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Ground Control Instrumentation

A Manual for the Mining Industry

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°F	degree Fahrenheit	min	minute
ft	foot	μin	microinch
ft•lbf	foot pound	μin/in	microinch per inch
h	hour	pct	percent
in	inch	psi	pound per square inch
in^2	square inch	psi/min	pound per square inch per minute
in^3	cubic inch	V	volt
in/in	inch per inch		
lb	pound		

GROUND CONTROL INSTRUMENTATION

A Manual for the Mining Industry

By Eric R. Bauer[1]

ABSTRACT

This Bureau of Mines manual is intended to provide a better understanding of ground movement and the technology available for measuring it. The manual deals with convergence, strata separation, lateral roof movement, stress, and support load in underground mines. The instruments that measure these ground control parameters are described in detail. Step-by-step procedures for selecting the appropriate instrument are presented, which consider such factors as approximate cost, installation procedures, data collection, and data interpretation; and an instrument selection worksheet is provided to facilitate the instrument selection process. Actual instrument case studies and a list of instrument suppliers are presented in the appendixes.

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INTRODUCTION

Ground control is the control of the immediate area surrounding an underground excavation, including the stability of the mine roof, ribs, and floor. Since ground instability can result in unsafe mining conditions, it is vitally important that mine operators have effective means of controlling the mine area. To apply ground control techniques effectively, it is essential to ascertain the type of movement involved and the extent of the hazard created.

Each instrument available for measuring ground movements has particular characteristics, and the instrument to be used in each situation must be carefully selected to achieve optimum results. This manual is designed to assist mine operators in making such selections. Operational features of the instruments are included only as an aid to selection. Manufacturers of the devices should be consulted for instructions in their use. Additional information can be obtained from instrument suppliers and from sources listed in the references and bibliography for effective instrumentation use.

It is hoped that this instrumentation manual will improve the understanding of ground control movements and provide the information needed for efficient instrument selection.

ACKNOWLEDGMENT

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INSTRUMENT SELECTION GUIDELINES

Efficient instrument selection depends on the mine operator's (user's) ability to define the requirements and parameters of each ground control problem. At times this may be rather difficult, but even an educated estimate can provide adequate guidelines for choosing the appropriate instruments. As the requirements and parameters are defined, they should be listed on an instrument selection worksheet (fig. 1).

The first step is to identify the ground control movement that is occurring or needs investigation. This can be convergence (roof sag, rib failure, floor heave), separation of mine roof strata, lateral roof movement, stress, or support load. When the movement has been identified, it should be listed in the "movement occurring" column.

The next step is to determine the controlling parameters, namely cost, technical aspects, and data requirements. The cost parameter is the amount of money available for instrument purchases. The technical aspects parameter deals with the expertise of the people who will install and monitor the instrument and analyze the data. This expertise is designated as slight (no technical background or previous instrumentation use), moderate (some technical or engineering background and/or previous instrumentation use), or extensive (engineering degree and/or extensive instrumentation use). The data requirements parameter is the type and detail of data desired. Data can be either visual, simple numerical, detailed numerical, or a combination of these. As these controlling parameters are defined, they should be listed on the worksheet in the "desired elements" column.

The steps given in each chapter should then be followed to make a preliminary choice of the instrument(s) best suited to the ground control problem being investigated. To assist mine operators to make the final instrument selection, individual instruments are discussed in terms of principle and application, availability, description, installation and operation, data collection, and data interpretation.[2]

[2]Not all of the instruments described are commercially available at this time. For those that are, suppliers are listed in appendix B. For the others, instructions for in-house assembly are given where possible.

INSTRUMENT SELECTION WORKSHEET

Requirements	Movement occurring or measurement desired	Instruments available
Type of ground control problem		1. 2. 3. 4. 5. 6. 7.
Controlling parameters	**Desired elements**	**Instruments available**
Cost		1. 2. 3.
Technical aspects		1. 2. 3.
Data required		1. 2. 3.

Instruments satisfying all the above requirements and parameters:

1.
2.
3.

FIGURE 1. - Instrument selection worksheet for ground control measurements.

CHAPTER 1.--CONVERGENCE MEASUREMENTS

INTRODUCTION

Convergence is the vertical closure between roof and floor. It is also the horizontal closure between two parallel ribs. It involves three distinct movements: roof sag, rib failure, and floor heave. Roof sag, the downward movement of the immediate roof, occurs after the coal is mined and is due to the weights of the immediate roof and overburden. Rib failure--the spalling, lateral expansion, or shear failure of the pillars--is due to excessive loading of insufficient-size pillars by the overburden. Floor heave, the upward movement of the floor, results from the combination of small pillars and soft floor; overburden weight pushes the pillars downward and this pushes the soft floor sideways and upward.

Convergence measurements are an important investigative tool that permits operators to detect rib, roof, and floor movements before they become major ground control problems, to analyze ground movements and prevent further occurrences, and to plan changes in mine design. Early detection of hazardous ground conditions can result in increased safety and production.

GROUND MOVEMENT INDICATORS

Ground movements have specific characteristics that serve as indicators. Unfortunately, some indicators are common to several types of movement. In some cases, determining which movement is occurring can be difficult, amounting at times to no more than an educated estimate. The following list of convergence movements and their indicators can help to identify the type of movement that is occurring.

