CONSIDERATIONS FOR USING ROOF MONITORS IN UNDERGROUND LIMESTONE MINES IN THE USA

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ABSTRACT

The Pittsburgh Research Laboratory of the National Institute for Occupational Safety and Health (NIOSH) endeavors to provide national and world leadership in the prevention of work-related illness, injury, and death. This is accomplished by using a scientific approach to gather information, assemble and create knowledge, then translate the knowledge and results into products and services. These products and services are then delivered to all personnel who can effect prevention. Obviously, the development and use of instruments to monitor mine roof conditions provides an opportunity to execute that mission.

In the late 1990's, based on observations at a number of underground limestone mines, only a few used roof monitors. Subsequently, NIOSH introduced the Roof Monitoring Safety System (RMSS) as an aid to roof inspection beyond traditional visual and sounding techniques. Initial expectations were that by gaining roof movement information, ultimately roof sag rates could provide indications of eventual failure.

During this investigation, RMSSs were installed in 13 underground limestone mines in six states and this paper analyzes the data obtained at three of these mines. This paper also provides an overview of the system, data, analysis, and applications relevant to the RMSS.

INTRODUCTION

Control of roof and rib rock under ideal conditions, where competent rock exists free of high stresses, can be accomplished by following some straightforward procedures for sizing room and pillars (1). The integrity of a mine structure is greatly affected by the natural weaknesses or discontinuities that disrupt the continuity of the roof and rib. Geologic discontinuities can originate while the material is being deposited by sedimentary or intrusive processes, or later when it is being subjected to tectonic forces (2).

Where natural weaknesses and discontinuities exist, roof monitors can provide additional information related to roof rock stability. Further, by obtaining measurements of rock movement and rates over time, the operator has information on the roof stability of the opening. This information can be used in the event of a potential problem to add support to the mine roof or remove equipment.

For example, at a mine in West Virginia the Miner's Helper[1], another type of monitor, was used to determine roof stability along a main haulage road. At one station a significant increase in the rate of roof movement was measured, at another only some movement occurred, and at a third no movement was detected. This was very helpful information, as the extent of the unstable area was identified. Upon further investigation, it was found that a significant separation had developed at the 5-ft (1.6-m) bedding plane and the area was determined unsafe for use. In the meantime the haul road was re-routed around this area (3).

Despite the value demonstrated by the above example, a relatively low number of mines use roof monitors. The sound of breaking or cracking rocks and visual inspection are often relied upon to indicate unstable ground conditions. In some cases, roof bolt holes can be examined for gaps or cracks with a scratch tool. If separations are detected a monitor can be installed to determine if the separation may expand. An additional safety component of the RMSS is that the readings from this instrument can be taken at ground level or further away from an unstable area by adding wire cable. In December of 1997, NIOSH introduced the RMSS at an Underground Stone Safety Seminar at Evansville, Indiana, USA. After the seminar, nine mine operators indicated an interest in using the RMSS. Installation of the prototype monitor began in 1998. During the next three years, approximately 60 monitors were installed at 13 mines in six states (Table 1).

Table 1. Roof Monitoring Safety System Installations 1998-2000.

State	Number of Mines	Number of Monitors
Illinois	1	4
Indiana	2	4
Iowa	1	2
Kentucky	5	15
Pennsylvania	3	35
Tennessee	1	*

*Mine operator built and installed own monitors based on RMSS design.

[1]Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

The basic premise for the RMSS was to provide a simple design combined with easy installation and use. Figure 1 shows the original design used during initial field trials. The open structure of the monitor created a problem with moisture and water. Installation also proved to be somewhat cumbersome. A revised enclosed design corrected both shortcomings and is shown in figure 2. These modifications provided simple construction and easy installation; two key criteria for use in the underground mine environment.

Figure 1. Initial design of RMSS and volt meter.

Figure 2. Revised design of RMSS.

BACKGROUND

Where and why are the essential questions when contemplating monitor usage. Obviously, in order to obtain data on rates, the RMSS or any roof monitor must be installed in strata that move or have some degree of instability. Monitor locations for some of the 13 mines in the study resulted from suspicion of unstable conditions. At other mines, RMSS usage reflected an interest in developing a ground control plan, collecting roof movement information for long term planning, and general safety and informational purposes.

