International Journal of Mining Science and Technology 27 (2017) 65–69

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Ground control monitoring of retreat room–and–pillar mine in Central Appalachia

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ARTICLE INFO

Article history:
Received 15 May 2016
Received in revised form 18 August 2016
Accepted 28 September 2016
Available online 9 December 2016

Keywords:
Retreat mining
Stress measurement
Microseismic monitoring
Pillar stability

ABSTRACT

In order to study pillar and overburden response to retreat mining, a ground control program was conducted at a Central Appalachian Mine. The program consisted of several monitoring methods including a seismic monitoring system, borehole pressure cells in the pillars, and time-lapse photogrammetry of the pillar ribs. Two parallel geophone arrays were installed, one on each side of the panel with the sensors mounted 3 m into the roof. A total of fourteen geophones recorded more than 5000 events during the panel retreat. A MIDAS datalogger was used to record pressure from borehole pressure cells (BPCs) located in two adjacent pillars that were not mined during retreat. A series of photographs were taken of the pillars that had the BPCs as the face approached so that deformation of the entire rib could be monitored using photogrammetry. Results showed that pillar stability and cave development were as expected. The BPCs showed an increase in loading when the face was 115 m inby and a clear onset of the forward abutment at 30 m. The photogrammetry results displayed pillar deformation corresponding to the increased loading. The microseismic monitoring results showed the overburden caving inby the face, again as expected. The significance of these results lies in two points, (1) we can quantify the safe manner in which this mine is conducting retreating operations, and (2) we can use volumetric technologies (photogrammetry and microseismic) to monitor entire volumes of the mine in addition to the traditional point-location geotechnical measurements (BPCs).

1. Introduction and background

Excavation of underground openings is a difficult job in a challenging environment. The rigor of the process is compounded by the lack of a method that allows quantification of changes within the rock mass as excavation progresses. Statistics kept by the Department of Labor, Mine Safety and Health Administration show that 16% of fatalities and lost time incidents in the underground mining industry are due to unexpected rock mass failure [1]. A recent example is the Crandall Canyon, Utah, coal mine accident caused by the vertical collapse of a longwall coal mine on August 6, 2007 [2].

Point-location measurements of deformation and change in stress form the basis for understanding ground control. There are several recent examples of the use of point-location geotechnical measurements in underground coal mines. Oyler et al. provided an excellent description of several case studies of point-location geotechnical measurements including vibrating wire stress cells used to show stress change in longwall panels and abutment pillars as the face retreated and extensometers reporting roof deformation [3]. Another example documents closure meters and borehole pressure cells being used to monitor load and deformation associated with pre-driven recovery rooms at a longwall mine [4]. Finally, the ground and tailgate support interaction was quantified at two longwall mines using instrumented tailgate supports so that numerical models could be calibrated. These numerical models provided the means for calculating the ground reaction curve [5].

Laser scanning of underground openings can provide relative measurements of convergence over much of an underground mine. This method has become more commonly used in the past decade. Huber and Vandapel reported on a demonstration of scanning an underground coal mine for mapping accuracy [6]. The information can be used to increase the accuracy of maps for active or abandoned mines. Building on this, an autonomous mobile robot has been developed to provide a 3D volumetric map of underground mines [7]. Finally, convergence measurements in an underground potash mine have also been mapped with laser scanning [8,9].

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http://dx.doi.org/10.1016/j.ijmst.2016.11.008
2095-2686/

One of the great challenges in the field of rock mechanics is imaging and understanding stress redistribution resulting from human activity. Seismic monitoring can be used to track changing conditions within a rock mass by monitoring the occurrence of mining-induced fracturing near the face. As the earth is perturbed by the excavation process, stress redistribution results in failure along new and/or previously existing faults or joints. The seismic energy produced by these relatively small failures is termed "induced seismicity" and typically has a local magnitude (M) between −3 and 2 [10].

An integrated suite of monitoring methods at a retreat room-and-pillar mine under 300 m of cover showed that pillar stability and cave development were progressing safely. Also, new methods offer additional insight into ground control conditions.

2. Methods and procedures

Ground monitoring instrumentation was installed in a retreat room-and-pillar mine in Central Appalachia. Cover depth above the monitored panel varied from 200 m to more than 300 m as shown in Fig. 1. Additionally, the immediate roof varied from a shale to a sandy shale with two sandstone channels in the panel. There were seven entries in the panel, and the row of pillars nearest to the subsequent panel was left unmined. When retreating, a slabbing cut is taken from the barrier pillar that separates the current panel from the previously mined panel. The panel was the fourth panel in its section to be mined, so there were three previously mined panels on one side of the monitored panel but no mining or development on the other side. The panel was retreated over a two-month period at a typical rate of one row per every day of production.

