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Mechanical Response of Split-Set Rock Bolts in Squeezing Ground

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ABSTRACT

Researchers from the National Institute for Occupational Safety and Health's Spokane Research Laboratory[1] installed Split-Set rock bolts instrumented with strain gauges to document the mechanical load response of the bolts in weak ground. Short-term monitoring of the bolts immediately after installation showed that some of the gauges went into tension. It was felt that the force exerted on the bolts to drive them into the hole should have caused the gauges to show compression. The tension probably resulted from the holes having crooked sections. Long-term monitoring over the course of a year also showed that the bolts were bending at some locations and that loads as high as 98 kN (22,000 lb) were recorded along sections of the bolts.

Load cells were placed on the head end of the bolts to determine head loads. Head loads up to 14.7 kN (3,300 lb) were generated during bolt installation. In addition, closure readings were taken across the drift to determine the convergence rate responsible for bolt loading. A Rock Mass Rating (RMR) was calculated at the site to compare with bolt response. The bolts were installed as part of the rebolting process in an area being repaired because the near-vertical beds in the walls were buckling and causing the wall to fail.

The instrumented Split-Set rock bolts will provide data that will lead to greater understanding of the behavior of the rock/bolt support mechanism. It may also be possible to explain the overall performance of the bolts in situ in terms of their design effectiveness. This work showed that load at the head of a Split-Set rock bolt was less than load along the interior of the bolt.

INTRODUCTION

Rock bolting is one of the most important methods of ground control in underground mines. Understanding the interaction between rock bolts and the ground they support is important when designing safe ground support systems.

Three basic types of rock bolts are used: mechanical shell, resin-grouted, and friction. The friction bolt was invented by Dr. James Scott in 1972 (1, 2). In 1973, Scott sold the rights to the invention to Ingersoll Rand Co., and in 1977, the company registered the name "Split-Set" as a trademark. Friction bolts have been commonly used for 30 years in underground metal mines because they are simple, have no moving parts, and can be installed in one step. The maximum load they can support is related to the diameter of the drill hole, diameter of the bolt, and length of the bolt. Split-Sets are the easiest bolt to install in ravelly or broken ground. Another advantage is that they have the ability to move as the ground moves, providing dynamic support along the entire length of the bolt (3, 4). Their main disadvantage is that they tend to corrode in certain environmental conditions.

Even though Split-Set rock bolts have been used for 30 years, little is known about their actual mechanical behavior when installed in mine rock. An elastic-plastic analysis of a Split-Set rock bolt by Davis (5) showed that loading was not an instance of simple uniform frictional stress distribution around the bolt's circumference, but a complicated mix of friction and point and free-surface loading. Movement along geologic discontinuities after installation also affects loading by bending the bolt and locking it in to the hole so that it holds larger loads. Figure 1 shows the manufacturer's concept of these loading parameters. While pull-tests are often used to determine the load-bearing potential of a rock bolt, these tests do not provide an understanding of how the bolts actually interact with the rock along their interior to supply support.

Rock bolts are often classified as either active or passive reinforcement (6). Active reinforcement means the bolt applies a positive force to the rock, while passive reinforcement means that the bolts depend on rock movement to activate the reinforcing action. Grasselli considers friction bolts a passive support system even though their inventor classified them as an active system (1). In actuality, rock bolts respond to rock deformation through an increase in axial loads. Mining geometry, geologic conditions, and cost determine which type of rock bolt system (active or passive) is the safest and most effective for a specific environment and use.

Researchers at the Spokane Research Laboratory (SRL) of the National Institute for Occupational Safety and Health (NIOSH) have investigated rock bolt systems for many years to determine their behavior so miners can be protected from roof falls (7, 8, 9).

