

Information Circular 9341

Instrumentation Procedures for Fully Grouted Rock Bolts

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°F degree Fahrenheit

h hour

in inch

lb pound

lbf pound force

min minute

μ in microinch

psi pound per square inch

INSTRUMENTATION PROCEDURES FOR FULLY GROUTED ROCK BOLTS

By Joanne L. Johnston¹ and Dennis J. Cox¹

ABSTRACT

Researchers at the U.S. Bureau of Mines have developed a new technique for bonding strain gauges to rock bolts. These instrumented bolts are used to determine load at intervals along the length of the bolt so that reliable, consistent measurements for the design of support systems can be obtained. In this Information Circular, this technique is described in detail and should result in improved miner safety in underground mines.

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INTRODUCTION

Since the introduction of rock bolts 40 years ago, their use to support and stabilize openings in U.S. mines has steadily increased. The number of roof falls has been significantly reduced where rock bolts have been installed, and they are now the primary support required by the Mine Safety and Health Administration (MSHA) in most mines. An additional benefit is that rock bolts provide an unobstructed opening for greater freedom of movement and improved ventilation.

However, roof falls still occur even in areas where rock bolts have been installed. While every effort is made to use scientifically gathered data and case study results to design and evaluate safe and economically feasible roof control plans, more information is needed to provide a better understanding of bolt response to strata movement. Not having this information could lead either to underdesign or overdesign with regard to bolt type, length, diameter, and spacing. Underdesign may result in roof falls, while overdesign may result in an unnecessary financial burden on a mine operator. Scientific knowledge

is needed to describe rock bolt behavior and to provide guidelines for design of effective roof control plans with respect to safety, economy, and integration with other mining activities. To formulate such guidelines, instrumented bolts used in investigations of support systems must be capable of providing reliable data.

Numerical modeling is one approach being used by researchers to study the support requirements of strata around underground openings. However, numerical modeling alone is not adequate because not enough is known about the required input parameters and the nonlinear nature of highly stressed rock. Additional laboratory and field experiments are necessary to provide a more complete understanding of support interaction relationships.

Resin-anchored, full-column rock bolts are one type of roof support used to support unstable openings in underground mines. Because the use of these bolts is increasing, improved design criteria and installation techniques will result in more effective support.

BACKGROUND

In an effort to gain a better understanding of the mechanics involved in the transfer of load between a bolt and the mine rock, a program was started by the U.S. Bureau of Mines to study the load transfer mechanics of passive, fully grouted rock bolts. This work was done in support of the Bureau's goal to improve underground safety for the Nation's miners. The first phase of the study was conducted in the laboratory and was directed to examining the linear, nonlinear, and time-dependent behavior of bolts under different loading conditions. This provided information necessary for the development of a numerical model.² The next task was to establish a correlation between the laboratory test results and grouted bolts installed in an actual mine roof.³ The load transfer mechanics of fully grouted bolts was then studied in four mines with different immediate roof conditions⁴ (Eagle Mine, Craig, CO; Wabash Mine, Keensburg, IL; Galatia Mine, Harrisburg, IL; and Warwick Mine, Greensboro, PA).

After these studies were completed, 12 fully grouted, instrumented bolts were installed in the Cyprus Plateau

Starpoint No. 2 Mine near Price, UT, during the development phase of the entry. These bolts were monitored for a year while two longwall panels were mined nearby, and changes in bolt loads were observed throughout the useful life of the entry.⁵ Thirteen instrumented bolts were also installed in the tailgate entry for a longwall at Jim Walters Resources' No. 7 Mine in Brookwood, AL. These bolts were used to observe roof conditions as the longwall was mined.

Because the bolts would be used for long periods and under severe conditions in an underground mine, special procedures were required for installation and protection of the strain gauges. Many different products and procedures were used as the rock bolt instrumentation process was developed and refined. Careful consideration was given to selecting gauges, adhesives, and moisture-proof coatings. Special care was also given to selecting the types of surface preparation product and implementing proper surface preparation techniques to ensure good adhesion. This procedure produced excellent test results, with gauges providing data that were stable, consistent, and reliable.

²Serbousek, M. O., and S. P. Signer. Linear Load-Transfer Mechanics of Fully Grouted Roof Bolts. BuMines RI 9135, 1987, 17 pp.

³Signer, S. P. Comparative Studies in the Mechanics of Grouted Roof Bolts. Paper in 7th International Conference on Ground Control in Mining: Proceedings, ed. by S. S. Peng (WV Univ., Morgantown, WV, Aug. 3-5, 1988). Dept. of Min. Eng., WV Univ., 1988, pp. 282-288.

⁴Signer, S. P. Field Verification of Load Transfer Mechanics of Fully Grouted Roof Bolts. BuMines RI 9301, 1990, 13 pp.

⁵Signer, S. P., and S. D. Jones. A Case of Grouted Roof Bolt Loading in a Two-Entry Gate Road. Paper in 9th International Conference on Ground Control in Mining: Proceedings, ed. by S. S. Peng (WV Univ., Morgantown, WV, June 4-6, 1990). Dept. of Min. Eng., WV Univ., 1990, pp. 35-41.

