# Use of strain-gauged rock bolts to measure rock mass strain during drift development

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ABSTRACT: An experiment is described in which instrumented rock bolts were used to measure strain in the rock mass during drift development at the Stillwater Mine, Nye, Montana, USA. Two strain-gauged rock bolts were grouted into the middle of the rib next to the face. The drift was excavated in three advances, each one-half drift wide. Strains were recorded hourly by a datalogger. Results show that the average change in axial bolt strain for the first and second advance was about the same and that there was almost no change in strain after the third advance. Bending strain was observed 19 cm from the head of the bolt.

## 1 INTRODUCTION

Unstable ground around openings continues to be a safety concern in underground mines, and ground falls are a major contributor to underground injuries and fatalities. Ideally, stability and design analyses should be conducted early in a mine's life so that problems can avoided or at least minimized to the greatest extent possible. The National Institute for Occupational Safety and Health (NIOSH) is advancing methods to validate computer models of a rock mass in order to assist in the design of a safer work environment for miners.

One method of validating computer models in rock mechanics studies is to compare field strains to calculated strains. Strain-gauged rock bolts can measure strains close to the skin of underground openings. By placing the gauges close together, strain gradients can be determined.

An experiment was conducted in which strains were measured during the advance of an underground drift. The purpose of this paper is to describe the instrumented bolts, the installation procedure, and the measured strains.

## 2 INSTRUMENTS

Serbousek & Signer (1987) describe the construction of the rock bolt used in this experiment. Although the strain-gauged rock bolts used in this experiment were constructed at SRL, they can be purchased commercially. Figure 1 shows the positioning of the strain gauges on the bolt. They are numbered 1 through 6 from the head of the bolt on side 1, and 7 through 12 on side 2. Strains are analyzed from pairs of gauges. Pair 1 is composed of gauges 1 and 7, pair 2 is composed of gauges 2 and 8, etc. A positive value indicates tensile strain. A negative value indicates compressive strain. Uniform tension would be indicated if both gauges of a pair have the same positive magnitude of strain. Differences in the magnitude of strain indicate some degree of bending. Axial strain is obtained from calculating average strain from each pair.

Each gauge on the bolt was calibrated. The calibrations showed that the response of all strain gauges was linear ($r^2 = 0.96$) except on gauge 4 of bolt 1. The gauges were read with a Campbell Scientific 21X datalogger.

## 3 INSTALLATION PROCEDURE

The test site was on the 3200 level of the mine at the eastern end of the footwall drift (Fig. 2). Two 1.5-m-(5-ft) long strain-gauged bolts were spaced 30 cm (1 ft) apart vertically and 15 cm (6 in) back from the face in the southern rib. The bolts were installed in exactly the same manner to ensure reproducibility of field data. A jackleg drill was used to drill holes 3.8-cm (1.5-in) in diameter, 1.5 m (5 ft) deep, and about 5° below horizontal.

The holes were pumped full of a nonshrinking grout, after which the bolts were inserted and oriented

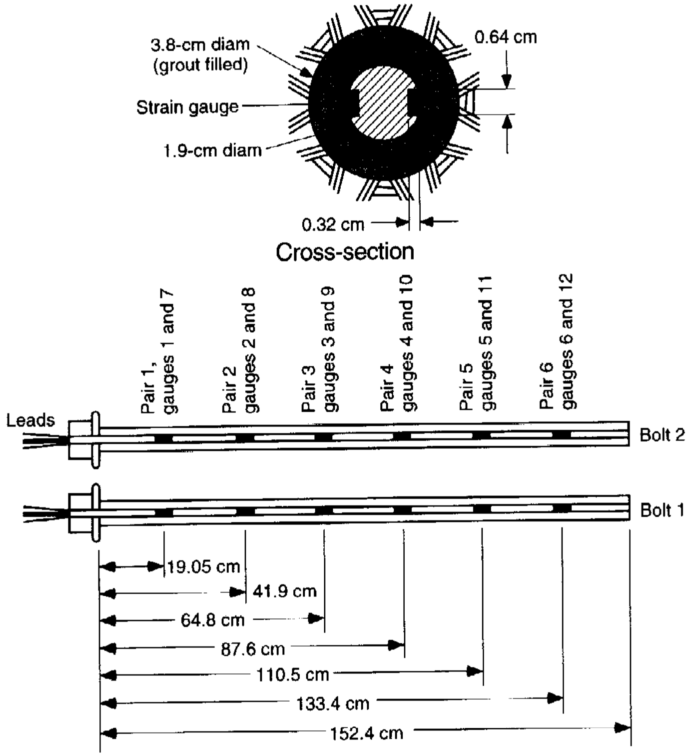


Figure 1. Location and orientation of strain gauges on bolts.

