FIELD TEST WITH STRAIN-GAUGED FRICTION BOLTS AT THE GOLD HUNTER MINE, MULLAN, IDAHO, USA

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ABSTRACT

To measure the loading behavior of friction bolts, researchers at the Spokane Research Laboratory of the National Institute for Occupational Safety and Health (NIOSH) installed strain gauges on the interior of friction bolts and developed a battery-powered miniature data acquisition system (MIDAS) that fits inside the hollow portion of the friction bolt. The advantages of this system are that it is protected from face blasts and eliminates the need for external wiring. Laboratory pull-out tests showed that friction bolts installed in a concrete block with resin were loaded to about 1.8 tons/ft of bolt length; bolts installed without resin were loaded to 1.3 tons/ft. Three strain-gauged friction bolts were installed at Hecla Mining Company's Gold Hunter Mine, Mullan, ID, in the wall or rib of a mechanized cut-and-fill stope. The object of these tests was to establish an installation procedure for the bolt-and-MIDAS combination and to evaluate performance. The stope was advanced in three 15-ft increments and strains induced in the rock bolts by stress changes in the rock were recorded every 30 minutes. The MIDAS proved to be rugged enough to withstand the shock and vibration from nearby (5 ft) face blasting. Data from MIDAS showed that the friction bolt installed with resin was the most sensitive to each face advance. It showed a steady increase in loading to a maximum value of 1000 microstrain. The friction bolt installed without resin showed stick-slip behavior with loads to a maximum of 400 microstrain before the stope was completed.

INTRODUCTION

Ground control is the most important aspect of safety in underground mining. Today, rock bolting is the most effective and economical means of ground support. A commonly used rock bolt is the friction bolt, invented by Dr. James Scott in 1972 (Scott, 1981). In 1973, Scott sold the rights to the Ingersol Rand Company, who registered the name "Split-Set" as a trademark in 1977. An elastic-plastic analysis of a Split-Set bolt by Davis (1979) showed that loading on a friction bolt was not a simple uniform frictional stress distribution around its circumference, but a complicated mix of friction, point, and free-surface loading conditions. Willaescusa and Wright (1977) directed their research at increasing the support load of friction bolts by filling the cavity of the friction bolt with cement. The conclusions of their work state that "grouted bolts are likely to provide up to four times the initial bond strength per meter of embedment length provided by the ungrouted bolts."

Although the use of cement grout is a very effective method of increasing bond strength, it is not as convenient as placing epoxy resin cartridges into the hole. However, resin cartridges need to be mixed properly to develop full strength. The jackleg drill commonly used to install friction bolts is not able to mix the resin completely, but rather punctures and thrusts its way into the resin. Although the resin is not properly mixed, the amount of mixing the resin does receive is sufficient to cause the resin to harden and increase pull-out load on the bolts.

Friction bolts have been used for 30 years, but little is known about their actual mechanical behavior when installed in mine rock. To learn more about such behavior, researchers at NIOSH's Spokane Research Laboratory (SRL) developed a miniature data acquisition system (MIDAS) (figure 1) that would fit inside the center of an installed 46-mm friction bolt (Sunderman, personal communication, 2001). To fit inside a 39-mm bolt, the first 12 in of the bolt hole must be overdrilled or reamed with a 1-5/8-in bit so that the wall of the friction bolt will not collapse.

LABORATORY TESTS

Laboratory tests consisted of uniaxial tension tests in a loading machine and pull-out tests in a large concrete block performed on a 39-mm in diameter, 5-ft-long friction bolt equipped with 16 strain gauges. The bolt had a measured thickness of 0.086 in, an average diameter of 1.453 in, an average gap width of 0.666 in, and a cross-sectional area of 0.335 in^2. Nine axial gauges were attached to the bolt beginning 6 in from the ring and spaced every 6 in to the end of the bolt. The circumferential gauges were started 12 in from the ring and spaced every 6 to 12 in from the end of the bolt.