PREPARATION OF BOLT

No. 6, 3/4-in-diameter, rebar bolts with forged heads were used. Various grades of steel were tried; however, the last series of bolts were of 60-grade steel. To prepare the bolts for gauge installation, a 1/4-in-wide by 1/8-in-deep groove was milled the full length of the bolt (fig. 1). When the bolt was removed from the milling

machine, it was thoroughly degreased with Chlorothene SM degreaser.⁶ This type of degreaser was preferred because it breaks down machine or lubricating oils on specimen surfaces and removes dust, dirt, and other contaminants. Degreasing is an important task that must always be completed before preparing the surface of a rock bolt.

PREPARATION OF GAUGE

GAUGE SELECTION

Because it is necessary for a gauge to fit into a confined area, the length and the width of the strain gauge was an important consideration in selecting the appropriate type of gauge. For this project, Micro-Measurement's EA-06-250BF-350 LE gauge was chosen. This gauge has superior elongation capabilities and an operating temperature range suitable for most high-elongation testing. The EA series gauges are capable of measuring high-elongation strain and obtaining information on yield points. The LE option meant that the gauges had preattached soft copper lead wires and a thick layer of

polyamide film covering the entire gauge. This layer provides excellent protection during handling and installation. It also protects the gauge from the environmental conditions found underground, although additional protective coatings were also applied. In addition, the LE option allows soldering to be done a short distance from the gauge, which avoids problems resulting from overheating the gauge during soldering or splattering the gauge with solder.

⁶Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

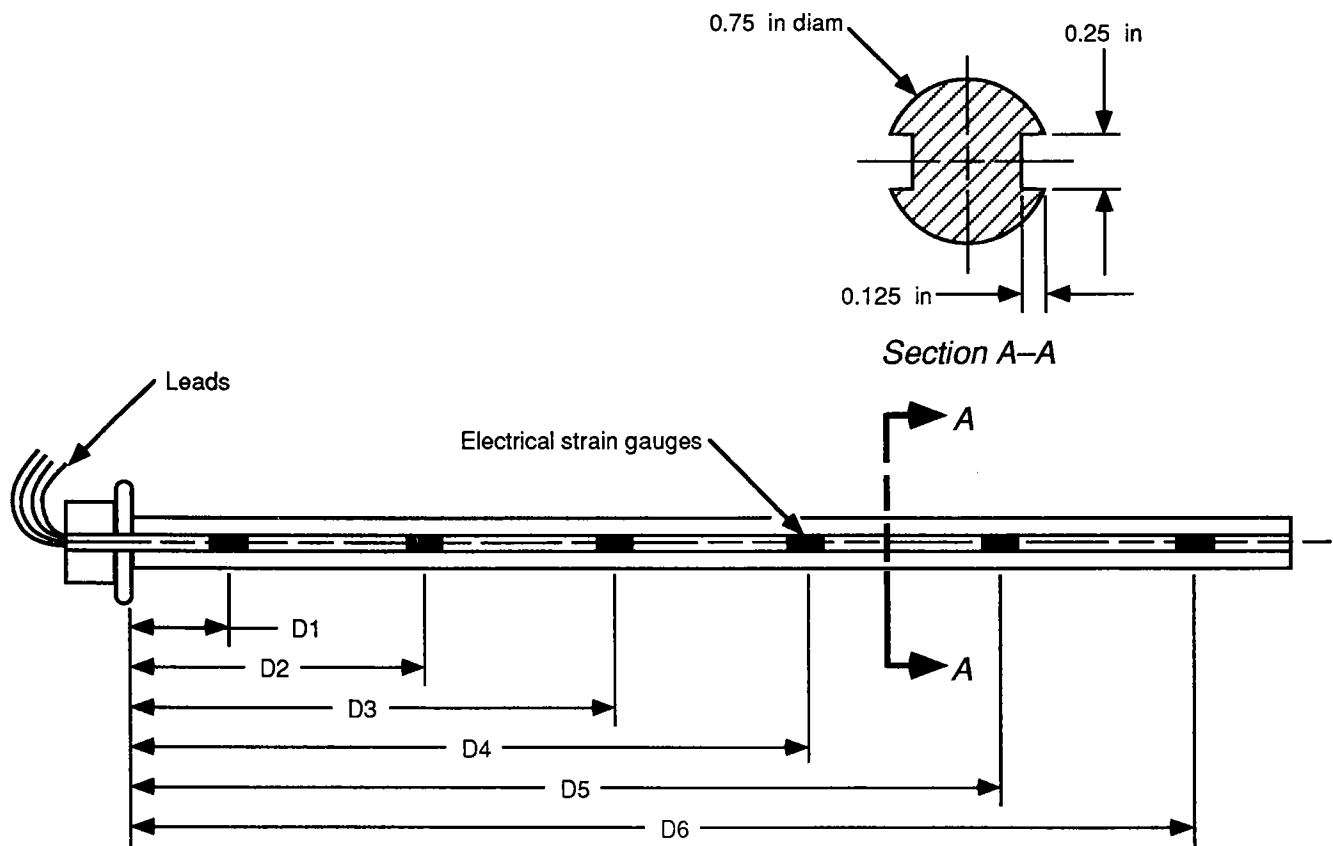


Figure 1.—Gauge locations on instrumented bolts.

