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Detection of Roof Instability by Monitoring the Rate of Movement

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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITS OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	in/min	inch per minute
h	hour	min	minute
in	inch	pct	percent
in/d	inch per day		

DETECTION OF ROOF INSTABILITY BY MONITORING THE RATE OF MOVE

By Hamid N. Meleki[1] and James R. McVey[2]

ABSTRACT

Cooperative efforts by the Bureau of Mines and Agapito & Associates, Inc., Grand Junction, CO, achieved the research objective of showing that data from measurements of the rate and change in rate of mine roof movement can be effective in detecting roof instability. Several instruments and techniques have been used to monitor roof movement and to detect imminent roof caves during pillar robbing. Early detection of unstable conditions can provide time either to withdraw personnel and equipment or to allocate supplemental support to prevent injury or downtime. Critical convergence rates were determined both manually and electronically. The detection of critical rate of movement has been shown to be an effective tool in ground control efforts.

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INTRODUCTION

The Bureau of Mines and Agapito and Associates jointly pursued research to detect unstable ground in response to a recognized need in pillar robbing operations. The Bureau developed both the electromechanical and ultrasonic rate units and jointly conducted field trials with Agapito and Associates. The research was conducted under the Bureau's Health and Safety, Ground Control Program. One of the goals of this program is to detect, and reduce miner exposure to, hazards associated with roof falls in underground coal mines. It is toward this goal that this research is directed.

Effective ground control is the key to improved safety and high productivity in underground mining. Even though in some coal mines up to 25 pct of the production budget is used for ground control, roof falls still occur because the operator is unable to detect unstable ground. This can result in the burial of the continuous miner during pillar robbing operations and an interruption of production due to the roof collapse in longwall gate roads, and even worse, it can cause injury to mining personnel. An effective ground control program is one that identifies unstable areas, thus allowing either withdrawal of personnel and equipment or allocation of supplemental support for maintaining open gate roads.

Because of the need to detect unstable roof, much research has been conducted on monitoring mechanisms and systems. Table 1 presents a critical evaluation of the different monitoring systems used for roof fall detection. Some commercially available sag indicators can activate warning signals when a predetermined roof movement occurs. Even though helpful for some mines, total roof movement in itself is not believed to be as good an indicator of roof stability as rate of closure. However, sagmeters and other devices can be modified to measure the rate of roof movement and then become more reliable indicators of imminent failure.

Several researchers have used roof-to-floor extensometers (pogo sticks) to monitor roof-floor convergence and the rate of convergence. Parker (1)[3] used

[3]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

TABLE 1. - Critical review of monitoring systems for roof fall detection

Device and response type	Advantages	Disadvantages
Roof sag: Commercial sag indicator.	Requires no visual monitoring after installation.	Not as effective an indicator as rate of movement.
Entry convergence:		
Pogo sticks................	Inexpensive, quick to install	Requires calculations.
Transit and spad...........	Does not obstruct entry.	Requires calculations and is time consuming.
Electromechanical rate unit.	Optimum for daily use by section supervisor in pillar robbing.	None.
Ultrasonic rate unit.......	Does not obstruct entry......	Not as sensitive as electromechanical rate unit.
Seismic: Microseismic.......	None........................	Requires data analysis, is expensive, and requires several geophones and data analysis to determine exact location of instability.

extensometers equipped with dial gauges, while Maleki (2) used transit and spads, and McVey (3) used electromechanical and ultrasonic devices. The latter devices are the most effective for production use underground. Repsher (4) used seismic emissions, produced as a result of changing stress conditions in the roof, to predict roof falls. However, this technique requires some data analysis, and the location of the instability may not be accurately predicted unless several instruments (geophones) are used.

MONITORING AS APPLIED TO ROOF FALL DETECTION

Ground movements were monitored in two coal mines to help detect roof falls. These mines, although typical of those found in the Western United States, were quite different from each other in ground conditions, support utilization, and mining systems. Roof lithology in these mines ranged from 2 to 5 ft of competent top coal to relatively incompetent mudstones. Primary roof support ranged from spot-bolting with resin bolts to a full-bolting plan using mechanical bolts and straps. Mining techniques included room and pillar with retreat mining as well as a longwall system.

Roof instability was detected by monitoring the rate of either entry closure or roof sag. The decision to monitor either entry closure or roof sag was based on the specific ground conditions at each mine.

