Rock Mechanics for Industry

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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 commer-cially. 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
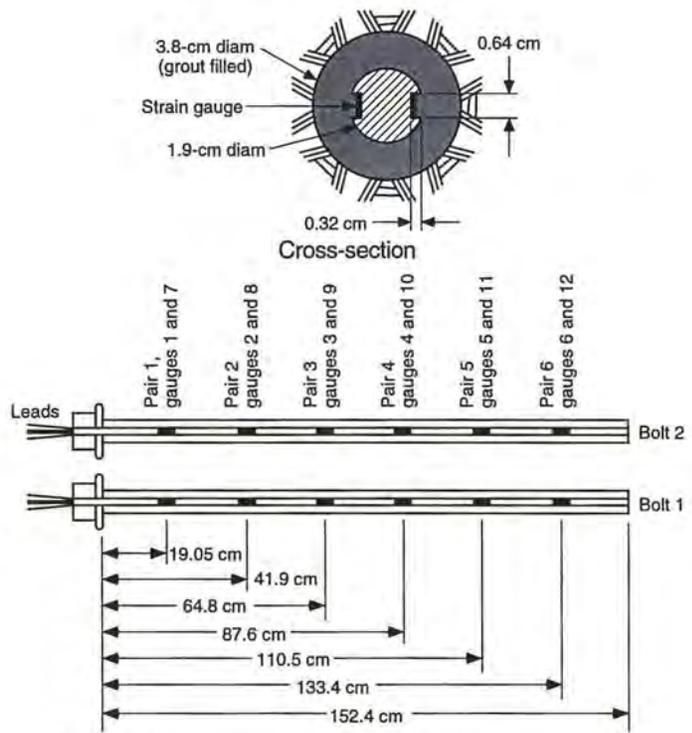
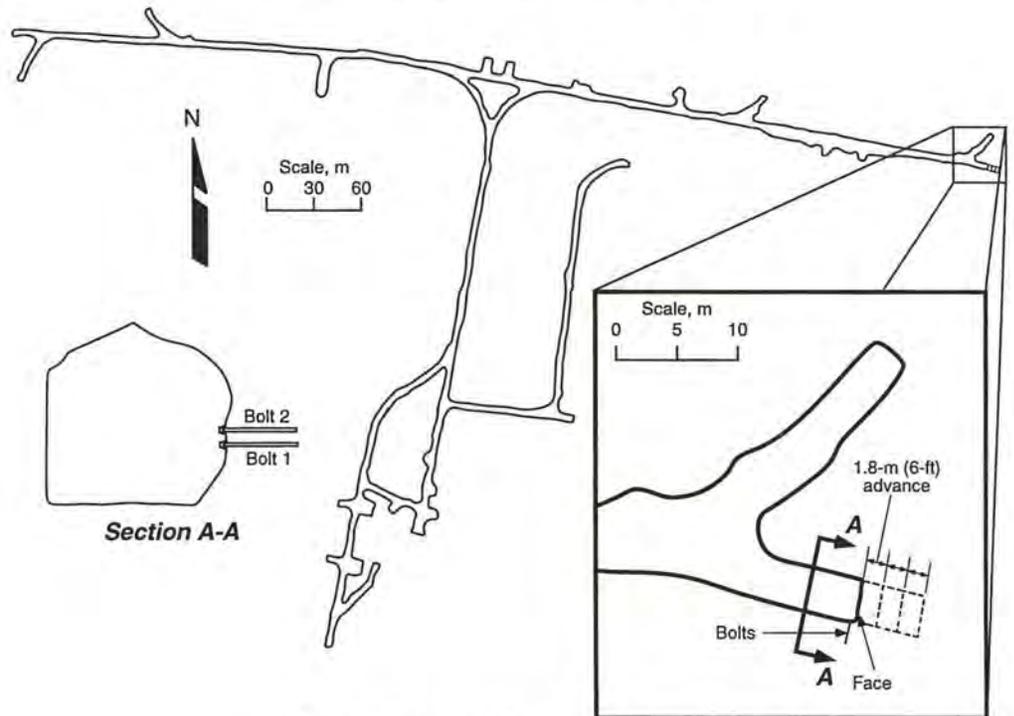Figure 1. Location and orientation of strain gauges on bolts.

