

INSTALLATION OF PC-BASED SEISMIC MONITORING SYSTEMS WITH EXAMPLES FROM THE HOMESTAKE, SUNSHINE, AND LUCKY FRIDAY MINES

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ABSTRACT

Researchers from the U.S. Bureau of Mines have installed low-cost, personal-computer-based data acquisition systems to monitor mining-induced seismicity and rock mass deformation at three underground hard-rock mines: the Homestake Mine, Lead, SD; the Sunshine Mine, Osburn, ID; and the Lucky Friday Mine, Mullan, ID. The basic components of the systems include geophones, amplifiers, signal-conditioning equipment, and data acquisition hardware and software. Each system is capable of automatically recording and storing full-waveform

information from seismic events in the mine. By combining data from these systems with rock mechanics information from the mine, a modified excavation plan may minimize rock burst occurrences and may allow recovery of more resources from highly stressed ground.

The process of selecting recording devices, designing system layout, and installing the equipment are described in detail. Examples from the systems at the three mines are included.

INTRODUCTION

The seismic monitoring systems described in this paper were developed as an integral part of the U.S. Bureau of Mines' (USBM) rock-burst research program. These systems, which are referred to as macroseismic systems, are capable of digitally recording the full waveform of a seismic event. The system control is provided by a program running on a personal computer (PC), which is also used to store the waveform information from the seismic events. The digital waveform records can be used to study the characteristics of rock bursts and provide valuable information regarding the location, amount of energy

release, frequency response, and probable first-motion planes. When this information is combined with operating data and information on geologic structure, development plans can be changed to reduce the incidence of rock bursts. The components of the monitoring system and basic installation procedures are discussed in this paper. Williams and others (1995)⁴ describe the applications of macroseismic systems.

⁴Williams, T. J., C. J. Wideman, K. F. Sprenke, J. M. Girard, and T. L. Nichols. Comparison of Data from In-Mine Rock-Burst Monitoring Systems and the North Idaho Seismic Network for the Lucky Friday Mine. Paper in Proceedings: Mechanics and Mitigation of Violent Failure in Coal and Hard-Rock Mines. USBM Spec. Publ. 01, 1995, pp. 265-281.

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PC-BASED SEISMIC MONITORING EQUIPMENT

The equipment making up a PC-based seismic monitoring system can be divided into three components: geophones, wiring network, and data acquisition equipment. Appendix A gives examples of seismic monitoring systems installed by the USBM.

GEOPHONES

Geophones are transducers sensitive to seismic energy traveling through rock. As energy radiates from a seismic source, it causes motion in the rock mass. Geophones produce a signal voltage proportional to this movement when the seismic energy is sufficient to cause displacement of the mass within the geophone.

Geophones are either single axis or triaxial. Single-axis geophones are sensitive to seismic motion in one direction only, usually in the direction of the geophone's longitudinal axis. Triaxial geophones are sensitive to seismic motion on three mutually orthogonal axes. While a single-axis geophone produces one signal, a triaxial geophone produces three independent signals.

Velocity Geophones

Geophones that produce an output voltage proportional to the velocity of a rock particle are called velocity geophones. These typically consist of a coil of fine wire wound around a core, which in turn surrounds a permanent magnet suspended from a spring (figure 1A). Relative motion of the magnetic mass in the coil windings induces a voltage linearly proportional to rock particle velocity. The frequency response for velocity geophones is typically in the range of 1 to 2,500 Hz, with a resonant frequency for the mass and spring of about 10 Hz.