RATE OF ENTRY CLOSURE

The rate of entry closure (roof-floor convergence) was used for the detection of roof falls at mine 1. Maleki (2) had demonstrated that these measurements were reliable indicators of roof movements (stability) because the ratio of roof to floor movements was constant, with the floor movements being less than 40 pct of the total roof-to-floor convergence. The roof at mine 1 was generally competent and consisted of 2 to 4 ft of top coal and 1 ft of mudstone, overlain by sandstone and claystone. The floor was a competent sandstone.

Roof instabilities occurred adjacent to the major faults and during retreat mining. Retreat direction and pillar robbing sequence are schematically shown in figure 1. During development, spot bolts were installed in the vicinity of major faults with more than 10 in of displacement. Prior to the commencement of pillar robbing, wooden posts were installed in the entries. Typical top coal roof and support upon completion of pillar robbing are illustrated in figure 2.

Major faults facilitated roof movements because fractures are zones of diminished frictional resistance. As the roof span increased during pillar robbing, lateral confinement perpendicular to the faults was reduced. This accelerated movements of rock blocks between fracture sets. Spot bolting with resin bolts postponed the occurrence of roof falls in the entries by suspending the roof from higher strata and by tying adjacent blocks, as shown by Lang (6). Failure eventually occurred because of the loss of confinement, generally within 1.5 h prior to roof failure.

In mine 1, roof-floor convergence was monitored by pogo sticks as well as with transit and spads. Marked spads were installed in the roof during pillar robbing and measured by a transit located in a crosscut. Figure 1 schematically shows the monitoring locations. Entry convergence was monitored for a full shift or daily until roof failure occurred in the vicinity of the instruments.

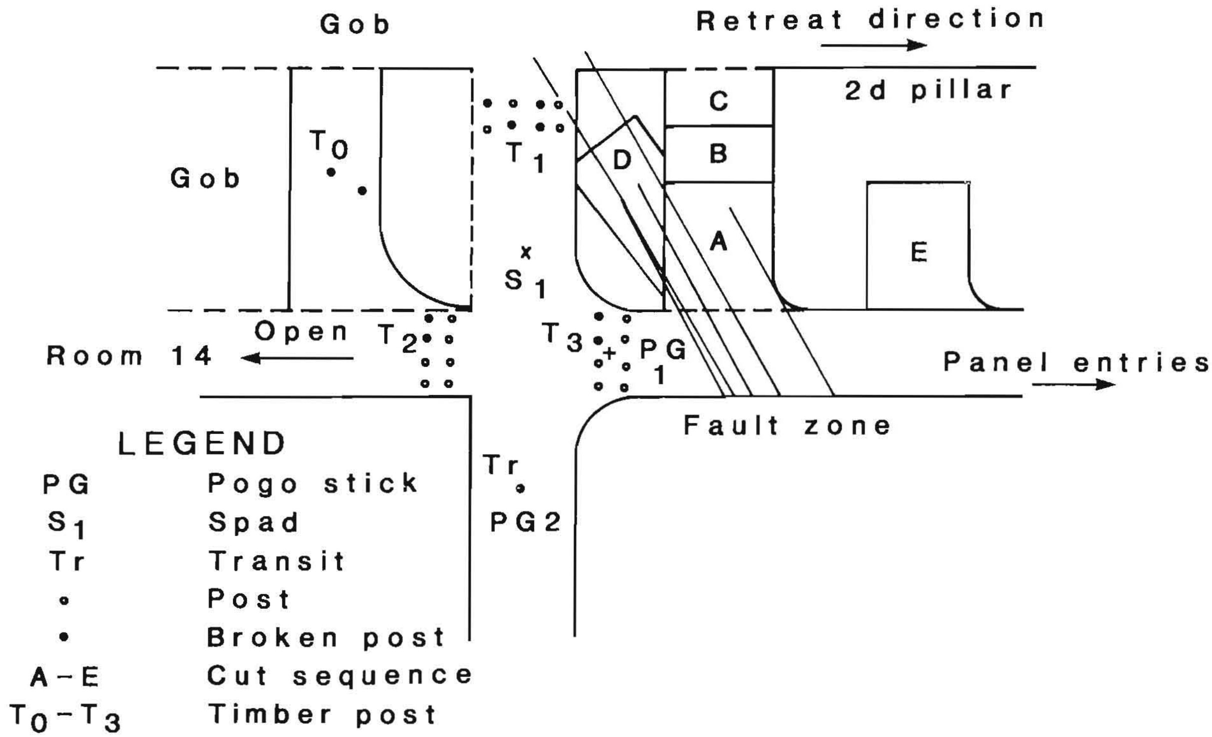

FIGURE 1.–Schematic presentation pillar robbing sequence and the relative positions of instruments.