[1] The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

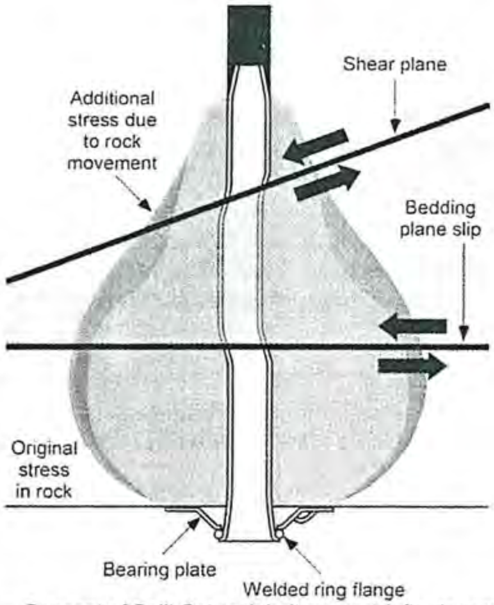

Figure 1.—Concept of Split-Set rock bolt support (after Ingersoll Rand).

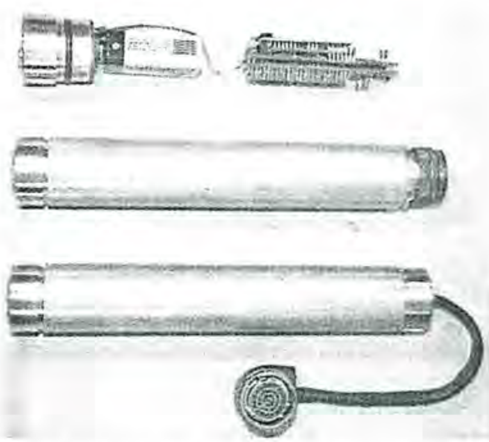

Figure 2—Miniature data acquisition system (MIDAS).

A miniature data acquisition system (MIDAS) (figure 2) was developed at SRL in 2002. This system records data from strain gauges and other types of electronic instruments (10, 11). Six field trials of instrumented Split-Set bolts monitored with the MIDAS have now been conducted successfully at the Lucky Friday and Galena mines in northern Idaho (12). MIDAS has proven to be a valuable tool in determining how rock bolts actually function in a mine environment.

TEST SITE

The Coeur d'Alene Mining District of northern Idaho and westernmost Montana lies within the Middle Proterozoic depositional basin of the Belt Supergroup. The area is a thick sequence of marine sediments interspersed with quartzite and argillite strata containing significant numbers of carbonate-rich intervals. The district is an area of base and precious metal mineralization within the west-northwest-trending Lewis and Clark zone, which is approximately 100 km (60 miles) wide and 250 km (150 miles) long (13).

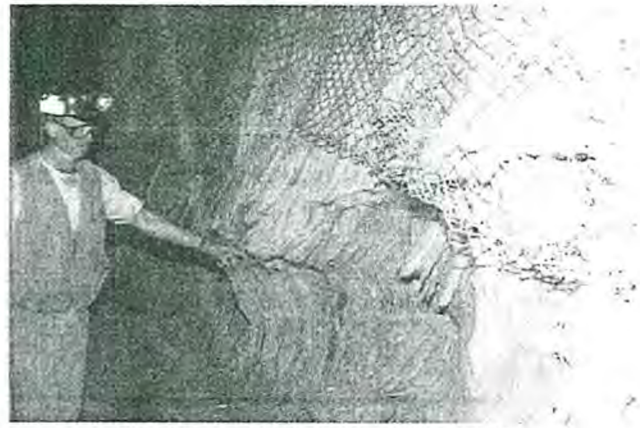

Figure 3.—Buckling of thin argillite bedding.

The Gold Hunter Mine is an old metal-producing property originally incorporated in 1925. Due to economic losses, the mine was forced to close in 1951. Forty years later, in 1991, Hecla Mining Co., Mullan, ID, discovered several mineralized structures containing some high-grade silver ores below the old workings approximately 1.6 km (1 mile) northwest of the then-existing Lucky Friday workings. The property is proving, once again, to be an economic silver- and metal-producing mine.