ABRADING

The gauge surface was sanded first with 100-grit emery cloth, then with 320-grit silicon carbide paper. Sanding was done by hand to prevent any dips, surface irregularities, or scratches that can occur when using mechanical sanding equipment. The final surface abrading was done with 400-grit silicon carbide paper, using Micro-Measurement's M-Prep Conditioner A as a wetting agent. M-Prep Conditioner A is a mildly acidic solution that generally accelerates the cleaning process and acts as a gentle etchant. The surface was kept wet during this process.

The residue and conditioner were removed by slowly wiping the gauge surface with a cotton gauze sponge (fig. 2). Cleaning an area somewhat larger than needed for gauge installation prevented wiping contaminants back through the area and minimized the chance of recontamination during subsequent operations. The surface was abraded to a finish designated as 32G⁷ (0.000032 μin) to develop a surface texture suitable for bonding.

CONDITIONING

The surface was again wetted with M-Prep Conditioner A and scrubbed with a cotton-tipped applicator until a clean applicator was no longer discolored by contaminants (fig. 3). Residue and conditioner were removed by wiping the gauge surface with a cotton gauze sponge with a single, firm, steady stroke in one direction. The cleaned surface was then wiped in the opposite direction with another clean gauze sponge.

NEUTRALIZING

A liberal amount of Micro-Measurement's M-Prep Neutralizer 5 was applied to the cleaned surface, and the area was scrubbed with cotton-tipped applicators. It was important not to allow any neutralizer to dry on the surface, since it may leave an unwanted film and prevent proper adhesion of the gauge. Therefore, the neutralizer was removed by wiping the surface slowly in one direction with a clean gauze sponge. The neutralizer is an alkaline solution, which, when applied to an acidic surface, leaves the surface with a pH between 7 and 8.

BONDABLE TERMINALS

The bondable terminals installed adjacent to the strain gauges were produced from a thick copper foil

electroplated on a Teflon fluorocarbon polymer film. The Teflon polymer-backed terminal strip was used because it is more flexible than other types and combines resistance to high temperatures with resistance to solder damage. In addition to good electrical properties, it has a relatively high thermal expansion coefficient and is suitable for long-term use. The primary purpose for using terminals is to provide an anchor for both the small, delicate jumper wires that connect the strain gauge and the main lead

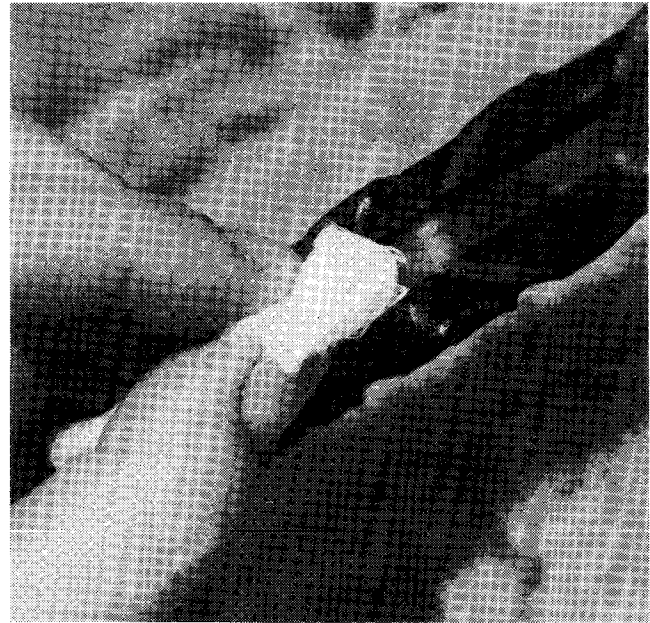


Figure 2.—Cleaning gauge surface with gauze sponge.

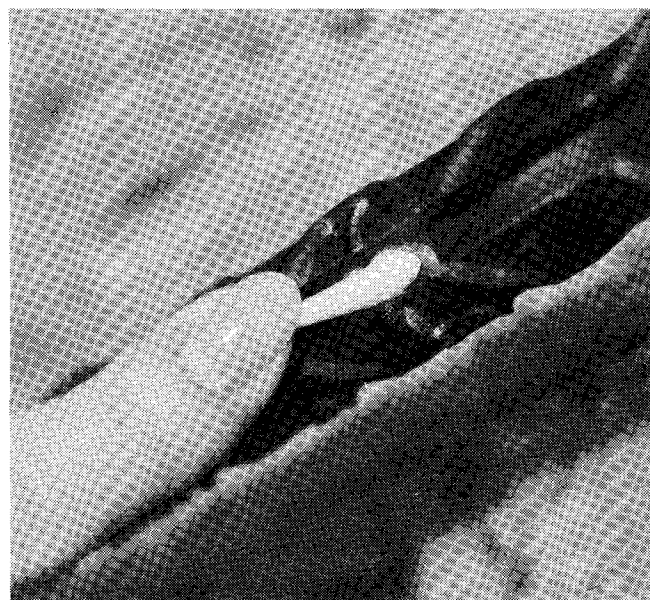


Figure 3.—Scrubbing gauge surface with cotton-tipped applicator.

⁷The smoothness of the surface was determined by comparing it with a GAR S-22 Microfinish Comparator Surface Finish Scale, available from GAR Electroforming, Augusta Drive, Danbury, CT 06810.

wires, and to prevent the forces transmitted along the main lead wire system from damaging the strain gauge or degrading its performance.