Typical results from these measurements are shown in figure 3. Analysis of the results shows that the rate of entry closure (i.e., the slope of the convergence curve) was a reliable indicator of roof instability. Roof-floor convergence accelerated significantly within the 90-min period immediately preceding a roof fall. The breakage of timbers, which is conventionally used for detection of roof instability, only provides an adequate warning when the total entry closure reaches 3 to 4 in. After the breakage of the posts, however, the posts could no longer indicate whether the roof movements were stabilizing or accelerating towards failure. From figure 3, since other posts in the area had still not failed, the operator kept mining coal while the convergence measurements continuously indicated further movements and deterioration of ground conditions. The experience shows that the breakage of the posts is not always followed by a roof collapse, depending on post installation practice (time of installation, location, and the wedging conditions). The convergence rate device, on the contrary, can be installed at any time to assess ground conditions continuously.

From the analysis of entry convergence rates at nine locations (table 2), a critical rate of convergence equal to 0.20 in/min was established for mine 1. The value for the critical rate was refined to 0.25 in/min through several years of production monitoring using electromechanical convergence methods (3). The critical rate of convergence was observed between 30 and 90 min prior to a roof fall, thus providing ample time for removing personnel and equipment from unstable areas.

FIGURE 2.–Typical roof conditions upon the completion of pillar robbing in mine 1.

