U.S. Department of Labor

Mine Safety and Health Administration
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Mine Waste and Geotechnical Engineering Division

January 15, 2008

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

THROUGH: STANLEY J. MICHALEK
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FROM: DAI S. CHOI
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SUBJECT: Summary of Geophysical Void Detection Demonstration Project, In-Seam Seismic Method by Pennsylvania State University, MSHA Account Number B2532532, RFP Number MSHA J53R1011

Pennsylvania State University has fulfilled their Phase 1 contract to demonstrate the in-seam seismic reflection technology for detecting underground mine voids. Dr. Dai Choi served as Contract Officer's Technical Representative (COTR) for the project. The purpose of this memo is to provide a general summary of this ongoing multi-phase project and discuss the results obtained during the Phase 1 study.

BACKGROUND

In October 2004, Pennsylvania State University (PSU) was awarded the demonstration contract in two phases to be completed within 3 years. The PSU team proposed to write a manual for the in-seam seismic technique at the end of the Phase 2 work. The Phase 1 work was completed and fully paid in December 2006. The first year of the Phase 2 work is currently in progress.

During the project execution, one of the co-principal investigators resigned from the project team in September 2005. The project was carried out by the remaining principal investigator, Dr. Maochen Ge and his assistants. The project team had three consultants for site arrangement and instrument installation. They were Drs. R. V. Ramani, H. R. Hardy, Jr., and M. C. Radomsky.

The void detection field surveys were conducted at the Harmony Mine, FMC Mine, General Chemical Mine, and Agustus Mine. Harmony Mine is an anthracite mine in Northumberland County in eastern Pennsylvania. The FMC and General Chemical Mines are trona mines located in Sweetwater County, Wyoming. The Agustus Mine is a bituminous coal mine located in Somerset County in central Pennsylvania.

The collected field data was analyzed at the University. Draft versions of the Phase 1 report and user's manual were delivered to the Pittsburgh Safety and Health Technology Center on April 6, 2006. The draft reports were disseminated to the Peer Review team members for feedback. The draft reports were revised several times based on feedback from the COTR and peer reviewers and resubmitted on July 13, September 17, and October 29, 2006, respectively. The October 29, 2006, report addressed the comments from the Peer Review team and was accepted as the final Phase 1 report.

FIELD TESTS OF IN-SEAM SEISMIC REFLECTION

The PSU team collected the in-seam seismic data using a sixteen channel data acquisition system manufactured by Engineering Seismology Group Canada, Inc. (ESG). The recording system has been approved for use in a gassy environment except for the triggering mechanism.

The sensors for the data acquisition system are accelerometers and geophones. These sensors are powered by 28V DC and are not permissible for use in a gassy mine environment. Thus, intrinsic safety barriers are used to limit any surge of current to the sensors. An addition of an intrinsic barrier for the 9V triggering mechanism would make the entire system permissible for a gassy environment. The sensors have been installed in a small borehole with use of epoxy resin and threaded connections and are retrieved for reuse. The sensor installation technique has been developed for this project with help of the consultants. A typical installation of sensors is shown in Figure 1. Claiming that information regarding the particle movement direction is needed for data interpretation, the PSU team has installed sensors in orthogonal pairs in close proximity at the expense of a larger coverage area.

Seismic sources were generated by either detonating a blasting cap or small explosives in holes drilled into the pillar rib. Mechanical seismic sources were ruled out based on the result of laboratory tests. Tapping near each sensor was used to check the performance of each sensor.

The recorded signal was processed using a technique called Garbo wavelet transform. A typical result of the wave transform is shown in Figure 2. The travel distance was plotted with information from the source and sensor locations. The plotting usually results in multiple ellipses near or at the reflection boundary.

Site No. 1: UAE Coalcorp Associates' Harmony Mine

The PSU team conducted field tests on November 15, 2005, February 7-8, 2006, and April 29, 2006. The site for the first field test was conducted along a 60-foot-wide barrier pillar, while the second and third tests were conducted along a 150-foot-wide pillar developed for the field tests. The 150-foot-wide pillar will be left to protect the main access tunnel of the mine. Figure 3 shows the location of the test sites.

