Real-Time Monitoring of Field Measurements for Mine Design: Greens Creek Mine, Admiralty Island, Alaska
U.S. Department of the Interior
Mission Statement

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Real-Time Monitoring of Field Measurements for Mine Design: Greens Creek Mine, Admiralty Island, Alaska

By T. J. Orr and M. J. Beus
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### Metric Units

<table>
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### U.S. Customary Units

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REAL-TIME MONITORING OF FIELD MEASUREMENTS FOR MINE DESIGN:
GREENS CREEK MINE, ADMIRALTY ISLAND, ALASKA

By T. J. Orr¹ and M. J. Baue²

ABSTRACT

Researchers at the U.S. Bureau of Mines conducted field investigations at the Greens Creek Mine in southeast Alaska for the purpose of validating computer design of mining methods and assessing real-time monitoring capabilities. The field study required the application of new technology because of the remoteness of the study site, the need for timely acquisition of data, and a limited budget for instruments and data acquisition. Various sensors were installed to monitor rock mass deformation and strain, temperature, SO₂ gas emissions, and blasting. Data were collected through a distributed personal computer network and high-speed modems. These readings were used to develop visualization models of underground metal mining operations and drift-and-fill mining and real-time graphics displays of ground conditions. Results of the field tests showed that it is possible to gather, process, visualize, and verify mine designs on a real-time basis.

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INTRODUCTION

Utilization of mineral resources is contingent upon the development of methods to recover deposits under strict environmental constraints and often in remote locations. Of increasing public concern is the effect of mining on pristine environments. Underground mining alleviates many environmental concerns. Mining methods that enhance ground control and ground-conditioning operations are a primary consideration; the choice of method affects both mineral recovery and amount of disturbance to an ecosystem. These are key considerations in remote regions because of the high cost of mining and mineral transport and the potential for damage to a fragile, pristine environment.

The design and development of underground mining methods and a mining infrastructure that minimizes environmental damage are of crucial importance. Verifiable design procedures for controlling mine openings are, therefore, important aspects of overall mine design. The most direct approach is to compare analytical results derived from computer models with actual field measurements. However, uncertainties arise when establishing "fixed conditions" for computer models, i.e., initial boundary loads and material properties. Conversely, a high level of confidence can be given to rock mass displacement measurements. The accuracy of sensors and data acquisition systems can, in most cases, be traced to a recognized standard. Therefore, if statistical significance can be established between calculated and measured values, a model can be deemed validated, and one can have confidence in further conceptual design studies. If movement of a rock mass is controlled by time-dependent functions or geologic structure or both, then long-term field-based data are also needed to verify analytical results.

In addition, because increases in productivity are needed to sustain a domestic metal mining industry, ground control can be expected to be a greater problem. That is, an increase in extraction rates results in rapid changes in stress, creating ground control problems where none previously existed. Large-scale pillar collapse and failure, rock bursts, and creeping ground can be especially severe, causing death, injury, and/or environmental damage. Other changes will be a decrease in the ability of operating personnel to detect hazardous conditions in a timely manner. Therefore, economical and reliable sensors and data-collection hardware and software, user-friendly interfaces, and easily interpreted real-time data displays are important.

Research by the U.S. Bureau of Mines (USBM) focused on developing basic ground-condition sensors and integrating them in a comprehensive geosensing network. Monitoring both instantaneous and long-term rock movement forms the backbone of the present system. Sensors are configured to record movement and are triggered by displacement alarm levels and excavation-induced vibrations. Ultimate objectives are to validate computer models with an in-mine, real-time monitoring system that is cheap, simple, fast to install, and durable.

SITE DESCRIPTION

This study was conducted at the Greens Creek Mine, which is located approximately 29 km (18 miles) southwest of Juneau, AK, on Admiralty Island (figure 1). It is considered to be a volcanogenic-hosted massive-sulfide (VMS)-type deposit and is geologically similar to a large number of ore bodies in southeast Alaska and coastal British Columbia. The main access is by an adit driven into the hillside to a maximum depth of about 760 m (2,500 ft). Figure 2 shows the 920 portal with Greens Creek in the foreground. Presently, the mine has been developed on two levels: the main haulage level at 280 m (920 ft) above sea level and an access level at 410 m (1,350 ft), which is used for return ventilation. Depending primarily on thickness and dip, mining methods are cut-and-fill, drift-and-fill, or room-and-pillar. The surface topography has considerable relief and is covered with loose organic material; these conditions, coupled with high precipitation in the area, results in fairly precarious hillside.