The test site is in the 5180 cross-over drift where near-vertical argillite beds are almost parallel to the drift. At the time the test bolts were installed, a portion of the north and south walls of the drift was being rebolted because beds in the drift wall were buckling (figure 3). Some rings of the original Split-Set bolts had broken off in the failed area. The original drift dimension was approximately 4 by 4 m (12 by 12 ft). The test site is over 1.6 km (1 mile) below the surface.

TEST PLAN

The test plan consisted of installing three 2-m- (6-ft-) long SS39 Split-Set bolts at mid-height on the walls to determine the load pattern on the bolts. The bolts were installed on December 16, 2003, in holes drilled with a jackleg and a 35-mm (1-3/8-in) bit. Two bolts, north 1 and 2, were installed in the north wall of the drift, and one, south 1, was installed in the south wall. These bolts had been instrumented with strain gauges along the interior parallel to the axis, and a load cell was installed between the head of the bolt and the 15- by 15-cm (6- by 6-in) load plate. Convergence was also measured between the walls at the same height. The MIDAS was set to take readings once an hour. The structural integrity of the wall rock at the test site was determined using a Rock Mass Rating (RMR) system. Combining these data determined the parameters for the use of Split-Set rock bolts under the specific rock conditions at the site.

Table 1.—RMR characterization

Parameter	Description	Value
Strength	R3 (50 MPa+)	7
RQD	<25%+	3
Spacing	50 mm	5
Condition	Slight to open/talc	12-6
Groundwater	Dry	10
Rating		37-31%
Design		35%

The bedding and joints of the Gold Hunter strike 195° and dip 65°S on the 5180 level of the Lucky Friday Mine. An RMR map showed an RMR value of 35, which is defined as weak rock. Specific characteristics are shown in table 1. The rock is not expected to be burst-prone, but relieves stress along the structure.

INSTRUMENTS AND DATA

Load Cells

Anclo 250 load cells that had been calibrated at SRL prior to installation were placed between the end of each 2-m- (6-ft-) Split-Set bolt and the bearing plate. Immediately after the bolts were installed using a jackleg drill, the cells showed initial loads of 6.0 kN (1,350 lb) at north 1, 3.8 kN (850 lb) at north 2, and 16.7 kN (3,300 lb) at south 1. During normal installation, the hammering action of the jackleg drill would have created a much higher initial head load, but to avoid damaging the load cells, the bolts were not hammered in hard. Data were recorded every 2 min throughout installation.

Loads decreased over the next few hours, to 5.2 kN (1,180 lb), 3.2 kN (720 lb), and 13.3 kN (3,000 lb), which represented reductions of 13%, 15%, and 9% (figure 4). The reason for this relaxation is not known, but could be related to readjustments of the bearing plate and bolt due to misalignment of the bolt hole relative to the rock face. It could also be the result of a slight rebound of the bolts following the force used to insert them into the drill hole, or because of deformation of the soft (RMR 35) argillaceous wall rock. The head loads 1 year after the test began were 17.8, 14.2 and 18.9 kN (4,000, 3,200, and 4,240 lb) (figure 5), which are far below the loads needed to break off the Split-Set rings. These data indicate that head loads increased over time, as would be expected as the rock mass buckled into the drift.