The field tests demonstrated the retrievable sensor installation could record signals with a wide frequency range. The channel wave in the coal seam was detected with the data acquisition system. The system was able to detect the reflected wave at a distance of 150 feet.

Discussion of Results

The PSU team determined the void location using the elliptical location method. The location is determined by plotting multiple of ellipses without applying migration correction. Because of the sensor arrangement, the recorded wave forms show the presence of a channel wave in the frequency range of 400 to 600 Hz. Because of the irregular reflection surfaces, the data interpretation was not clear-cut. In Figure 4, two groups of ellipses were calculated using a channel wave velocity of 5,200 ft/s and represent two reflection surfaces shown in red lines. The results shown in this figure were from the April 29, 2006, field test. Confirmation drilling was not necessary at this site since the test area was fully accessible and surveyed.

Site No. 2: FMC's Trona Mine

The next series of tests was conducted at FMC's Trona Mine on March 7-8, 2005, and August 23, 2005. Transmission tests were performed at an underground shop near an area designated as the 592 South Development. Seven sensors used for the test were installed in a room driven by a boring type continuous miner (Site B in figure 6). The source of seismic energy was located at a distance of approximately 302 to 345 feet from the sensor array. The reflection tests were conducted at the 349 West Development (Site

A in figure 5). It was separated by about 260-foot-wide flooded workings. This site was used for both field tests. Because trona is stronger than the roof and floor rock of the trona bed (Bed 17), no channel wave was generated. Void detection was achieved by determining the arrival time of reflected P- and S-waves.

Discussion of Results

The propagation velocity of the P-wave in the trona was determined to be 16,777 ft/s, while that of the S-wave was 8,572 ft/s. The tested signals contained high frequencies in the range of 3,000 to 5,000 Hz. The data acquisition system was able to pick up these signals.

The signals used to detect the mine void are the reflected P- and S-wave signals. The data analysis is somewhat compounded by presence of push-ins in the development entries as well as by the flooded workings. An example of the ellipses calculated based on the travel distances is presented in Figure 6. No attempt was made to confirm the test results since the flooded workings had already been accurately mapped by the company.

Site 3: General Chemical's Trona Mine

On March 9 to 10, 2005, the project team conducted field tests at General Chemical's mine. The test site, shown in Figure 8, is one of barriers left to support the I-80 highway. The barrier pillar was approximately 340 feet wide. The sensors were installed in seven pairs. The test site has push-ins at the sensor installation site as well as the reflection site. However, the sites are parallel to each other so it was not necessary to perform a migration correction.

The seismic sources used for the tests consisted of blasting caps and a small amount of explosives, usually 1 to 3 inches long. The sampling rate and the recording time window for the tests were 25,000 samples per second and 0.8 seconds, respectively.

Discussion of Results

The test results from General Chemical's mine are similar to those from FMC's mine. These mines are adjacent and operate in Trona Bed No. 17. The measured P- and S-wave velocities are 16,740 ft/s and 8,754 ft/s, respectively, for the mine. The recorded wave forms are similar to those obtained from FMC's mine in terms of characteristics of transmitted and reflected signals. The team did not find any difference in characteristics of signals reflected from a water-filled void versus an air-filled void. A void mapped using the ellipse method is shown in Figure 8. The red line in the figure is the reflection boundary of waves. Confirmation drilling was not necessary at this site, since the test area was fully accessible and surveyed.

Site 4: RoxCoal's Agustus Mine

Another field test was performed at Agustus Mine, a bituminous coal mine in Somerset County, in central Pennsylvania. The mine recovers coal from the Upper Kittanning coal seam using a room and pillar mining method. The seam is about 48 inches thick with roof and floor consisting of shale.