The ore body is a high-grade sulfide deposit containing significant amounts of silver, gold, lead, and zinc, and minor amounts of copper. According to company reports, the vein is very complex and difficult to characterize. The hanging wall is mainly composed of a series of tuffites of average strength and foliation that parallels the ore body. The ore is generally very competent and stronger than the host rock and consists of two types of massive sulfides: "white" ore and "black" ore. Approximately 50 pct of the east ore body is less than 10 m (33 ft) thick. The footwall consists mostly of argillites and varies from incompetent to moderately strong and competent. The country rock, particularly the argillites, tends to have more stability problems because of foliation created during folding. The 5- to 45-cm (2- to 18-in) thick hanging wall argillites are far more competent than the footwall argillites, which often have graphite layers that create slip planes. Some areas of the hanging wall contain very weak, greasy chloritic serpentine. The ore body dips from vertical to horizontal with most of the ore body lying at angles below 30°. Figure 3 shows the instrumentation site (circled) at section 28 and the mine development and ramp system.
SYSTEM DESCRIPTION

The approach taken in this field study involved application of new technology to mine monitoring. The major advance in this project was a data acquisition and processor system that collected and processed data in real time. Earlier mine monitoring systems have often not met requirements for cost effectiveness, sensor diversity, simplicity, and ruggedness and have not been able to withstand the rigors of underground, long-term, unattended operation. The USBM has done extensive work in developing mine-ready sensors and computerized data acquisition systems for coal and metal mines and packaging them for protection from harsh mine environments. Based on many years of in-mine testing and experience, unique combinations of cost-effective hardware have evolved for metal and nonmetal mines. A "factory floor" personal computer (PC) in a NEMA IV box has been adapted for use underground. The present configuration is a 80486 motherboard (arrow in figure 4) mounted in a stainless steel box containing an air-to-air heat exchanger.

An interface card installed in the PC provides up to 600 channels for data collection or mine process control. Up to four interface cards may be installed for a total of 2,400 channels. A serial port on the card is used for bidirectional communication with isolated measurement pods (IMP's) developed by Schlumberger, Inc., Tulsa, OK. IMP's are multi-channel, remote measurement and output devices to which sensors are connected. This system uses a wide variety of sensors to provide input-output (I/O), signal conditioning, and analog-to-digital conversion with scanning rates up to 18 times every second. Voltage, current, resistance, temperature, and most configurations of strain bridges can be incorporated. The IMP's are inherently protected from the environment and require no further packaging, although they often are stacked in a larger enclosure with a power supply and connector blocks. The network (S-Net) can extend in a parallel configuration up to 1 km (0.6 mile) in either direction from the PC; this distance can be increased in 1-km (0.6-mile) increments with S-Net repeaters. Communication to the overall system for data retrieval and system maintenance is via shorthaul and high-speed (9600 baud) modems. Figure 5 shows the overall layout for the system as currently installed in the mine.

The data acquisition and processor system is also packaged to protect it from the harsh mine environment. In-mine sensors were repackaged to survive underground conditions and mining operations, including limited access and cramped space; hot, humid, and corrosive atmospheres; water and falling rock and debris; and shock loads from blasting. In addition to durability, sensor design has emphasized cost effectiveness and simplicity and speed of installation. The current design uses linear or rotary potentiometers linked to four or five individually anchored sensing positions distributed down the length of a borehole. The mechanically anchored mounting head allows the potentiometer head to be adjusted in the hole to accommodate a large range of rock movement. In addition, the potentiometer head is recoverable when monitoring is no longer required at that site.

Considerable research has been done in developing and testing procedures for processing and visualizing output from ground-condition sensors. For the results to be useful, the data must be available in real time. Real time has been defined in a broad sense as the "amount of time sufficient to make decisions." Real-time monitoring depends on the scope of the process being controlled. For example, during the monitoring of ground movement during mining, mining operators make decisions daily. Therefore, the data must be available within minutes or hours of the activity. Figure 6 shows the location and orientation of multipoint borehole extensometers (MPBX's) on section 28 displayed as a real-time monitoring screen of ground movement.

The key to real-time operation is the processing and communication software. PC-based DOS software has been used exclusively because it is widely available and because there are large numbers of experienced users. The applications work in both the background and the foreground and as subroutines to general purpose communication and spreadsheet programs. The core of the software chosen for this task was Real-Time Multitasking (RTM), a data acquisition and process control package running under DOS and Microsoft Windows. This program allows data to be displayed in a variety of formats, including row-by-column spreadsheets, bar graphs, trend graphs, and alarm summaries. The coprocessor can be left operating in the background, which permits other programs, such as communications or plotting packages, to be operated in the foreground.