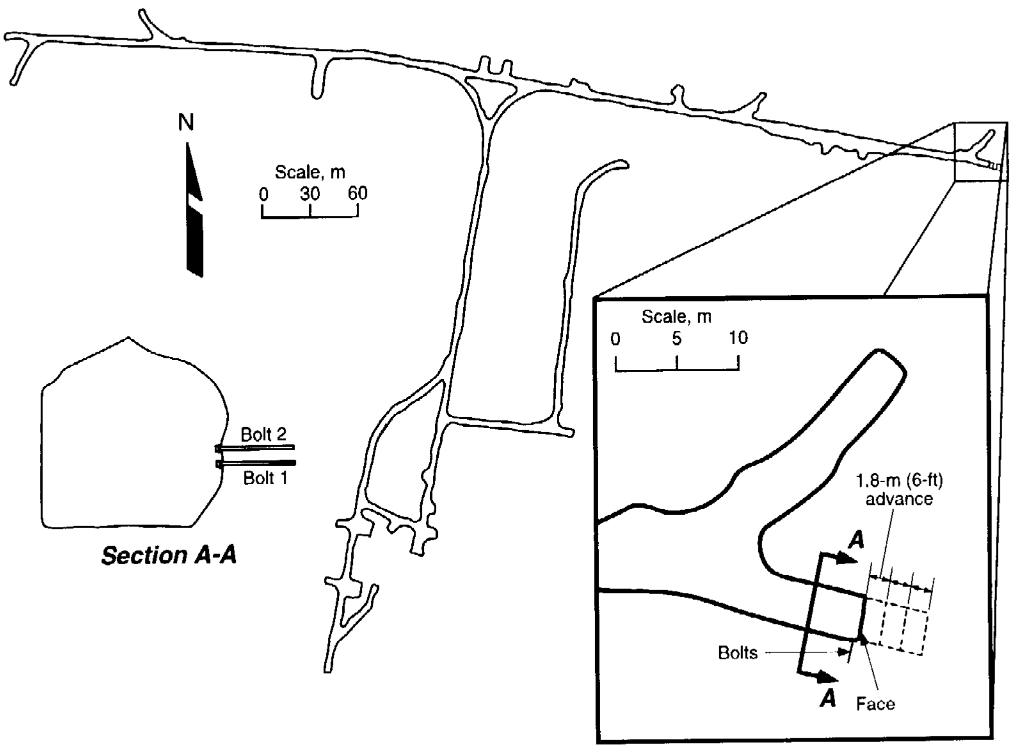


Figure 2. Locations of bolts and advance of drifts.

