Borehole Camera Aides Colorado Subsidence Investigation

By Al Amundson

The Country Club Circle (CCC) Colorado Springs neighborhood is underlain by the abandoned Rapson Coal mine, which was worked from 1900 to 1915 prior to residential development. Through the years, numerous subsidence events have repeatedly occurred, causing serious safety hazards and damaging structures, streets, and utilities. Considerable subsidence mitigation work has occurred during the past several years as sinkholes have propagated to the surface.

The shallow mine workings lying 50 to 100 ft beneath the neighborhood continue to subside, causing damage and posing serious hazards to the public and homeowners. Some of the undermined areas experienced several inches of differential settlement, while sinkholes with dimensions of up to 12 ft in diameter and 12 ft in depth can still occasionally occur, as shown on Figure 1.

Figure 1 – Sinkhole Development and Mitigation in Residential Neighborhood, Colorado Springs

As a result of continuing subsidence issues, the Colorado Division of Reclamation, Mining and Safety (CDRMS) issued a request for proposals to evaluate the CCC neighborhood using geophysical methods to delineate subsurface voids, and develop a more refined understanding of the condition of the mine workings under the subdivision. Zapata Incorporated, Blackhawk Division (ZAPATA) was selected through the RFP process to perform the work using multiple advanced geophysical technologies.

Geophysical investigations began in August 2008 using a multi-channel analysis of surface waves (MASW) technique characterizing the shallow subsurface ground conditions. This was followed by reconnaissance drilling to evaluate the MASW geophysical anomalies and prepare for the deployment of the reverse vertical seismic profiling (RVSP). The RVSP was used to detail the location of mine workings (void/rubble/pillar). Tethered robotic tools (laser, video camera, sonar) were used, to provide images of mine workings. The crosshole seismic tomography (XHT) technique was used to evaluate the ground modification treatment.

RVSP – Data Interpretation. Figure 2 shows the interpreted RVSP section obtained at borehole CCC3. Borehole CCC3 encountered coal at a depth from 99.5 to 104 ft bgs, so the position of the reflection event corresponding to this level is easily located. The extent of the interpreted void/rubble is highlighted in yellow, while the dark blue shows the interpreted solid coal (pillar). The RVSP data results were then used to focus the subsequent borings and to align the historic mine map. Borehole CCC5 was located approximately 13 ft away from borehole CCC3 along the northwest RVSP line. This borehole confirmed the presence of the void/rubble zone at a depth of 88 to 101 ft bgs.

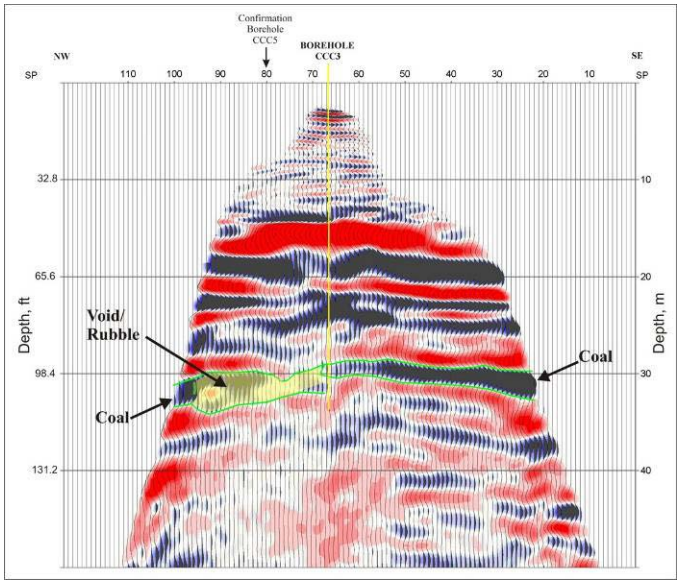

Figure 2 – RVSP Data Interpretation

Borehole CCC13, shown in Fig. 3 is the second of the two surveyed voids which occur at a depth of 54.0 to 61.0 ft bgs within the borehole. The laser survey was performed in an adjacent room, extending off from the main haulageway discovered in CCC6. The resulting image confirms the location of several pillars in the mine workings seen in the scan from CCC6. The 3-D image contributes considerably to the understandings of the mine workings and their alignment.