Several commercially available communication programs have been tested to allow access to the underground PC from a remote computer on the surface. The communication software is installed in the PC and loaded into high memory using a DOS memory manager. The RTM software is then executed normally. When a connection is made, operators on the surface see a copy of the display from the data acquisition system. Keyboard commands entered on the surface computer are treated as though they were typed on the underground computer. Operators can display or transfer data from any of the system sensors from a remote computer on the surface or from any other location that has adequate telephone access.

approach

The locations of sensors used at the Greens Creek Mine to monitor rock mass deformation and strain, temperature, and blasting are shown in figure 6. MPBX’s E1, E2, and E3 were installed in 15-m (50-ft) long boreholes positioned vertically, normal to the vein, and horizontally, respectively, in the hanging wall of the 29 incline accessway.

Movement across the 29 incline access to the ore body was monitored with a string potentiometer connected to the hanging wall at E4. A data scan is triggered when displacement magnitude exceeds a preset value. A geophone monitored rock movement. Temperature detectors provide an indication of overall system reliability and also show significant changes that might affect sensor response. Tables 1 and 2 show IMP addresses, channel assignments, and other pertinent data for the sensors.

Electrochemical sulfur dioxide (SO2) sensors were purchased by the mine and connected to the USBM’s data acquisition system to detect SO2 gas emissions from blasting remotely before personnel entered the mine at the beginning of each shift. SO2 gas, a byproduct of the secondary combustion of airborne sulfide dust, is highly toxic; several mining zones and, in some cases, the entire mine, have had to be shut down until concentrations were reduced to permissible levels. These between-shift inspections required about 30 min between each of three shifts per day. Such inspections required about 1-1/2 h/day using hand-held SO2 detectors.

Seven sensors, strategically located in various places in the mine ventilation system alerted operators to elevated SO2 concentrations. By comparing concentrations detected at the sensors, the location of a SO2 emission could be determined. The sensors were connected to the USBM’s data acquisition system, which was in constant communication with a mine computer located in the mine office. Sensor data were displayed in real time on a computer screen in the form of a strip chart, which eliminated the need for dangerous manual inspections and lost production time. A data plot for SO2 concentrations at two locations is shown in figure 7.

The location, orientation, depth, and size of MPBX installation holes were predetermined by using existing drill holes and preliminary structural analyses (figure 6). Figure 8 shows an adjustable and recoverable MPBX being installed into a borehole oriented across the vein at the 28 cross section. E4 was placed in a 27-m (90-ft) long borehole aligned normal to the hanging wall and extended downward across the vein and 3 m (10 ft) into the footwall. The platinum resistance temperature detector was located at the collar of E2.

The geophone was installed on a rock anchor in the back over the drill station to monitor blasting and trigger an accelerated data scan. The string pot was attached to the E4 anchor head and is periodically extended manually to the E2 anchor head to measure change across the incline.

<table>
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<tr>
<th>IMP address</th>
<th>Input channel</th>
<th>Instrument name</th>
<th>Display slot</th>
<th>Display low, cm</th>
<th>Display high, cm</th>
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Table 2.—Calibration data and channel assignment for IMP address 02 using chemical transducers

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<tr>
<td>26</td>
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<td>28</td>
<td>SO2-8</td>
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NOTE.—For all input channels, the display low was 0.000 ppm, the display high was 20,000 ppm, input lows were 4,000 mA, and input highs were 20,000 mA.

results

Table 1.—Calibration data and channel assignment for linear potentiometers

Figure 9 shows a temperature profile at the 29E drill station on the 28 cross section. Seasonal changes are obvious over the 600-day sampling period. This plot shows the effects of data smoothing using a moving average of 10 data points.

The initial segment (through day 400) is the complete data set as logged to the file. The data segment through day 800...
has been smoothed using a moving average, which makes determining a trend much easier.

The data have been filtered using a time-filtering routine based on an exponential smoothing function,

\[ F_{t+1} = F_t + a(A_t - F_t), \]

where \( F_t \) = forecast value at time t,
\( a = \) smoothing constant (1 - damping factor),
and \( A_t = \) actual reading at time t.

Figure 10 shows the 700-day displacement history for E1 through E4. Displacements at E1 through E3 were computed relative to the 15-m (50-ft) deep anchor position, and displacement at E4 was computed relative to the 27-m (90-ft) deep anchor position.