TAPE

The tape found to be the easiest to work with during strain gauge placement was the HM series of Temp-R-Tape, manufactured from Teflon fluorocarbon polymer TFE film. The film has been manufactured by a unique process that lowers elongation and increases breaking strength for handling ease. Tapes that stretch can also cause damage to the gauges. The HM series tapes have a nonstick back and are resistant to high temperatures; other tapes have a tendency to get very sticky and are not easily removed after the adhesive has cured.

GAUGE PREPARATION

Before handling the gauge, 1/4-in strips of Teflon fluorocarbon polymer tape were placed on either a chemically clean glass plate or an empty gauge box. Care was taken not to contaminate the gauge by touching it. One end of the tape was lifted so as to leave the other end on the working surface. The gauge was then positioned in approximately the middle of the tape strip using tweezers, with the bonding side down toward the glass. The solder terminal strip was placed on the tape at the same time and positioned near the solder tabs on the gauge, leaving a 1/16-in space from the gauge backing (fig. 4). To remove the gauge, the tape was lifted at a shallow angle, which brought the gauge and terminal strip up with it.

ADHESIVE SELECTION

Measuring high-elongation strain places extreme demands on the adhesive. The adhesive must be rigid enough to prevent gauge creep, yet flexible enough to permit deformation without cracking. The Micro-Measurements M-Bond AE-15 adhesive system was selected for its properties of high elongation, extended pot life (that is, working time after mixing), stability

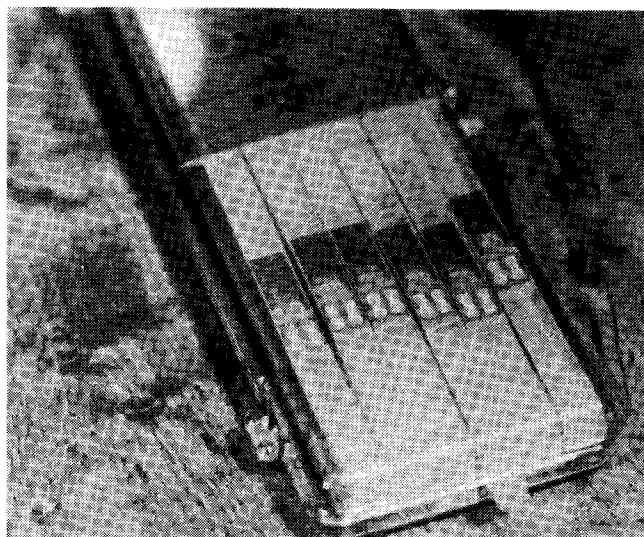


Figure 4.—Gauges prepared for installation.

during long-term tests, and high resistance to moisture and most chemicals. M-Bond AE-15 adhesive is a two-part epoxy system that consists of resin AE mixed with curing agent 15. Pot life is approximately 1-1/2 h at 70° F. Since the resin is stored under refrigeration, it should be allowed to reach room temperature before it is opened. If crystals form during storage, it can be reliquified by warming it to 120° F for approximately 1/2 h and then allowing it to cool to room temperature before it is mixed. If the temperature rises above room temperature, it will shorten the pot life of the mixed adhesive.

PRESSURE PADS

A resilient rubber pressure pad was used to provide a uniform clamping pressure over the gauge surface. Because the material should be soft enough to conform to slight irregularities, but not so soft as to be extruded under the pressure plate when force is applied, the recommended hardness of the rubber was 40 to 60 durometers. Silicone gum was preferred because it holds up under high temperatures, and its surface does not adhere to a gauge or a backup plate.

ATTACHING GAUGE TO BOLT

Twelve gauges were placed in pairs, six on each side, with the long axis parallel to the length of the bolt (fig. 1). The gauges were positioned in predetermined locations along the length of the bolt. The tape with the gauge attached was placed in the groove by holding the tape at a shallow angle, tacking one end of the tape to the bolt, and carefully wiping the full length of the assembly with a

cotton swab. The alignment marks on the gauge were closely aligned with marks on the bolt. When the gauge was in proper alignment with the bolt, one end of the tape was lifted at a shallow angle until the gauge and terminal strip were free of the bolt. The tape was laid back over a finger, so the gauge would be supported while adhesive was applied to the bonding side of the gauge (fig. 5). A

thin layer of the prepared adhesive was applied to the gauge as well as to the bolt surface (fig. 6), just thick enough to cover the gauging area without creating bubbles or voids. Any foreign matter, such as unmixed adhesive, lint, or dust, was removed before continuing. The gauge and tape assembly was then replaced on the bolt and matched to the alignment marks, and the area was slowly wiped with a cotton swab. A very thin layer of adhesive is desired for optimum bond performance.

To limit the absorption of moisture by the uncured adhesive, the gauge was set in place immediately after the adhesive was applied so that the tape could act as a temporary moisture barrier during curing. A clean silicone gum pad was placed over the gauge-terminal area and held in place while a backup plate, in this case a 1/4-in strip of plastic, was applied along the entire length of the bolt to distribute pressure uniformly over the area. The backup plate was held in position with electrical tape, and then the area was wrapped with fiber-reinforced tape, which does

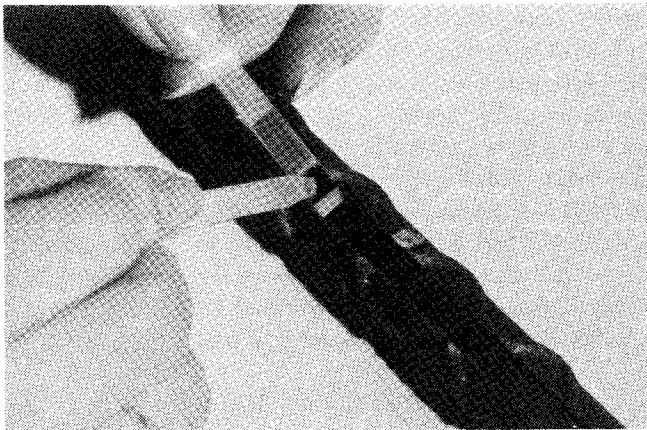


Figure 5.—Applying adhesive to gauge.