Roof sag indicators:

- Visible closure or convergence of entry.
- Tension cracks in middle of roof span.
- Increase in water dripping from cracks in the roof.
- Bent or broken roof supports.
- Falls of large blocks of rock.
- Shear cutters in roof along rib line.

Rib failure indicators:

- Sloughing of ribs at top, center, or bottom.
- Cracks developing in ribs.
- Bumps or bursts from ribs.

Floor heave indicators:

- Fractures developing in floor along centerline of roadway.
- Visible closure of entry.
- Unevenness developing in floor.
- Excessive seepage of water from floor.
- Sloughing of pillars at floor line only.
- Fractures developing in floor along rib line.

INSTRUMENT SELECTION

As requirements and parameters are defined, they should be listed on an instrument selection worksheet (fig. 1). The convergence movement (roof sag, rib failure, or floor heave) that is occurring or needs investigation should be listed in the "movement occurring" column. The controlling parameters, as defined in the section "Instrument Selection Guidelines," should be listed in the "desired elements" column.

Once the requirements and parameters have been defined and listed on the worksheet, the user should refer to figures 2 through 5 and follow steps 1 through 6 to make a preliminary choice of the instrument(s) best suited to the ground control problem being investigated.

Step 1: From figure 2, choose the instruments that satisfy the "movement occurring" requirement of the worksheet. List these instruments on the worksheet under "instruments available," across from the "movement occurring" parameter.

Instrument	Type of convergence measurable		
	Roof sag	Rib failure	Floor heave
Glowlarm	●	○	○
Guardian Angel	●	○	
Horizontal roof strain indicator	○	○	
Infrared scanner	○	○	
Infrared thermometer	○	○	
Plumb bob	●		○
Spider roof monitor	○		
SRC closure rate instrument	○		○
Tape extensometer	●	●	○
Tube extensometer	●		○
Visual roof sag bolt	●	○	

KEY

○ Can measure ● Best suited to measure

FIGURE 2. - Type of movement measurable by each convergence measuring instrument.

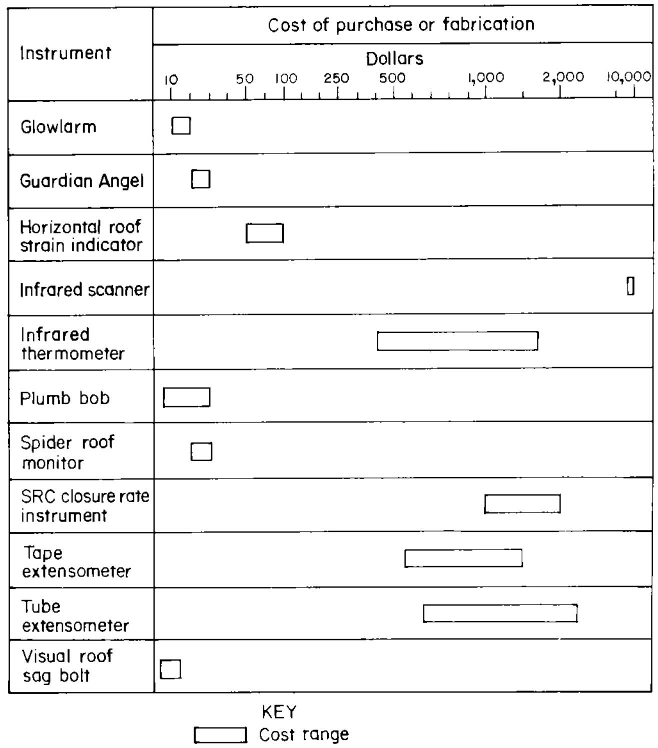

FIGURE 3. - Cost range of purchase or fabrication of convergence measuring instruments.

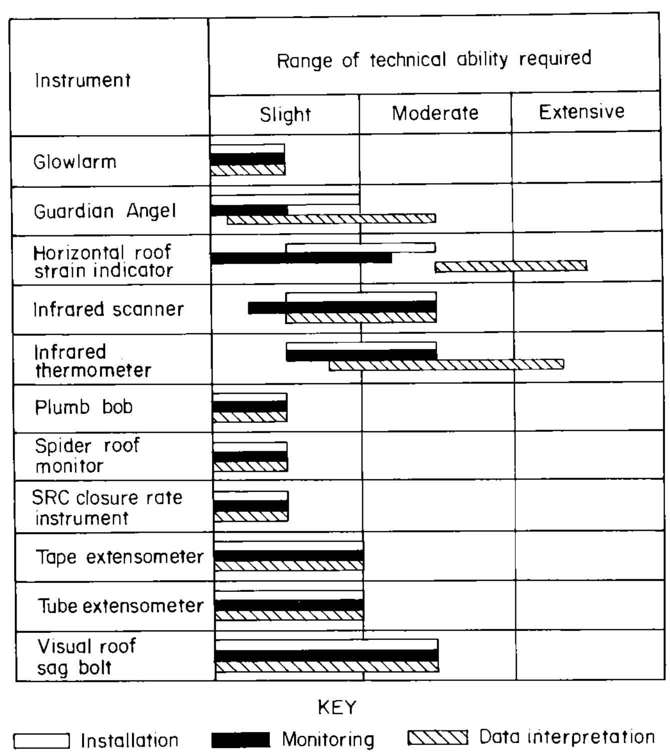

FIGURE 4. - Range of technical ability required for installation, monitoring, and data interpretation of convergence measuring instruments.