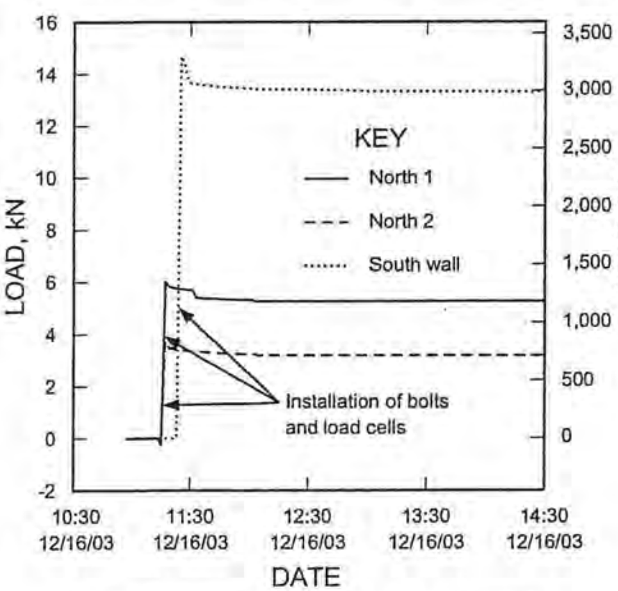

Figure 4—Load cell readings at time of installation.

Instrumented Split-Set Rock Bolts

The instrumented bolts were 2-m- (6-ft-) long SS39 Split-Sets with strain gauges installed at 0.61, 0.91, 1.2 and 1.5 m (2, 3, 4, and 5 ft) along the interior and are called gauges 1 through 4, respectively. The strain gauges were Micro Measurement's LWK-06-W250B-350. After the bolt interior had been sandblasted, the gauges were welded

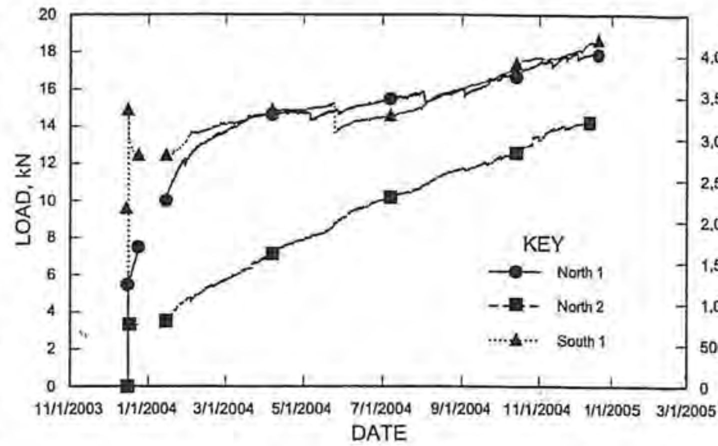

Figure 5—Head loads on load cells.

parallel to the axis of the bolt opposite the split. Before installation, MIDAS's were hooked to the bolts to obtain zero readings on the strain gauges to determine gauge response to hammering the bolt into the drill hole. The dataloggers had to be removed while the bolts were installed, but were hooked up again immediately after installation.

After installation, strain change observed in the bolts was both positive and negative from zero. Table 2 shows the strain changes. Driving the bolt into the hole with the jackleg should cause negative readings on the strain gauges because the steel is compressed by friction. Positive changes indicate the bolt is being bent at the gauge location. A pattern of compression near the head and tension near the end appears in the data, indicating the back of the hole was deviating from the front of the hole. This caused the bolt to bend. Because pressures differ on the jackleg during drilling, which causes the bit to change directions slightly, drill holes are not always straight. This is likely the reason for bending and positive strain changes.

Table 2.—Microstrain changes with bolt installation

Location	Gauge 1, 0.6 m	Gauge 2, 0.9 m	Gauge 3, 1.2 m	Gauge 4, 1.5 m
North 1	-224	-1,045	+875	+931
North 2	-152	-197	+173	+87
South 1	-1,644	-1,582	-1,722	+2,804

- = Compression. + = Tension.

After initial bolt installation, the MIDAS's were programmed to take readings once an hour. The following is a summary of the data collected over 1 year by bolt location. The data were zeroed out so that they represented readings taken after the bolts were in the hole Data collected installing the bolts are not included. Loads were obtained by multiplying microstrain by 11, which was the calibration factor obtained from the laboratory pull tests.