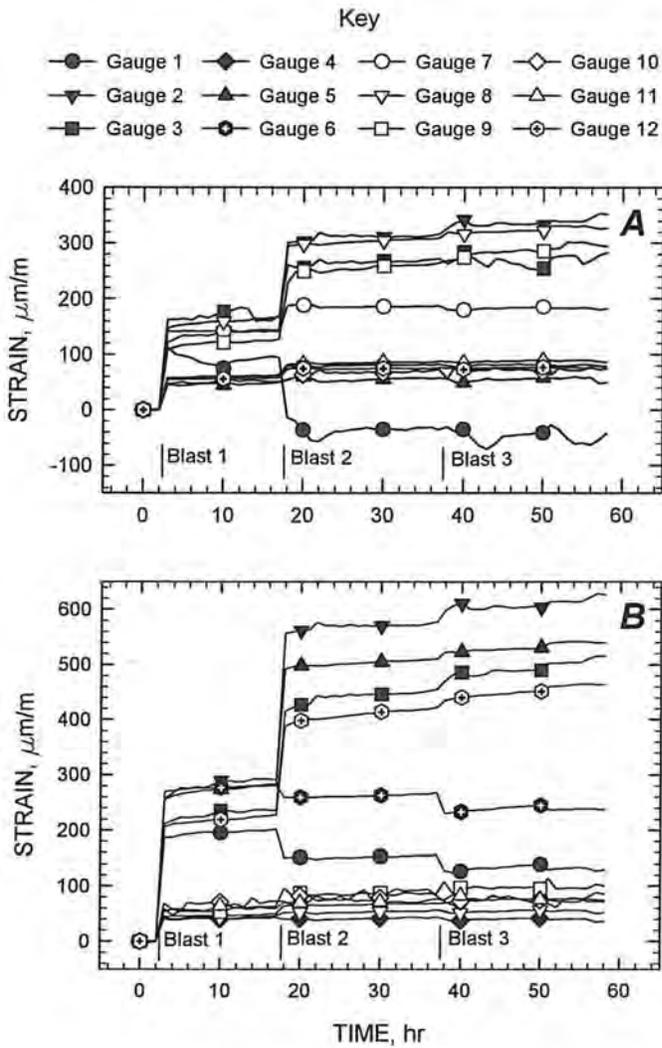Figure 2. Locations of bolts and advance of drifts.

Key

- Gauge 1   - Gauge 4   - Gauge 7   - Gauge 10
- Gauge 2   - Gauge 5   - Gauge 8   - Gauge 11
- Gauge 3   - Gauge 6   - Gauge 9   - Gauge 12

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

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

Gauge pair	Blast 1			Blast 2			Blast 3		
	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

499

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

Gauge pair	Blast 1			Blast 2			Blast 3		
	Side 1	Side 2	Average	Side 1	Side 2	Average	Side 1	Side 2	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

