

MOBILE ROOF SUPPORT SAFETY RESEARCH—AN UPDATE

John Owens and Wayne Howie
Spokane Research Laboratory, National Institute for Occupational Safety and Health

Hamid Maleki
Maleki Technologies

ABSTRACT

Initial studies of the effectiveness and safety of mobile roof supports (MRSs) by researchers at the Spokane Research Laboratory of the National Institute for Occupational Safety and Health focused on the mechanics of the interaction of MRSs and mine strata and evaluation of suitable measurements for detecting roof stability problems during pillar extraction. These studies indicated that overall stress distributions and strata movement were most influenced by the stiffness of coal-measure rocks and the design of mining layouts, but that MRSs played a critical role in controlling the stability of immediate and middle roof strata. Pillar failure was often associated with an increase in pressure on the hydraulic gauges of the MRS, and roof failure was often preceded by rapid changes in the rate of roof-floor convergence. A reliable warning system can be developed by combining both convergence and load rate data to alert miners to roof instabilities within active mining areas.

These studies led the authors to develop a monitoring system that displays the loading rate on an MRS in real time. With the cooperation of a major MRS manufacturer, the system was installed and tested on an MRS in the laboratory. New field studies focus on evaluating the performance of the load-rate monitoring system, measuring roof-floor convergence rates, and optimizing the safety of MRS operations through proper layout design.

INTRODUCTION

Room-and-pillar retreat mining is one of the oldest methods for extracting ore from tabular bodies. However, the room-and-pillar retreat method is at a disadvantage when compared to other mining techniques, such as longwall mining. Because of economies of scale, the productivity of room-and-pillar retreat mining is significantly lower. The longwall method is also much safer because the retreat is completed under the protection of self-advancing hydraulic support systems at the face.

Room-and-pillar retreat mining is desirable when large, consistent blocks of coal are not present or capital resources cannot justify the purchase of longwall equipment. During the last two decades, federal laboratories, mining companies, and equipment manufacturers have co-operated to improve understanding of strata mechanics and develop a remotely controlled, self-advancing support system called a mobile roof support (MRS). The result has been improvements in the safety and productivity of room-and-pillar retreat operations.

RETREAT MINING LAYOUTS

Figures 1 and 2 illustrate generic panel layouts and pillar extraction sequences for two typical room-and-pillar retreat systems. Figure 1A presents a mine layout at four stages of pillar recovery with a three-entry access panel developed on advance to the panel boundaries. Narrow rib pillars are developed to the side and extracted. After pulling one row of pillars, another row is driven into the solid coal block, and the sequence is repeated until the panel is extracted. Pillar recovery operations consist of splitting the pillars and fenders. Figure 1B shows the sequence of the pillar cuts, typical position of posts, and the location of unmined stumps for the extraction of a pillar using the split-and-fender method. New applications of the three-entry systems involve the use of MRSs instead of posts and the elimination of fenders completely.

In Figure 2, a nine-entry access is developed on advance to the panel boundaries. The pillars are then extracted until the entire panel is mined. Figure 2A presents the panel layout and the location of MRSs at three intermediate stages of pillar recovery using the Christmas tree method. Figure 2B shows the sequence of cuts taken from two pillars where MRSs are used as secondary support. Many variations of these two panel layouts and excavation sequences are practiced in U.S. coal mines.

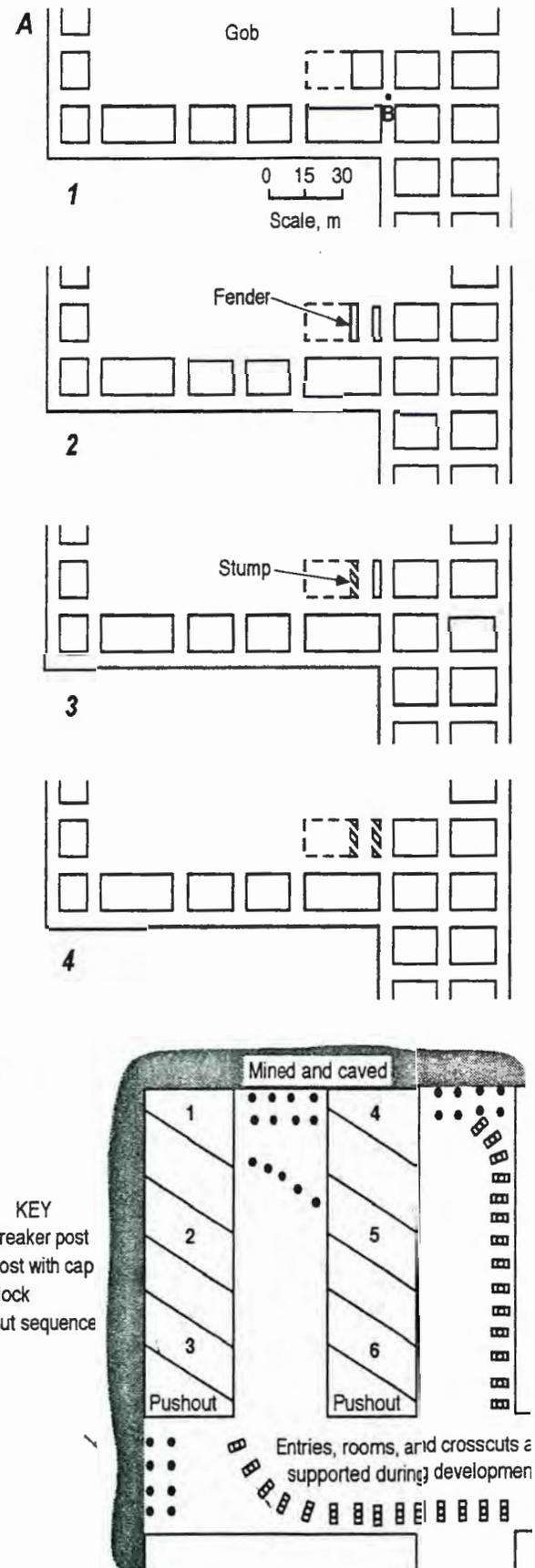


Figure 1—Mine layout (A) and pillar extraction sequence (B) using split-and-fender method with posts