On December 8, 2005, transmission tests were conducted at a pillar developed in preparation of confirmation drilling to locate an abandoned coal mine. Reflection tests were conducted from the 1 Right Development near the abandoned mine. The 1 Right Development section has push-ins and the abandoned mine has two protruding entries toward the 1 Right Development section. Sensors were located near the protruding entries which is 270 feet away. The location of test sites is shown in Figure 9.

The seismic source for the transmission tests was a blasting cap without explosives. In addition to blasting caps, 375 grams of permissible explosive was used to generate seismic source for the reflection tests.

Discussion of Results

The channel wave at the test site propagated with a velocity of approximately 3,300 ft/s with dominant frequency of 200 Hz. However, Dr. Ge stated that air shock waves which had large amplitudes and long durations overshadowed the arrival of reflected channel waves. Thus, no void was detected during the tests.

CONCLUSIONS

The work in Phase 1 has been partially successful in detecting mine voids. Reflected waves from mine voids were detected at the anthracite and trona mines. However, the elliptical mapping technique used by the team needs further refinement to predict the location of voids more precisely. Although the project team claims an accuracy of ±10′ for these tests, MSHA could not fully confirm this precision based solely on the test data. Additional testing is being performed at bituminous coal mines in conjunction with Phase II of the project, which will hopefully shed additional light on the issue of the accuracy of the method.

If you have any questions, please contact me.

Attachment

cc: M. Hoch – Chief, PS&HTC

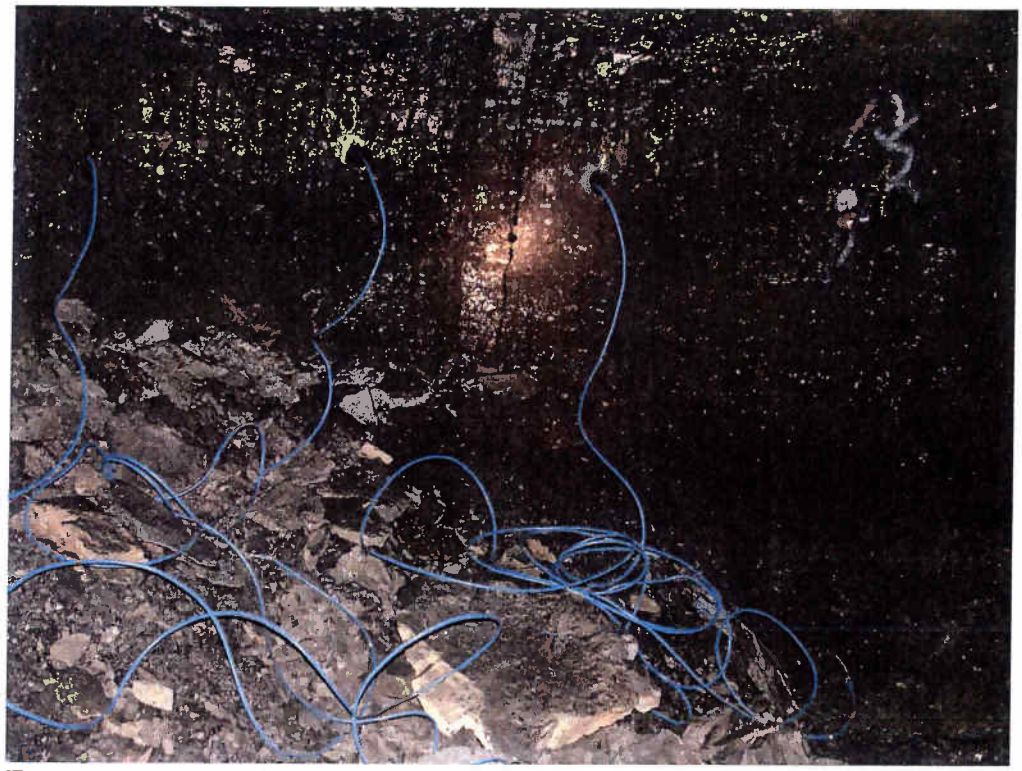

Figure 1: Sensors installed in a coal seam.