The bolt was then attached to a Tinius-Olsen stiff testing machine. An initial load of 1000 lb was applied to set the bolt, followed by increases in load in 1000-lb increments up to 12,000 lb. A yield load of 16,000 lb and an ultimate load of 20,000 lb was assumed for the bolt. Figure 2*A* shows axial strains as a function of applied load. All axial strain gauges 12 in from the end of the bolt

Figure 1.—Minature data acquisition system (MIDAS)

show a linear response with an r-squared value of 0.96. Measured elastic modulus was about 10% higher than steel's nominal value of 30 million psi. 2*B* shows circumferential strains as a function of applied load. The circumferential strains were also linear, with Poisson ratios ranging from 0.20 to 0.25 as computed from pairs of axial and circumferential gauges. Circumferential strains are all negative, indicating that radially the bolt is in compression and getting smaller in diameter. This aspect will be important for explaining the effects of resin in pull-out tests.

The pull-out tests were performed using a large concrete block and installing the bolts with and without resin. The first test (without resin) used the same bolt as used for the uniaxial tension test. A 1-3/8-in hole was drilled into the concrete block, and the bolt was inserted. All the radial gauges showed extremely large strains, and most did not survive insertion. Because of the low survival rate of the circumferential gauges and to keep the costs of the experiment at a minimum, all friction bolts were then constructed with only axial strain gauges. Figure 3*A* shows axial strain versus pull-out load for a 5-ft-long friction bolt installed without resin. A zone in the center shows most of the axial gauges behaving similarly. The gauges at both ends, the ring, and the tapered end are outside the center zone.

The center zone shows that along most of the length of the friction bolt, an approximately equal amount of strain is developed. This finding is different than that shown during pull tests on grouted bolts, where a decrease in load is seen with distance from applied pull load. Pull-out load is about 6.5 tons, or 1.3 tons/ft, which is a normal value for a pull test on a friction bolt. Calculated stiffness of the bolt using the pulling force and the measured strains is 33.3 million psi, which is about 11% higher than the nominal 30 million psi value.