DEVELOPMENT AND TESTING OF MRS

A prototype MRS was developed by the U.S. Bureau of Mines in cooperation with an equipment manufacturer and a mining company (Thompson and Frederick 1986) to reduce the many injuries occurring each year during cutting and installing wooden posts to support the roof during pillar extraction. Commercial units have since been developed by U.S. and Austrian manufacturers. The commercial MRS units are more rugged and have higher capacities (5,340 to 7,120 kN [600 to 800 tons]) than the prototype (Wilson 1991; Howe 1998). An MRS consists of a roof canopy, four hydraulic cylinders, a caving shield canopy, and associated electro-mechanical systems mounted on crawler tracks (Figure 3). These machines are operated via radio from a remote location, which eliminates the necessity of exposing miners to hazardous work areas. They can be moved quickly from place to place, thus allowing mining to take place more rapidly and improving the productivity of the mining process. Because of their greater mobility and because they allow higher resource recovery, MRSs are currently being used in 36 U.S. coal mines, as well as a number of Australian mines (Shepherd and Lewandowski 1992; Habenicht 1988).

Researchers at the Pittsburgh and Spokane Research Laboratories of the National Institute for Occupational Safety and Health (NIOSH) have monitored MRS performance both in the laboratory and in the field. Laboratory investigations focused on evaluations of support stiffness and load-carrying capacity under controlled static loading conditions. System stiffness was quantified as a function of machine height for both two- and three-stage hydraulic cylinders under controlled loading conditions at the Pittsburgh Research Laboratory (Barczak and Gearhart 1997, 1998).

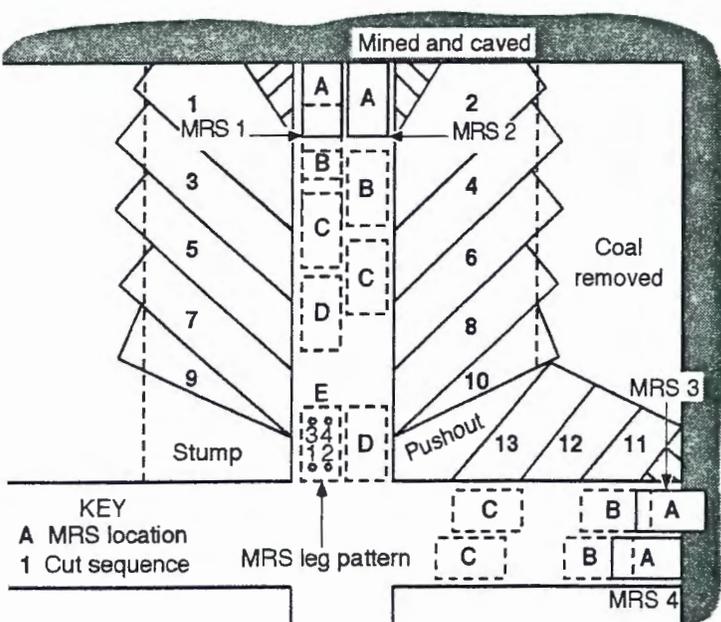
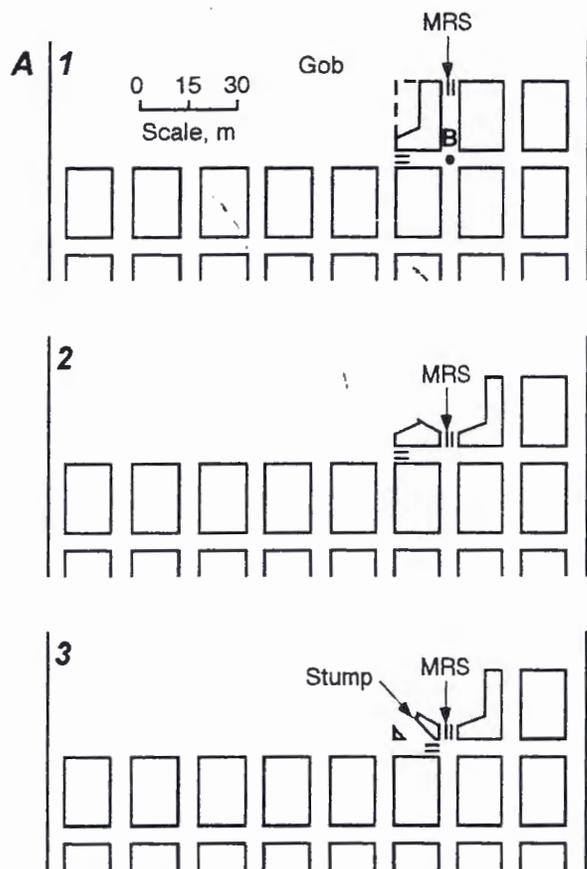


Figure 2—Mine layout (A) and pillar extraction sequence (B) using Christmas tree method with MRSs as support