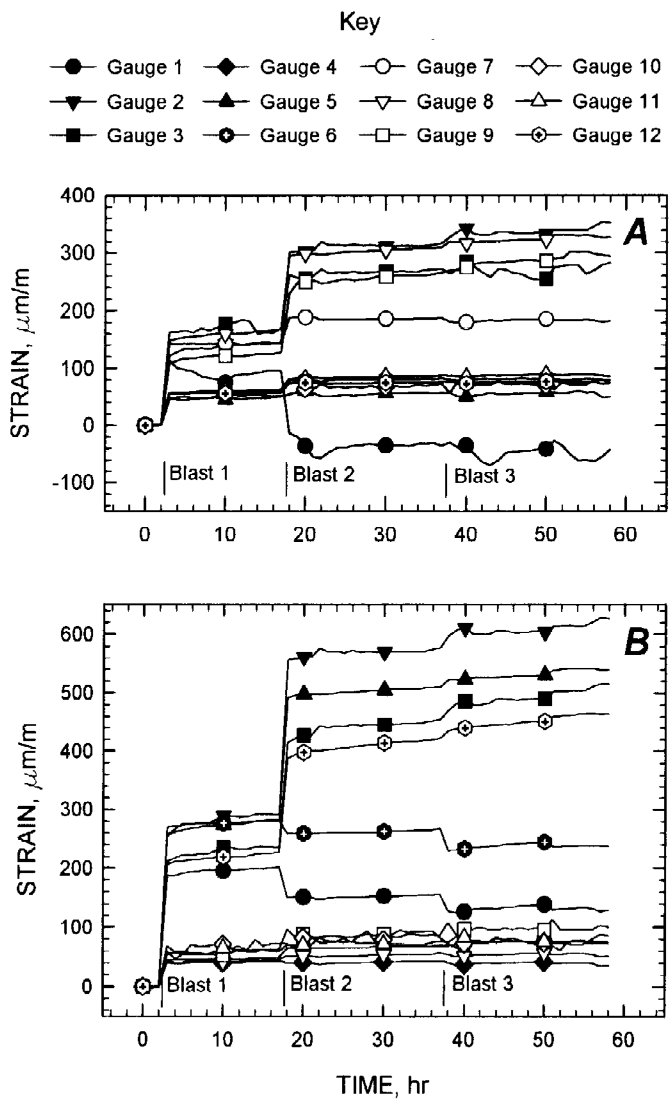


Figure 3. Measured strains versus time. *A*, Bolt 1; *B*, bolt 2.

Table 1. Accumulated strain change after blasts, bolt 1, μm/m

| Gauge | Blast 1 | | | Blast 2 | | | Blast 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| pair | Side 1 | Side 2 | Average | Side 1 | Side 2 | Average | Side 1 | Side 2 | Average |
| 1 | 113 | 142 | 128 | -14 | 188 | 87 | -30 | 181 | 76 |
| 2 | 121 | 147 | 134 | 301 | 295 | 296 | 328 | 320 | 324 |
| 3 | 163 | 108 | 136 | 261 | 229 | 236 | 263 | 269 | 266 |
| 4 | NA | 44 | NA | NA | 53 | NA | NA | 57 | NA |
| 5 | 48 | 58 | 53 | 55 | 82 | 75 | 57 | 87 | 72 |
| 6 | 57 | 55 | 56 | 79 | 74 | 75 | 80 | 76 | 78 |

NA - Not available because of nonlinear response during calibration

Table 2. Accumulated strain change after blasts, bolt 2, µm/m

| Gauge pair | Blast 1 Side 1 | Blast 1 Side 2 | Blast 1 Average | Blast 2 Side 1 | Blast 2 Side 2 | Blast 2 Average | Blast 3 Side 1 | Blast 3 Side 2 | Blast 3 Average |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 187 | 45 | 116 | 150 | 64 | 107 | 128 | 69 | 99 |
| 2 | 257 | 43 | 150 | 556 | 52 | 304 | 598 | 55 | 327 |
| 3 | 211 | 68 | 140 | 415 | 96 | 256 | 470 | 108 | 289 |
| 4 | 41 | 59 | 50 | 40 | 72 | 56 | 41 | 73 | 57 |
| 5 | 255 | 54 | 155 | 492 | 70 | 281 | 523 | 74 | 299 |
| 6 | 270 | 206 | 238 | 258 | 388 | 323 | 230 | 435 | 333 |