As noted in Fig. 1, solid line is 300 m cover depth contour and dashed line is 200 m cover contour and tan areas are location of sandstone channels.

The instrumentation installed at the mine included borehole pressure cells in two adjacent pillars. Pressure cells were installed at the midpoint of each pillar. The cells were grouted in place and initially pressurized to 10.3 MPa. The pressure transducers were wired into a MIDAS data acquisition unit, which is MSHA-approved for use in return air [11]. The pressure readings were written to the memory card in the MIDAS unit every two hours, and all data were downloaded via wireless transmission every two weeks.

The photogrammetry procedure was straightforward. A pillar was photographed using a Sony CyberShot camera when the face was 12 rows inby and then again when the face was 3 rows inby the pillar of interest. The process included starting at the stopping in one crosscut, moving along the entry around the pillar, and finishing at the stopping in the opposite crosscut. A straight-line method was used to photograph the pillar, in which photos were taken at regular intervals with the camera directed orthogonal to the pillar. The interval distance should allow for each photo to overlap the previous photo by 1/3–2/3 so as to capture features of the pillar in multiple photos. At each interval, three photos were taken: one orthogonal to the pillar to capture the full rib, one angled upward to include the roof, and the last one angled downward to include the floor. This process was repeated until the pillar-seal border was met at the next crosscut.

A three-dimensional point cloud of the pillar's exterior was created from the collection of pillar photos using a free software program, Autodesk 123D Catch. The program was then used to export the point cloud as a three-dimensional surface mesh. Two surface mesh models were created, one representing the pillars during November 30 and another during December 11. The models were then imported into another free software program, MeshLab, for scaling, alignment, and mesh difference measurement. The pillar meshes were scaled to the dimensions of the rib bolt pans supporting the pillar, which were 46 cm across. The two meshes were then overlapped so that any displacement over the twelve-day span could be measured. This required that the meshes were oriented so that identical locations on the pillar were overlapped. However, if the reference locations were displaced due to stress redistribution, this could have caused an unwanted error along the rest of the pillar. The rib bolts were used as the reference points for the surface meshes, because it was assumed that the bolts would be displaced significantly less than the coal around them. The distance between the scaled, aligned meshes was then found by using the Hausdorff distance sampling tool in MeshLab. The color quality tool was then used to create a color scale for the sampled points generated by the Hausdorff distance to show the displacement of the pillar over the twelve-day span.

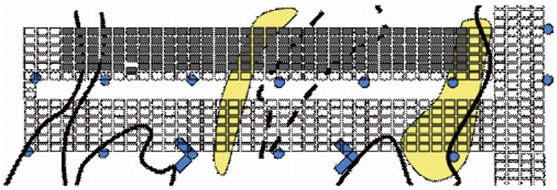

Fig. 1. Panel layout and geophone locations.

Two arrays of geophones were installed 3 m into the roof at approximately 100 m intervals for microseismic monitoring. One array, consisting of six uniaxial geophones was located in the previously-mined panel, while the second array, consisting of four uniaxial geophones and two triaxial geophones, was located in the current panel. An additional two geophones were located in the main entry (Fig. 1). The uniaxial geophones were placed in 3.2 cm diameter holes, while the triaxial geophones were placed in 5.7 cm diameter holes. Intrinsic safety barriers allowed the geophones to be installed in return air, while the data collection was near the power center near the main entries. Cable was strung from the geophones to the data collection center and hung from the roof. The system recorded continuously, and the data files were transferred from the underground location to a surface hard drive every three days.

When processing the seismic records to determine event locations, a uniform velocity was assumed and a simplex location method was used. It is preferred to conduct calibration events so that a correct velocity model is used when processing the data. In this study a calibration event from the surface above the mine was conducted; however, it was later determined that on the day the calibration was conducted the seismic system was not receiving power and so did not record data. Additionally, event locations would be the most precise if a velocity model was used that included the low-velocity caved zone retreating with the face on a daily basis.

3. Results and discussion

Borehole pressure cells, photogrammetry, and microseismic monitoring were used to monitor response to retreat mining. Results of the BPC monitoring are shown in Fig. 2. Pressures at three specific face locations are highlighted. They are when the face is: four pillar rows inby, two pillar rows inby, and at the monitored location. The results from the further inby pillar show a small increase in pressure cell readings of approximately 0.7 MPa when the face is three rows inby, followed by another 0.7 MPa when the face is one row inby, and then an increase of 3.5 MPa when the face moves one row outby the monitored pillar. Results