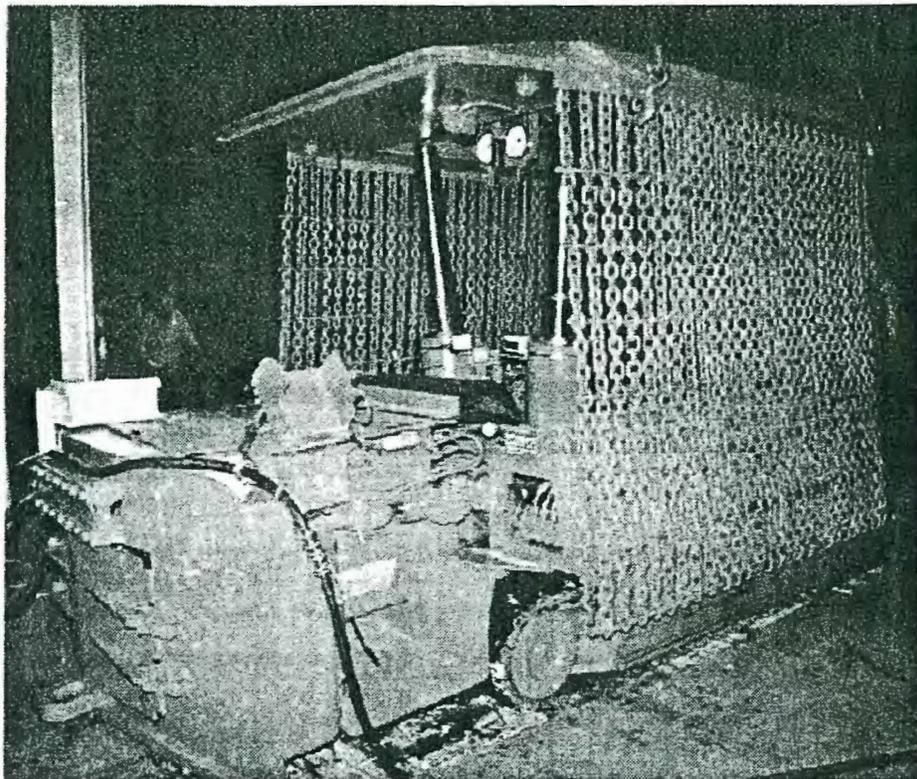


Figure 3—Mobile roof support

It was found that three-stage cylinders are needed in thick seams, but reduce support stiffness. Each unit had the load-bearing capacity of six hardwood posts and the stiffness of two hardwood posts (Barczak and Gearhart 1997). Also identified were inaccuracies in hydraulic cylinder pressure measurements of roof loads when the bottom cylinder stages were fully extended.

Early field evaluations focused on a comparison of ground movements at two room-and-pillar retreat sites where the split-and-fender method with posts (Figure 1B) and the Christmas tree method with MRSs as the secondary support system (Figure 2B) were used. In addition, the history of hydraulic pressure was analyzed on all four MRS legs (Hay, et al 1995). In these studies, greater strata movements were measured in the intersection at the site where the Christmas tree method was being used.

LOCALIZED STRESS DISTRIBUTION IN THE MINE ROOF

The mechanics of load transfer from pairs of MRSs to mine strata was analyzed using laboratory results, boundary-element modeling, and analytical solutions (Maleki and Owens 1998). The results showed that MRSs support roof rocks near the machines, but do not have the capacity to control overall roof-floor convergence and overall stress distributions in a panel because the MRSs are considerably less stiff than coal-measure rocks. In comparison to wooden posts, however, an MRS is capable of maintaining the yield load after significant amounts of roof-floor deformation. Because the use of MRSs can greatly accelerate the mining cycle, the potential for time-dependent roof falls can be reduced.

Analytical solutions (Das 1994) were used to determine stresses induced into the mine roof by MRSs (Maleki and Owens 1998). Figure 4 shows stresses induced in the mine roof by two pairs of MRSs positioned 5.5 m (18 ft) apart in the intersection for mining the pushout. The figure shows that a pressure arch is formed in the immediate roof that reduces the potential for roof falls in the space confined by the MRSs. This situation is beneficial for protecting a continuous miner when it is operating within this space.

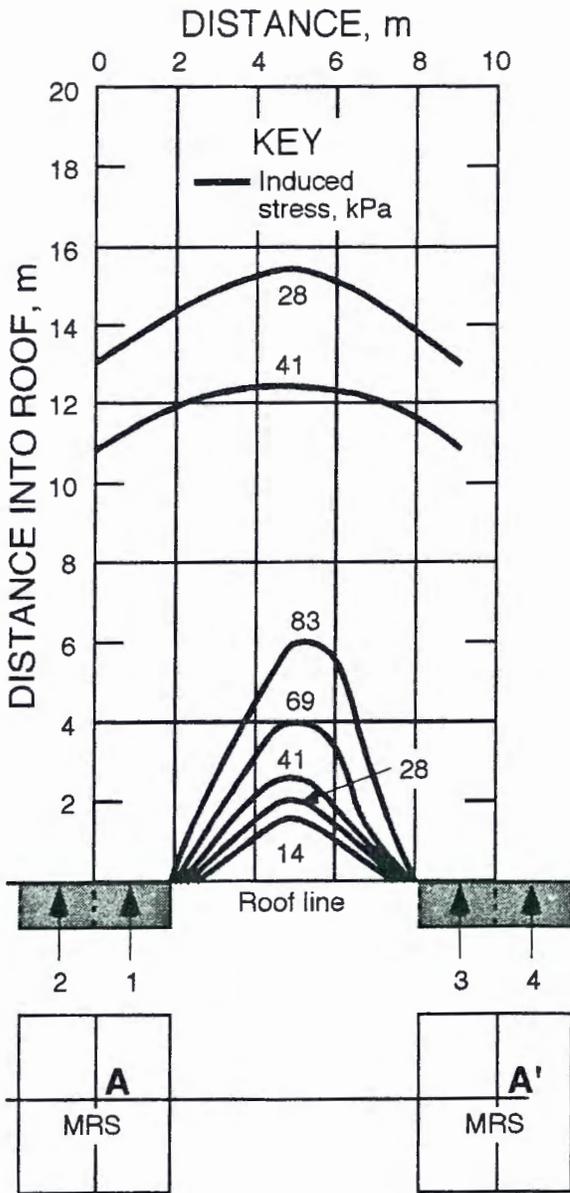


Figure 4—Stress isobars along A-A' for two pairs of MRSs at 5.5-m spacings

Figure 5 shows the pressure isobars above a pair of MRSs set side-by-side in an entry. Results indicate that pressure applied to the roof reaches a maximum near the opening and becomes insignificant by a distance of 18 m (60 ft) into the roof. Because MRSs have a limited area of support influence, it is important to place them under bolted roof during pillar-pulling operations. Since stresses induced into the mine roof are quite small in comparison to the strength of typical coal mine roof rocks (55 to 110 MPa [8,000 to 16,000 psi]), the best method of inducing a cave is through proper mine orientation with respect to geological discontinuities. It was also found that higher MRS capacities and setting pressures are useful for stabilizing middle roof strata, but may contribute to differential loading on the immediate roof and reduction in the stability of the immediate roof.