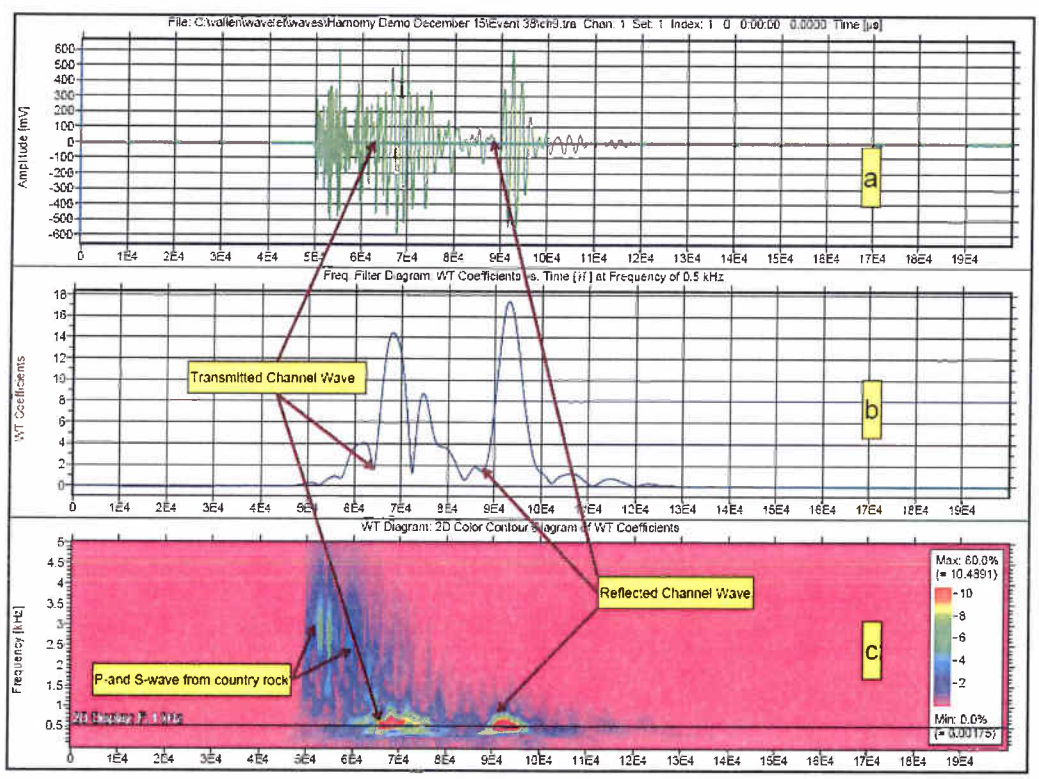

Figure 2: Garbo wavelet transform of a wave train.