North 1: Figure 6 shows loads at the strain gauge positions and head load from the load cell for the north 1 rock bolt. Data from strain gauges at 0.6 and 0.9 m (2 and 3 ft) show what would be a theoretical "normal" load pattern for a Split-Set rock bolt. The gauges went into compression when the bolt was installed and into tensile loading for the rest of the test. Gauges at 1.2 and 1.5 m (4 and 5 ft) went into tension at installation, indicating they were undergoing some bending. The gauge at 1.2 m (4 ft) showed tensile loading for 3 months after installation before load readings decreased, indicating the bolt was bending again near the gauge. The gauge at 1.5 m (5 ft) showed some compressive loading for a couple of weeks after installation before it started being loaded under tension. At the end of 1 year, the four strain gauges showed an average load of 23.8 kN (5,350 lb). The

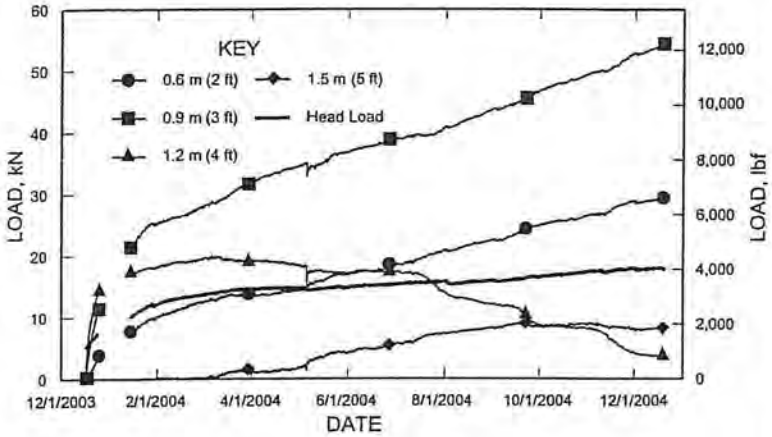

Figure 6—Loads on north 1 bolt, 5180-level cross-over.

