary part of this demonstration was to install a seismometer into the coal seam to attempt to characterize the seismic waves associated with the active mining operation. The instrument deployed was a Geospace Technologies GS20DX 10 Hz, 3-component seismometer. The instrument is encased in a 1.8-inch-diameter stainless steel waterproof cylinder with a pair of downward angled spring clamps mounted on one side. The seismometer was installed between the top of the coal and the middle of the seam (one-quarter of the seam thickness from the top). This location was chosen to provide information for both the Love and Rayleigh seam waves.

At the time of data collection, the active mining was approximately 700 feet east-north-east of the seismometer. A comparison of the data collected during the spans of mining activity and the times between reveals that the mining related seismic energy observed is dominated by a strong 14 Hz periodic signal. This strong signal is evident on both the vertical and east-west components and is nearly absent on the north-south component. This 14 Hz periodic signal was also observed in the seismic waves recorded at the surface which were scattered from the vicinity of the wet mine margin.

DEMONSTRATION OF THE REFRACTION ATTENUATION METHOD

This demonstration includes a man-made surface source of seismic energy positioned at a sufficiently large distance from a spread of surface geophones placed across an unknown mine margin. From this setup, refraction waves could be generated which would travel along strata deeper than the coal seam and return to the surface across the mine margin. The expectation was that the refraction energy returning to the surface would experience greater attenuation in mined areas than areas with an intact coal seam.

The surface setup included a 48 station spread of 4.5 Hz geophones placed at 10-foot centers (480 feet total length). A Bison Elastic Wave Generator (EWG) was used to generate seismic energy at 300-foot intervals away from the surface geophones to distances up to 2100 feet (figure 3). Repeated hits were summed (stacking) to help the recorded signal overcome the ambient noise levels at greater distances. The original plan was to use a Vibroseis source; however, with the dramatic rise in the price of oil and gas before starting the field work it became impossible to contract for or lease the Vibroseis equipment. The Vibroseis has some inherently beneficial noise mitigating characteristics, but because of the availability issues, the weight drop system (EWG) was substituted.

Although windy conditions and vehicle related noise had to be accounted for in the data, clear refraction arrivals were recorded from a source offset distance of up to 2100 feet using the EWG. The first break refraction arrivals on both the wet and dry mine recording spreads show a distinct reduction in refraction amplitude in the area of the respective mine.

CONCLUSION

The most attractive feature of the primary method demonstrated, "forward-looking surface seismic," is that data is collected entirely on the surface and the method requires active mining. Consequently, the method has no negative impact on, or interruption of, underground mining operations. The researchers felt that the testing at the wet mine location was a success. Although confirmation drilling revealed that the data had actually missed the margin of the mine by 90 feet at a source (miner) distance of 1200 feet. The data did show that location and orientation of the miner at the time of data recording did not significantly affect the results. Researchers hypothesized that the offset was due to collapse of the mine roof that was determined during the drilling and the inability of the waves to travel vertically through the broken material. This theory was substantiated by a hypothetical numerical model, although other causes are possible. The researchers concluded that the lack of similar seismic signature from the dry mine location was primarily due to the fact that the mine was younger than the wet mine location. They felt that the collapsing of the roof in the wet mine and more weathered, uneven surfaces would lend to greater scatter of the waves intersecting the voids. On the other hand, the more planar vertical boundary that would be present in the younger dry mine would lend to waves being directed back through the seam instead of scattering and propagating to the surface.

The researchers reported that the secondary demonstration, the "Refraction Attenuation" method showed limited success, but definitely had an effect on the relative amplitude of the refracted wave arrivals passing through the old mine works.

If you have any questions, please contact this office.