Step 2: From figure 3, choose the instruments that satisfy the cost parameter previously determined. List them on the worksheet under "instruments available," across from the cost parameter.

Step 3: From figure 4, choose the instruments that satisfy the technical aspects parameter. List them under "instruments available," across from the technical aspects parameter.

Step 4: From figure 5, choose the instruments that satisfy the data requirement parameter listed on the worksheet. List them under "instruments available," across from the data requirement parameter.

Step 5: Determine from the "instruments available" column of the worksheet the instruments that satisfy all of the requirements and parameters. List these instruments at the bottom of the

Instrument	Type of measured data obtained		
	Visual	Simple numerical	Detailed numerical
Glowlarm	○	○	
Guardian Angel	○	○	
Horizontal roof strain indicator			○
Infrared scanner	○		
Infrared thermometer		○	
Plumb bob	○	○	
Spider roof monitor	○		
SRC closure rate instrument	○	○	
Tape extensometer		○	
Tube extensometer	○	○	
Visual roof sag bolt	○		

KEY
○ Data obtainable

FIGURE 5. - Type of measured data obtained from convergence measuring instruments.

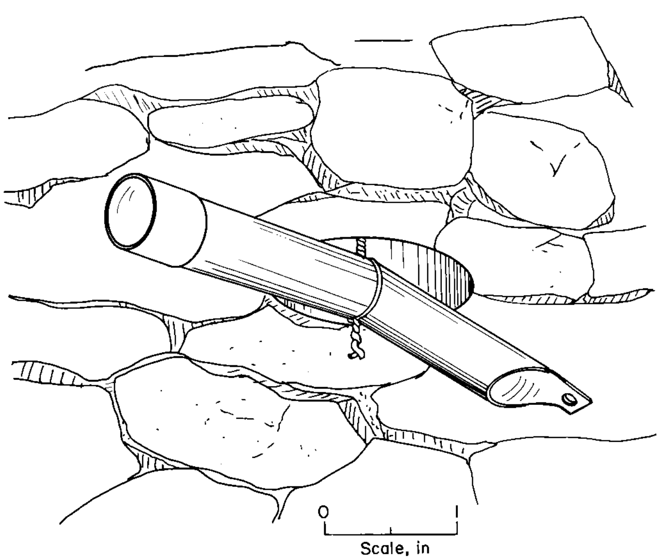

FIGURE 6. - Installed Glowlarm (1).

worksheet. They represent the best possible choices, relative to need, for the ground control problem being investigated. If no instruments satisfy all the requirements and parameters, it may be necessary to change the parameters or to choose the instruments that satisfy the most requirements and parameters.

Step 6: At this point, it is up to the user to make the final decision as to the most suitable instrument(s), based on the following detailed descriptions.

DESCRIPTION OF INDIVIDUAL INSTRUMENTS

Glowlarm[3]

Principle and Application

The Glowlarm is a device that gives visible warning of impending failure of roof, rib, or floor (1).[4] It detects roof sag, rib expansion, and floor heave by "lighting up" when movement occurs.

Availability

It is available from Glowlarm Rock Fall Warning Devices. Cost is approximately $10 per unit.[5]

Description

The Glowlarm warning device consists of a flexible see-through plastic tube about 6 in long and 0.5 in. in diam, which is held in place by an anchor and stainless steel wire (fig. 6). It contains two liquids separated by an inner glass tube. It is the mixing of these two liquids, after the glass tube breaks because of ground movement, that produces the bright yellow warning light. This light persists for 24 h.

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[3]Reference to specific products does not imply endorsement by the Bureau of Mines.

[4]Underlined numbers in parentheses refer to items in the list of references at the end of this chapter.

[5]Instrumentation costs are the best available estimates based on manufacturers' information at the time the research was completed.

Installation

Step 1: Drill a hole in the roof or rib to a stable zone of rock at a depth greater than the anchorage zone of the roof bolts being used.

Step 2: Push the anchor, with wire attached, to the end of the hole and set by rapping it sharply with a stick.

Step 3: Wrap wire around the Glowlarm and tighten it so that the Glowlarm has the desired bend. The amount of bend at installation determines the amount of movement to be detected. The larger the bend the less movement needed to break the glass tube, allowing the instrument to light up. The bend can be measured with a straightedge and rule (fig. 7).

Step 4: Trim off the excess wire. The Glowlarm is now ready to monitor ground movements.

Data Collection

The Glowlarm should be observed at least once every 24 h, since this is the life span of the warning light.