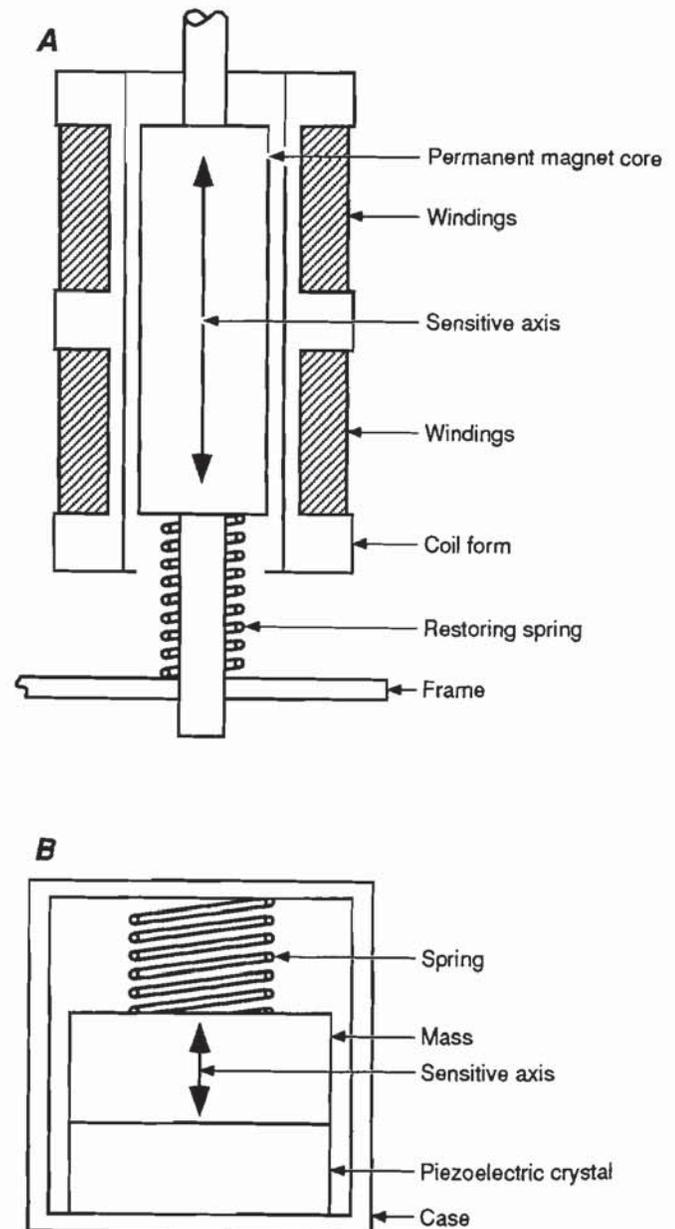
Accelerometer Geophones

Geophones that produce a voltage proportional to the acceleration of a rock particle are called accelerometer geophones or accelerometers. Accelerometers are often smaller than velocity geophones and typically employ a mass acting on a piezoelectric device to produce a signal (figure 1B). When these transducers are displaced by an incident seismic wave, the pressure exerted by the spring-loaded mass on the piezoelectric crystal produces a signal voltage proportional to particle acceleration. Accelerometers are typically dampened to have flat frequency responses in the range of 100 Hz to 10 kHz and pronounced rolloff outside this range.

Preamplifiers

The signals produced by most geophones are generally very weak and often must be transmitted long distances to a data acquisition and monitoring system. Preamplifiers

Figure 1
Inner Workings of *A*, Velocity Geophone and *B*, Accelerometer Geophone.



near the geophones are therefore required to amplify the signal to a level well above the level of any noise that may enter the transmission path. Figure 2 shows a geophone and a preamplifier.

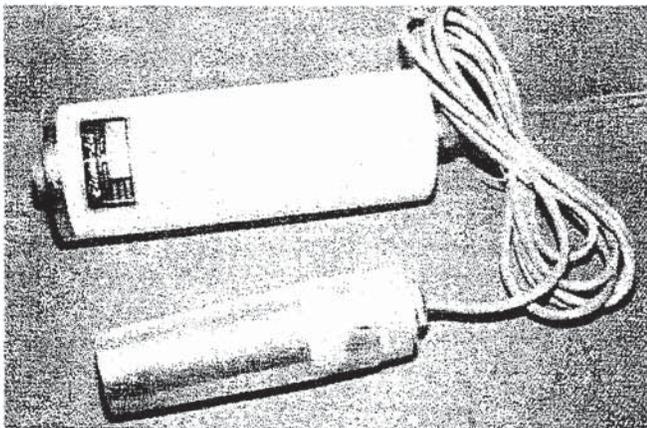
Power Supplies

The location of power supplies should be as close to the geophones and preamplifiers as practical to avoid an excessive voltage drop for signals being transmitted over long distances. Different brands of geophones have different voltage requirements. This should be taken into consideration when designing a system. Voltages not falling within the allowable range for the equipment selected may cause malfunctions, such as data loss or the generation of erroneous data.