cc: M. Hoch - Chief, PS&HTC
J. Erlinger – TS

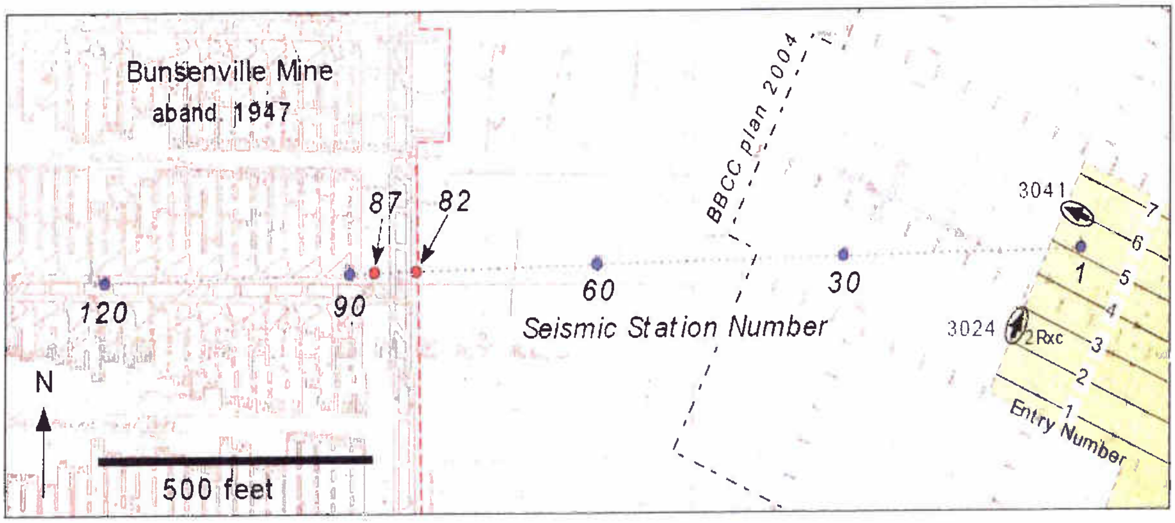

Figure 1. Plan view of mine layouts for wet mine demonstration. Yellow denotes the developing Riola mine, Brown denotes the abandoned Bunsen mine.

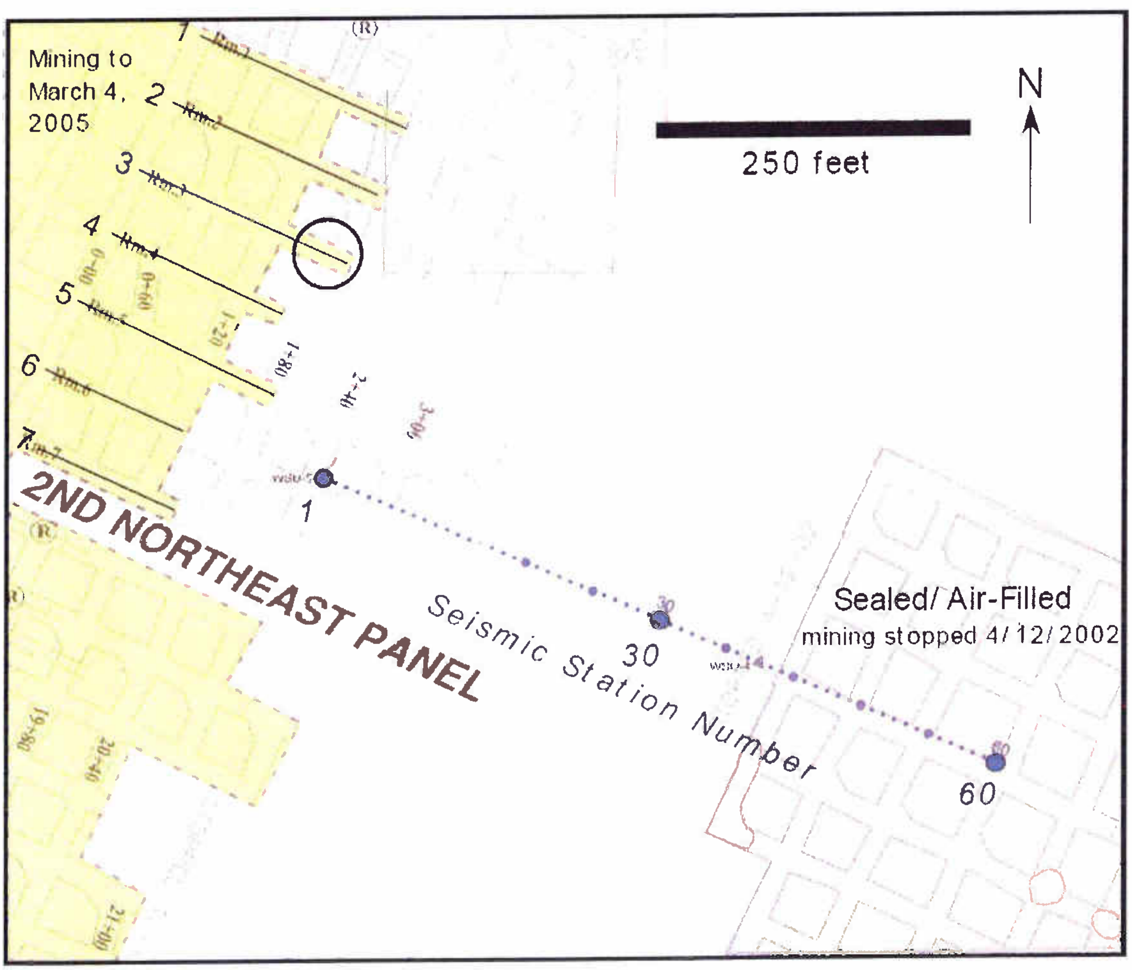

Figure 2. Plan view of mine layouts for dry mine demonstration. Yellow again denotes the active Riola mine, Gray denotes the abandoned area of the Riola mine.

