U.S. Department of Labor

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Mine Waste and Geotechnical Engineering Division

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MEMORANDUM FOR IRVING McCRAE
Contracting Officer
MSHA Headquarters, Arlington

THROUGH: KELVIN K. WU
Acting Chief, Pittsburgh Safety and Health Technology Center

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FROM: STEVEN J. VAMOSSY
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SUBJECT: Summary of the Geophysical Void Detection Demonstration Project by Blackhawk, a Division of Zapata Engineering, Conducted at the Riola Mine Complex, Black Beauty Coal Company, Mine I.D. No. 11-03060, Vermillion County, Illinois

Blackhawk Division of Zapata Engineering (Blackhawk) has recently fulfilled a contract to demonstrate both the 3-D High Resolution Seismic (HRS) Reflection technology and the Crosshole Seismic Tomography (XHT) technology 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 success of the geophysical results.

BACKGROUND

The geophysical methods demonstrated at the site were being used in an attempt to locate abandoned mine works within the Herrin #6 coal seam. The seam is located at an average depth of 235 feet below the ground surface and has an average thickness of

approximately 6 feet. The specific mine layout in the area that Blackhawk attempted to image consisted of a set of 4 main entries running in the north-south direction and a set of 2 submain entries running in the east-west direction. The entries were 10 feet wide and were separated by pillars which were 20 feet wide and ranged from 40 to 60 feet long.

After Blackhawk was awarded the contract, a project kick-off meeting was held on October 28, 2004. The field work was then completed as follows: 3-D HRS survey from November 12 - December 3, 2004; XHT survey from April 17-30, 2005; and void drilling confirmation and sonar mapping from October 3-7, 2005. I was onsite and subsequently wrote a summary memorandum for each phase of the field work. Blackhawk completed the field data processing and submitted a draft project report on February 21, 2006. Following a technical review of the report, Blackhawk revised the report and submitted the final project report on June 7, 2006.

DISCUSSION OF RESULTS

The methods used at the site yielded mixed results. The 3-D HRS survey (a surface seismic method) obtained clear reflection from the Herrin #6 coal seam, and showed consistent data quality throughout the survey. The boundary of the north-south mains was well-defined while the east-west submains were less well-defined. The survey also produced high amplitude anomalies outside of the area of old mine works depicted on the mine map. Blackhawk claims that these anomalies may correspond to old mine works not shown on the existing mine map, thinning of the coal seam, the presence of rolls, and/or variations in the vertical and horizontal stresses. One particular high amplitude anomaly was found north of the east-west submains. This anomaly was further investigated during the void drilling confirmation program, and a boring in this area confirmed that the coal seam was unmined and only five-feet thick in this location. It was originally thought that this anomaly may have indicated the presence of a large void rather than solid coal. Blackhawk and BBCC's head geologist explained that the anomaly may have been indicative of the presence of rolls in the coal seam roof. The P-wave data, and to a lesser degree the S-wave data, from the 3-D HRS survey did identify the general area of the old mine works, but did not identify the location of the individual rooms (voids) and/or pillars. In addition, the survey produced additional anomalies outside of the mapped mine workings which could not be fully explained.

The XHT survey (crosshole seismic method) produced low quality data and did not detect the mine workings (voids). With this method, coal seams and voids are typically indicated by low velocity zones, while surrounding rock strata, such as sandstone, are indicated by high velocity zones. Blackhawk's XHT tomograms did not produce any low velocity zones at the depth of the coal seam. A separate guided (channel) wave test was performed, and it also did not detect any voids. Blackhawk postulates that these

methods did not work due to larger than optimal borehole spacing and the presence of high velocity layers above and below the coal seam which were faster routes of travel for the seismic waves than through the coal seam, masking the low velocity coal seam and voids. Also, the presence of water produced potentially poor velocity contrast between the coal and the water-filled voids. It was disappointing that this method was not successful at this test site because Blackhawk and other geophysicists have claimed success with the crosshole seismic methods in similar circumstances.

One additional geophysical method was conducted, at Blackhawk's expense, in conjunction with the crosshole seismic field work. During the crosshole seismic testing, as the seismic source unit was activated in the borehole, Blackhawk had placed one line of geophone receivers along the ground surface. This configuration is generally known as Reverse Vertical Seismic Profiling (RVSP). The method is a variation of traditional vertical seismic profiling (VSP), where the receivers (hydrophones) are located within the borehole, and the seismic source is generated along the ground surface. The data collected in the surface geophones was processed for Blackhawk by Sterling Seismic Services (Sterling) using a proprietary technique that they developed specifically for this purpose. Upon processing, the results appeared to clearly define the boundary of the mains and submains, and in some cases, it appeared to map individual entries within the mains.

Blackhawk concludes their project report by indicating that RVSP is the most effective method to accurately and economically detect the location of old mine works. Although this method appeared to work well at this test site, additional tests should be performed in other topographic, geologic, and cultural settings (such as the Appalachian coal fields) to determine its effectiveness in various conditions. In addition, the RVSP method may be improved by using a larger source (i.e. bigger air guns) within the borehole, using more lines of surface geophones to create a 3-D image of the subsurface, and using longer (horizontal) lines of geophones resulting in better seismic raypath coverage.

In conjunction with the confirmation drilling program, Blackhawk conducted borehole sonar surveys in an attempt to better define the voids and the boundary between the old mine works and solid coal. Sonar surveys are designed to map the size of the void and the lateral distance to solid contact away from the drill holes. The sonar work was sub-contracted to Workhouse Technologies, LLC. The surveys proved to be a success and significantly increased the information obtained from the drill holes. The sonar information obtained from the boreholes was used to determine, with a high level of confidence, the boundary of the rib line (void/solid boundary). The sonar surveys are not a method for detecting voids, but rather a complimentary tool to map the vertical and lateral extents of mine voids once they have been drilled into. As such, they are a valuable tool to assist with georeferencing of mine maps. Sonar surveys only work in

water-filled voids; however, alternative instrumentation can be used in air-filled voids to conduct borehole laser surveys.

CONCLUSION

In summary, Blackhawk had limited success in detecting mine voids with the surface seismic method (3-D HRS), and slightly greater success using the RVSP method. The crosshole seismic method (XHT) was not successful in this situation. It appears that the RVSP method shows some promise, and it may be beneficial to obtain additional information on the success of this method as it is applied under other conditions. Blackhawk indicated that they have conducted some additional work using RVSP and are willing to share the results with MSHA once the data processing is finalized. Finally, where mine voids are successfully located, sonar surveys have proven to be useful tools for mapping their extent.

If you have any questions, please contact me.

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