WIRING NETWORK

Transmission of the seismic signal from the geophone or geophone-preamplifier to the data acquisition system is the function of the system's wiring network. The network consists of multipair cables and junction boxes where all connections are made. Experience has shown that whenever possible, the data acquisition system should be located on the surface. However, depending on the depth of the mine, a surface monitoring room may require an impractical amount of cable. In such cases, the monitoring system will have to be located underground.

Figure 2
Geophone With Preamplifier.



Multipair Cables

The greatest threat to the operation of an underground seismic system is water seeping into the cables, which will cause intermittent short circuits and ground loops and will allow various degrees of noise to be induced into the lines, and, in an extreme case, will cause system failure. The most common ways that water enters a cable are through nicks and cuts in the outer sheath or improperly or inadequately sealed junctions.

Use of direct-burial-type cable solves most water infiltration problems. This type of cable has been used exclusively for all new cable installed in USBM seismic systems in recent years. The cable features a tough polyethylene outer sheath, a flexible aluminum foil shield, and color-coded copper wires that are completely surrounded by waterproof gel. Even if the sheath and shield were to become nicked, the gel surrounding the wires resists the intrusion of water.

Direct-burial cable is available with various numbers of pairs and in various gauges. Care must be taken to match the requirements of the geophones and the type of wire. The wrong gauge may not be capable of carrying the current. The wires from individual geophones are usually connected to multipair feeder cables at junction boxes installed on specific mine levels, and the feeder cables are connected to a larger multipair cable in a shaft that connects the levels with the monitoring room.

Junction Boxes

The selection and preparation of junction boxes is as important as the selection of cable to prevent problems with water in underground seismic systems. Junction boxes must have waterproof door seals and watertight cable grips for all cables entering the box. The size of the box should be large enough to accommodate the terminal blocks, power supplies, and ac power receptacles. Terminal blocks and other insulating parts should not be made of materials such as bakelite because these materials absorb moisture and swell. Crimp spade connectors with screwdown barrier terminal blocks or direct clamp terminal blocks provide the most reliable wire connections. The box should also be large enough to permit easy access when installing the cable initially and when making wiring changes later.

DATA ACQUISITION EQUIPMENT

The data acquisition system consists of components for conditioning, processing, and recording the seismic signals. These components are filters, special connector boards, an analog-to-digital (A/D) board, and a PC to run the software and store the data.

Antialiasing Filters

The purpose of the antialiasing filter is to prevent the data acquisition system from producing false signals. A problem can occur when the data acquisition system's rate of sampling is less than about three times the highest frequency component in the analog signal. If insufficient samples are taken (i.e., the sampling rate is too low), a false or alias signal component with a frequency much lower than that of the original will be reproduced. The filter prevents aliasing by functioning as a low-pass filter and cutting off high-frequency components of the signal and then amplifying them before they are digitized.

Hardware

Data Acquisition Card and Screw Terminal Panel

The A/D board is a circuit board installed in the computer of the data acquisition system that converts analog signals to digital codes for computer processing and storage. Wire pairs from each geophone are connected to a general-purpose screw terminal panel that permits all input signals to be transferred via a ribbon cable from the wire pairs to the A/D board in the PC. The ribbon cable plugs into the connector on the data board, allowing the signals from each channel to be monitored continuously by the computer. The number of input channels on the A/D board should be greater than or equal to the number of geophones in the system and should be capable of monitoring all channels simultaneously.

Computer

High speed and ample memory are the two most important features of the PC monitoring system. Sampling rates of the digitized data are influenced by both the A/D board and the computer speed. Sampling rates that are too low allow the wave to travel large distances between sample data, which increases the likelihood of error in the

measurements. For example, a rock-burst wave traveling at 5,100 m/s will travel 10.2 m between sampling points on a system with a digitizing rate of 500 samples per second, whereas the same wave would only travel 2.04 m between samples on a system capable of digitizing 2,500 samples per second. As the sampling rate increases, however, the size of the waveform file also increases, and more data must be stored in random access memory (RAM). Depending on the application of the system, the accuracy desired, the amount of hard disk storage capacity available, and the level of seismic activity, a tradeoff may have to be made between file size and sampling density.