In a massive roof beam devoid of discontinuities, no movement would be expected (figure 3). If a discontinuity such as a wedge exists, and a monitor is not installed within the rock affected by it, the monitor will not show movement prior to failure (figure 4). Conditions most conducive to the use of monitors for collecting roof movement data are in layered strata of roof rock as shown in figure 5. Installation of the RMSS in the middle of an intersection under these conditions presents the best opportunity to capture roof movement data. The middle of the intersection is commonly regarded as the area most prone to roof sag.

Figure 3. Monitor installation in massive roof rock.

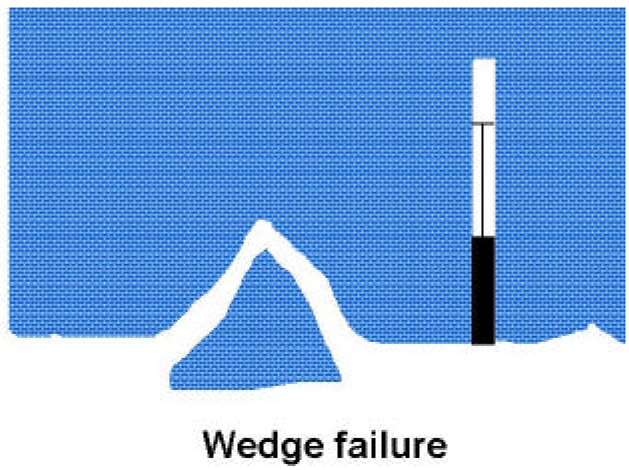


Figure 4. Monitor installation in wedge failure vicinity.

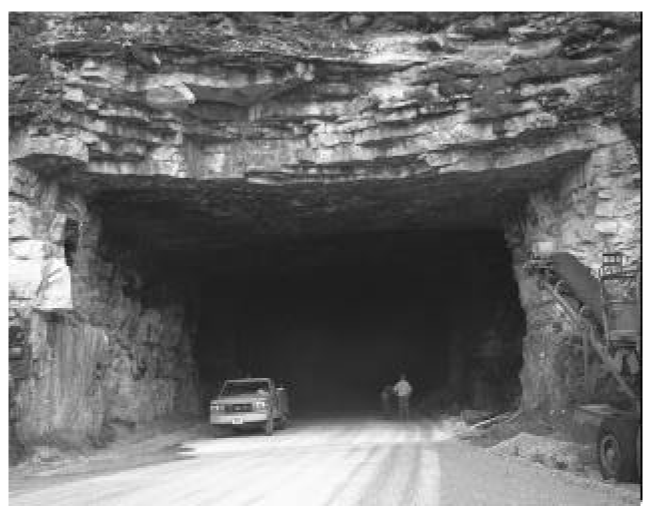


Figure 5. Layered strata.

The RMSS requires a 2-in (5-cm) diameter hole extending typically about 13 ft (3.9 m) into the roof. The RMSS anchoring system, however, can be adjusted to accommodate any depth hole. In most installations, two 6 ft (1.8 m) lengths of setting rods are attached to the approximate 1 ft (0.3 m) RMSS. The anchorage material is strips of metal banding sized to firmly secure the top setting rod and the RMSS itself at the bottom of the hole. Roof movement between the anchorage points at the top and bottom of the hole is detected through a potentiometer attached to a rack and spur gear connected to the setting rods. Movement, measured in ohms, is converted to inches as determined by prior calibration. A conductive cable is extended from the monitor across the mine roof and down the rib to the readout device at eye level. If the installation site is located at an active face, the RMSS can be modified by attaching jack and plug combination to the wire. The wire can then be unplugged during blasting and easily reconnected afterwards. Readings are taken with an ohm meter (4).

If dangerous roof beam deflection values are known, they can be used as a clear indicator of roof instability. Therefore, observing and monitoring sag is an important ground control measurement tool. Research has indicated that the rate of roof movement may often be more meaningful than the specific magnitude of movement (5). Vertical stresses within limestone mines are roughly equivalent to the weight of the overburden (1.0 psi/ft of depth). Local conditions attributed to discontinuities or faults and in mountainous areas may somewhat affect the vertical stress but in general the above approximation has been found to hold true. The horizontal stress component can vary from the Poisson's ratio component of the vertical stress to many times this value, depending on the geologic factors and the topography of the region (6).

RMSS INSTALLATION PROCESS AND INSTRUCTIONS

Typical mine site installations of RMSSs by NIOSH personnel were conducted in the following manner (figure 6):

Figure 6. Installation of RMSS.