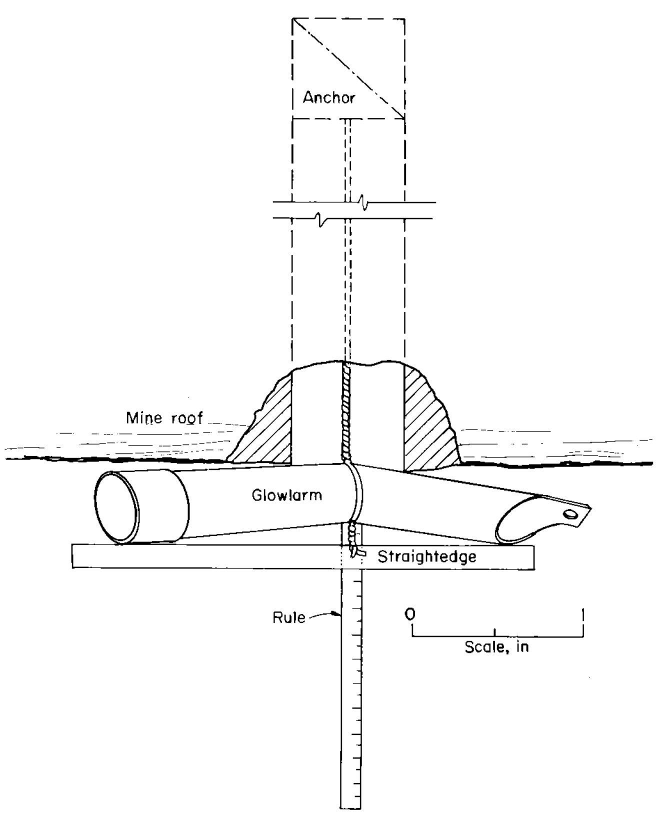

FIGURE 7. - Method for measuring bend of Glowlarm at installation.

These observations should be made during routine travel throughout the mine. A glowing instrument should be reported immediately to the appropriate mine personnel, who should initiate corrective action as soon as possible.

Data Interpretation

A glowing instrument means that some convergence has taken place; however, the amount of movement that indicates unstable conditions varies from mine to mine. Only through experimentation with this instrument can mine personnel become knowledgeable as to the amount of bend required at installation.

Guardian Angel

Principle and Application

The Guardian Angel is a device for measuring and monitoring roof sag (2). A reflector flag drops when the preset amount of movement is reached, to signal that movement has occurred. The instrument is also available with a graduated scale that measures the amount of movement numerically.

This instrument can be used where travel must not be impeded and over permanent installations, such as belt lines, haulageways, etc., where other instruments are impractical.

Availability

The Guardian Angel is available from Conkle, Inc. The price is $30 per unit.

Description

The Guardian Angel consists of anchor clips, threaded rod, reference head, trigger mechanism, and reflector flag (fig. 8).

Installation

Step 1: Drill a 1-in-diam roof bolt hole to a stable zone of rock and deeper than the anchor horizon of the roof bolts in the test area.

Step 2: Connect the desired lengths of rods, making sure to tighten the connecting locknuts.

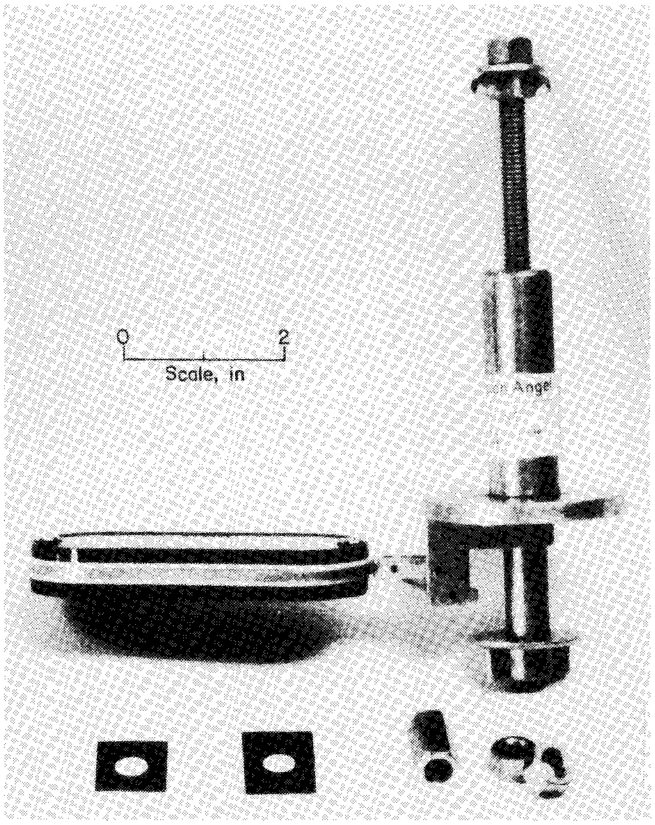

FIGURE 8. - Guardian Angel.

Step 3: Connect two anchor clips to the rod, making sure to tighten the locking nuts.

Step 4: Install the rods by manually pushing them upwards into the hole.

Step 5: Slide the monitor assembly onto the rod, then screw on the adjusting wingnut until the assembly is in contact with the roof (fig. 9).

Step 6: To set the monitor for the desired amount of movement detection, latch the flag in the "up" position (as shown in figure 9). Turn in the adjusting nut until the flag drops. Back the adjusting nut off a few turns, relatch the flag, then turn the adjusting nut back in until it just unlatches the flag. Reset the flag by slightly backing off the adjusting nut. Using the adjusting nut wings for reference, back the nut off to the desired amount of movement to be detected (3): Each quarter turn equals 0.015 in, etc.