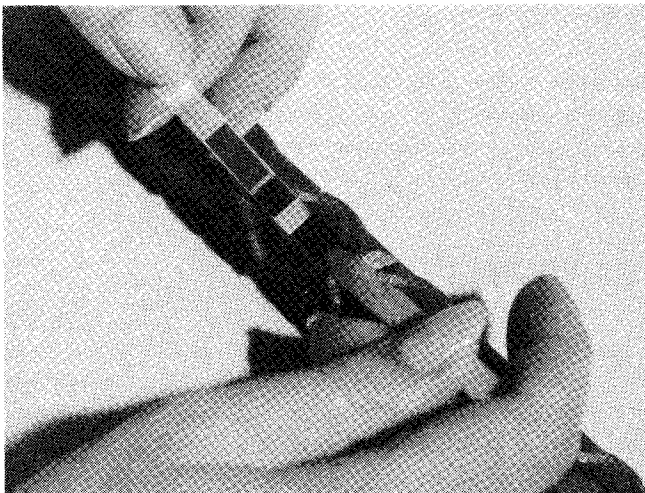


Figure 6.—Applying adhesive to bolt.

not stretch during heat curing. The optimum recommended pressure throughout the curing process is 5 to 20 psi. Using tape to apply pressure makes it difficult to measure the force. If too much force is applied, the gauge will stretch and cause high initial strain readings that will limit the range of the gauge.

CURING GAUGE ADHESIVE

The gauged bolts were immediately placed in an oven to cure overnight at temperatures between 125° F and 130° F. However, 6 h at 125° F is adequate. Although the adhesive may be cured more rapidly at higher temperatures, the lower temperatures were chosen to eliminate any possibility of damage to the gauge during curing. To ensure proper polymerization, the curing cycle should begin within 1-1/2 h after the epoxy is mixed.

After the adhesive had properly cured, the tape was removed and the gauge checked to see that it was securely attached to the bolt. Any residue remaining from the Teflon fluorocarbon polymer tape was wiped away with M-Line Rosin Solvent. A cotton-tipped applicator was gently rubbed across the gauge to highlight bubbles or loose areas. If the gauge did not have a good bond, it would be removed and replaced, because readings would provide inaccurate data. Other contaminants, such as lint, dust, or other particles in the glue line, could also affect the accuracy of the gauges.

ATTACHING LEAD WIRES

Sometimes a little adhesive remained on the jumper wires and terminal strips; if that occurred, the jumper wires were lifted gently with a pair of tweezers, and the copper pad on the terminal strip was lightly sanded to remove any adhesive that might prevent solder from adhering to the surface. The jumper wires were cut to the appropriate length, with care being taken not to twist or kink the wires. A small amount of solder was placed on the copper pads, and the trimmed jumper wires were soldered to the terminal strip, using only sufficient solder for proper connection of the jumper wires. Attention was given to leaving adequate strain relief loops to minimize forces applied to the gauge tabs and to prevent wire failure at the solder joints.

Next, the lead wires attaching the gauges to the connector were prepared by stripping a small amount of insulation from each wire, twisting the strands together, and tinning the bundles with a small amount of solder. The ends of the lead wires were soldered to the other end of the copper pad on the terminal strip. Generally, it was a good idea to clean the gauges with M-Line Rosin Solvent when soldering was finished to remove any soldering flux residue, which could contribute to gauge instability

and drift. The far ends of the lead wires were also stripped and tinned in preparation for pretesting the gauges.

GAUGE PRETEST

Before continuing, the gauges were tested to evaluate the range of their performance and stability. This process involved placing the bolts in a pipe assembly, positioning a pull collar around the bolt at its head, and putting the bolt through the ram in a hydraulic jack (fig. 7). At the other end of the pipe assembly, the bolt was held by a clamp. Each gauge wire was attached to a bridge completion circuit and plugged into a data acquisition system. The bolt was then tensioned and released three to five times before readings were taken. Five readings were taken at 0 and at 9,200 lbf applied to the bolt, and the data were evaluated. If the gauges responded well, the readings returned to 0.

Gauges were replaced when significant drift indicated a bad gauge or improper installation. When all gauges were tested and were functioning properly, they were sealed with protective coatings.

APPLICATION OF PROTECTIVE COATINGS

Moisture is a potential cause of strain gauge failure in the field. As a result, gauges require protection from the environment in which they must operate.

Micro-Measurement's M-Coat D was selected as a moisture barrier. This material forms a thin white coating

capable of high elongation, and it protects intrabridge wiring and jumper leads against electrical leakage. M-Coat D is easily applied and requires no mixing.