As an example, a 16-channel array recorded for 5 s with a sample density of 1,500 samples per second will produce a file approximately 200 kbyte in size. To overcome space limitations, a removable mass storage device (such as a magneto-optical drive) can be installed. The magneto-optical platters can be written to as events are recorded, and each platter can be removed and replaced when full. Currently, magneto-optical platters can store up to 1.7 Gbyte.

Another option is to back up data files periodically on a tape, then erase the files from the computer's hard drive. (Note: A tape backup unit would be unsuitable for recording events because the read-write access time for tapes is much too slow.) In addition to sufficient hard disk space, a computer must have enough RAM to store the digitized data while the software determines whether a rock burst is occurring. While high sampling rates are more accurate, the increased number of digitized points may cause buffer overflow errors if the PC has insufficient RAM. The minimum computer requirements for USBM systems are given in appendix A.

Software

To detect seismic events, data from all channels must be monitored continuously and evaluated simultaneously. A typical detection algorithm first checks for an abrupt change in the incoming signal and sets a flag if one is encountered. Another parameter is used to confirm the number of geophones that experienced the abrupt signal change. In addition, a short-term average (STA) is computed for a window of data and compared with the long-term average (LTA). When a critical number of flags are set and the STA/LTA ratio exceeds user-specified criteria, the data are recorded on the PC.

INSTALLATION OF PC-BASED SEISMIC MONITORING SYSTEM

The successful installation of any underground seismic monitoring equipment requires careful planning and attention to detail. One of the most important steps in designing a system is choosing locations for the geophones. The geophones should surround the area of interest in all three dimensions, and the distance from each geophone to the area of interest should be roughly equal. While this may appear to be a simple task, the irregularities and complexities of mine openings do not always allow geophones to be placed in an optimum location.

Once sites have been chosen, a second important step is to make a reconnaissance of the site to ensure that the geophone will not be damaged by mining equipment and is not near any source of constant vibration, such as a pump house. In addition, the geophone should be in an area that is easy to access and where the rock is competent, so as to provide good seismic coupling with the rock mass.

While doing a reconnaissance, plans for positioning the junction boxes and laying the cable should be made. It may be necessary to change or expand the geophone array as new areas are developed. If the wiring network is designed with such possible future changes in mind, expanding or moving the array will be much simpler.

Modern seismic equipment is generally rugged and well sealed to resist hostile underground mine environments. Most problems with seismic systems come from faulty electrical connections or moisture in the wiring. Physical damage to underground equipment can be minimized by careful planning and installation. Figure 3 is a schematic of all components of an installed system. An explanation of each phase of the installation follows.

GEOPHONES AND PREAMPLIFIERS

Geophones must be mounted in a location that will provide a solid coupling with the surrounding rock mass and must be in an area reasonably safe from physical damage. In addition, some geophones require an installation in an exact vertical or horizontal orientation.

Mounting

The rock surrounding underground openings is often fractured from the blasting that formed the opening. When choosing a location, the geophone must be mounted in rock that is solidly a part of the surrounding rock mass. If the geophone is mounted in fractured rock, the fractures will tend to insulate the geophone from the seismic energy

traveling through the rock and the strength of the induced signals will be reduced. In locations where solid rock cannot be found, it may be necessary to drill a hole through the fractured zone into solid rock and mount the geophone at the end of the hole. Geophones with a threaded stud can be mounted by first installing a mounting plate with a tapped hole for the stud. This plate can be secured to the rock with a cement such as an epoxy or a quick-setting plaster such as hydrostone. In some cases, existing rock bolt plates may be drilled and tapped. Tapered geophones are easily mounted by machining an aluminum tube with a matching taper. The outer tube is positioned and mounted with cement, and when the cement is set, the geophone is inserted in the tube.

Because many of the geophones used in underground seismic systems are long and slender and are mounted by a stud at the end, they are readily damaged if bumped. When a protected location cannot be found, the geophone can be mounted in a drill hole. The geophones should not be installed near any machinery that generates vibrations in the surrounding rock, such as a pump station, because these machine vibrations will appear as background noise in any seismic signals from the geophone.