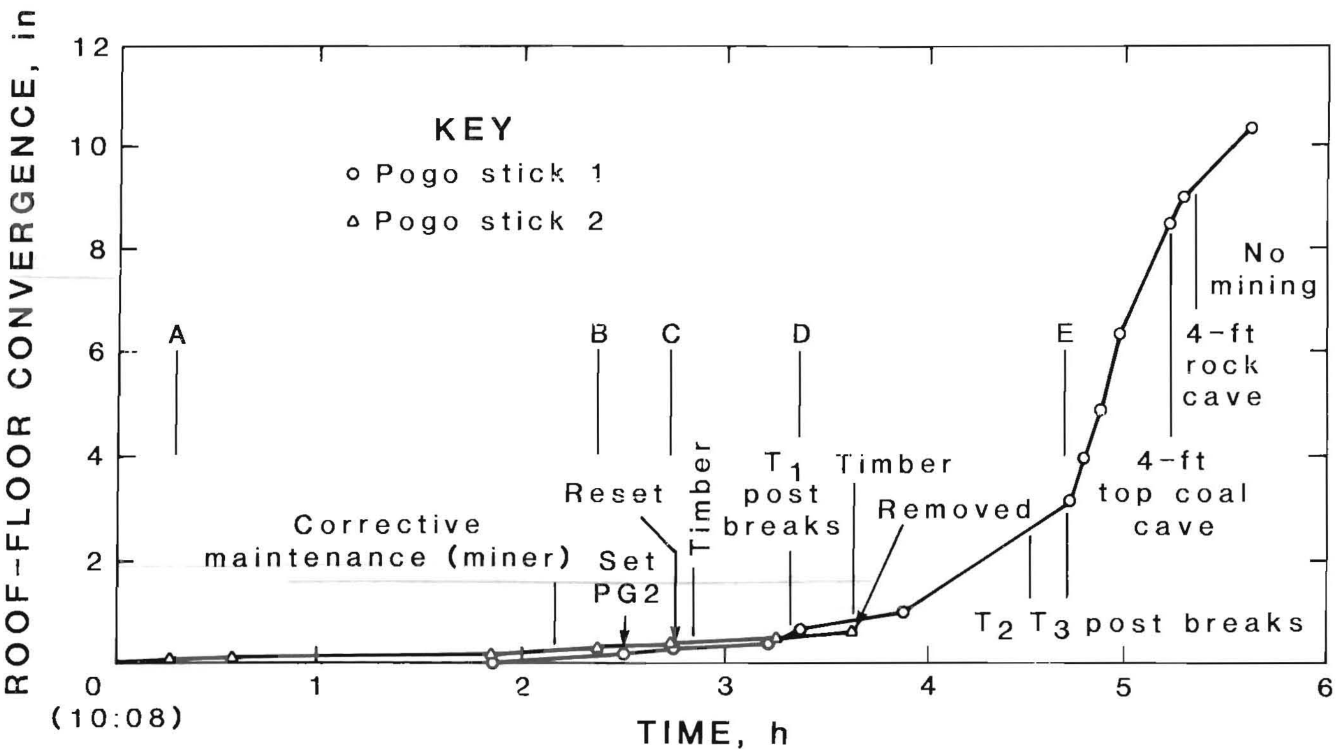

FIGURE 3.–Roof-floor convergence history versus mining position.

TABLE 2. - Summary of measured maximum rate of convergence versus roof conditions

Site	Top coal thickness, ft	Convergence rate, in/min	Time prior to failure, min	Roof stability
1.................	2	0.03	NAp	Stable.
2.................	2	.04	NAp	Do.
3.................	5	.10	NAp	Marginally stable.
4.................	2	.09	NAp	Do.
5.................	4	.20	30	8-ft failure.
6.................	5	.24	NAp	Do.
7.................	2	.20	60	10-ft failure.
8.................	2	.19	90	Do.
9.................	2	.20	90	Do.

NAp Not applicable.

RATE OF ROOF SAG

In mine 2, the stability of the roof was assessed by measuring roof movement (sag) and calculating the rate of roof sag. Roof sag was measured within the immediate roof by both mechanical and remote-readout electronic sagmeters, and then the rate of roof sag was calculated and correlated with roof stability. Roof-floor convergence rates could not be used at this mine because roof-floor convergence was too strongly influenced by the heave of soft bottom coal, relative to the movements of more cohesive roof rock. The ratio of floor to roof movements was not constant, but varied between 3 to 10 depending on face position.

FIGURE 4.—Typical roof and primary support in mine s.

Roof lithology consisted of 0 to 10 ft of mudstone overlain by sandstone-siltstone layers. Sandstone channels were frequently found to be intruding into the underlying mudstone, causing differential compaction and fracturing. Mechanical bolts and straps formed the primary support (fig. 4).

A reduction in roof stability occurred adjacent to the sandstone channels. Furthermore, roofs became unstable when loads were transferred from the gob to the gate roads during the longwall retreat. The sandstone channels caused instability by both reducing the strength of the underlying mudstone and transferring higher loads to the gate roads. Sandstone is more competent and thus more resistent to fracturing in comparison with the other strata. As a result, shear failure occurred adjacent to ribs that extended to the mudstone-sandstone contact.

From the analysis of sagmeter data collected along 3,000 linear feet of two longwall gate roads, it was concluded

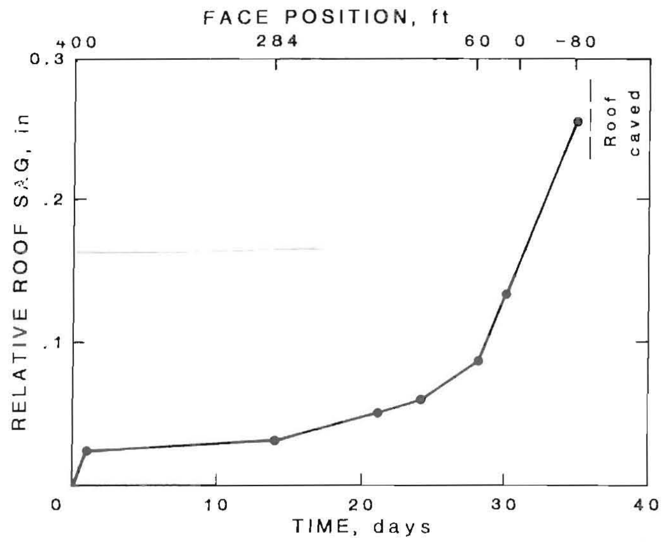

FIGURE 5.–Roof sag history versus longwall face position.

that the rate of sag was reliable in detecting roof instability. The data reveal two accelerated cycles of roof movements (fig. 5). The first cycle occurred during longwall development, but the roof stabilized shortly after mining began. The second cycle generally occurred when the longwall face approached the instrumented area. This cycle ended in roof failure if a critical rate of sag (slope of the curve) was achieved.