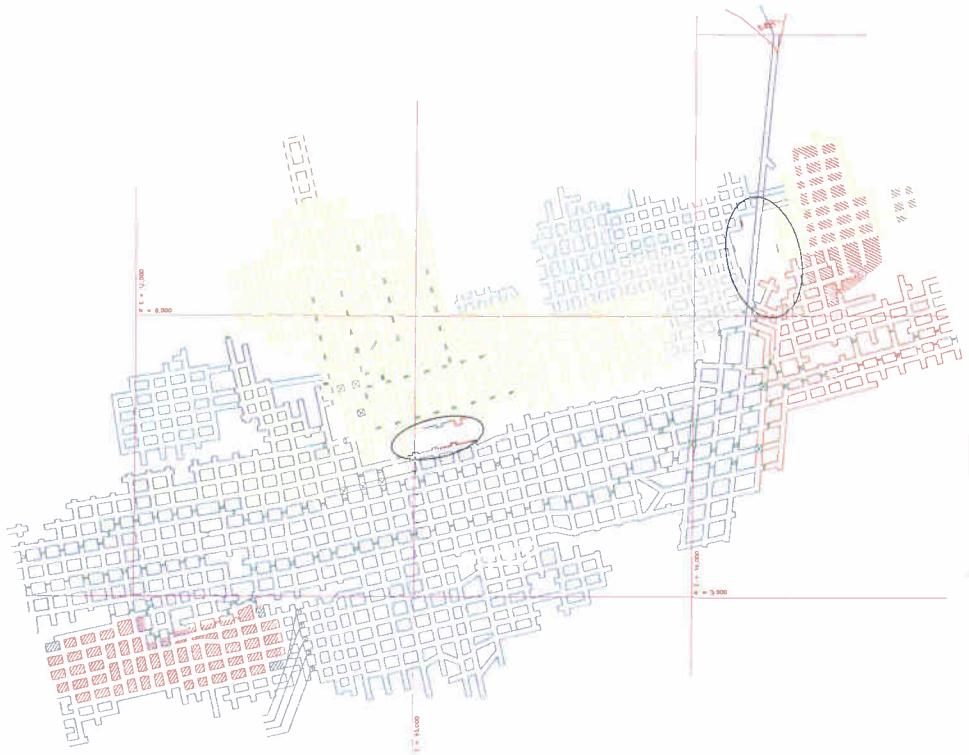

Figure 3: Test sites at the Harmony Mine.

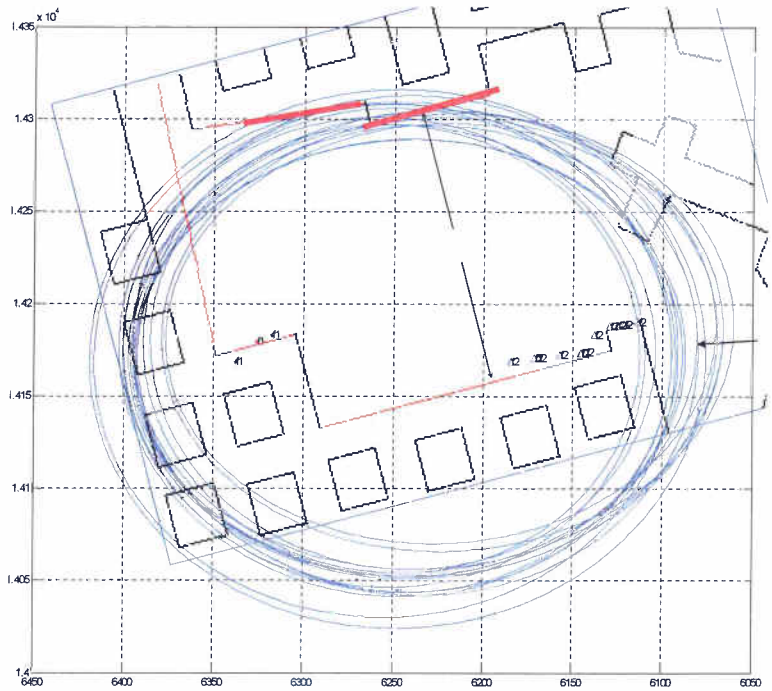

Figure 4: Void located by the ellipse method.

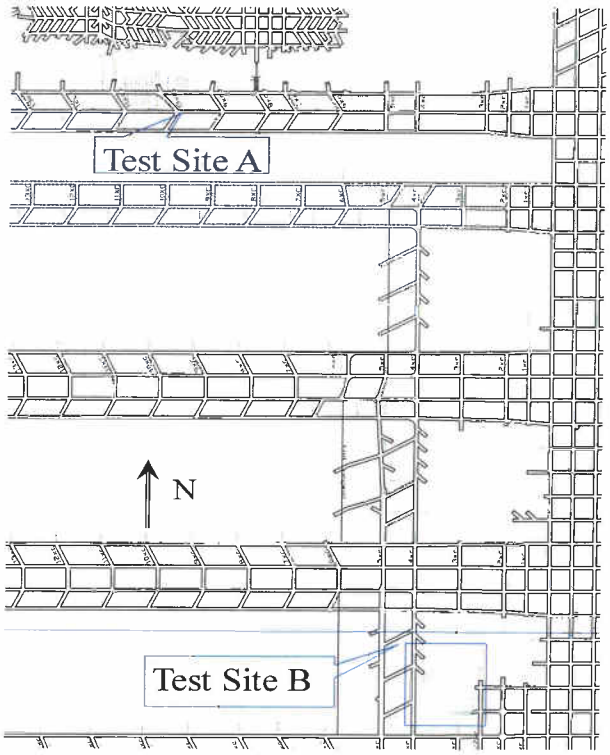

Figure 5: Location of test sites at FMC's Mine.