Orientation

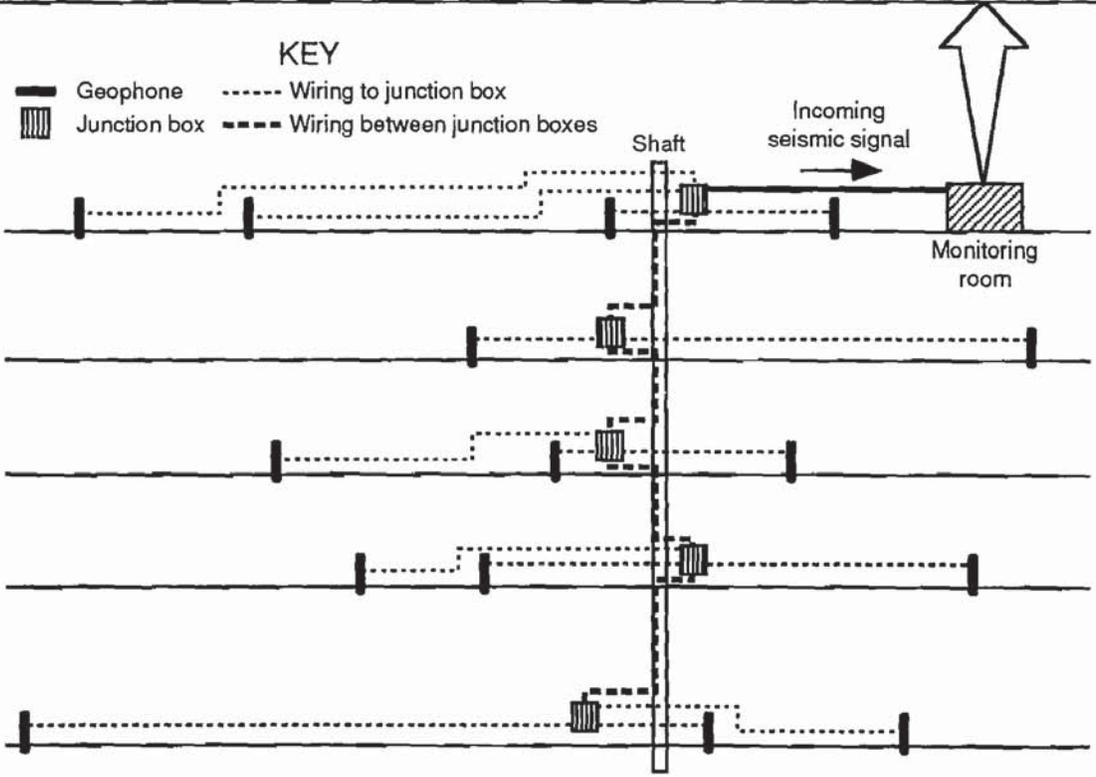
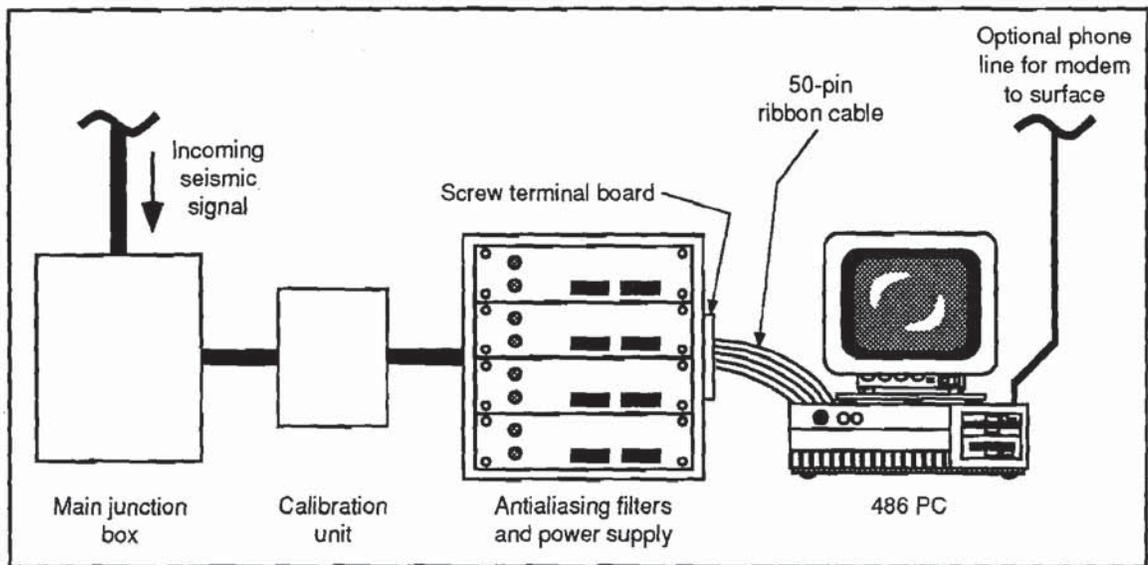
The orientation of the longitudinal axis of an installed velocity geophone is critical for proper operation, while accelerometers will function properly installed in any position. In general, single-axis velocity geophones must have their longitudinal axis within a few degrees of vertical if designed for vertical mounting, or within a few degrees of horizontal when made for mounting in the horizontal position. The frequency response of the geophone will not be correct if improperly mounted.