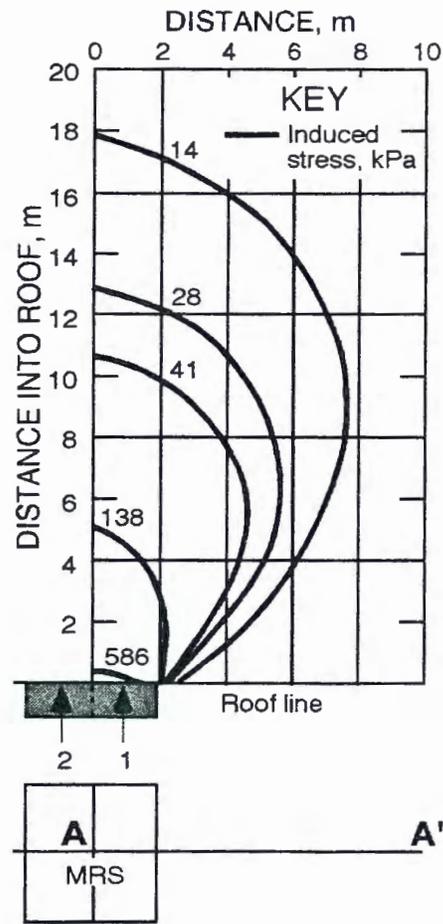


Figure 5—Stress isobars along A-A' for one pair of MRSs

PANEL LAYOUT DESIGN

Field observations of MRS retreat operations identified the importance of mine layout designs and revealed the dangers of overconfidence in the ability of MRSs to support the entire area. Such overconfidence contributed to workers choosing unsafe operating locations. Thus it became apparent that to improve stability, layout designs that control convergence and stress should be developed. To illustrate this point, boundary-element analyses were completed in which stress distributions were calculated for two pillar-pulling plans using MRSs. These analyses were also helpful in tailoring the type of monitoring required to assess changes in the stability of the mining system.

Stress Analysis of Room-and-Pillar Layouts Using MRSs

Stress distribution and convergence patterns were compared for two pillar recovery plans using MRSs: split-and-fender and Christmas tree. Model input was based on extensive laboratory and field measurements in one of the study mines (Maleki 1981), and modeling procedures were based on a methodology developed for coal mine excavations (Maleki 1990; Maleki and Owens 1998). The analyses were completed for a typical depth of 305 m (1,000 ft).

Figure 6 presents the vertical stress distribution for the Christmas tree method at step 3 (figure 24). The analyses showed that MRSs do not have the capacity to control overall roof-floor convergence and overall stress distributions in the panel because of their low support stiffness and load capacity compared to coal-measure rocks. They do, however, play a critical role in controlling the stability of both the immediate roof and the middle roof.

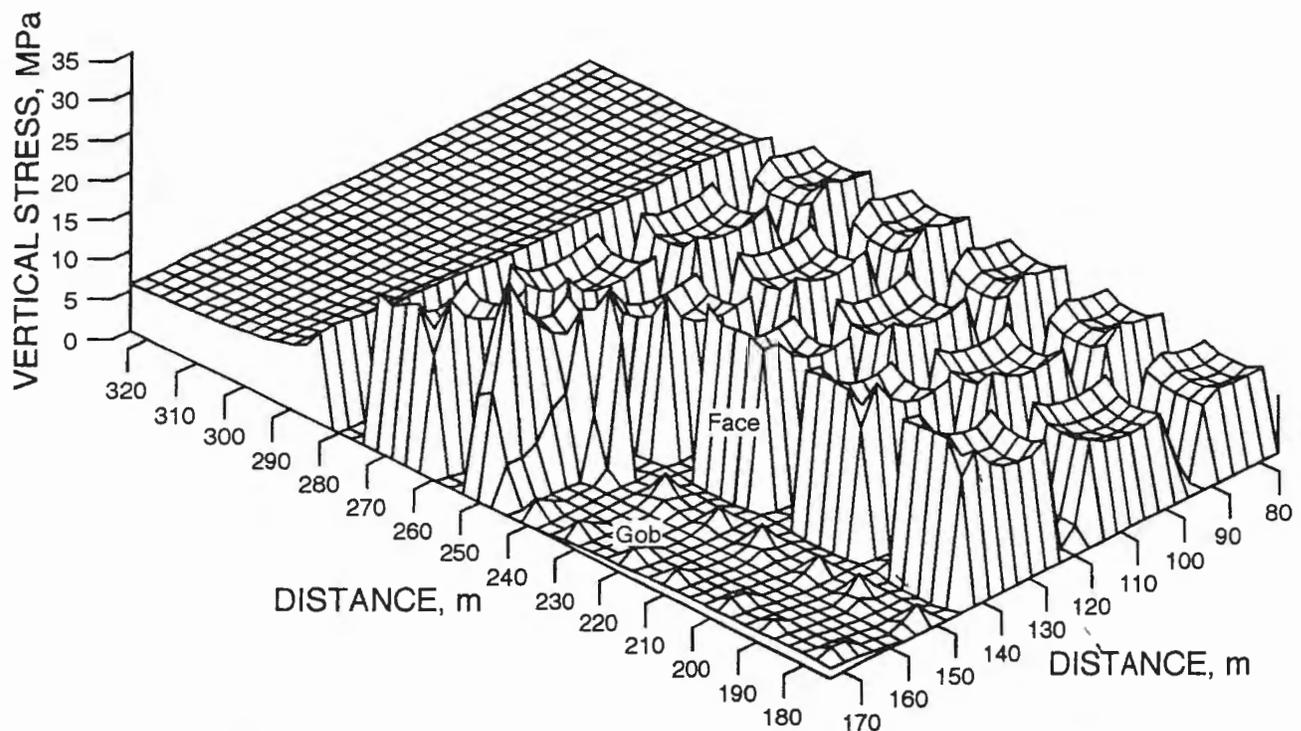


Figure 6—Vertical stress distribution for Christmas tree method, step 3

Figure 7 presents calculated roof-floor convergence at a similar point in the intersection for two pillar recovery methods (point B in Figures 1A and 2A) and provides guidance for selecting monitoring systems. Note that calculated deformation significantly increases within a single mining step, which is associated with the failure of fenders and stumps. MRSs will therefore experience an increase in both vertical and lateral support loading as fenders fail. Since fender failure induces differential movement in the mine roof, a roof fall may be triggered. Such an impending roof fall may be sensed through monitoring either convergence rate or pressures on MRS legs; that is, a change in convergence rate may be large enough to cause a change in leg pressure.