Key

- Gauge 1 ◆ Gauge 4 ○ Gauge 7 ◇ Gauge 10
- ▼ Gauge 2 ▲ Gauge 5 ▽ Gauge 8 △ Gauge 11
- ■ Gauge 3 ◉ Gauge 6 □ Gauge 9 ⊕ Gauge 12
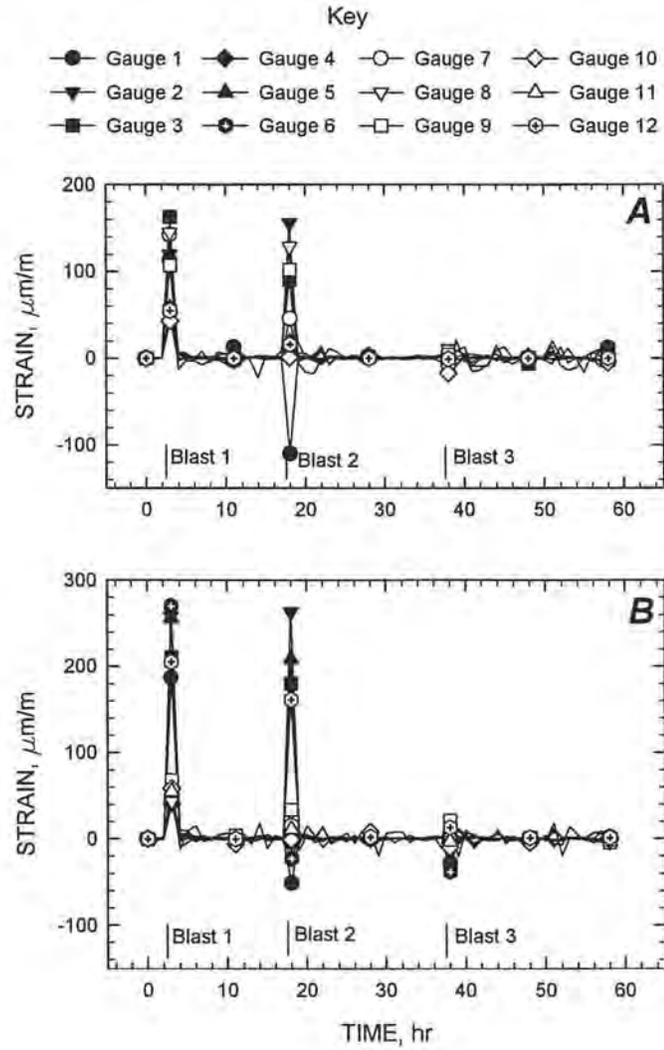

Figure 4. Incremental strain changes after blasts. A, Bolt 1; B, bolt 2.

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

Gauge pair	Blast 1			Blast 2			Blast 3		
	Side 1	Side 2	Average	Side 1	Side 2	Average	Side 1	Side 2	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			Blast 2			Blast 3		
	Side 1	Side 2	Average	Side 1	Side 2	Average	Side 1	Side 2	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

Key

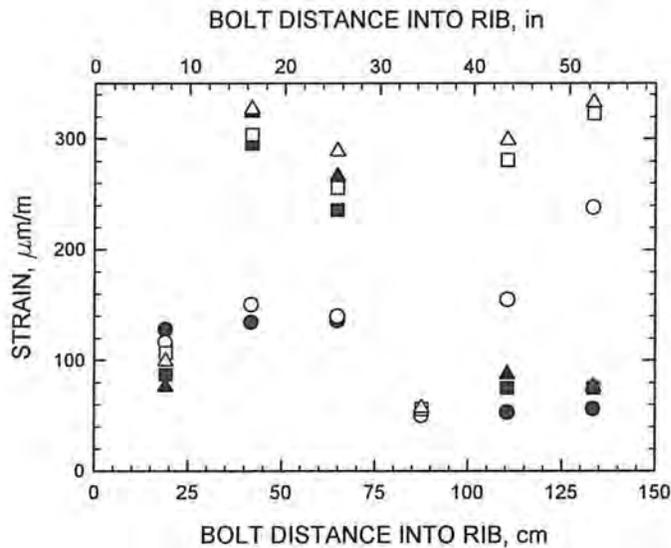|			
●	Blast 1, bolt 1	○	Blast 1, bolt 2
■	Blast 2, bolt 1	□	Blast 2, bolt 2
▲	Blast 3, bolt 1	△	Blast 3, bolt 2

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.

Mishnaevsky, Jr., Leon L.   90 5410 699 9
Damage and fracture in heterogeneous materials – *Modelling and application to the improvement of drilling tool*
1998, 25 cm, 230 pp., EUR 54.50 / $64.00 / £38
The efficiency of many technological processes, particularly in mining and civil engineering, depends essentially on the damage and fracture processes in tool and working materials (rocks), which are typically very heterogeneous. Damage and fracture processes of heterogeneous non-plastic materials are very complex, and are influenced by many nonlinear and random factors at both the macro- and the microlevel. In this book the general problems related to the destruction of heterogeneous materials are examined, and physical mechanisms of destruction, traditional and advanced methods of damage and fracture modelling and the practical application of models of material destruction on the improvement of drilling efficiency are detailed. The book is designed for specialists, working in the fields of strength of materials and mining technology, for scientists, professionals and graduate students.