Each geophone must be precisely surveyed to locate seismic events accurately. The orientation of the axis or axes of the mounted velocity geophones must also be determined with respect to the mine coordinate system.

WIRING NETWORK

The wiring network consists of (1) all the cable connecting the underground geophone array with the data acquisition system and (2) the junction boxes where connections are made. The wiring should be laid out in a network that branches out from a multipair trunk line cable in the shaft through junction boxes to the geophones on each level.

Figure 3
Components of Installed Seismic Monitoring System.



Installation of the wiring network requires special care because a system that is properly installed will be relatively trouble free, while a system that is poorly installed will be a constant source of problems.

Cable Routing and Mounting

The routing of cable in underground mines is often difficult because space, which is at a minimum, must be shared with other signal and communication cables, power cables, compressed air and water lines, and ventilation lines. On underground levels, cable is often subject to damage by mining equipment, and in shafts, it is subject to damage from falling rock.

Whenever possible, it is good practice to route seismic system cable by itself, away from other cables. Shielding the cable is crucial when the seismic transmission lines are near power lines. The shields on the cables coming from the geophones must be connected to the shield of the cable leading toward the data acquisition equipment. The shield must only be grounded at one point on the network to prevent noise from induced ground loop currents. A ground rod or some other positive grounding point located at the data acquisition equipment can then be used to ground the system. On underground levels, the cable can be suspended from cable ties with plastic chain-link mesh, rock bolts and plates, and other hangers found in drift openings. In shafts, the cable will probably have to be routed through the utility compartment and can be hung from the shaft lining with cable grips. The grips must be placed close enough together so that no part of the cable will be subjected to excessive tension, which would stretch the cable.

Junction Boxes

The installation of seismic system junction boxes is greatly simplified if they are planned and preassembled prior to taking them underground. Preassembly can include installing the terminal strips, marking individual or groups of terminals, and installing geophone power supplies and ac power receptacles. Holes should not be drilled in the boxes for cables until the box has been installed.

Junction boxes should be protected from water in wet locations and possible damage by mining equipment, yet

convenient to access. Junction boxes with power supplies for the geophones must be located near 110-V ac power. This is seldom a problem on shaft stations, but ac power is not always available at convenient places away from the shaft. In very humid locations, condensate may form on everything inside the box and cause problems, such as corrosion and electrical short circuits. One method of preventing condensation is to place a heat source in the box, such as a 75-W light bulb.

Calibration

A means of testing and verifying the operation of the geophones and preamplifiers, wiring network, and data acquisition components of a seismic monitoring system is provided by a calibration signal generator. By sending a known signal through the wiring network to all the preamplifiers and geophones, the instruments will return a proper response if installed correctly. The polarity of the wiring can be checked by comparing the first motion of the calibration signal with the first motion of the instrument response.

DATA ACQUISITION EQUIPMENT

The most convenient location for the data acquisition equipment is in a building on the surface. When this is not practical, such as in a large mine where the geophone array is a long distance from a convenient surface location, the monitoring system can be located in an underground room. The system computer can then be accessed from the surface by modem to retrieve files if a telephone line is installed between the surface and the underground room.