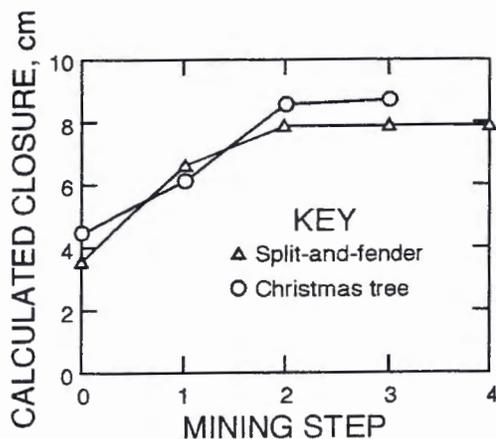


Figure 7—Calculated closure for split-and-fender and Christmas tree methods at location B

Roof-floor convergence is at least 10% higher using the Christmas tree method, as illustrated in Figure 7. To control convergence, a stump (Figure 2A) is left in the model (no pushout). Further improvements in stability and convergence can be achieved by changing the size of the stumps and pillars left behind.

DEVELOPMENT AND TESTING OF GROUND MONITORING SYSTEMS

During field tests in underground mines, the authors identified three factors that might adversely influence worker safety in an MRS section:

- Elimination of posts reduced a worker's ability to assess roof conditions.
- Overconfidence in the ability of MRSs to support the entire area caused some miners to chose unsafe operating positions.
- MRSs were used routinely under adverse geologic and mining conditions to recover reserves that were otherwise unminable.

It became apparent from these studies that there was a need to develop a warning system that would alert workers to unstable roof conditions so that miners and equipment could be moved before a fall occurred. Two monitoring methods were chosen on the basis of mine measurements and numerical modeling. These were roof-floor convergence and load-rate monitoring on the hydraulic legs of MRSs. The rationale was that (1) convergence pins could be placed over the entire area of interest to monitor the stability of the whole section (Maleki 1988) and (2) monitoring the rate of loading on MRS legs could warn miners of major events, such as failures of fenders and pillars, that generally trigger roof falls. A reliable warning system could be developed by combining both convergence and load-rate data.

Roof-Floor Convergence Rate Monitoring

Convergence measurements were obtained from four mines that use different primary and secondary support systems under variable amounts of cover (90 to 360 m [300 to 1,200 ft]) and both flat-lying and dipping seams (0° to 8°). Figure 8 presents measured total convergence and shows that roof falls occurred generally after 2.5 cm (1 in) of convergence (and occasionally up to 50 cm [20 in]). However, *total* convergence by itself is not a suitable indicator of roof stability.

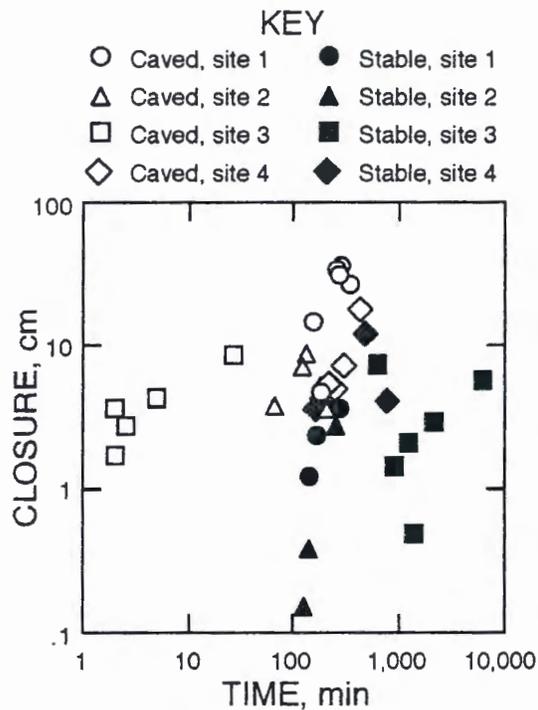


Figure 8—Total measured roof-floor convergence prior to roof falls at four mines

Rate of convergence is a reliable measure of roof stability (Figure 9). Note that there were no roof falls when the convergence rate was lower than 0.5 cm/min (0.2 in/min). Minor falls were recorded at a convergence rate of 0.5 to 0.65 cm/min (0.2 to 0.25 in/min). Critical rates exceeding 0.65 cm/min (0.25 in/min) were measured prior to roof falls in all four study mines. Results of these studies are very encouraging, although site-specific convergence measurements should be taken in any new mine to verify this critical rate.

MRS Load-Rate Monitoring System

In the past, cracking sounds emitted by wooden posts and visual observations of pillar and post displacement and failure warned miners of dangerous loading conditions. With the use of MRSs, miners have come to rely on the hydraulic dial gauges on the machines to determine when to cease operations and remove themselves and equipment from the active

mining face before a dangerous roof fall occurs. These gauges monitor pressure in the hydraulic cylinders of the MRS and often show a rapid increase in pressure when there is a change in ground stability.

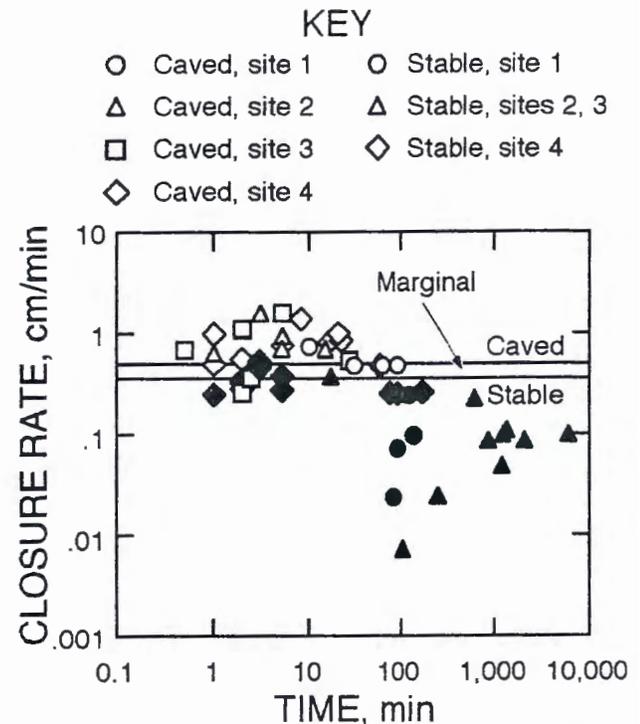


Figure 9—Roof-floor convergence rates prior to roof falls at four mines

However, these gauges are difficult to read and require that miners approach the MRS to see the gauges, which brings them close to the active mining face. Not only is this area susceptible to roof falls, but mobile equipment poses additional safety risks. For these reasons, and because miners are often busy performing other work, the gauges are only checked periodically.