The critical rate of roof sag was established through the study of the measurements, (table 3). The roof was very stable when the rate of sag was less than 0.01 in/d, but roof flaking occurred at higher sag rates. Roof movements with rates exceeding a critical value of 0.025 in/d resulted in roof falls.

TABLE 3. - Summary of roof sag

Site	Thickness of mudstone, ft	Total sag, in	Sag rate, in/d	Time prior to failure, days	Roof condition
1 through 14............	([1])	0.05-0.23	0.010	NAp	Stable.
15......................	10	.40	.010	NAp	Do.
16......................	5	.10	.010	NAp	Do.
17......................	NAp	.14	.010	NAp	Do.
18......................	6	.11	.020	NAp	Do.
19......................	5.5	.28	.015	NAp	Do.
20......................	2	.26	.025	8	Failed.
21......................	2	.15	.040	9	Do.
22......................	NAp	.60	.054	18	Do.
23......................	NAp	.38	.066	7	Do.
24......................	5.5	.64	.130	7	Do.

NAp Not applicable.
[1]Varies from 0 to 10 ft.

AVAILABLE INSTRUMENTS

As discussed by Parker (1), Maleki (2), McVey (3), and Hawks (5), a variety of techniques have been used for roof movement measurements. However, there are few instruments that can provide a direct measurement of the rate of movement.

The Bureau has developed two such instruments. One uses an expandable electromechanical extensometer (pogo stick) connected to a remote readout box (fig. 6). The other uses an ultrasonic transducer located on the mine floor or attached to roof bolts (fig. 7). The ultrasonic wave is reflected off the floor or roof and is used to calculate the rate of closure. Both instruments determine the rate of closure by taking two readings within seconds of one another and comparing the results. Any difference is multiplied by the time between readings and converted to a rate of closure (inch per minute). The operator watches the digital readout on the remote readout box, and when a critical

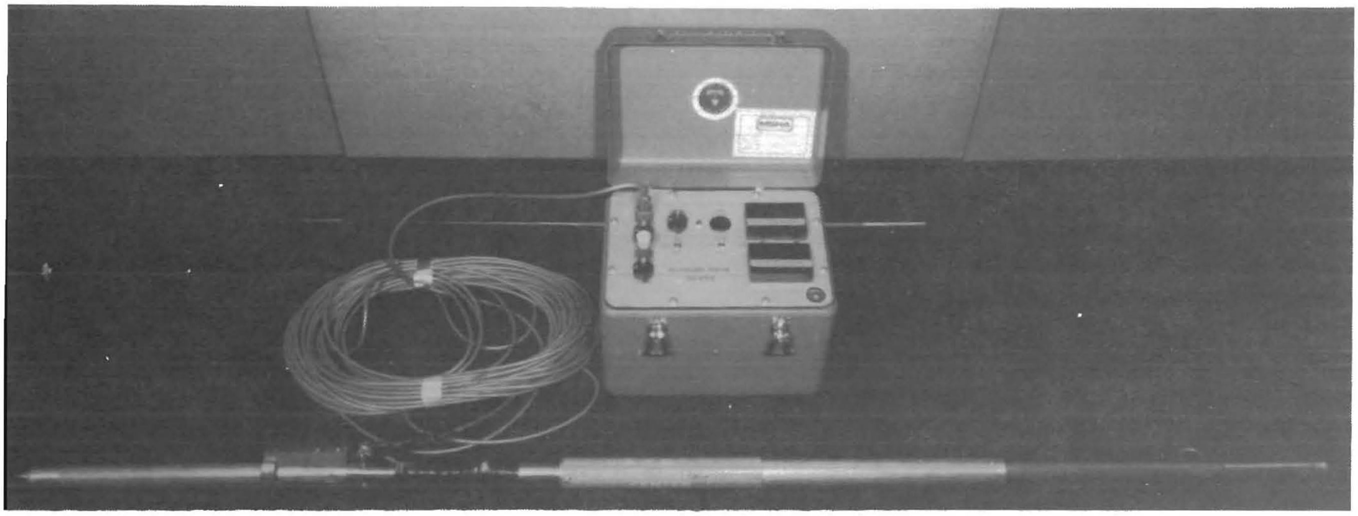

FIGURE 6.–Electromechanical closure rate instrument.