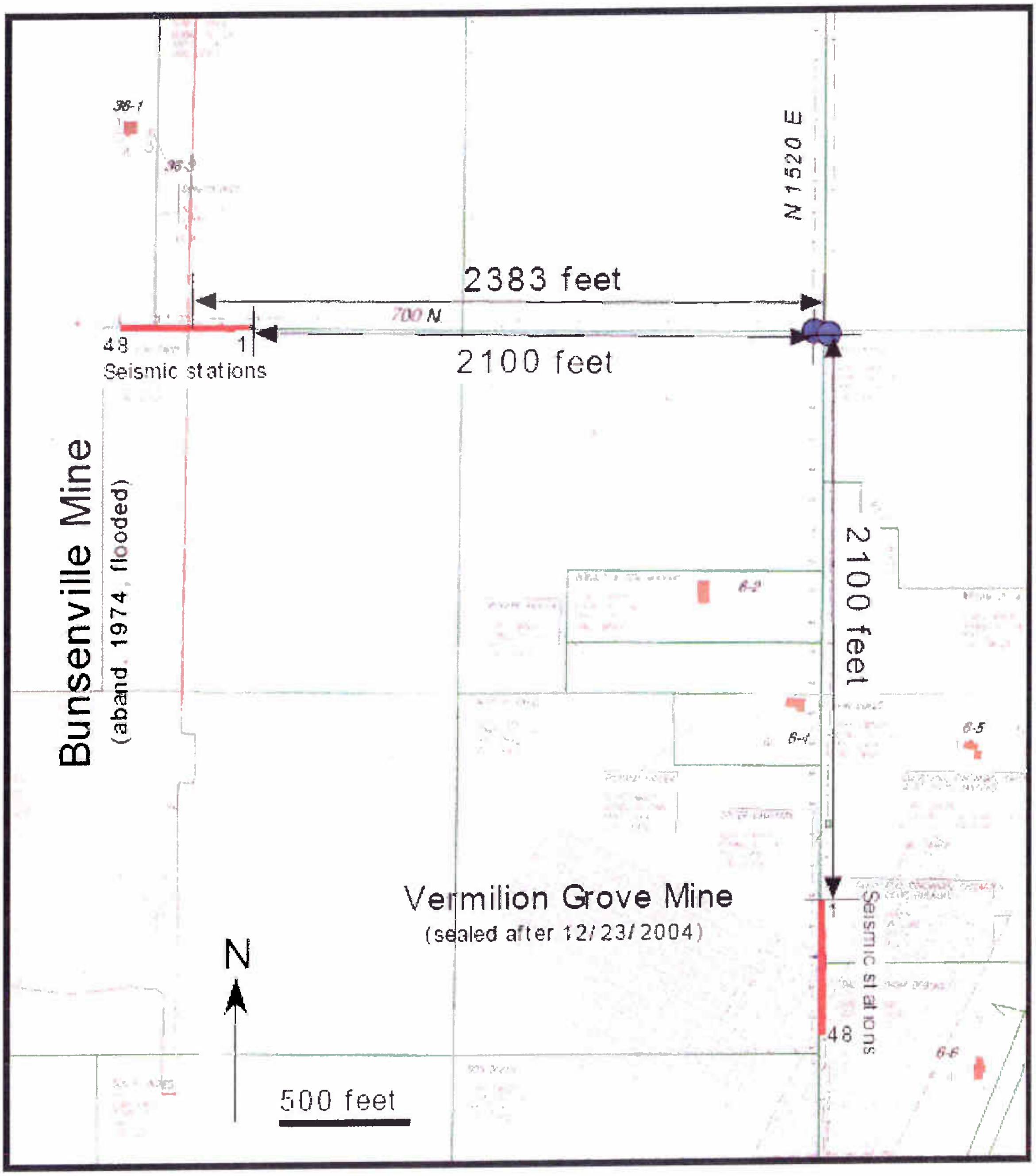

Figure 3. Plan view of mine layouts for refraction attenuation demonstration.