A load-rate monitoring system was developed by personnel of the Spokane Research Laboratory to track and display loading rates on an MRS in real time. Such a system installed on an MRS could warn of major events, such as failures of fenders and pillars that generally trigger roof falls. The system was designed to be seen easily by all miners in the vicinity of an MRS.

Figure 10 is a block diagram of the load-rate monitoring system. The system uses a dedicated embedded Micro-485 programmable controller to monitor pressure inside two hydraulic systems using standard analog pressure transducers (0 to 34.5 MPa [5,000 psi]). Pressure is translated by the transducer to an analog voltage of 0 to 5 Vdc, transformed by the analog-to-digital converter to a 12-bit (0 to 4096 level) digital value, and sent to the embedded processor via its integral interface for processing. The controller is based on a highly

integrated version of the world standard 8051 microcontroller family. It calculates loading rates using Assembly and C languages and controls output signals to the three load-rate indicator lamps. A socketed 80C51FA central processing unit (CPU) is ideally suited to the control and data acquisition requirements of the system. Figure 11 shows the nonintrinsic components of the system installed in an electrical starter box located at the front of the MRS.

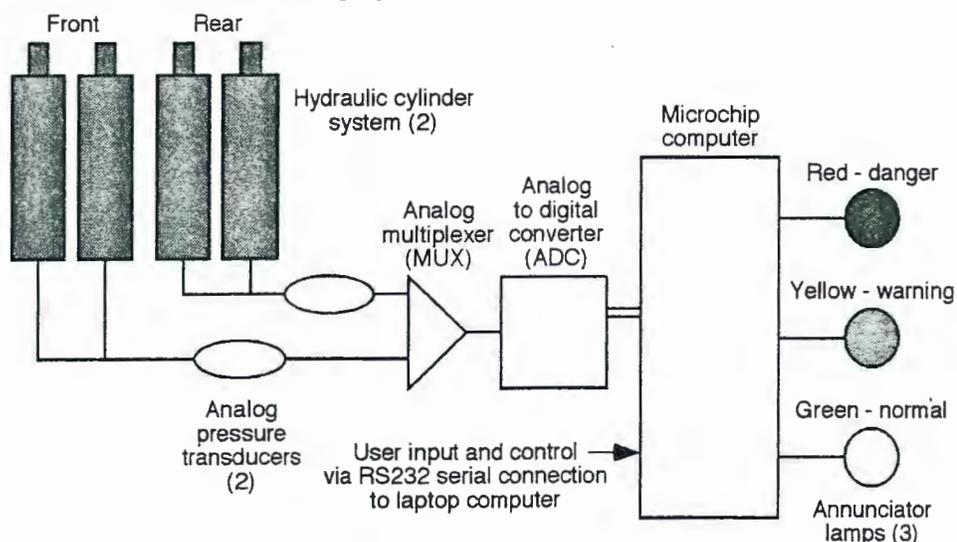


Figure 10—Diagram of load rate monitoring system

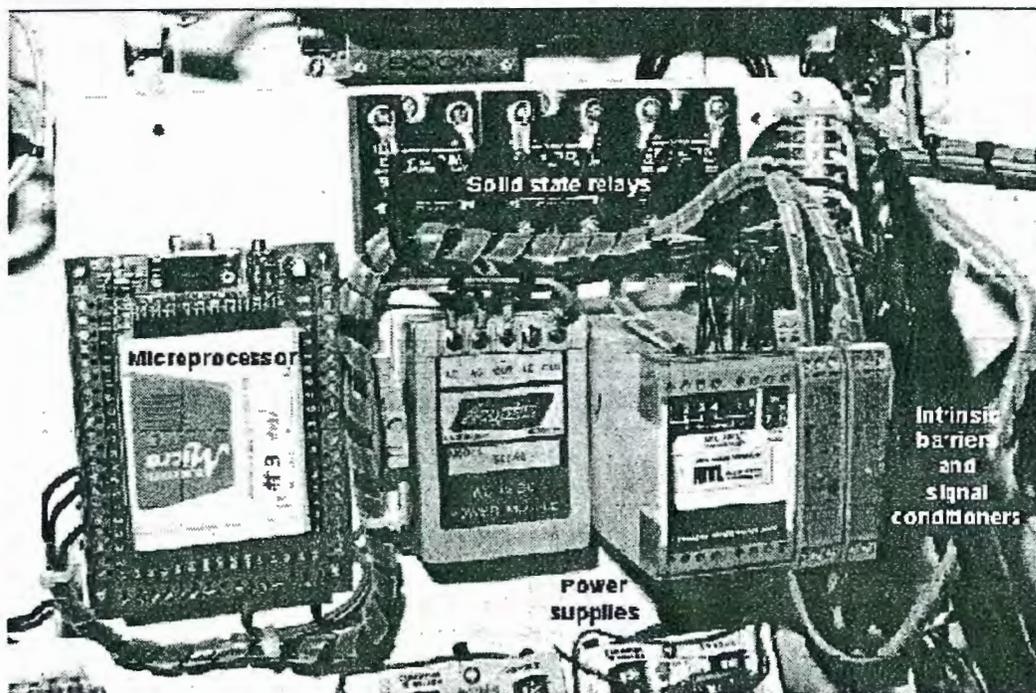


Figure 11—Load-rate components installed in electrical box on MRS

Loading on a hydraulic cylinder is proportional to internal pressure and surface area of the piston head and is determined by the formula

$$F = A \times P,$$

where F = force (N), A = area (m^2), and P = pressure (Pa). The embedded processor reads changes in cylinder pressure through two multiplexed data acquisition channels of the controller and converts these pressure changes to load rates. Green, yellow, and red globe lights are activated as the load rate increases. Green indicates that there is minimal change in load rate on the MRS.