FIGURE 7.–Ultrasonic closure rate unit.

rate is reached or the roof movements begin to accelerate, it is evident the roof is becoming very unstable. Both instruments have alarm set points with an audible and a visual alarm.

Serata Geomechanics,[4] Berkeley, CA, is currently marketing a closure-rate meter similar to the Bureau unit. This rate meter is microprocessor-based and provides multiple functions.

Drum-type recording extensometers, can also be helpful in daily or weekly recording of convergence and for calculating the rate of convergence (fig. 8). This instrument is made by Slope Indicator Co. (SINCO), Seatle, WA. The recording drum is clock driven, and the user can obtain the convergence rate from the chart recording. A less expensive method uses a mechanical extensometer and caliper in order to take multiple readings at designated times.

Any electromechanical extensometer with a potentiometer can be used to measure rate of sag. Measuring the change in electrical resistance with time using an ohm-meter will give the same result. The extensometer can be calibrated in ohms per inch. Conkle Inc., Paonia, CO, built a resistive sagmeter that has a spring-loaded rotary potentiometer (fig. 9). The resistance change measured by the potentiometer is directly proportional to the sag between the anchor point and the roof surface. With the addition of a timing circuit, the unit can be used to measure rate. Figure 10 shows the Bureau's roof sagmeter and readout box. Readout is displayed digitally with a resolution of 0.001 in. Sag ranges are 2, 4, and 6 in.

Roof movement measurements are necessary in any roof control plan at any mine. Mine management should have tools available on a moment's notice to monitor

[4]Reference to specific products does not imply endorsement by the Bureau of Mines.

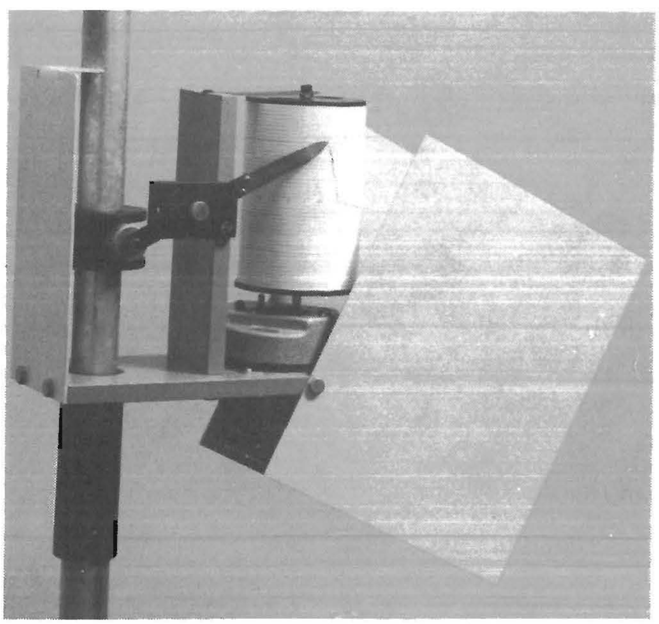

FIGURE 8.–Drum recording convergence meter.