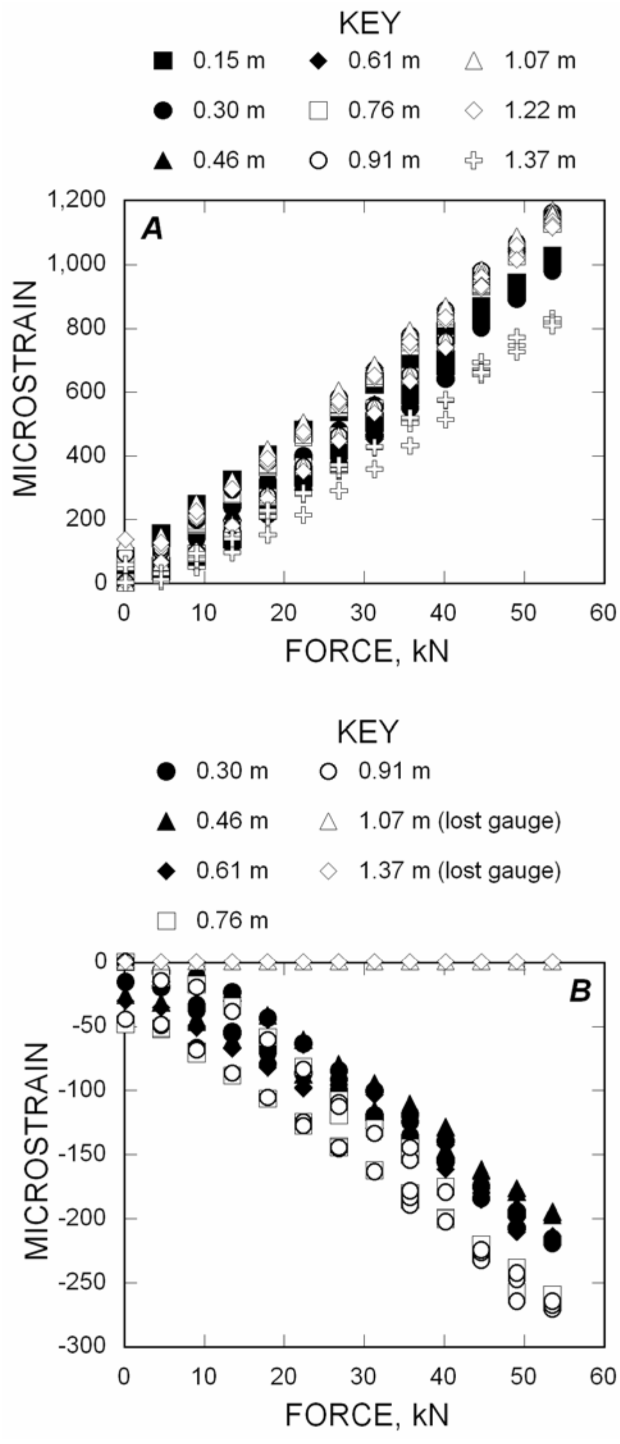

Figure 2.—Uniaxial tension (positive) test on strain-gauged friction bolt. *A*, Axial strains; *B*, circumferential or radial strains.

Resin cartridges were used in two pull-out tests. Two sticks of 1-1/8- by 24-in tubes of medium-setting resin were placed in the drill hole and a strain-gauged friction bolt was inserted. Only three strain gauges were installed on the bolts, one in the middle of the bolt and the two others in the middle portions of the top and bottom halves.

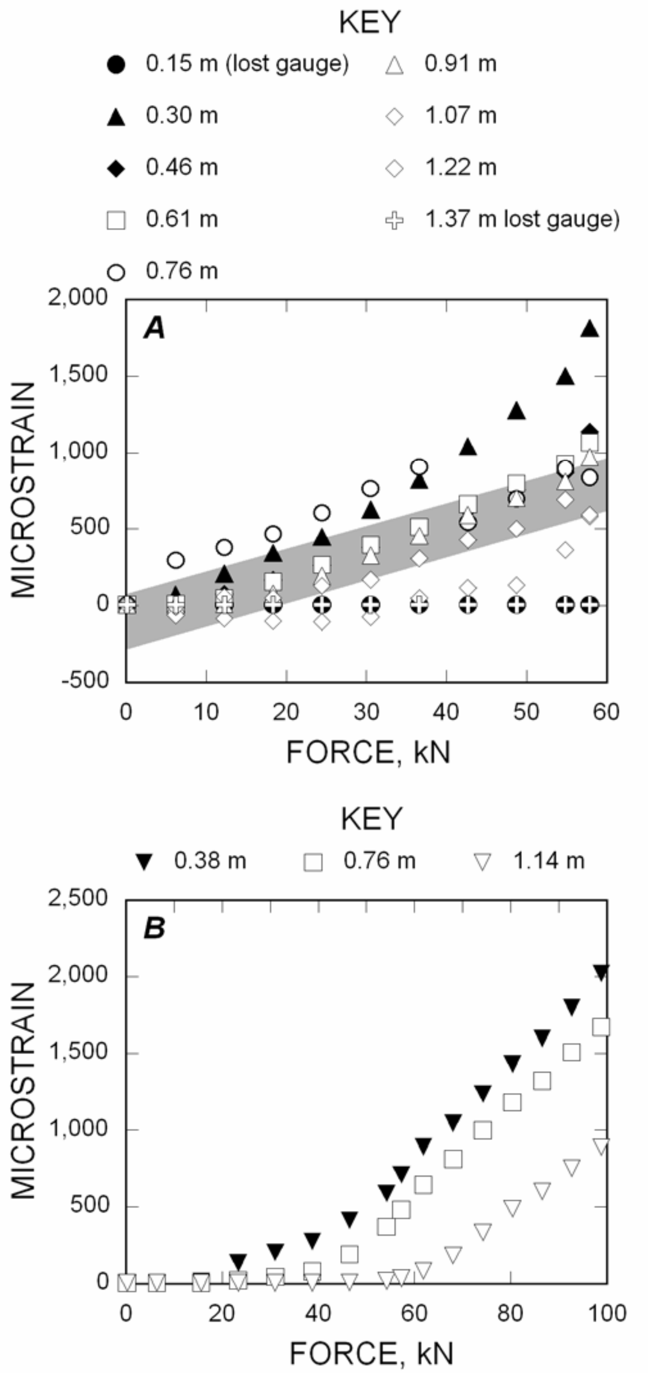

Figure 3.—Pull-out test on strain-gauged friction bolts. A, Without resin showing uniform axial strains along most bolt lengths; B, with resin showing axial strain related to distance from applied load.