- Mine operator selects sites for installation.
- Installation holes are drilled in roof to appropriate depth.
- Bucket\Basket truck with an operator is provided to obtain access to the roof.
- RMSS is inserted in hole and cable is attached and extended along roof and down the rib.

Once the installation hole is drilled, the RMSS can be in place and operating in less than 20 minutes. A book for logging the roof movement or stability is provided to the operator. The book contains information on how the RMSS works, a schematic of the components, an RMSS parts list, a data collection (ohms readings) sheet, and a table converting ohms to inches of movement. Also provided is the Roof Monitor (RMSS) General "Rules of Thumb" as shown in figure 7.

RMSS ROOF MONITOR

General "Rules of Thumb"

1. ALWAYS take readings with same voltmeter.

2. If the readings which are in ohms continue to go up take readings more often.

3. Every 14 ohms equals 1/16th of an inch(.16cm) (56 ohms equals 1/4 of an inch)(.64cm).

4. If you read a monitor every week for 2 or 3 months and no change occurs, it may be acceptable to begin reading every 2 weeks, still no change every month.

5. If a reading (monitor) goes up more than 5 ohms once again begin reading more often.

6. Please send a copy of your readings every 3 months to NIOSH (fax number provided).

Figure 7. Roof Monitor (RMSS): General "Rules of Thumb."

INSTALLATION OUTCOMES

As reported at the 19th International Conference on Ground Control in Mining (7), related below is a communication about a roof fall that occurred and was recorded by an installed RMSS.

> *"The mine foreman called today at about 9:00 a.m. and said that the monitor (RMSS) at 39-A was showing movement that amounted to 0.255 inch (0.648 cm) over two days. The roof where the monitor was located did not look bad to the eye prior to the roof fall according to the mine foreman. He said he would danger off the area and work at some other faces since he could hear the roof working now and the monitor (RMSS) was showing movement. At 12:40 p.m. the area caved in taking the monitor (RMSS) with it."* (Note: the associated data will be presented in the Data Analysis section).

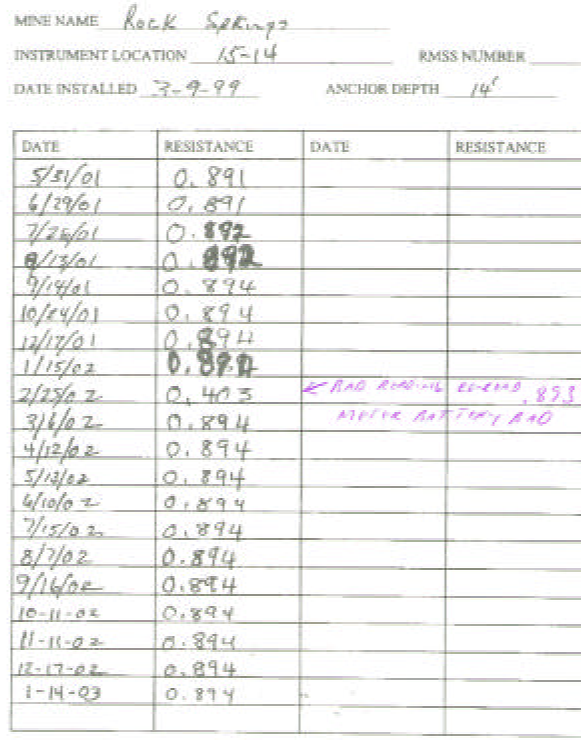
Obviously, this was a best-case scenario in RMSS utilization, in that the use of the RMSS allowed an unstable area to be identified. At other mines, however, the results were less than ideal, both in terms of roof movement information and operators incorporation of the RMSS into a ground control plan. Detailed below is a case in which the concept of the RMSS was not understood or utilized as intended. An RMSS was installed on May 31, 2000, and the initial reading was 670 ohms. The next reading was taken on June 20th some 20 days later, and an increase to 832 ohms was recorded. That increase in ohms equates to nearly 0.75 in (1.9 cm) in roof movement. Such a reading would suggest caution and require that frequent readings be taken. However, the next reading was not taken until July 30th, 40 days since significant movement was recorded. The reading on July 30th was 797 ohms, or a decrease from the previous reading by 35 ohms. At this point, it should have been realized that a problem existed with the voltmeter or instrument. From this time, the recorded readings were taken on average three times a month and remained at 793 ohms for about nine months. A possible explanation for this is that how the monitor worked was not fully understood. A contributing factor could also be that ground conditions were generally stable thus limiting the interest in utilizing the RMSS as a detection tool.