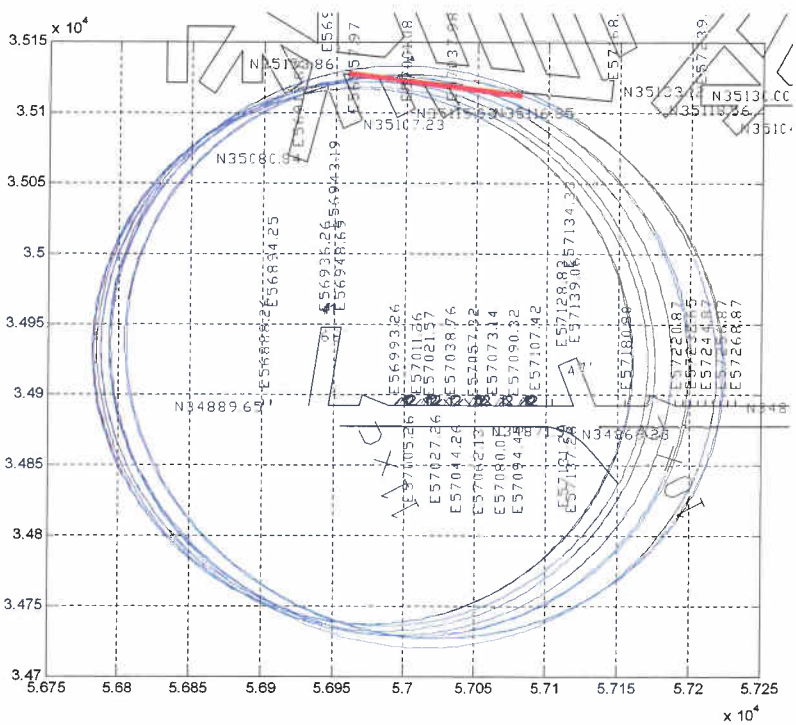

Figure 6: Void mapped using ellipses at FMC's Mine.