Figure 3*B* shows axial microstrain versus pull-out load for a friction bolt installed with resin. Loading behavior is similar to that with grouted bolts, such as reinforcement bars (Serbousek et al. 1987; Signer 1990) and for cable bolts (Martin et al. 2002).

The increased strain in the friction bolt may come from two conditions: bonding of the rock–bolt interface and filling the hollow portion of the bolt at the back end of the drillhole. When the friction bolt is inserted into the resin cartridge, it first pushes the cartridge back into the hole. It then punches holes in the cartridges, spreading the resin between the bolt and the rock, but also packing a large portion of the resin into the hole and filling the center cavity. When a friction bolt takes axial load in tension, the diameter of the bolt is decreased according to Poisson's ratio, allowing the bolt to come out of the hole more easily. The resin in the back of the hole fills the cavity and the slot that prevents the bolt from getting smaller in diameter, as demonstrated in the laboratory uniaxial tension test. The resin has an effect similar to filling the cavity with cement grout to increase pull-out load.

FIELD TESTS

On October 10, 2002, four strain-gauged friction bolts were installed in the Gold Hunter Mine. The Gold Hunter is accessed from the Lucky Friday Mine, both owned by the Hecla Mining Co. (figure 4). The mining method is underhand mechanized-cut-and fill. The purpose of the field test was to test the MIDAS and measure the strains developed in friction bolts during actual mining. All bolts were 5 ft long; two were 39-mm in diameter, and two were 46 mm in diameter. For these tests, each bolt was equipped with four strain gauges placed 1 ft apart, as shown in figure 5. The strain gauges were numbered sequentially (1, 2, 3, and 4) from the ring end and read using the MIDAS.

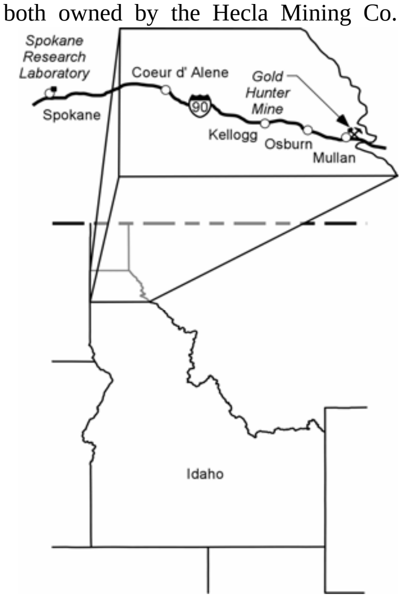

Figure 4.—Location of Gold Hunter Mine.

Three bolts were installed in a vertical row approximately 5 ft back from the face on the 4520 level of the mine and 3, 5 and 6 ft above the floor (section AA, figure 6). A 39-mm bolt was installed without resin at the 6-ft position and with resin at the 5-ft position. A 46-mm bolt was installed without resin at the 3-ft position. All bolts were installed during the regular mining cycle, and no special training or equipment was needed. However, the size of the MIDAS required that the first foot of the 39-mm bolts had to be reamed with a 1-5/8-in bit to allow the MIDAS to be inserted into the friction bolt. A newer model of MIDAS will fit inside the 39-mm friction bolt without the need to ream the bolthole. All bolts were installed with the friction bolt slot down to allow water to drain from the hole and to keep the gauges as high as possible on the back side of the drill hole. A fourth bolt was installed near an ore pass about 100 ft back from the face. The ore pass was chosen by mine personnel because the area was being loaded and causing the end rings of the friction bolts to yield. No resin was used in the ore pass hole.

Figure 6 shows the advance of the stope (dashed lines) and the date corresponding to the position of the face so they can be compared to the bolt strain data. Each advance was about 15 ft. Data from the strain gauges were collected from October 10 to October 30, 2002, at which time the MIDAS was removed from each bolt, and the stope was backfilled.