The outcomes from the other 11 mines could be characterized as somewhere in between the two cases described above. At four mines, interest after installation failed to materialize, management changes also occurred and after approximately six months these installations were abandoned. During this time, based on the few readings received, no roof movement occurred. At two other RMSS installation sites, the underground operations were converted to surface mines. At one of these mines, the RMSSs effectively showed roof movement, although only for a short duration because of the conversion to a surface operation. Moisture problems related to the original open design instrument as previously discussed negated valid data collection at another site and geologic conditions of the wedge failure nature as shown in figure 4, existed at another site, which was also shortly abandoned.

At two other mines, the use of the monitor or the monitor itself was modified for a specific application. In one case the RMSS was used to determine if roof rock stability was affected by mechanical scaling with an impact hammer. The test showed that little or no movement resulted from this method of scaling under the particular conditions at this mine (7). In the other instance of adapted RMSS usage, an operator needed to monitor the stability of the immediate roof of a haulage way in a benched area with ceiling heights of 100 ft (33 m). As previously stated, the RMSS requires a 2-in (5-cm) diameter hole for insertion; however, only roof bolt holes of a smaller diameter were available and it was not possible to drill new holes at that height. Therefore, the operator attached a 2-in (5-cm) diameter collar at the roof line and was able to modify the top anchor of the setting rod to accommodate the smaller diameter bolt hole. The readings from these monitors were initially stable. However, because the monitors used at this mine were of the original open design, moisture became a problem.

Another mine provides insights relative to the usefulness of monitors without actually detecting roof movement. In this case no roof movement provided useful information to the operator. Installations at a mine operated by Liter's Inc., Louisville, KY, showed a long-term application of monitoring despite apparent stable roof conditions. In 1998, four RMSSs were installed at the Rock Springs Mine located near Louisville, the highest populated and largest city in the state of Kentucky. This mine began underground operations about a decade before this time. In 2000, the company began planning for expansion that would necessitate tunneling underneath a major interstate highway system. By that time, housing in the area had also expanded and encroached upon the mining operation. During the permitting process a major concern of all parties was blasting, with citizens primarily concerned about potential structural damage to their homes.

One of the numerous items presented at the public hearings and in the permit documentation was the roof movement readings from the RMSS installations at the Rock Springs Mine. In this case, because the readings showed no movement, the operator was able to show a history of roof stability. As shown in figures, 8 and 9, the readings were recorded monthly by the mine worker and communicated to NIOSH and graphed on approximately a quarterly basis.


MINE NAME Rock Springs
INSTRUMENT LOCATION 15-14 RMSS NUMBER
DATE INSTALLED 3-9-99 ANCHOR DEPTH 14'

DATE	RESISTANCE	DATE	RESISTANCE
5/31/01	0.891		
6/29/01	0.891		
7/26/01	0.892		
8/13/01	0.892		
9/14/01	0.894		
10/24/01	0.894		
12/17/01	0.894		
1/15/02	0.89[illegible]		
2/25/02	0.403	← BAD READING RE-READ	.893
3/6/02	0.894	METER BATTERY BAD	
4/12/02	0.894		
5/13/02	0.894		
6/10/02	0.894		
7/15/02	0.894		
8/7/02	0.894		
9/16/02	0.894		
10-11-02	0.894		
11-11-02	0.894		
12-17-02	0.894		
1-14-03	0.894		

Figure 8. RMSS readings sheet from Rock Springs Mine.

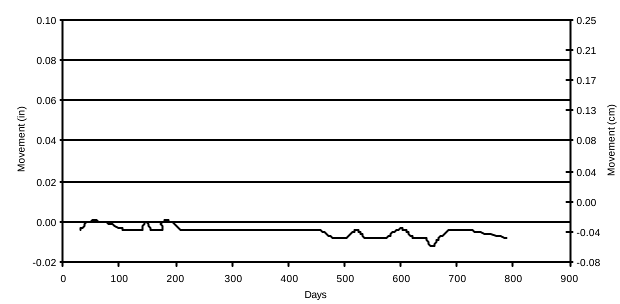


Figure 9. RMSS movement at Rock Springs Mine.