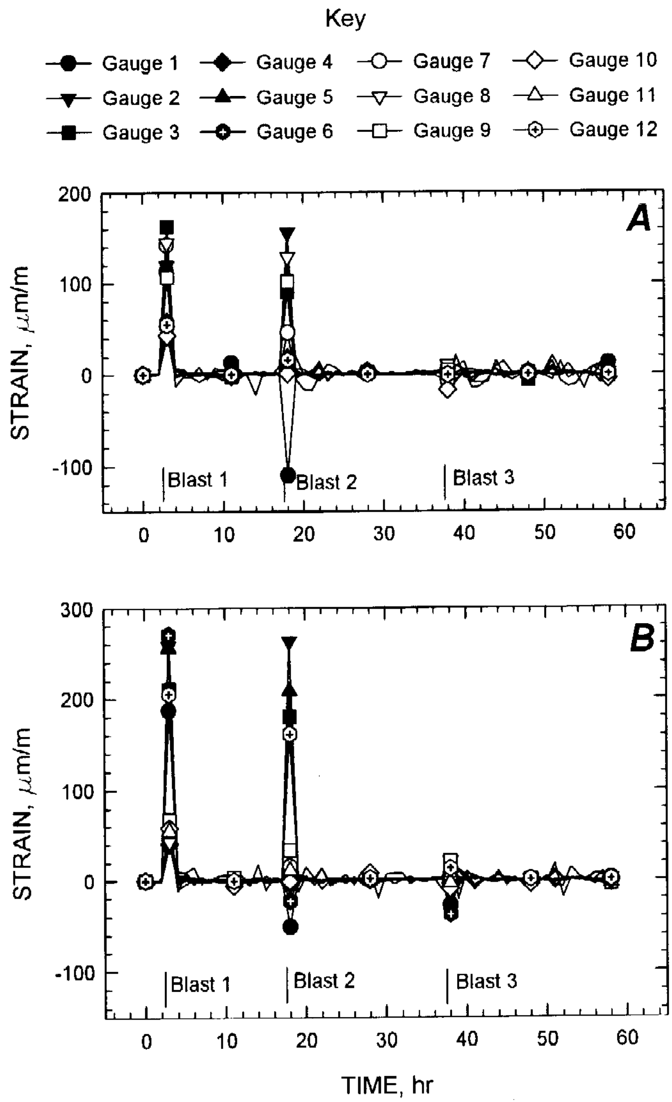


Figure 4. Incremental strain changes after blasts. *A*, Bolt 1; *B*, bolt 2.

Table 3. Incremental strain change after blasts, bolt 1, μm/m

| Gauge pair | Blast 1 Side 1 | Blast 1 Side 2 | Blast 1 Average | Blast 2 Side 1 | Blast 2 Side 2 | Blast 2 Average | Blast 3 Side 1 | Blast 3 Side 2 | Blast 3 Average |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 113 | 142 | 127 | -110 | 46 | -32 | 5 | -8 | -1 |
| 2 | 120 | 145 | 133 | 156 | 129 | 142 | 11 | 10 | 11 |
| 3 | 163 | 107 | 135 | 91 | 102 | 96 | -9 | 4 | -2 |
| 4 | NA | 43 | NA | NA | 1 | NA | NA | -17 | NA |
| 5 | 47 | 58 | 53 | 5 | 19 | 12 | -2 | -1 | -1 |
| 6 | 57 | 55 | 56 | 16 | 16 | 16 | -4 | -1 | -2 |

NA - Not available.

Table 4. Incremental strain change after blasts, bolt 2, μm/m

| Gauge pair | Blast 1 Side 1 | Blast 1 Side 2 | Blast 1 Average | Blast 2 Side 1 | Blast 2 Side 2 | Blast 2 Average | Blast 3 Side 1 | Blast 3 Side 2 | Blast 3 Average |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 187 | 45 | 116 | -51 | 15 | -18 | -28 | 0 | -14 |
| 2 | 258 | 43 | 150 | 263 | 6 | 135 | 21 | -2 | 9 |
| 3 | 211 | 68 | 139 | 180 | 34 | 107 | 15 | 21 | 18 |
| 4 | 41 | 58 | 50 | -3 | -1 | -2 | -4 | -10 | -7 |
| 5 | 256 | 55 | 155 | 208 | 11 | 110 | 13 | -3 | 5 |
| 6 | 270 | 205 | 237 | -23 | 161 | 69 | -38 | 13 | -12 |