Monitoring Rooms

The monitoring room must be clean and dry. Air conditioners, dehumidifiers, and air filters can be used to maintain the environment for computers and electronic equipment. The room should be large enough to provide space to operate and maintain the equipment, store data processing and office supplies, and contain a workbench to test equipment and make minor repairs.

CONCLUSION

Attention to detail and preplanning will minimize problems associated with installation of a microseismic monitoring system and data collection. The systems described here are easy to install and have been used successfully by the USBM for several years. The system can be designed to fit the particular needs of each mine. While equipment brands other than those listed in appendix A can be used

when designing a system, components should be carefully chosen for compatibility. By recording and analyzing rock-burst data collected by the system, ground-control engineers may be able to devise alternate mining plans to minimize the occurrence of rock bursts and optimize resource recovery.

APPENDIX A.—EXAMPLES FROM ACTUAL INSTALLATIONS

DATA ACQUISITION SYSTEM

Software

The USBM's seismic monitoring system was adapted from earthquake monitoring software developed by the U.S. Geological Survey (USGS).^{1,2} The USGS software is published and maintained by the International Association of Seismology and Physics of the Earth's Interior (IASPEI).

For information on becoming a registered user of the IASPEI software write to

International Association of Seismology
and Physics of the Earth's Interior
P.O. Box I
Menlo Park, CA 94026

This system is capable of recording full waveforms from up to 16 receivers. Some modifications to the system were necessary to adapt the software to monitoring mine seismicity instead of earthquakes. However, the hardware is essentially the same for either type of system.

Computer

The absolute *minimum* requirements for a computer to run this type of seismic data acquisition system are

- 80286 IBM-compatible PC with math coprocessor.
- CPU speed of at least 8 MHz.
- 2 Mbyte of RAM (120 nanoseconds or faster), first 640 kbyte of RAM as base memory and the remaining kbyte of RAM as extended memory.
- Hard disk with at least 30 Mbyte of free space and access time <40 m/s.

¹Lee, W. H. K., and S. W. Stewart. Principles and Applications of Microearthquake Networks. Advances in Geophysics, Supplement 2, Academic Press, 1981, 293 pp.

²Lee, W. H. K., D. M. Tottingham, and J. O. Ellis. A PC-Based Seismic Data Acquisition and Processing System. U.S. Geol. Surv. OFR 88-751, 1988, 31 pp.

- DT2821 A/D input-output board with a DT707 screw terminal connecting a panel and a 50-pin ribbon cable.

- EGA monitor.
- Stable ac power source with surge protection.

All computers used for seismic data acquisition by the USBM are 486/33 MHz machines with 200 Mbyte hard drives, 8 Mbyte RAM, 9600 baud send-receive modems, and VGA monitors.

Analog-to-Digital Boards

The A/D boards used in the USBM's systems are 2821 Series boards made by Data Translation, Inc., Marlboro, MA. These boards have 16 channels and a sampling rate of 50 kHz. Each channel then has a sampling rate of 3.13 kHz. These boards have 12-bit resolution, which is a measure of the accuracy with which the digitized signal matches the analog signal. A resolution of 12 bits means that the maximum amplitude of the analog signal may be divided or resolved into 4,096 parts or counts. This is 0.024 pct of the analog signal's range. While other A/D boards may work in this type of system, neither IASPEI nor the USBM have tested other brands.

SEISMIC MONITORING EQUIPMENT

Geophones

The geophones used by the USBM in the three mines discussed in this report are manufactured by Electro-Lab in Spokane, WA. Some of the geophones in use at the Lucky Friday Mine and the Sunshine Mine are 1131-series triaxial velocity geophones, but most of the geophones at the Sunshine Mine are model 11SB velocity geophones. The Lucky Friday Mine also has 1130-series velocity geophones installed in the macroseismic system. All of the geophones in use at the Homestake Mine are 272 accelerometer geophones. The types of geophones used in the USBM systems are summarized in table A-1.