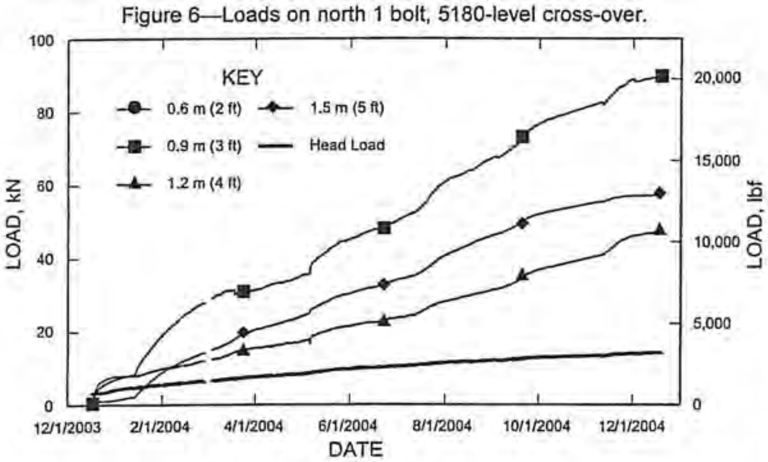

Figure 7.—Loads on north 2 bolt, 5180-level cross-over

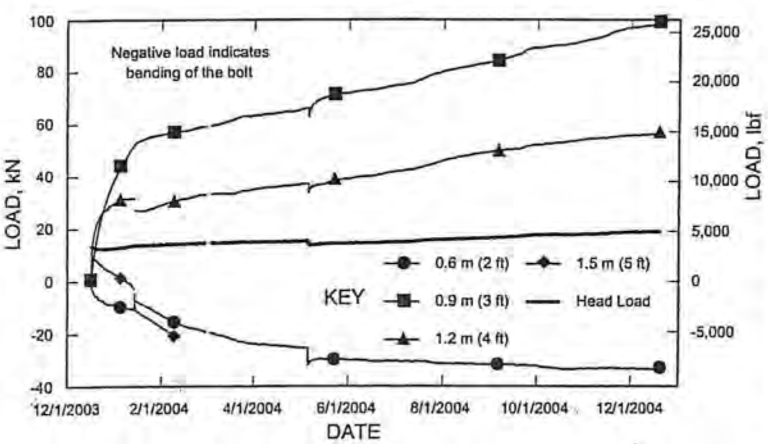

Figure 8—Loads on south 1 bolt, 5180-level cross-over.

load cell at the head of the bolt showed a gradual increase in load throughout the test, from 6.0 to 17.8 kN (1,350 to 4,000 lb) a year later.

North 2: Figure 7 presents the load data for the north 2 bolt. Bolt behavior followed the same pattern as did the north 1 when installed. The gauge at 0.6 m (2 ft) quit working shortly after installation, and the gauges at 0.9, 1.2 and 1.5 m (3, 4 and 5 ft) showed tensile loading throughout the test. After a year, they were taking loads of 89.9, 57.4 and 47.6 kN (20,200, 12,900, and 10,700 lb), for an average of 64.9 kN (14,600 lb). The load cell on this bolt also showed a gradual increase in load during the test, from 3.2 to 14.2 kN (720 to 3,200 lb).

South 1: Figure 8 shows the load data for the south 1 bolt. Data from gauges at 0.6 and 1.5 m (2 and 5 ft) showed compressive loads, indicating bending at these positions (ground movement would normally create tensile loading on the bolt). The gauge at 1.5 m (5 ft) failed after 2 months. The gauges at 0.9 and 1.2 m (3 and 4 ft) had tensile loads of 98.8 and 56.5 kN (22,200 and 12,700 lb), respectively, after 1 year, with the gauge at 0.6 m (2 ft) indicating -33.3 kN (-7,480 lb) of compressive load. The load cell reading on this bolt increased from 13.3 to 18.9 kN (3,000 to 4,240 lb).

Closure Data

A tape extensometer was used to monitor closure between the walls of the drift at mid-height in seven locations in the test area. The cross-over continued to close at an average rate of 0.41 mm/d (0.016 in/d) with total closures from 86.1 to 160.0 mm (3.39 to 6.3 in). The closure data show that wall closure as a result of buckling was the driving force for increasing loads on the rock bolts in the test area. Table 3 and figure 9 show closure data for a 10-month period beginning on February 12, 2004.

DISCUSSION

Ground support in weak rock presents special challenges. Underdesign can lead to costly failures, whereas overdesign can lead to high ground-control support costs. Test data after 1 year showed loads at the bolt heads of 17.8, 14.2 and 18.9 kN (4,000, 3,200, and 4,240 lb), while interior axial strain gauges showed average loads of 23.8, 64.9, and 40.8 kN (5,350, 14,600, and 9,140 lb) The large difference between the head loads and interior axis loads suggests the bolts were acting similar to a grouted bolt, where the largest loads can be along the central part of a grouted section (14). Loads along the bolt are not always transferred to the bolt head and bearing plate.

Table 3.—Closure measurements, mm (in)