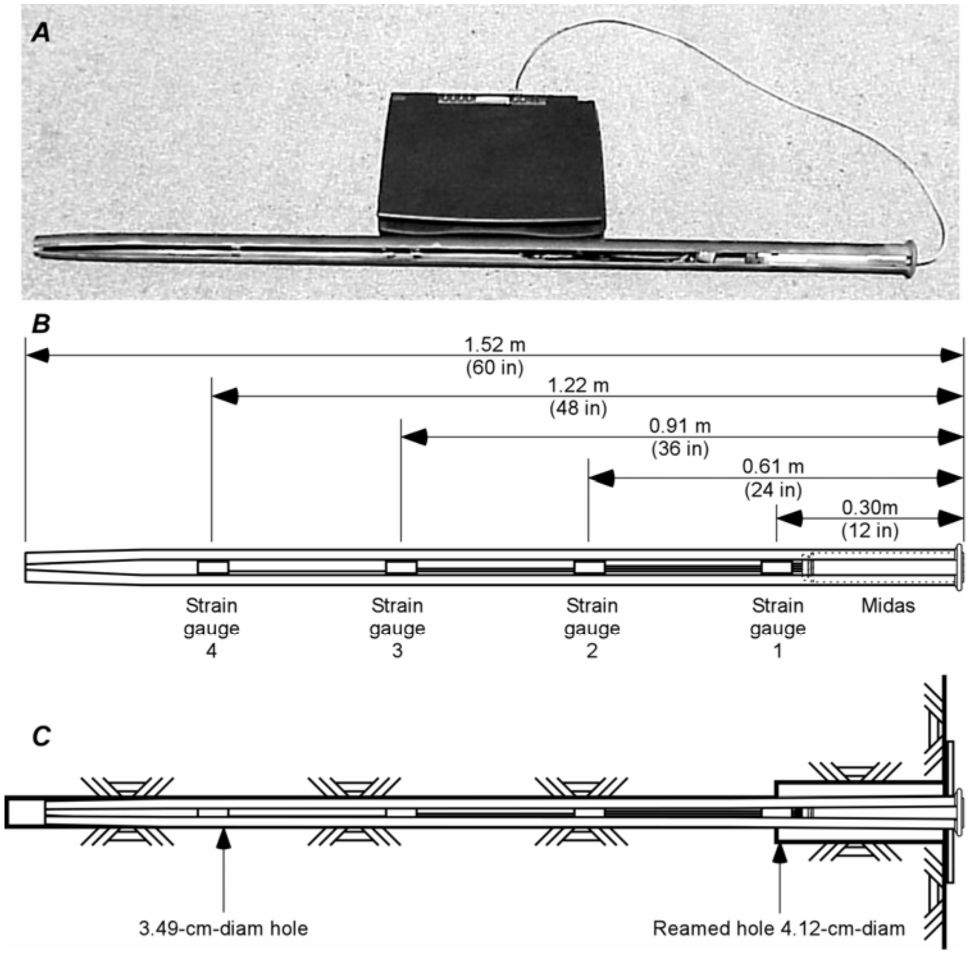

Figure 5.–*A*, Strain-gauged friction bolt with MIDAS attached to laptop computer; *B*, Diagram of friction bolt showing locatin of strain gauges; **C**, diagram showing installation of 39-mm strain-gauged friction bolt and reamed section of hole.

FIELD DATA AND RESULTS

Figure 7 shows the data plots of axial strains versus time. Since the MIDAS was zeroed out, the first movement in strain resulted from the first advance of the drift, resulting in a new face (October 11 on the figure). A day later, the second advance was made (October 12 on the figure). The third advance was 5 days later, resulting in the final face of the stope on October 17.

Figure 7*A* shows the strain on the 39-mm friction bolt installed with resin. Strain gauge 3, at 3 ft back from the ring end, shows the greatest amount of initial and final strain. Tensile strain is positive. The initial instantaneous strain shown by gauge 3 is 400 microstrain and resulted from the first face advance. The sharply rising increase to 700 microstrain resulted from an additional 300 microstrain of tensile strain from the second face advance. A 5-day pause in mining resumed with the third and final face advance on October 17, which completed mining of the stope and resulted in another increase of slowly creeping tensile strain of 300 microstrain. Final strain reached 1000 microstrain. The final stress in the bolt at gauge 3 is found by multiplying the strain by the Young's modulus of the steel (30 million psi), resulting in a bolt stress of 30,000 psi that is about one-half the yield strength of the bolt.