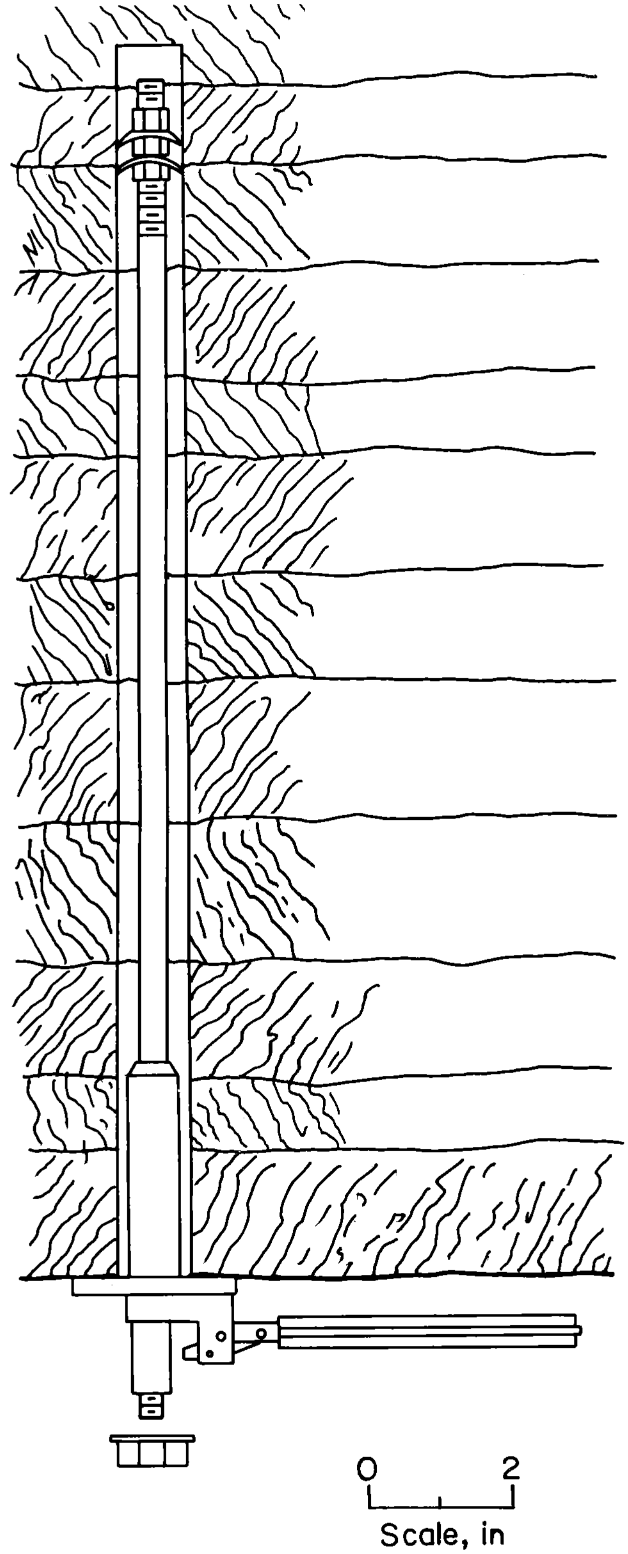

FIGURE 9. - Cutaway view of roof and installed Guardian Angel (2).

Data Collection

This instrument is designed to give a visual indication of roof movement. The flag drops when the preset amount of movement has occurred. The amount of movement can be determined by either of the following methods (2).

Method 1: If it is desirable to know the amount of roof sag prior to the flag's dropping, screw in the adjusting nut while counting the number of turns until the flag drops. Subtract the inches of deflection corresponding to the number of turns from the preset inches of deflection to obtain the amount of movement that has occurred. The system must now be reset to the previous, or a new, preset amount of movement to be detected (step 6 of installation).

Method 2: If the flag has dropped, back off the adjusting nut while counting the turns until the flag just resets. Screw the nut in while counting the turns until the flag unlatches. Subtract the second count from the first, and add the corresponding inches of deflection to the original preset amount of movement to obtain the total amount of movement that has occurred. Again, the instrument must be reset if additional movement detection is desired.

Each instrument can be observed as often as desired. For short-term installations or potential movement areas, observations can be made each shift, daily, or weekly. For long-term, stable areas, observations can be made weekly or monthly.

Data Interpretation

The Guardian Angel detects a preset amount of roof sag. The preset amount is arbitrary. Allowable movement limits must be determined for each mine, based on prior experience and/or ongoing instrumentation. Values for safe movement, movement indicating a need for caution, and movement indicating unstable roof must be established. The process of determining these values can be time consuming and can require hundreds of measurements. From these values, the appropriate presetting for movement detection can be determined. The values, however, may not be constant throughout the mine area.