Date	A	B	C	D	E	F	Ave/day
2/12/04	0	0	0	0	0	0	
3/4/04	0	8.7 (0.34)	11.6 (0.46)	16.8 (0.66)	8.5 (0.34)	7.9 (0.31)	0.51 (0.020)
4/1/04	14.7 (0.58)	26.4 (1.04)	28.1 (1.11)	13.6 (0.54)	17.4 (0.69)	15.7 (0.62)	0.41 (0.016)
4/21/04	21.7 (0.85)	28.5 (1.12)	34.9 (1.37)	42.9 (1.69)	24.2 (0.95)	19.9 (0.78)	0.41 (0.016)
5/26/04	39.0 (1.53)	59.0 (2.32)	59.2 (2.33)	45.8 (1.81)	39.2 (1.54)	34.9 (1.38)	0.46 (0.018)
6/23/04	43.7 (1.72)	94.9 (4.75)	69.3 (2.73)	54.9 (2.16)	46.8 (1.84)	42.4 (1.67)	0.48 (0.019)
8/10/04	63.7 (2.50)	95.0 (3.74)	92.0 (3.62)	72.5 (2.86)	58.4 (2.30)	54.6 (2.14)	0.41 (0.016)
10/7/04	83.9 (3.31)	125.2 (4.63)	120.4 (4.74)	94.2 (3.71)	73.3 (2.88)	69.0 (2.72)	0.41 (0.016)
12/20/04	106.2 (4.18)	160.0 (6.30)	150.9 (5.94)	118.4 (4.66)	89.5 (3.53)	86.1 (3.39)	0.41 (0.016)

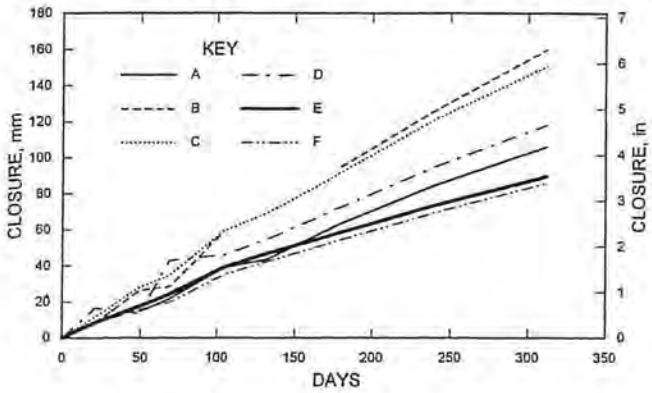

Figure 9.—Closure data measured by tape extensometer.

Some of the original Split-Set rock bolts in this area failed when the welded rings detached from the steel of the bolt. Laboratory pull-tests on new bolts showed that a load of at least 90 kN (21,000 lb) was needed to break off the rings. In actual application, less load would be needed because the rings are weakened when they are deformed during installation, and, in fact, head loads recorded during the test period were considerably below 90 kN (21,000 lb). Those bolts that had their rings broken off when the walls failed prior to the test were installed close to the face during initial mining of the drift. It is likely that differential movement along bedding associated with stress redistribution during initial mining locked these bolts in place, thus allowing loads on the heads to exceed the strength of the collar rings. This condition did not exist when the drift was rebolted a year later.

The Split-Set rock bolts provided adequate support to keep the walls from falling into the drift, but they did not prevent the walls from buckling and closing in on the drift (see figures 3 and 9). Wall closure was not a problem because the drift had been widened when being repaired. If closure had been a problem, a stiffer type of bolting system could have been used, perhaps fully grouted rebar bolts. Another alternative would have been to fill the Split-Set rock bolts with grout after they were installed. Research in Australia shows this practice can increase the pull-out strength of Split-Set rock bolts by up to four times (3).

CONCLUSIONS

A database on the support used in their mines can help companies to analyze unexpected ground conditions. The results from these in-mine bolt tests at the Gold Hunter Mine, where weak rock presents special challenges, are aimed at assisting mine professionals in their task of designing a safe workplace in a cost-effective way.

The data show that Split-Set rock bolts should be considered active rock bolts because a load is applied at the head and between the zones on the bolt when the bolt is installed. This load imparts compressive load to the rock mass immediately. Installation of the Split-Set bolt also imparts radial load to the rock.

Compressive and tensile strain changes along the axes of Split-Set rock bolts at the time of installation indicate that the bolts buckle and bend as part of the installation process, and the load-bearing capability of the bolts will be affected by the straightness of the drill hole as well as by hole diameter, length of bolt, and local geology.

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