Strain gauge 2, 2 ft back from the ring end, showed behavior similar to that of gauge 3, but lower in magnitude, with microstrains of 150 (initial), 300 (secondary), and 400 (final). Gauge 1, in the reamed out portion of the hole, responded to the initial advance with a slight negative or compressive strain and was flat until the third advance, where it showed a slowly creeping tensile load increase of 100 microstrain. Gauge 4 showed an initial instantaneous tensile response of 200 microstrain that then declined gradually but steadily to 50 microstrain at the end of mining.

Figure7*B* shows the 39-mm friction bolt installed without resin. The most prominent feature is the "stick-slip" pattern of the second gauge, which occurred near the time of the third face advance. A slowly creeping stick-slip resulted in a final of value of about 400 microstrain. Gauge 3 showed a pattern similar to that of gauge 2 without the stick-slip for the second and third face advances. This gauge went into compressive strain with the first face advance. Gauge 4 showed an initial tensile strain of 200 microstrain that decreased to about 100 microstrain at the end of mining. Gauge 1 showed an initial strain of 325 microstrain that deceased quickly to a value of 200 microstrain for most of the mining.

Figure 8*A* shows the 46-mm bolt installed without resin. One or two of the lead wires of strain gauge 2 were apparently torn off during installation. Gauges 1, 3, and 4 went into compression (-100 microstrain) during the first face advance. The second face advance caused gauges 3 and 4 to go slightly into tension while gauge 1 continued to increase in compressive strain to -400 microstrain. The reason for this compressive state is thought to be