Table A-1.—Geophones used in USBM microseismic systems

Geophone series number	Axis	Type		Mine		
		Velocity	Accelerometer	Homestake	Lucky Friday	Sunshine
11SB	Single	X		No	No	Yes
1130	Single	X		No	Yes	No
1131	Triaxial	X		No	Yes	Yes
272	Single		X	Yes	No	No

Triaxial velocity geophones such as the series 1131 have the y-axis parallel to the longitudinal axis of the geophone. The x, y, and z axes are mutually orthogonal and form a right-handed coordinate system. The z-axis is normally the vertical coordinate, and in the USBM systems, positive in the up direction. A flat, milled end on the geophone provides a reference surface to orient the axes properly.

Wiring Network and Junction Boxes

The cable used in the wiring networks is 22-gauge, direct-burial, shielded cable and includes 6-pair, 25-pair, and 50-pair cables. The junction boxes accommodate 25- and 50-pair cables and are made of fiberglass. The junction boxes have watertight seals and measure 76.2 cm high by 61.0 cm wide by 20.3 cm deep. Smaller steel boxes with watertight door seals have been used for the junctions of the smaller geophone cables with the feeder cables.

Antialiasing Filter

The antialiasing filter used in the USBM data acquisition systems is an Electro-Lab type 405 AA filter. This unit provides a separate channel for each geophone and can accommodate up to 64 channels. Each channel contains an amplifier with the gain adjustable in 10 db steps from 0 to 50 db. The filter is actually a band-pass filter in that both high-frequency signal components and those below 10 Hz are cut off. The 10-Hz cutoff is fixed while the high frequency cutoff may be set between 1 kHz and 9.9 kHz in 100-Hz increments by means of a switch.

Calibration Unit

The USBM systems also include an automatic calibration unit. The calibration pulse generator developed by Electro-Lab generates a 7.5-cycle pulse of 60-Hz ac at an amplitude of 24-V RMS. When the calibrator is triggered, this signal burst is transmitted on a separate pair of wires in the wiring network to all the preamplifiers. Properly installed preamplifiers respond to the calibration pulse by producing a 1-V peak-to-peak square wave. The calibration signal always starts with a positive wave so that the polarity of the wiring can also be checked.

Monitoring Rooms

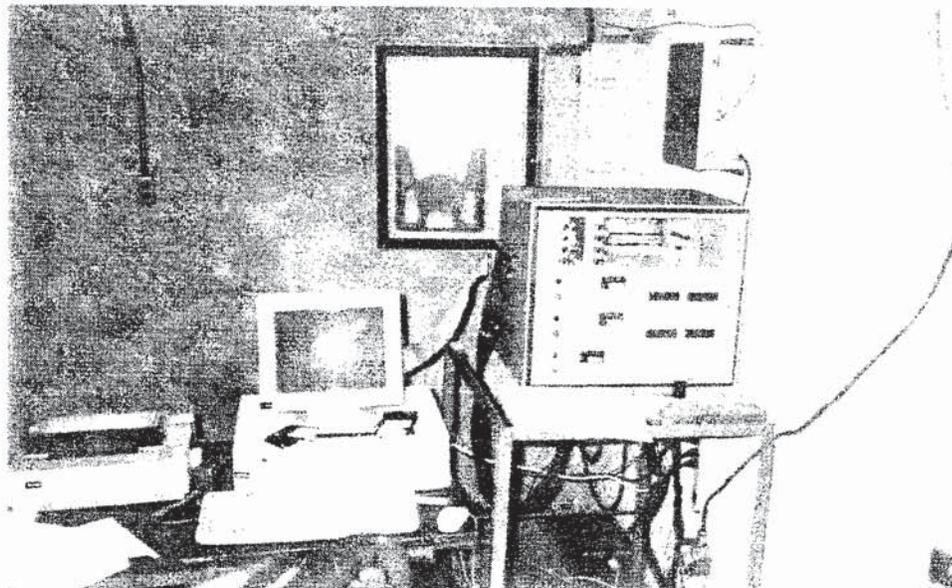
The monitoring rooms at the Lucky Friday and Sunshine mines are located on the surface. However, since the seismic monitoring system at the Homestake spans levels between 2,043 and 2,384 m below the surface, the monitoring room was located underground (figure A-1).

Seismic Equipment Specifications

For specific information about the seismic equipment in use by the USBM at these three mines, contact the authors at

Spokane Research Center
315 E. Montgomery Ave.
Spokane, WA 99207-2291
(509) 484-1610

Figure A-1
Underground Monitoring Room at Homestake Mine.



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