Horizontal Roof Strain Indicator

Principle and Application

The horizontal roof strain indicator (HORSI) is a device that measures the horizontal roof strain that accompanies roof sag preceding a roof fall (4). It is based on the principle that the horizontal distance between two roof bolts will increase as the roof sags, producing a measurable strain difference that can indicate stable or unstable roof conditions (fig. 10).

Availability

The HORSI is not yet commercially available. Consequently, it must be fabricated in-house. Cost of fabrication and materials is approximately $50; an additional $35 to $50 is needed to purchase the dial gauge.

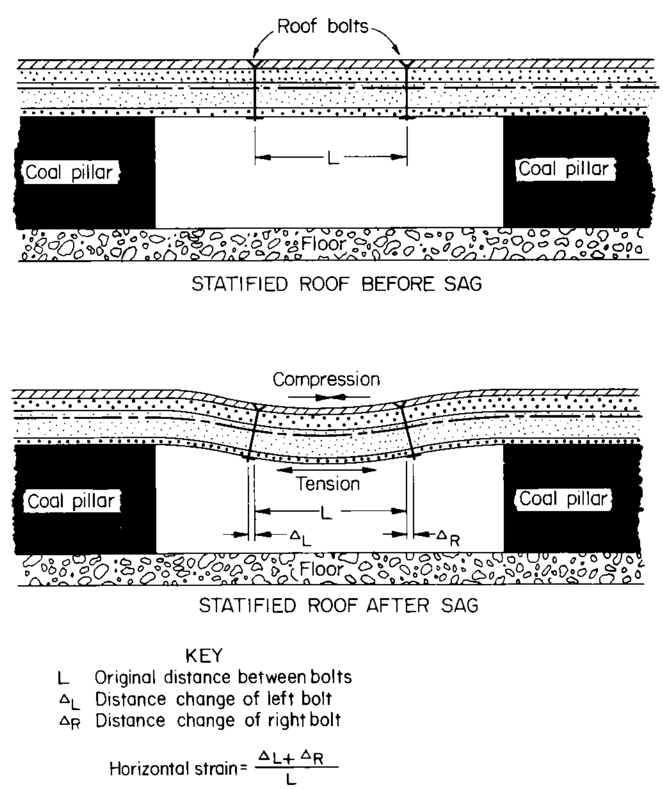

FIGURE 10. - Cross section of a typical coal mine opening illustrating the HORSI principle (4-6).

Description

The HORSI consists of two caps that attach to two adjacent boltheads with setscrews, a length of piano wire, a spring-tensioned plunger, a fitted collar, and a standard dial gauge indicator (fig. 11).

Installation

If installation is to be in the face area, the two bolts should be instrumented immediately after installation, because the strain usually stabilizes within 2 days, unless the roof is trending to an unstable condition. In previously mined and bolted areas, the HORSI can be installed whenever desired (5).

Step 1: Attach one of the bolt caps (anchor cap) to the head of one of the roof bolts, using the setscrews to secure it.

Step 2: Attach the spring-loaded plunger cap (measuring cap) to the other roof bolt head, using the setscrews to secure it. The removable dial gauge is connected to this cap by a fitted collar.

Step 3: Attach the piano wire to the spring plunger. Use a wire clamp to fasten it securely.

Step 4: Connect the free end of the piano wire to the other bolt cap. The wire must be lightly tensioned, then secured with the setscrews.

Step 5: Use the dial gauge indicator to take an initial reading, which will serve as the reference point for all additional readings.

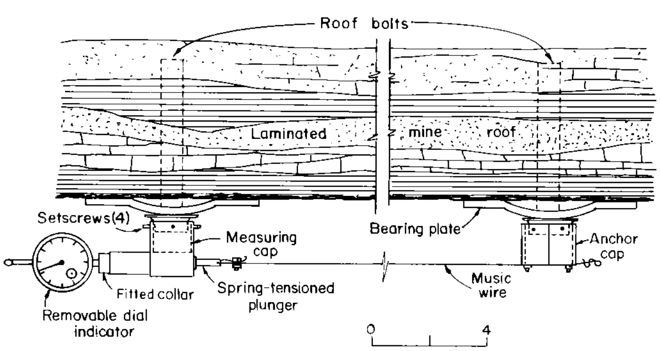

FIGURE 11. - Horizontal strain measuring apparatus (4-6).

Data Collection

After the initial reading, the dial gauge should be read on each shift for the first 2 days after installation, then once a week if the readings have stabilized. If the readings have not stabilized, they should continue to be taken on each shift until stabilization or roof failure occurs. In old workings, which may be considered stabilized, readings can be taken daily or weekly, as desired. Any unusual changes should be reported to the appropriate mine personnel immediately.

Data Interpretation

Previous experiments by the instrument developers have shown that a 0.0001-in/in strain within 2 days could indicate unstable roof conditions (4, 7-8). However, this may not be the case in all mines. Mine operators must determine, through experiments and use of this instrument, what amount of strain will indicate unstable roof conditions for a particular mine.

Infrared Scanner

Principle and Application

The infrared scanner senses temperature differences between loose rocks and their background and expresses those differences as a visual image (9). Temperature differences appear as light and dark areas on the visual image. The infrared scanner is one of two instruments that detect loose rock from a safe distance. (The other is the infrared thermometer.)