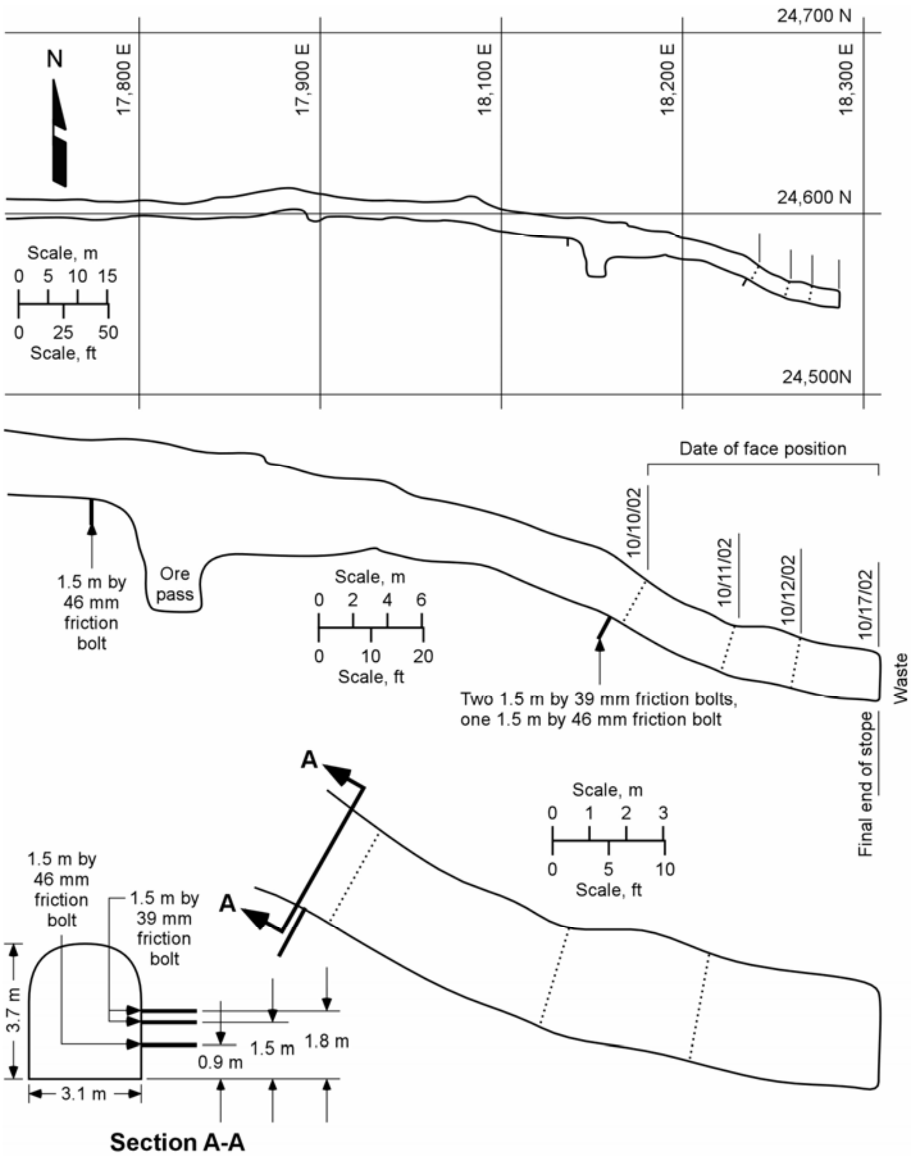

Figure 6.—Plan view of 4520 level. Section A-A shows location of three strain-gauged friction bolts installed 5 ft from stope face on October 10, 2002. Three advances of 20, 13, and 16 ft were made and the date of the new face labeled. A fourth bolt was installed near the ore pass.

that the bolt was bending. The third face advance shows all operating gauges undergoing slow tensile creep for an additional 100 microstrain.

A summary of the readings from the friction bolts at the face is that these bolts showed a slowly creeping tensile strain increment of 100 microstrain from the third face advance. The 39-mm friction bolt installed with resin was the most sensitive to each face advance and underwent the largest amount of strain. The 39-mm bolt installed without resin showed stick-slip loading, but generally showed the same pattern of loading as the bolt installed with resin. In general, the gauges at the center of the bolts (2 and 3) carried more load than the end gauges (1 and 4). The smaller strains on gauge 1 on the 39-mm bolts may have resulted from the reamed borehole. The reason for the lower strains at gauge 4 is not known.

The fourth friction bolt was installed in the rib near an ore pass about 100 ft from the initial stope face. Because some of the rings on the friction bolts were coming off in the mine, a bolt was placed there to determine the amount of loading taking place near the ore pass. Figure 8*B* shows that the initial face advance did not load the bolt significantly. A slight amount of loading (from 50 and 75 microstrain) occurred near the third face advance for gauges 2 and 1 respectively. The ring damage on the friction bolts may have resulted because bolts installed early in the mining cycle of the stope are initially loaded from the face advance and then are loaded by slow creep that ultimately exceeds the strength of the ring weld on the friction bolt.

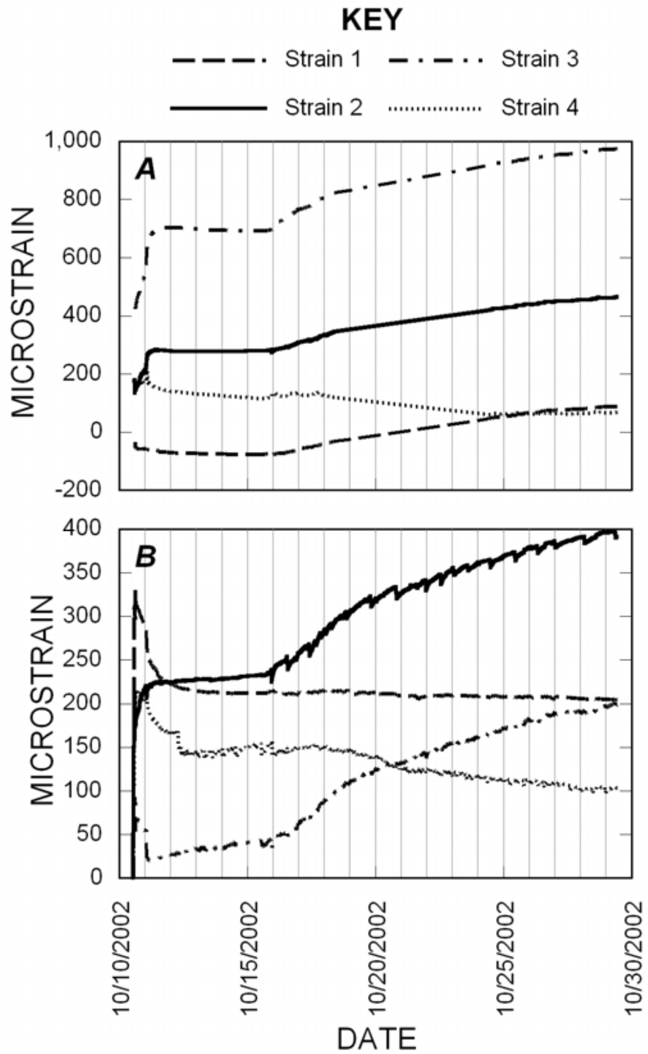

Figure 7.—Axial strain versus time for 39-mm friction bolts installed 5 ft from face. *A*, With resin; *B*, without resin.