The first coat was left to dry at room temperature, then an overcoat was applied 30 min later. After the second coat was applied, the gauge was left at room temperature for 24 h. When the M-Coat D was completely cured, a coating of Micro-Measurements M-Coat W-1 wax was applied.

Since this coating is a microcrystalline wax, it must be heated to at least 170° F to melt. It also helped to heat the bolt to at least 100° F, although in this case, the specimen was heated to 130° F. The wax was easily spread over the gauge surface and beyond with a small paintbrush. The wax dried quickly, and no curing time was required. Small amounts of wax were left on the edges of the bolt groove, but the residue was easily removed with a hobby knife while the bolt was still warm. Failure to remove the excess wax could prevent the epoxy from adhering to the bolt near the gauges. This wax application protects the gauge installation from air and moisture, which is critical to preventing oxidation of the strain gauges.

APPLICATION OF EPOXY

For single lead wires, the wires were laid to the sides of the bolt with weights attached to the ends of each wire (fig. 8). The 3M 1838 B/A epoxy adhesive is a high-strength product used to protect the gauge installations and wiring from adverse environmental conditions and to

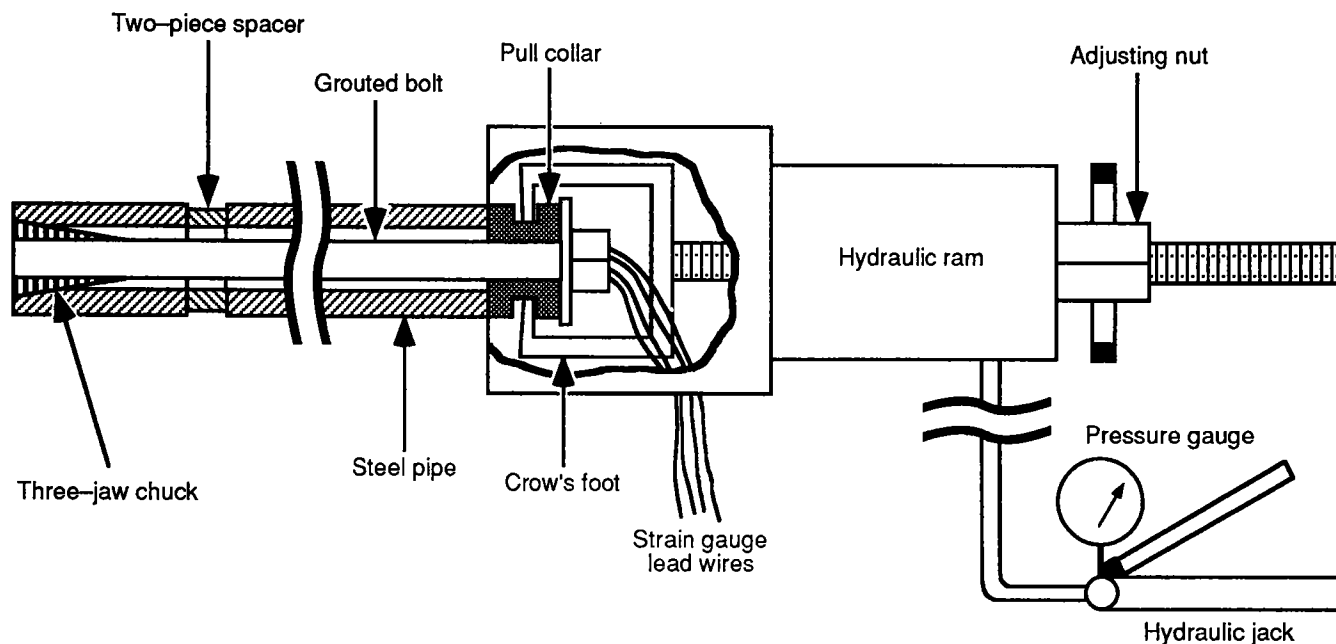


Figure 7.—Hydraulic test assembly.

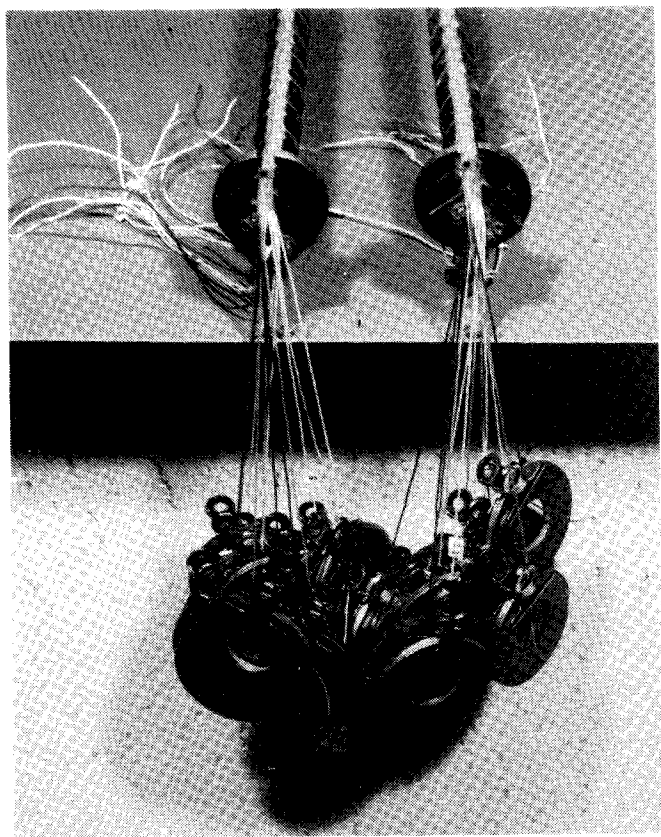


Figure 8.—Lead wires held in place by weights.

fill the groove in the rebar bolts. It is a two-part epoxy that must be weighed to measure for mixing, with a pot life of approximately 45 min at 73° F.