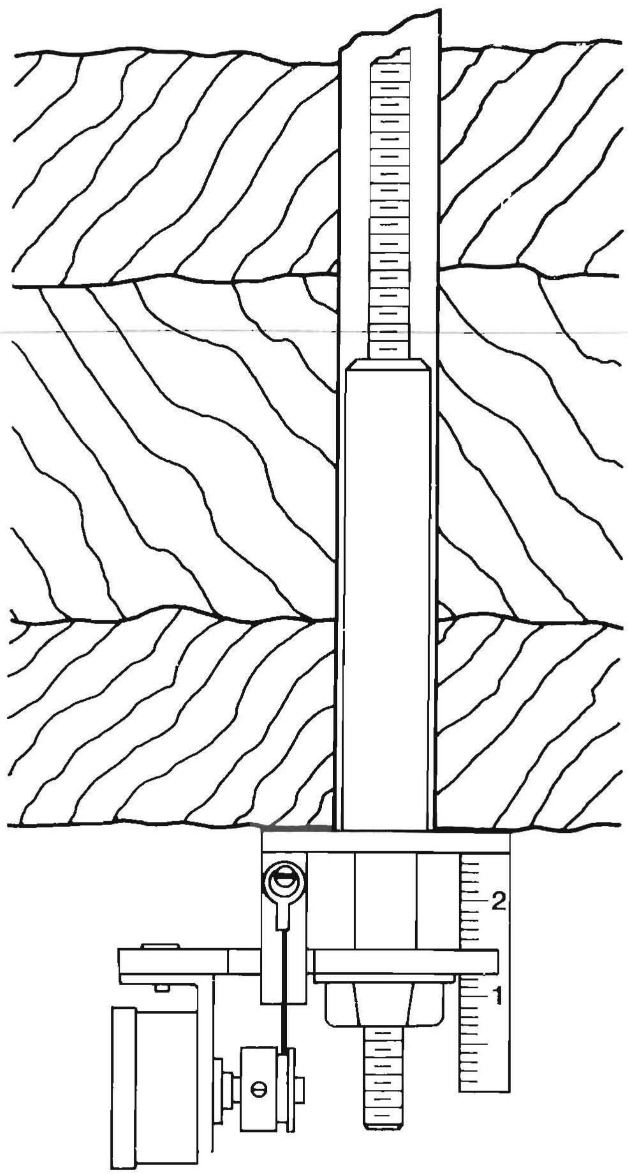

FIGURE 9.–Conkle sagmeter–electrical readout.

FIGURE 10.–Bureau of Mines sagmeter with electronic readout.

questionable roof conditions. Monitoring tools can be relatively inexpensive and can provide invaluable information to the ground control engineer.

CONCLUSIONS

Roof movements were monitored along several panels in two coal mines until either roof failure occurred or access was no longer possible. The monitoring included collecting data on a variety of roof lithologies and support systems, excluding the resin bolts.

This study has shown that the rate of ground movement is a reliable indicator of roof stability. It can be used to effectively determine when removal from an area is necessary and when secondary support is required.

The critical rates of movement are site-specific and are functions of roof lithology, bolting practice, and loading conditions. For the first mine studied, it was shown that a critical rate of entry closure equal to 0.25 in/min predicted the occurrence of roof falls within 90 min. For the second mine, a critical rate of roof sag equal to 0.025 in/d was shown to indicate the potential for a roof fall up to a week before the actual failure occurred.

Monitoring has been routinely used in these mines to increase safety and productivity. The rate of entry closure is conveniently monitored in the first mine by the section supervisor, adjacent to the major faults, using the electronic convergence rate units. Productivity has been significantly increased by enabling the supervisor to efficiently decide when to stop pillar robbing. This type of monitoring has greatly reduced the chances of the continuous miner being buried during roof caving. Equipment caught by caving generally require 0.5 to 2 days to dig out. Monitoring has also improved mining conditions, thereby reducing the chances of injury to miners.

Monitoring in the second mine has increased safety and productivity by optimizing allocation of secondary support. The rate of roof sag is being used to efficiently decide where and when to install secondary support in order to maintain open gate roads.

Similar monitoring can readily be performed in other mines for the detection of roof falls and for increasing safety and productivity. The critical rate of movement needs to be established for each mine's specific ground conditions. At present, convergence rate can be readily monitored using electronic convergence rate units, but further development work is necessary in order to more efficiently monitor the rate of sag.

REFERENCES

1. Parker, J. How Convergence Measurements Can Save You Money. J. Min. Eng., v. 174, Aug. 1973, pp. 92-97.

2. Maleki, H. N. Coal Mine Ground Control. Ph.D. Thesis, CO Sch. Mines, Golden, CO, 1981, 432 pp.

3. McVey, J. R., and W. L. Howie. New Closure Rate Device for Retreat Mining Operations. Min. Eng. (Littleton, CO), v. 25, Dec. 1981, pp. 1699-1700.

4. Repsher, R. C., and B. J. Steblday. Structure Stability Monitoring Using High Frequency Microseismics. Paper in Proceedings of the 26th U.S. Symposium on Rock Mechanics. A. A. Balkema, Boston, MA, 1985, v. 2, pp. 707-713.

5. Hawkes, I. Measurements of Mine Roof Movement (contract H0366033, Ivor Hawkes Associates). BuMines OFR 106-80, 1978, 238 pp.

6. Lang, T. Theory and Practice of Rockbolting. Trans., AIME (Mining), v. 223, 1962, 333 pp.

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