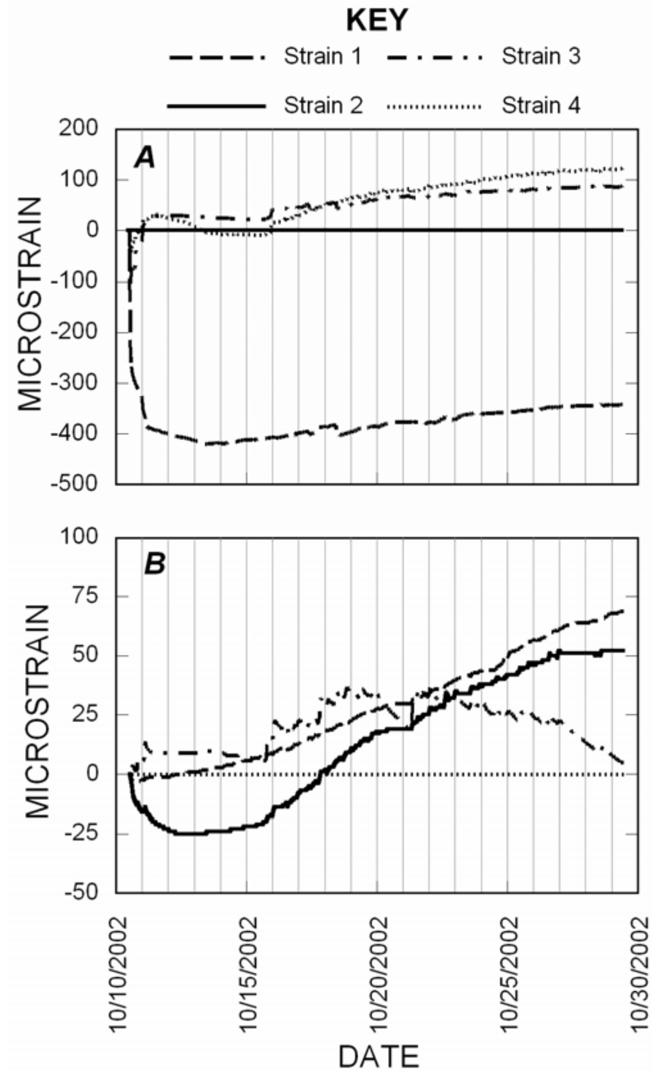

Figure 8.—Axial strain versus time for 46-mm friction bolts installed without resin. *A*, Bolt installed 5 ft from face and 3 ft above floor; *B*, bolt installed 100 ft from face and 5 ft above floor.

CONCLUSIONS

Strain gauges installed on friction bolts can be useful for studying loading conditions. In a uniaxial test, friction bolts were loaded as simple rods. In a pull-out test in which no resin was used, the bolt was loaded uniformly along its length. In a similar test with resin, bolt load was a function of the distance from the applied load. In the field, strain gauges showed stick-slip behavior in friction rock bolts installed without resin and no slippage when installed with resin. The latter bolt developed a higher load than the former. However, it should be noted that pull-out loads increase on friction bolts with time due to the effects of rock movement interlocking with the bolt and other environmental factors. Future work needs to be done to determine the effects of bending on friction bolts and strain gauges.

ACKNOWLEDGMENTS

Special thanks go to Dr. Alan Campoli of Fosroc, Inc., for information and resin cartridges; staff of Hecla Mining Company who assisted in the installation of the strain-gauged friction bolts; Tom Brady, Lewis Martin, and Mike Jones of SRL for laboratory assistance with drilling the concrete test holes and with the pull-out tests; Dr. Rimas Pakalnis and his students for discussions of friction bolts; and John Goris of Thiessen TEAM and Terry Karlsen of Inter-national Rollforms, Inc., for supplying the bolts.

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