Another element of this situation worth noting is that during this time three different Mine Superintendents were responsible for recording and transmitting the monitor data. In addition, the mine expansion permit also required monitoring the two, 395-ft (132-m) tunnels that opened the reserves on the other side of the highway (figure 10). Installation of that system was completed in March 2003. Each tunnel has three RMSSs deployed that are tied to a data recording system with the capability to provide hourly readings of the roof conditions in the tunnels (figure 11).

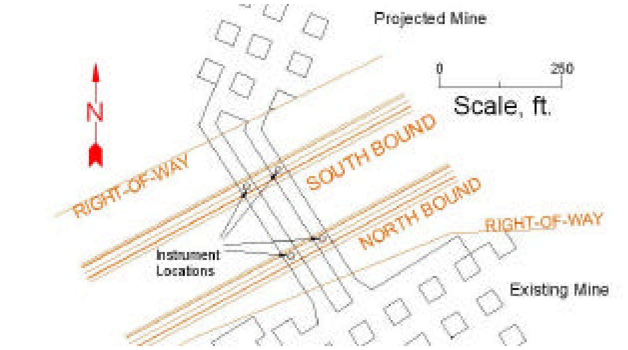


Figure 10. Map showing existing mine workings with projections.

Figure 11. Underground tunnel in Rock Springs Mine.

DATA ANALYSIS

Of the 13 mines in the study, three mines provided sufficient data for assessment. The first, the Rock Springs Mine, used the RMSS readings to show that a pattern and history of stable conditions existed underground over a prolonged period of time. The other two appeared to exhibit elevated levels of horizontal stresses that caused unstable ground conditions.

Another Liter's, Inc. mine, Big Bend, Meade County, KY, also utilized RMSSs. This mine began development in August of 1999 and unstable roof and ground conditions were in evidence by January of 2000. Aware of the monitors used at the Rock Springs Mine, Big Bend's mine personnel requested assistance and RMSS installations. Two RMSSs were installed and both of these monitors, shown as RMSS #1 and RMSS #2 in figure 12, were located in the high roof area, the original roof line.

Some early movement of these monitors most likely resulted from blasting or face advancement because of the proximity of the instruments to the working faces (8). Another RMSS (RMSS #3) was installed in August as the mine advanced and showed significant movement (figure 13). That area was bermed off in September, due to a roof fall located in the proximity of this RMSS #3. Also during this time, monitor readings were taken on a daily basis as would be expected under the circumstances.

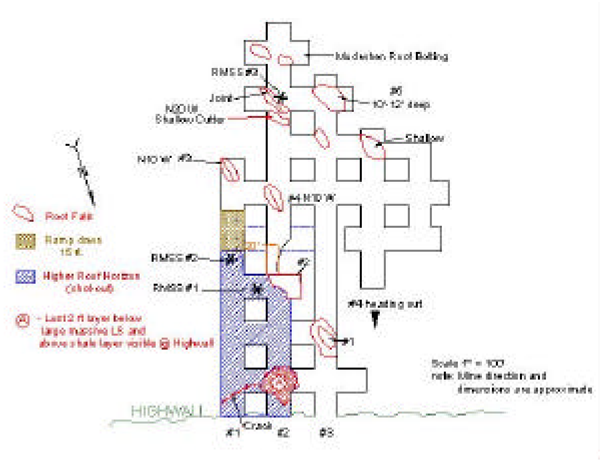


Figure 12. Mine development and RMSS locations.

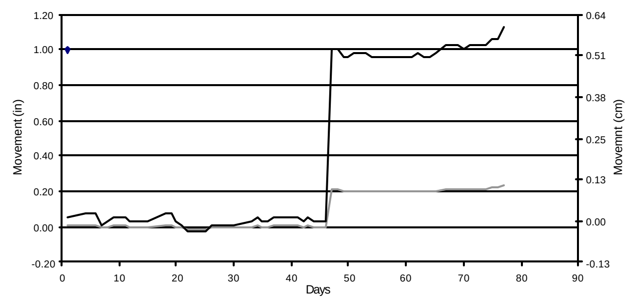


Figure 13. Roof movement at RMSS #3.