Rustan, Agne (Editor-in-Chief)   90 5410 441 4
Rock blasting terms and symbols – *A dictionary of symbols and terms in rock blasting and related areas like drilling, mining and rock mechanics*
1998, 25 cm, 204 pp., EUR 100.00 / $116.00 / £70
Terminology is important in the process of development of a science because it is the language for communication between students, teachers, technicians, scientists and practioners in the field of blasting. This dictionary contains 1980 terms, 316 symbols, 93 acronyms, abbreviations and shortened forms, 221 references, 31 figures, 32 formulas and 28 tables. In this book, not only short definitions of the terms are presented, but also a quantification of some terms is included, and their relationship to other parameters in blasting is highlighted. This dictionary represents today the most extensive rock blasting dictionary available and it is therefore a valuable tool and essential for research and writing reports, papers to international journals, etc. All students, teachers, technicians, engineers, scientists and practioners in the field of blasting should get a copy as a desk reference book. If we all use the same symbols for example, the reading of blasting papers is speeded up and facilitated a lot.
Absolutely essential reading for students, teachers, engineers, earth scientists, etc. in this field and will assist dramatically in ensuring the different specialists are using terms consistently. AMF Reviews 26.

Rossmanith, H.P. (ed.)   90 5410 955 6
Mechanics of jointed and faulted rock - *MJFR-3 Proceedings of the third international conference, Vienna, 6-9 April 1998*
1998, 25 cm, 674 pp., EUR 114.00 / $132.00 / £80
Topics: Geology and structural geology; Mechanics; Dynamics of jointed and faulted rock; Physical modeling and testing; Constitutive modeling; Seismicity and tectonics; Instrumentation; Hydraulics; Applications; etc.

Villaescusa, E., C.R.Windsor
& A.G.Thompson (eds)   90 5809 045 0
Rock support and reinforcement practice in mining – *Proceedings of the international symposium on ground support, Kalgoorlie, Western Australia, 15-17 March 1999*
1999, 25 cm, 448 pp., EUR 105.00 / $125.00 / £80
The topics covered include: Design and analysis of support and reinforcement in metalliferous mines, mesh, shotcrete and membrane support systems; strata control in coal mines; and, safety and training. Many practical applications are describes and the book is a valuable addition to the library of many professionals involved in the implementation of rock support and reinforcement.

Sheorey, P.R.   90 5410 670 0
Emperical rock failure criteria
1997, 25 cm, 192 pp., EUR 79.00 / $93.00 / £56
Student edn.: 90 5410 671 9, EUR 40.00/$47.00/£28
This book concentrates on emperical criteria for rocks and jointed rock masses, and their applicability to triaxial test data as well as excavation case studies. In an appendix, triaxial and polyaxial test data sets of 321 rocks are provided. Included are new closed-form interrelations between triaxial strength parameters, methods to derive an equation to Mohr's envelope, influence of rock anisotropy on all triaxial strength parameters, an anisotropic rock failure criterion and three excavation case studies with complete details. A comprehensive list of related references is given at the end of the book.

Daemen, Jaak J.K.
& Richard A.Schultz (eds.)   90 5410 552 6
Rock mechanics: *Proceedings of the 35th US Symposium* – *Lake Tahoe, 4-7 June 1995*
1995, 25 cm, 950 pp., EUR 121.00 / $142.00 / £85
Session topics include: Construction; surface excavation, stability and shear strength of fractured rock; laboratory testing; rock dynamics; stress measurements; tunnels and groundwater flow; petroleum; tool-rock interaction; building stone durability; rock reinforcement; fracture mechanics; radioactive waste disposal; underground mining; fragmentation and blasting; metal mining; coal mining; planetary rock mechanics; rock properties; stochastic methods; theoretical and model studies; hydrology; and rock creep; etc.

Andreev, G.E.   90 5410 602 6
Brittle failure of rock materials – *Tests results and constitutive models*
1995, 25 cm, 456 pp., EUR 126.50 / $149.00 / £89
Comprises different basic aspects of brittle failure for rocks. Classical & contemporary models are considered theoretically as well as failure patterns under different loading schemes. Terminology; Strength theories; Contemporary models about brittle fracture; Laborational methods for determining some mechanical properties of rocks; Mohr strength envelopes; Experimental investigation of brittle behaviour; Size effect; Concluding remarks and references.