Availability

This instrument is still in the experimental stage with respect to use underground. The Bureau of Mines has a prototype that may soon be commercially available. Scanners approved by the U.S. Mine Safety and Health Administration may soon be available from Hughes Aircraft Co.; Seco, Standard Equipment Co.; and Wahl Instruments, Inc. The approximate cost of the infrared scanner ranges from $8,000 to $9,000.

Description

The infrared scanner is a handheld, 6-lb instrument, powered by a 6-V rechargeable battery (fig. 12). It produces a visual image of the heat waves from the material viewed.

Installation

No installation is needed, except to connect the battery to the scanner (some have internal batteries).

Data Collection

Turn the scanner on, point it toward the area to be observed, look through the eyepiece at the image, focus if necessary. No numerical data are obtained, only a visual picture of the viewed area, which cannot be recorded for future reference.

The scanner should be used at the face prior to mining or roof bolting, at roof falls before cleanup begins, in aircourses where loose rock is likely to develop, and any place where roof can be tested only from a distance.

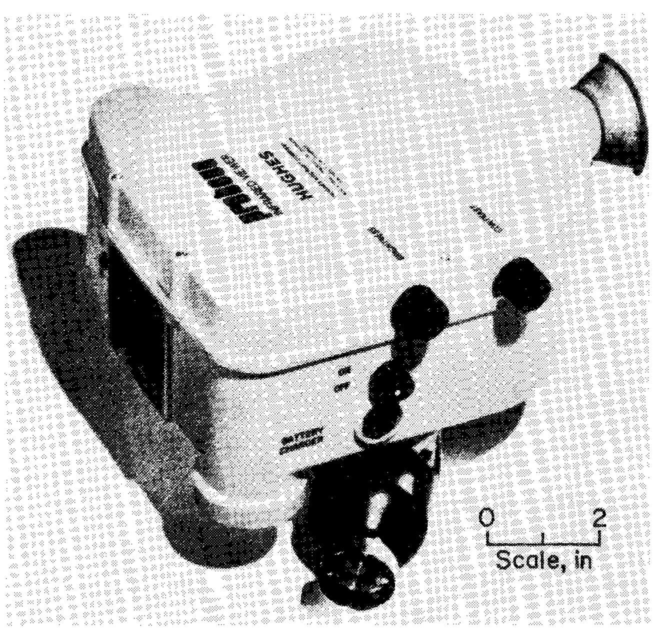

FIGURE 12. - Infrared scanner (10).

Data Interpretation

The visual image will show light areas for warmer temperatures and dark areas for colder temperatures. Generally, loose rock will be colder and will produce the darker image, but this does not hold true 100 pct of the time. Care must be taken to accurately determine which rocks are loose before attempting to correct the hazardous conditions. Also, external heat sources such as mining equipment may cause false readings.

Infrared Thermometer

Principle and Application

Infrared thermometers are designed for temperature measurements where direct contact is impossible or impractical. They may be useful in mines to detect temperature differences between loose and stable roof rock; however, it has yet to be definitely established that they can perform this function.

Availability

Infrared thermometers are available from the following suppliers: Barnes Engineering Co.; Extech International Corp.; Industrial Products Co.; Mikron Instrument Co., Inc.; Raytek, Inc.; Seco, Standard Equipment Co.; and Wahl Instruments, Inc. The approximate cost ranges from $400 to $1,715.

Description

The infrared thermometer is handheld, with the gauge on the back facing the operator. It is shaped like a pistol with barrel and pistol grip. Infrared thermometers are made with different temperature ranges, either Fahrenheit or Celsius. Most are autocalibrating; some have sights for locating the object to be measured (fig. 13).

Installation

No installation is necessary, but the thermometer must be calibrated, either manually or automatically.

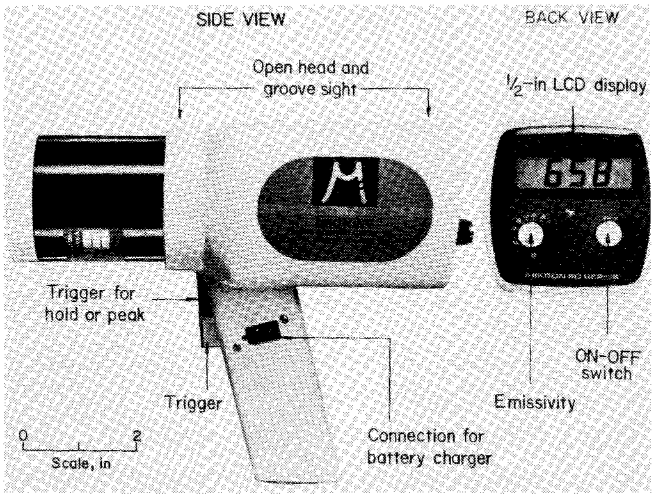

FIGURE 13. - Typical digital-readout infrared thermometer (11).

Data Collection

Point the instrument at the roof area to be measured. Distance from object should be 20 ft or less. This means that the area can be monitored while the person monitoring remains under supported roof. Slowly scan the area to detect any significant changes in temperature. Loose rock will be either warmer or colder, depending on whether the mine air is warmer or colder than the solid rock.