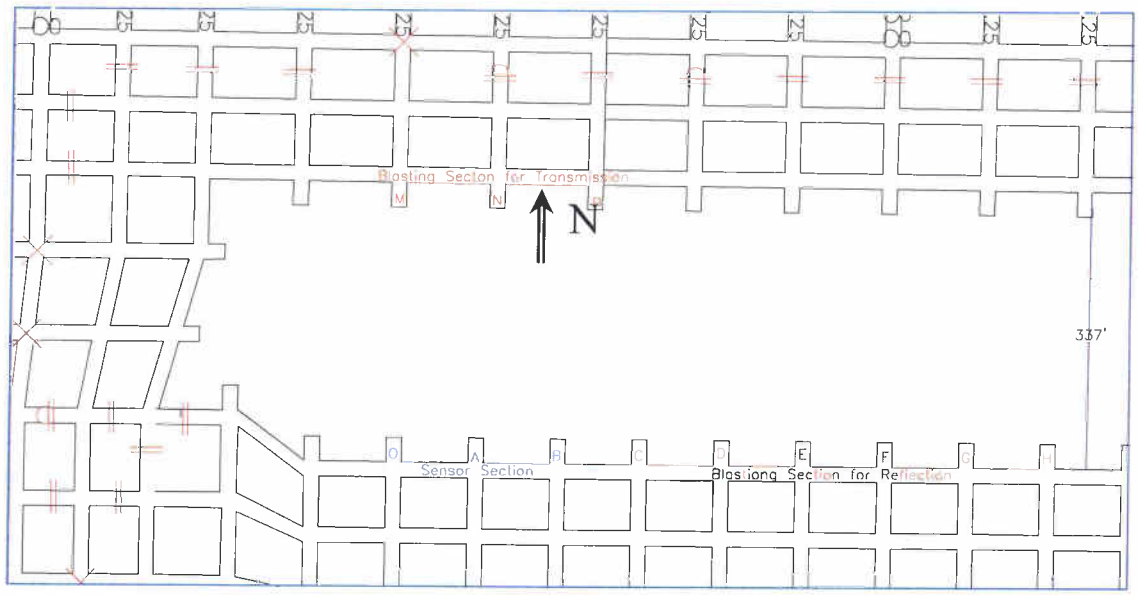

Figure 7: Test site at General Chemical's Mine.

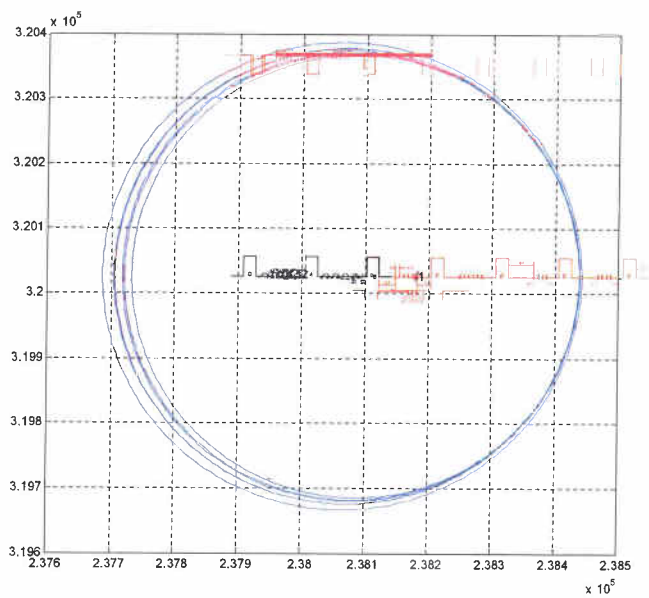

Figure 8: Void mapped using ellipses at the General Chemical's Mine.

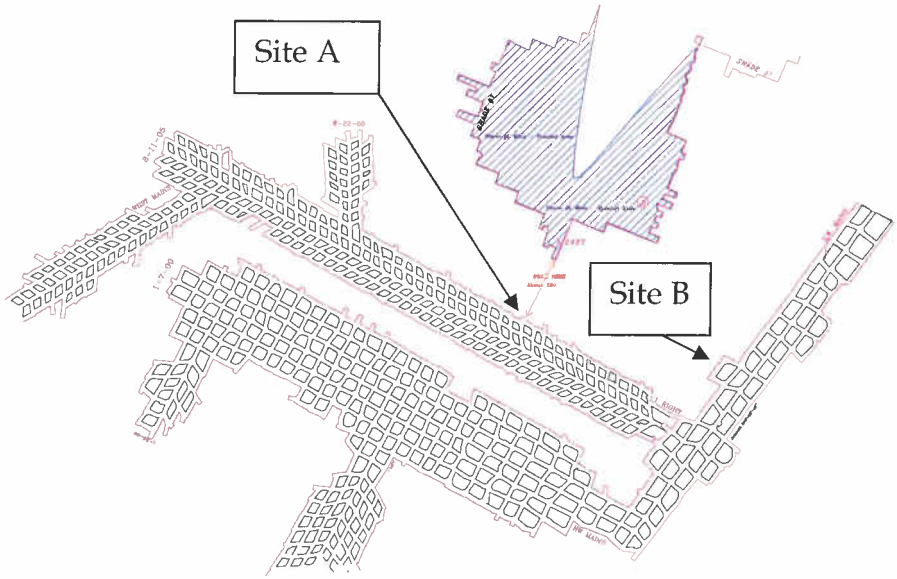

Figure 9: Test sites at the Agustus Mine.