Conditions at Big Bend continued to deteriorate and attempts to mine at other roof horizons failed to substantially improve the situation. On November 3, 2000, because of safety considerations, Liter's decided to surface mine the reserve and abandoned underground mining operations. Figures 14 and 15 illustrate the now exposed roof of the former underground mine after blasting. Figures 16 and 17 provide a close-up view of what had been the mine roof rock. Underground observations relating to the geology combined with the roof movement measured with the RMSSs were apparent once these exposures were reviewed.

Figure 14. Big Bend Mine portal.

Figure 15. Exposed roof rock at Big Bend Mine.

Figure 16. Big Bend roof rock.

Figure 17. Close-up of roof rock.

At Big Bend, the RMSSs proved to be a useful tool in measuring roof movement, as related in the following correspondence received from the Mine Manager at Big Bend on March 23, 2001.

"I just wanted to thank you and NIOSH for your help with the problems we had in our mine. The roof monitors you installed were a big help in keeping our crew safe. The information you gave us on horizontal stress and other geological situations helped us to determine that it was unsafe to continue underground mining. We have closed the underground and have started surface mining. I sincerely appreciate your help."

As discussed earlier, the best-case scenario for RMSS use as a safety tool occurred when the RMSS allowed an unstable area of mine roof to be identified. Additional information on roof movement measurements were also obtained at this same mine. Because of unstable ground conditions, attributed to high levels of horizontal stress, and the successful use of the RMSS this mine was extremely interested in utilizing more RMSSs. During the course of studies at this mine, more than 30 instruments were installed with the first RMSS installed in 1998.

RMSS utilization at this mine is reflected in roof fall data from MSHA during the 1998-2000 period. During that time, the 13 mines that installed RMSSs showed a total of 16 reports classified as "fall of roof or back" (9). The mine that installed more than 30 RMSSs accounted for eight of these reported ground falls. Conversely, the other mines in the study, that were characterized with interest that failed to materialize after installations, were listed as having only two of the falls of roof or back during this time. The one mine described as "not fully understanding or utilizing the RMSS concept" showed no falls of roof or back in this data system. Therefore, it appears the RMSS was used more in mines with less stable roof conditions.

Another aspect of beneficial deployment of monitors is that there is strength in numbers. The higher the number of monitors installed, the greater the coverage of roof area with potential to provide information on instabilities. As in the case with the Rock Springs Mine, this operation also established responsibility and a process for reading the monitors.

ROOF MOVEMENT

A breakdown of the 30 RMSS installations, as related to roof movement, is as follows: 3 significant, 2 moderate, and 25 low or no movement. Significant movements are characterized as reaching failure, moderate, as continuing to move or progress, and low, as no or some movement but subsequently stabilizing. Figure 18 shows an area of the mine where all three conditions occurred.

Figure 18. Mine map with RMSS locations.

The following discussion details the history of two RMSSs that showed significant movement to illustrate the complexity of defining critical rates of movement. One of the RMSS locations, that had roof failure, showed significant movement during a short period of time. RMSS #19 was installed on October 22, 1999, and the initial reading was 2,143 ohms. During the next 50 days, eight readings were recorded and movement occurred, as indicated by the increase in ohms to 2,156 or approximately 0.06 in (0.15 cm). In the next five days, readings were taken daily with movement progressing rapidly to 2,225 ohms, an increase equivalent to nearly 0.3 in (0.79 cm). Prior to failure in this area, a smaller roof fall occurred that disabled the monitor. Because of the deteriorating conditions no repair was attempted. Figure 19 shows the rapid progression of movement that preceded the eventual failure.

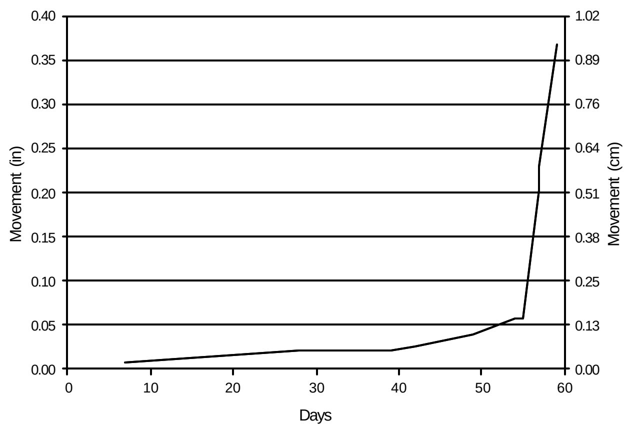


Figure 19. Roof movement RMSS #19.