After the mixture was prepared, it was put in a disposable caulking tube and inserted into a gun for easy application. A bead of epoxy was placed in the bolt groove (fig. 9). The wires were then laid in the groove one at a time, starting with the wires attached closest to the head of the bolt. They were then worked into the epoxy with a small wooden stick, continuing down the full length of the bolt (fig. 10). When the wires had been

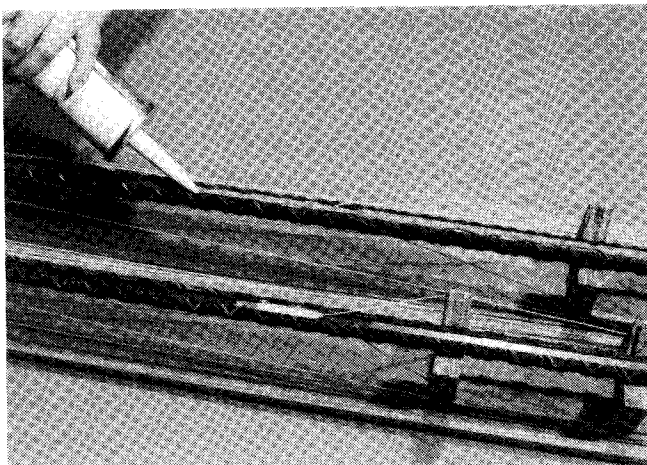


Figure 9.—Applying epoxy using caulking gun.

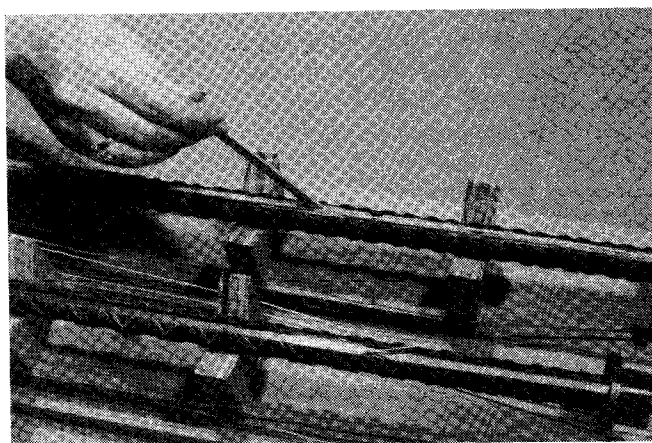


Figure 10.—Working wires into epoxy.

sufficiently covered with epoxy, they were allowed to cure overnight at room temperature. Usually some wires could be seen close to the surface, and so the next day, a small batch of epoxy was applied with a small stick to cover the partially exposed wires.

CALIBRATION PROCEDURES

The bolts were put in a uniaxial tension machine and loaded to the elastic range of the steel. The calibration procedure involved a linear regression analysis that established the relationship between applied load and voltage change. In order to ensure accuracy, calibration data were taken from three loading cycles of each bolt. The voltage change for each gauge was statistically correlated to the load to obtain a slope and an intercept. Information on each gauge on each bolt was stored in a computer file and was used to reduce the experimental voltage readings to

values for load automatically and to plot the results without manual data manipulation. Typically, the standard deviation of the predicted load using a least squares linear fit was approximately ± 50 lb. This meant that the strain gauges on the bolt measured the load to within 100 lb of the bolt load. This method eliminated problems of area reduction, gauge location, and localized inconsistencies in the bolt, and produced excellent test results having good repeatability (fig. 11).