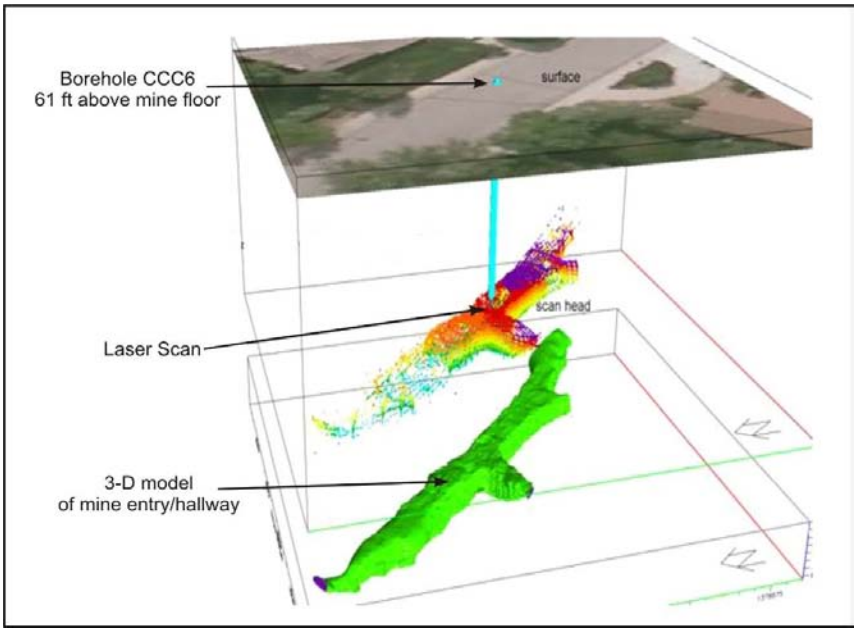

Figure 3 – Laser 3-D Model of Haulageway and Cross-cuts

Ground Modification Treatment

DRMS applied two ground stabilization techniques using foamed sand slurry and low mobility grouting (LMG) to eliminate or reduce subsidence hazards at the CCC neighborhood. In the event of large voids, a foam sand transport method was used. In areas of small discontinuous voids or rubble, compaction grouting was used to support and stabilize the surface overlying these areas.

Figure 4 – Foamed Sand Slury Injection

Hayward Baker was the successful contractor, and they began project work on March 28, 2009. A total of 8 houses were grouted using compaction grouting techniques and pressures ranging from 600 psi at the bottom of the hole, down to 200 psi near the top of the hole. The area under each house accepted from 206 cubic yards to 455 cubic yards for an average of approximately 348 cubic yards per house, costs ranging from $40,000 to $83,000, for an average cost per house of $66,600.00.

As part of the geophysical investigation, a void approximately 230 feet long, 10 feet wide and 6 feet high was discovered under the street, Country Club Circle (see Figures 3 and 5). Upon investigation with Laser survey and a borehole video camera, this void was determined to be an intact main entry, dating back to around 1901 or 1902. This wide open mine void was determined to be an ideal location to evaluate the foamed sand slurry method. Prior to injecting foamed sand slurry into the void, the geophysical contractor, Blackhawk Geophysical conducted a series of cross-hole tomography scans to evaluate the void.

Hayward Baker utilized foam reagents developed and supplied by Cellular Concrete. The foam is mixed with sand in this case, in a transit mixer (concrete mixer truck) where the foam takes the place of water, making the sand act similar to sand-and-water slurry. The sand was delivered to the site in transit mixers in six cubic yard loads, where approximately three cubic yards of foam was mixed and dropped by gravity down the four inch casing. Progress was monitored from approximately 50 feet away using the OSM borehole camera; as the sand filled the void and flowed like water. The foamed sand slurry filled the void to about half the quantity estimated by the laser scan, approximately 267 cubic yards of sand.

Following the foamed sand slurry placement, another series of cross-hole tomography scans was conducted. After waiting a few weeks to see if the sand would settle, another borehole was drilled and cased for grouting and approximately 299 cubic yards of grout was pumped into the sand-filled void through a borehole located 10 feet to the west of the foamed sand slurry borehole. No grout was seen at the monitoring hole which was located approximately 40 feet from the grout hole where the sand was seen flowing. This was extremely interesting, and likely explained by the difference in pressure between the foamed sand slurry at gravity pressure, versus the grout placed at pressures up to 400 psi to 500 psi. The greater pressure exerted by the grout likely pushed aside rubble or a ventilation stopping in a crosscut to allow grout to flow into

the other parallel main entry. Following two weeks of curing time, the grouted and foamed sand slurry filled void was again scanned using cross-hole tomography. The cross-hole tomography showed minor increases in velocity, indicating an increase in density of the sand and grout fill.