Yellow indicates that the load rate is increasing and that additional caution is recommended. Red indicates that the load rate is increasing rapidly and that a roof fall may occur soon. A continuously flashing red light indicates that the hydraulic cylinder load is approaching the yield of the MRS. As shown in Figure 12, these lights can be installed on the MRS canopy near the hydraulic pressure gauges. These lights can easily be seen at all viewing angles at a safe distance from the active mining area.

Other devices could be used to meet specific warning requirements requested by a mine operator or MRS manufacturer, including multicolor strobes, LEDs, or audible alarms.

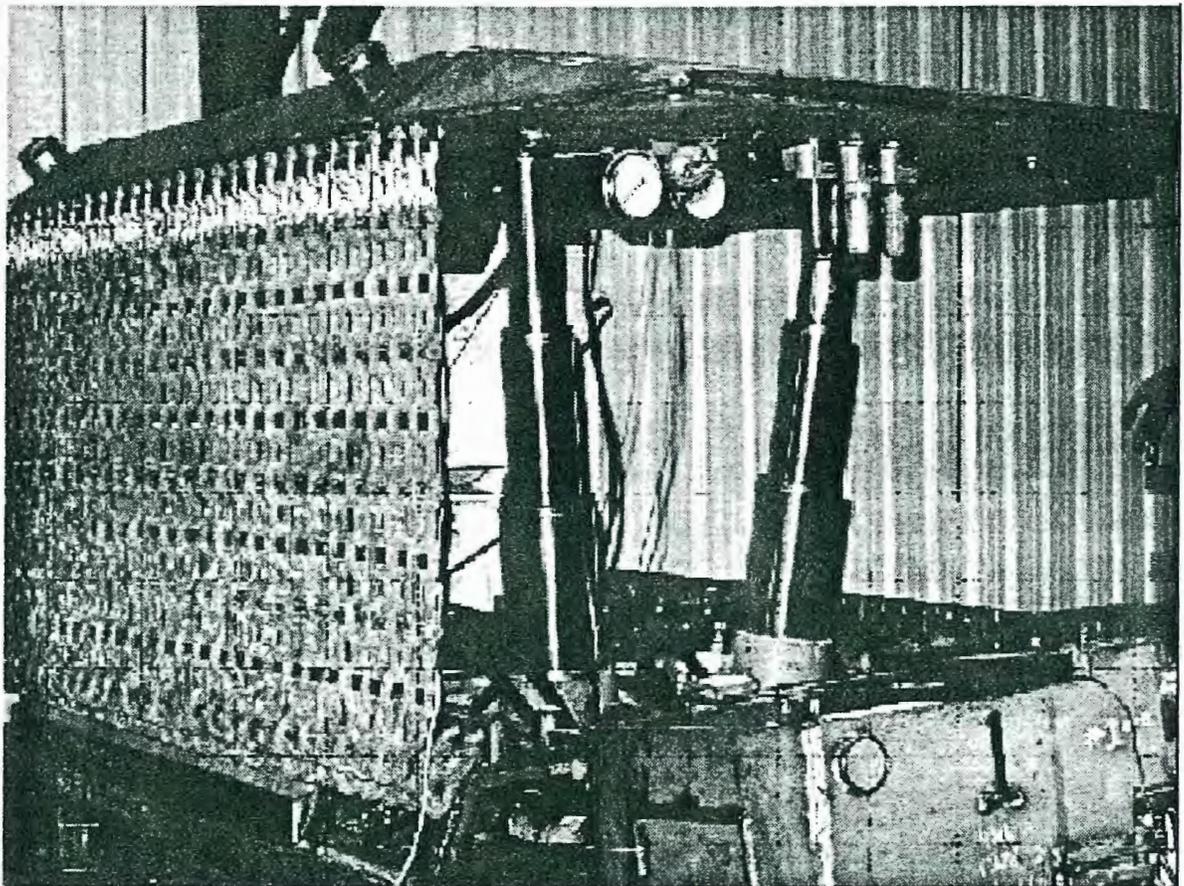


Figure 12—Load-rate indicators installed on MRS canopy

The system will operate as an integral part of an MRS. Operating parameters can be set prior to or during installation of the system or periodically as mine conditions change, but need not be done by operating personnel at the mine. Operating parameters are set by connecting the system to a laptop computer via an RS-232 null modem cable with the communication terminal emulator acting as the laptop client program. This allows a trained user to change parameters easily to trigger the various load rate indicator devices to suit geological conditions at a mine.

At the request of an MRS manufacturer and mines using MRSs, a static load indicator feature was added to the main load-rate monitoring system. The system is transformed into a static hydraulic pressure monitoring system by simply flipping a toggle switch to activate the static load program on the embedded processor. When the machine is operating in the static load mode, each light indicates a range of hydraulic pressure set by the user. The green light, for example, could easily be programmed to indicate hydraulic pressures between 0 to 13.8 MPa (0 to 2,000 psi), the yellow light to indicate pressure between 13.8 to 20.7 MPa (2,000 to 3,000 psi), and the red light to indicate pressure over 20.7 MPa (3,000 psi). The red light is programmed to flash continuously when the hydraulic cylinder is within 5% of yield pressure.

The load-rate monitoring system is designed to be MSHA permissible. With the cooperation of a major MRS manufacturer, an experimental permit was obtained from MSHA to allow testing of the load-rate monitoring system on an MRS at a retreat operation. The system was first tested on an MRS at the manufacturer's shop facility. Because of inaccuracies in hydraulic cylinder pressure measurements when the bottom stage of a multistage cylinder is fully extended, an MRS should be set against the mine roof with the bottom stage partially extended.

CONCLUSIONS AND RECOMMENDED WORK

To eliminate setting and handling posts and reduce the number of miners required to work near the cave line and other dangerous locations, a remotely controlled MRS has been developed and field tested. The MRS has undergone numerous modifications and has reached a level where it is accepted in today's room-and-pillar retreat mining operations. Optimum use of MRSs depends on design of panel layout, mine orientation, pillar-pulling method, location of MRSs, and primary support designs for the expected geologic and stress conditions. MRSs have a limited zone of influence around them and thus can best be utilized in combination with other MRSs and in conjunction with ground monitoring systems.