RMSS #21 was installed on November 11, 1999, the initial reading was 2,224 ohms. In contrast to RMSS #19, this monitor increased to 2,236 ohms or approximately 0.06 in (0.15 cm) in 235 days; during this time 31 readings were taken. In the next 45 days (seven readings) another 0.06 in (0.15 cm) of movement occurred. RMSS #21 reached 0.3 in (0.79 cm) of movement, the point at which RMSS #19 was approaching failure, in mid-September of 2000, a period of 340 days. During the next five months another 1.0 in (2.5 cm) of movement was recorded. Interestingly, during the next six months the rate of movement subsided, as movement for that time period was 0.18 in (0.95 cm). Failure finally occurred after a total of nearly 2 in (5.0 cm) of movement (figure 20).

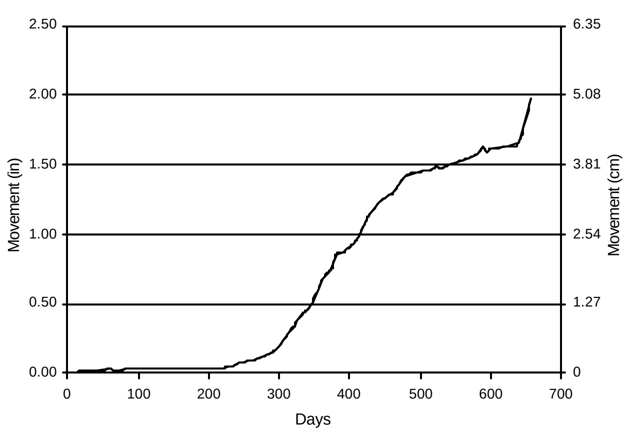


Figure 20. Roof movement at RMSS # 21.

The difference in failure rates and amounts of movement between these two RMSS monitoring sites apparently relates to the existing conditions relative to the locations. At RMSS #21, a roof fall had occurred approximately one intersection (40 ft-13.3 m) from this installation and the previous history of roof fall patterns indicated the direction of continuation would approach that of RMSS #21. The earlier fall apparently provided some relief of stresses, resulting in a more gradual progression to failure than observed at RMSS #19. At that location at the time of installation relatively stable conditions existed, unlike the area that affected RMSS #21.

At RMSS #27, another unique pattern of roof movement can be observed. At this site, failure has not occurred despite more than 2.25 in (5.68 cm) of roof movement. Two periods of rapid progression of movement have occurred followed by periods of gradual but increasing movement (figure 21). The variety of rates and amount of movement before failure illustrate the complexity of determining when a roof fall will occur even when using a monitor. However, the rates of movement provide the operator with useful information to address the change in ground conditions. The rates coupled with past mining experiences and knowledge can be used in decision-making regarding changes in roof support, direction of mining, or berming-off and unsafe area. The RMSS, or any instrumentation, is best utilized in conjunction with additional ground control information.

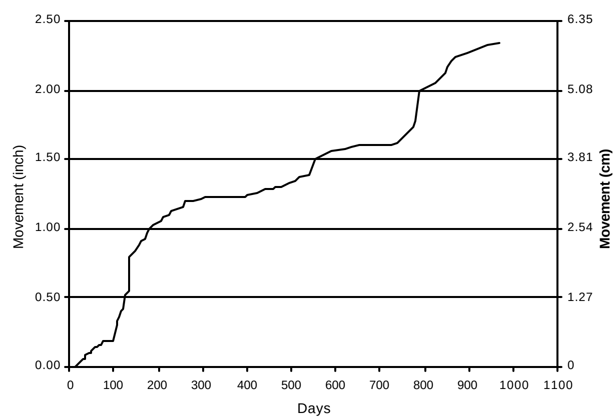


Figure 21. Roof movement at RMSS #27.

SUMMARY

Unless monitor readings become a dedicated or obligated responsibility or ground conditions become problematic the interest in monitoring is likely to wane over time. In two instances the RMSS may have served to assist in the prevention of injury or death to mine workers in the underground limestone industry. Roof monitors such as the RMSS can provide valuable information on roof conditions if installed, read, and evaluated with due diligence. As with any tool, proper use and understanding are essential to receive the maximum benefit of that implementation. Those mines and operators who recognize that simple yet imperative fact gain the greatest benefit from RMSS utilization.

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