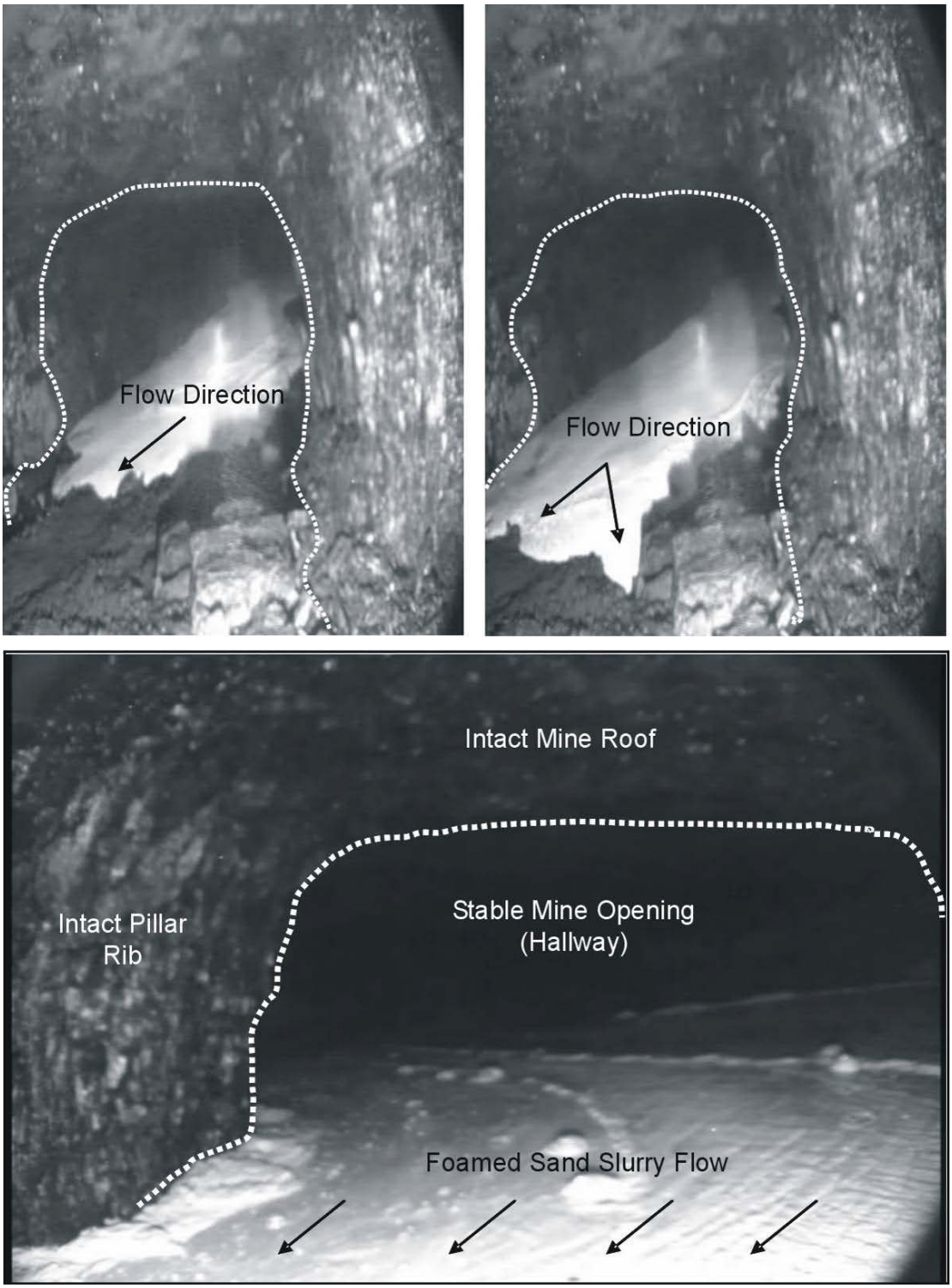

Figure 5 – Video Images in Borehole CCC13 During Foamed Sand Injection in Borehole CCC6