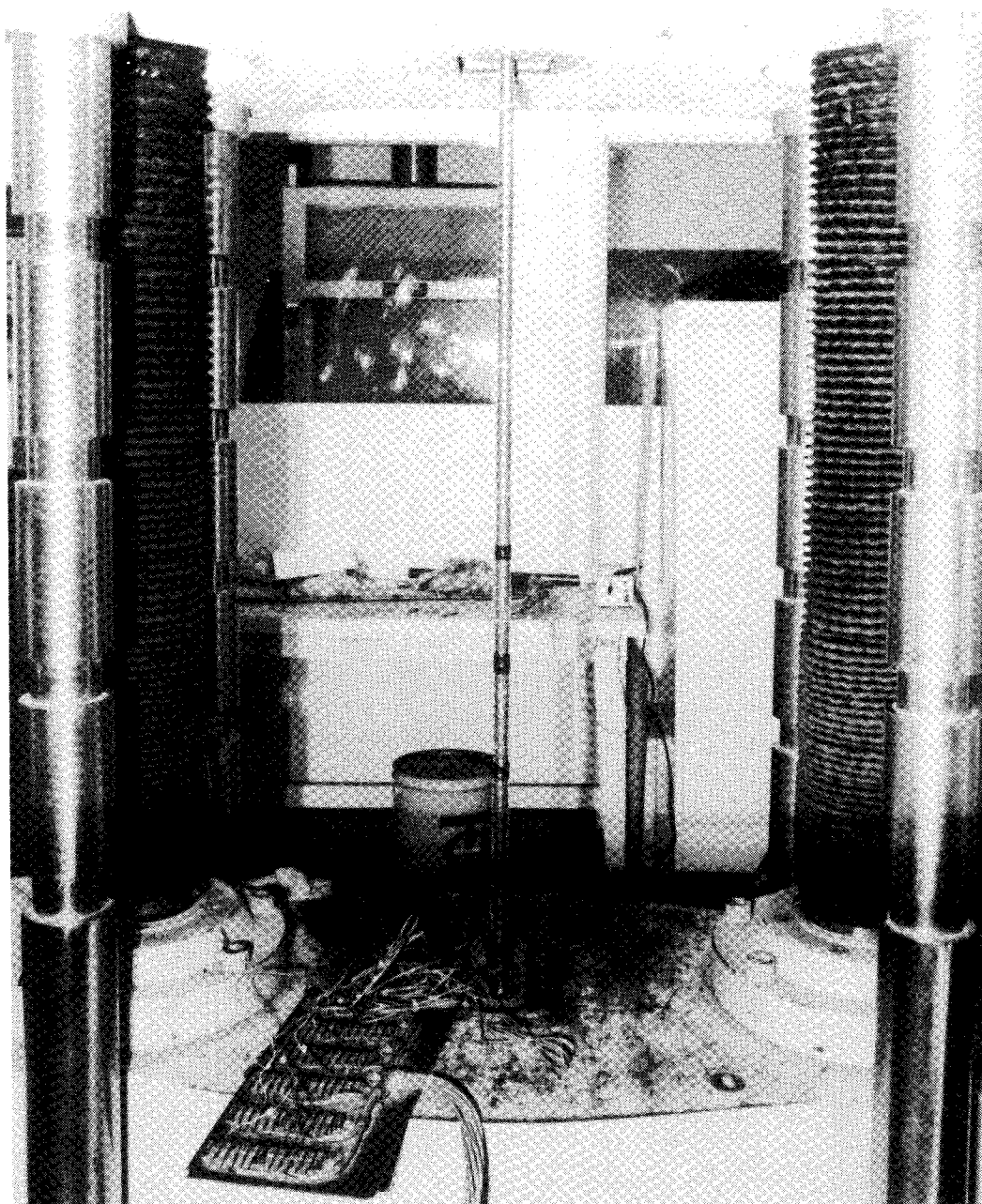


Figure 11.—Calibrating Instrumented bolts.

Connectors can be installed before or after final calibration; however, during the last tests, the connectors

were installed first in order to calibrate the system that collected and stored data during underground tests.

CONCLUSIONS

Results from various laboratory and field studies indicated that properly instrumented rock bolts produced stable, consistent, and reliable data. Proper preparation and gauge installation techniques must be established and carefully executed to ensure success. The preceding pages

explain in detail a process that produced excellent results during both laboratory and field experiments.

Abbreviated directions for preparation of instrumented rock bolts are given in the appendix.

APPENDIX.—ABBREVIATED DIRECTIONS FOR PREPARATION OF INSTRUMENTED ROOF BOLTS

1. Prepare bolt by milling two grooves, 1/4 in wide by 1/8 in deep, diametrically opposite each other for the full length of the bolt.
2. Clean entire bolt for gauge installation by wiping thoroughly with a chlorinated degreaser.
3. Sand bonding surface on the gauge first with 320-grit silicon carbide paper and then with 400-grit silicon carbide paper and a mildly acidic solution to keep the area wet.
4. Scrub surface area with M-Prep Conditioner A.
5. Clean area with liberal amounts of M-Prep Neutralizer 5. Do not allow any neutralizer to dry on the surface.
6. Place gauges and solder terminal strips on strips of Teflon fluorocarbon polymer tape.
7. Place tape with gauges on prepared surface of bolt with the long axis parallel to the length of the bolt.
8. Mix proper amounts of M-Bond AE-15 epoxy adhesive. Lay tape back over fingers and apply thin layer of epoxy to both gauge and bolt. Reposition tape on bolt.
9. Place silicone gum pad directly over gauge-terminal area, apply backup plate, and secure in place with fiber-reinforced tape using light pressure.
10. Cure gauges at 125° F to 130° F for a minimum of 6 h.
11. Remove tape and inspect gauge to make sure bond is secure.
12. Solder jumper wires, with adequate strain relief, to terminal strips.
13. Solder lead wires to terminal strips.
14. Preload bolt to mid-range, making sure that the gauge is properly installed before continuing.
15. Coat each gauge area twice with M-Coat D to protect against moisture.
16. Coat each gauge with M-Coat W-1, a microcrystalline wax. Heat bolt to approximately 100° F before the wax is applied.
17. Remove excess M-Coat W-1 wax on edges of bolt groove with hobby knife while the bolt is still warm.
18. Mix 3M 1838 B/A epoxy and place in caulking tube. Insert tube in caulking gun and apply epoxy by placing a bead in bolt groove. Place wires in groove and work epoxy around wires to ensure good coverage. Allow to cure overnight at room temperature.
19. Calibrate bolts using data acquisition system.