All MPBX's showed a direct response to excavation. E1 (figure 10A), oriented upward into the back of the 29 incline, showed an initial upward (compressive) movement of the rock mass as mining proceeded upward. As mining continued beyond and above the instrumented section, the rock mass around E1 further compressed toward the deep anchor position at 15 m (50 ft) with 5 to 10 mm (0.02 to 0.04 in) total movement before stabilizing after mining was discontinued on day 650.

E2 (figure 10B) showed greater movement and immediate closure (expansion) of the surrounding rock mass as the adjacent mining blocks extended laterally away on either side of the instrumented section. This extensometer, which was aligned normal to the vein, then gradually recovered across the null point. As new mining blocks were developed upward, closure was reversed and the rock mass tended toward compressive behavior. This flexure continued at a constant rate through day 800, at which point the trend reversed again toward an extensional movement until mining ceased. E3, which is oriented horizontally, showed very little movement beyond what might be considered background noise (figure 10C).

E4 extended from the diamond drill station in the hanging wall down across the vein and about 3 m (10 ft) into the footwall. The deep anchor position in the footwall was about 27 m (90 ft) from the extensometer head in the drill station. The borehole had been drilled only a few days before that section of the stope was to be mined. The deep anchor moved away from the head in the diamond drill station just prior to the blast in the stope. The succeeding blast destroyed the deep point on E4 (figure 10D). The 17-m (50-ft) anchor position also moved away from the hole collar as mining approached and then showed little movement as mining proceeded beyond. The plot shows the abutment load approaching the extensometer with the footwall point being displaced about 0.25 mm (0.01 in) away from the stope. The 17-m (50-ft) anchor in the hanging wall did likewise. The raw data indicate the blast pushed the rods for the 17- and 3-m (50 and 10-ft) anchors all the way into the head and overextended the potentiometers. The head unit was repositioned, but only the 15-m (5-ft) anchor was recovered. Mining of this stope was halted at day 250 for a month, and then resumed, bringing the final distance from the test site to over 55 m (180 ft).

It was of concern that mining upward on the vein could cause displacement on the inclined haulageway and instability in the footwall. However, later data showed that this situation did not occur, which supported the mining plan in effect.

**DISCUSSION**

Results from field tests show that the data acquisition and computer system improves the reliability of and increases confidence in ground control measurements. By providing real-time data regarding key operational parameters, such as mine atmosphere and ground stability, the system could improve mine productivity and decrease mining costs. Data scans can be triggered by blasting and recorded at predetermined intervals. Results can be displayed in real time with monitoring software that allows a novice user to visualize the process.

The integration of ground-condition monitoring and real-time visualization methods is important to improving mining processes. Displacements in rock can occur over a period of days, while a ventilation system needs to adapt in minutes to the changing needs of the operation. Results of field tests verify the capability to gather, process, and visualize data collected during comprehensive mine field tests on a real-time basis.

An information-gathering and decision-making tool for mine operators in which large amounts of data on the behavior of rock masses and supports in real time and in a format suitable for operator action will also improve a mine operator's capability to deal with ground control problems. Ground conditions and the overall mine environment have a direct influence on mining processes and production. With real-time monitoring, significant health, safety, and production benefits could be realized.
ACKNOWLEDGMENTS

The authors wish to acknowledge the cooperation of the management and operating personnel at the Kennecott Greens Creek Mine, particularly Jeff Earnshaw, former mine manager; Tom Albanese, general manager, who provided access to the test site; and Jim Vickery, mine engineer, who assisted with procurement and installation of instruments. Also, the assistance of technicians William Hand and Gene Stone, Spokane Research Center, USBM (retired), is sincerely appreciated.
Figure 1

Location of Greens Creek Mine on Admiralty Island, AK.
Figure 2

920 portal of Greens Creek Mine.
Mine development and ramp system.
Figure 4

Configuration of personal computer adapted for underground use. Arrow indicates PC and data acquisition computer.
Overall layout for data acquisition system and processor as currently installed in mine.
Figure 6

Computer screen showing sensor locations in section 28. Bar graphs show displacement as percentage of total.

Figure 7

Real-time monitoring screen showing concentration of SO₂ after blasting.
*Figure 8*

MPBX being installed in borehole in section 28.

*Figure 9*

Temperature profile at 29E drill station.
Figure 10

Displacement history for MPBX's. A, E1; B, E2.
Figure 10—Continued

KEY

- 1.0 m anchor
- 0.6 m anchor
- 0.3 m anchor
- 0.15 m anchor
- head

C, E3; D, E4.