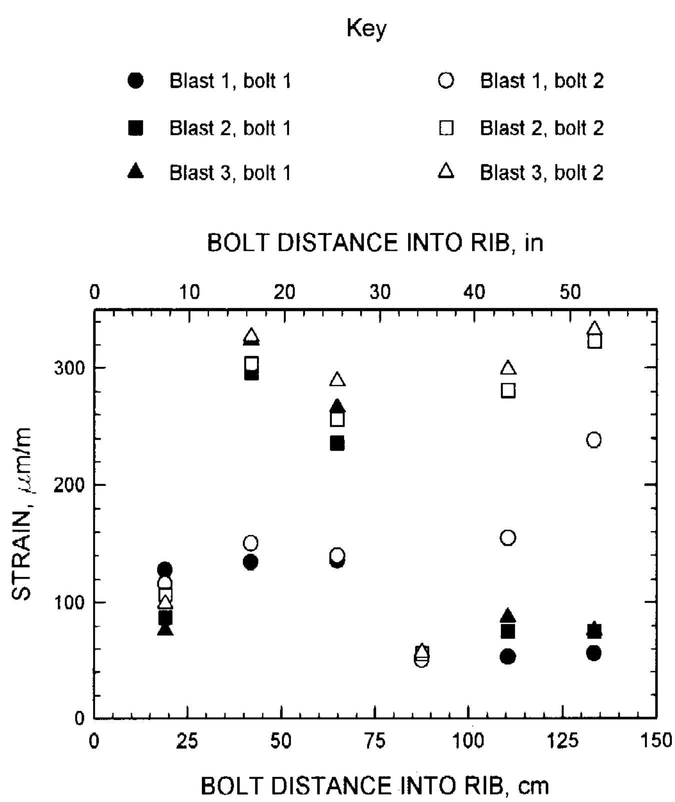


Figure 5. Average accumulated axial strain versus rib distance after blasts 1, 2, and 3

so that the gauges were in the horizontal plane, as shown in Figure 1. The grout was allowed to cure for about 2 weeks before the drift was advanced. Because the bolts were placed so close to the face, the instrument cables were placed inside a 5-cm (2-in) in diameter steel pipe, covered with old conveyor belts, and bolted to the rib for protection against blasting. The drift was extended in three blasts, each by a distance of the drift radius of 2 m (6 ft).

## 4 DATA AND RESULTS

Figure 3 shows the accumulated strains measured on bolts 1 and 2 by each gauge over time. Measurements were collected by the data acquisition system beginning at midnight on August 5, 1998. The first blast took place between hours 3 and 4, the second between hours 18 and 19, and the third blast between hours 38 and 39. Tables 1 and 2 show accumulated individual and average strains on bolts 1 and 2 after each blast.

Incremental strain was calculated by subtracting the strain reading for the current hour from the reading for the previous hour. Figure 4 shows incremental strain changes over time during advance of the drift since midnight of August 5, 1998. Large changes in strain were measured after the first and second blast. Very little change in strain occurred between blasts and after the third blast. Tables 3 and 4 provide incremental changes in strain on bolts 1 and 2 after each blast. Compressive or negative strain on side 1 of pair 1 on both bolts indicates bending from the second blast at a distance of 19 cm (7.5 in) into the rib. Each bolt in pairs 2 and 3 shows almost the same response as shown following the first blast. Pair 4 gave an anomalous reading and showed only small changes in strain for all blasts. Pairs 5 and 6 of bolt 1 showed small changes in strain while the same pairs on bolt 2 showed a much larger change in strain. Pair 6 even showed some bending from the second blast. Figure 5 is a plot of the average accumulated strain data versus position of the gauges on the bolt.

## 5 CONCLUSIONS

Two strain-gauged rock bolts were grouted in the middle of a rib near the face of a 3.7- by 3.7-m (12- by 12-ft) drift. The drift was advanced in three 2-m (6-ft) blasts of one-half drift wide. The average response in terms of axial strain to the first and second blasts was about the same for the gauge pairs 42 and 65 cm from the head of the bolt or the rib. Bending strains were observed on the gauge pair located 19 cm from the rib, mostly as a result of the second blast. There was very little change in strain from the third blast. Dynamic strains resulting from blasting were not measured. The grouted bolts cannot be recovered and checked to see if any damage occurred during blasting.

## REFERENCE

Serbousek, M. O. & S. P. Signer 1987. Linear Load-Transfer Mechanics of Fully Grouted Roof Bolts. U.S. Bur. Mines Rep. Invest. 9135, 17 pp.