An integrated ground monitoring system is being tested in which the simplicity of convergence measurements are combined with load-rate monitoring on MRS leg cylinders. Measurements from four mines having various geologic and support conditions have shown that monitoring roof-floor convergence rates enables miners to detect unstable roof conditions within the whole area of the interest at the face. Monitoring MRS loading rates provides information on the stability of pillars and fenders. Upcoming field studies will evaluate the performance of the load-rate monitoring system, develop a protocol on how to use the system as a tool for alerting miners to dangerous ground conditions during pillar extraction, and determine critical load rate settings for the system under different geological conditions.

ACKNOWLEDGMENTS

The support of J.H. Fletcher & Co. is gratefully acknowledged. Fletcher not only provided MRSs and multistage hydraulic cylinders for testing the load-rate monitoring system, but assisted in installing it and locating mine sites for the upcoming field tests. The company's diligent work was invaluable in obtaining an experimental permit from MSHA to test the system on MRSs in active retreat mining sections.

REFERENCES

- Barczak, T., and D. Gearhart, 1997. Full-Scale Performance Evaluation of Mobile Roof Supports. Paper in *Proceedings of 16th International Conference on Ground Control in Mining*, ed. by S. S. Peng and C. T. Holland (WV Univ., Morgantown, WV, Aug. 5-7, 1997). Dept. of Mining Engineering, WV Univ., pp 211-220.
- Barczak, T., and D. Gearhart, 1998. Performance and Safety Considerations of Hydraulic Support Systems. Paper in *Proceedings, 17th International Conference on Ground Control in Mining*, ed. by S. S. Peng (WV Univ., Morgantown, WV, Aug. 4-6, 1998). Dept. of Mining Engineering, WV Univ., pp. 176-186.
- Das, M. Braja, 1994. *Principles of Geotechnical Engineering*, 3rd ed., PWS Pub., 672 pp.
- Habenicht, H., 1988. The Alpine Breaker Line Support (ABLS): A Means to Promote Full Extraction. Paper in *3rd International Conference on Innovative Mining Systems*, ed. by J. M. White (MO Univ., Rolla, MO, Nov. 2-4, 1987). MO Univ., pp. 22-29.
- Hay, K., S. Signer, M. King, and J. Owens, 1995. Monitoring Mobile Roof Supports. Paper in *Proceedings of 14th International Conference on Ground Control in Mining*, ed. by S. S. Peng (WV Univ., Morgantown, WV, Aug. 1-3, 1995). Dept. of Mining Engineering, WV Univ., pp. 55-62.
- Howe, L., 1998. A Decade of Mobile Roof Support Application in the United States. Paper in *Proceedings, 17th International Conference on Ground Control in Mining*, ed. by S. S. Peng (WV Univ., Morgantown, WV, Aug. 4-6, 1998). Dept. of Mining Engineering, WV Univ., pp 187-201.
- Maleki, H., 1981. Coal Mine Ground Control. Ph.D. dissertation, Colorado School of Mines, Golden, CO, 432 pp.
- Maleki, H., 1988. Detecting Stability Problems by Monitoring Rate of Roof Movement. *Coal*, vol. 25, no. 12, pp. 34-38.
- Maleki, H., 1990. Development of Numerical Modeling Procedures for Coal Mine Stability Evaluations. Paper in *Rock Mechanics Contributions and Challenges: Proceedings of the 31st U.S. Symposium*, ed. by W. A. Hustrulid and G. A. Johnson (CO Sch. Mines, Golden, CO, June 18-20, 1990). Balkema, pp. 85-92.
- Maleki, H., and J. Owens, 1998. Analysis of the Interaction Between Mobile Roof Supports and Mine Strata. Paper in *Design and Construction in Mining, Petroleum, and Civil Engineering: Proceedings of the Fifth South American Congress on Rock Mechanics and Second Brazilian Conference in Rock Mechanics-SAR Rocks 98*, ed. by L. A. da Silva, E. F. de Quadros, and H. H. S. Conçalves (Santos, Sao Paulo, Brazil, Nov. 22-25, 1998). Univ. de Sao Paulo, Escola Politécnica, pp. 287-293.
- Shepherd, J., and T. Lewandowski, 1992. Modified Wongawilli Extraction with Mobile Breaker Line Supports: Preliminary Geomechanics. *Australian Coal Journal*, no. 38, pp. 41-47.

Thompson, R., and J. Frederick, 1986. Design and Field Testing of Mobile Roof Support for Retreat Mining. Paper in *Proceedings, 5th Conference on Ground Control in Mining*, ed. by A. W. Khair and S. S. Peng (WV Univ., Morgantown, WV, June 11-13, 1986). Dept. of Mining Engineering, WV Univ., pp. 73-78.

Wilson, H. G., 1991. Mobile Roof Support for Retreat Mining. Paper in *10th International Conference on Ground Control in Mining, Proceedings*, ed. by S. S. Peng (WV Univ., Morgantown, WV, June 10-12, 1991). Dept. of Mining Engineering, WV Univ., pp. 103-114.

PROCEEDINGS

THIRTIETH ANNUAL INSTITUTE ON MINING HEALTH, SAFETY AND RESEARCH

SALT LAKE CITY, UTAH
AUGUST 8-11, 1999

EDITORS:

F. Michael Jenkins
Research Mining Engineer
Spokane Research Center
National Institute for Occupational Safety and Health

John Langton
Chief, Division of Safety, Coal
Mine Safety and Health Administration
U.S. Department of Labor

Michael K. McCarter
Professor and Chair
Department of Mining Engineering
University of Utah

Bryan Rowe
Writing and Communications Program Coordinator
Department of Mining and Minerals Engineering
Virginia Tech

SPONSORS:

Department of Mining Engineering
University of Utah

Department of Mining and Minerals Engineering
Virginia Tech

Mine Safety and Health Administration
U.S. Department of Labor

National Institute for Occupational Safety and Health
Centers for Disease Control and Prevention

National Mining Association

National Stone Association

Utah Mining Association

Bituminous Coal Operators' Association

PUBLISHED BY:

Department of Mining and Minerals Engineering
Virginia Tech
Blacksburg, Virginia 24061-0239
540/231-6671

TN 295
159
1999