There is no specific time span for data collection. Possible collection could be at the face before any mining operations begin. This instrument could also be used in airways, escapeways, etc., when the need to detect loose roof arises. It might also be used at roof falls before cleanup begins, to detect any remaining loose rock.

Data Interpretation

Loose rock will register either as warmer or colder. Temperature differences will be minute, on the order of 0.36° to 0.9° F (9). Such small differences may not be detectable by the present infrared thermometers, which are sensitive only to 1° F. External heat sources may also affect the accuracy of this instrument.

Plumb Bob

Principle and Application

A plumb bob is a pointed weight that is suspended by a string. It can be used for imprecise measurement of entry convergence. This is accomplished by suspending the plumb bob from a point on the roof line and measuring its movement with respect to a reference pin in the floor (12). A plumb bob alone cannot differentiate between roof sag and floor heave.

Availability

Plumb bobs and associated materials are available from most hardware stores. The approximate cost ranges from $10 to $20.

Description

Instrumentation consists of a plumb bob, string, an eyebolt (which fastens to the roof bolt head), and a reference pin that is grouted into the mine floor (fig. 14).

Installation

Step 1: Drill and tap the head of a roof bolt to accept the eyebolt.

Step 2: Screw the eyebolt into the roof bolt and tighten.

Step 3: Using the plumb bob as guide (hanging from the eyebolt), drill or chip a hole into the floor vertically below the eyebolt.

Step 4: Grout the reference pin in the floor hole. This pin should be flat with a slight indentation at the center to accept the point of the plumb bob.

Step 5: When the grout has hardened (15 to 30 min), hang the plumb bob so that its point just touches the center of the floor reference pin.

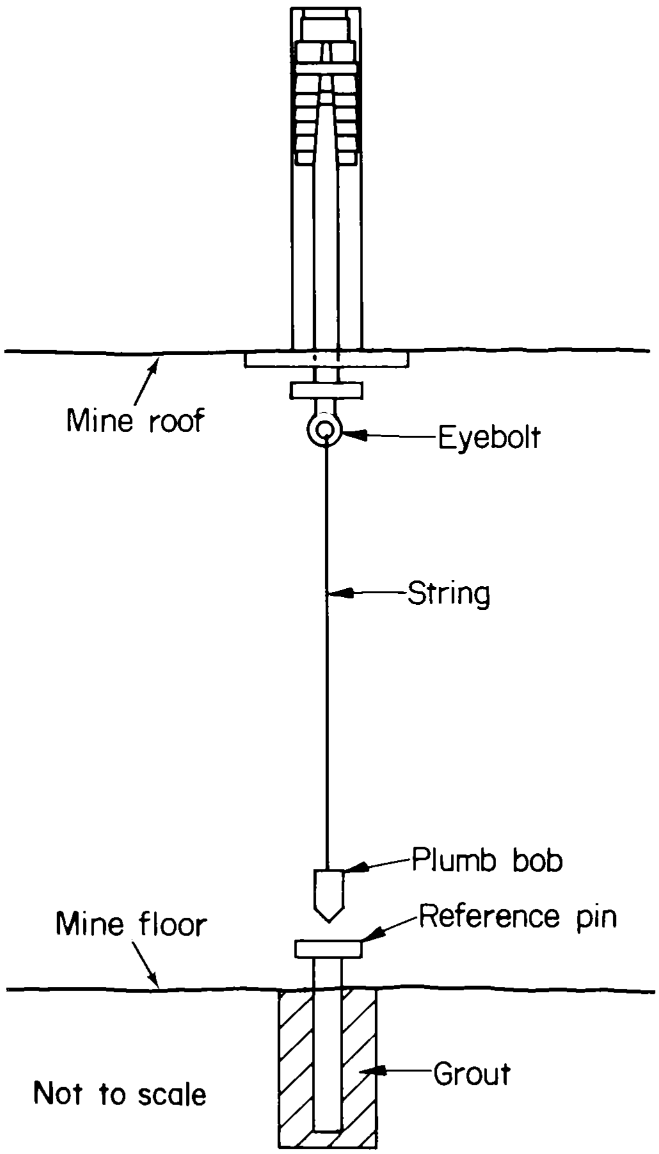

FIGURE 14. - Plumb bob setup for roof convergence measurement.

Data Collection

When the plumb bob starts to lean, the entry has begun to converge. If numerical values are desired, the plumb bob should be hung a specified distance above the floor reference pin. The amount of movement is the change in distance from plumb bob to pin.

A plumb bob installation should be checked as often as considered necessary. The frequency of observations should increase if substantial movement is detected.

Data Interpretation

The amount of movement indicating unstable roof or floor conditions varies from mine to mine. A continuing ground control instrumentation program can define this movement. In addition, humidity will cause slight variations in string length, resulting in reduced accuracy.

Spider Roof Monitor

Principle and Application

The Spider roof monitor is designed to signal roof movement (roof sag) (13). It attaches to an existing roof bolt in minutes and requires no special tools or drilling. It gives a visual display when a specified amount of movement has occurred, and can be reset to measure additional movement.

Availability

The Spider is available from The Spider Inc. The approximate cost is $30.

Description

The Spider consists of a plastic housing, latching mechanism, pin, reflective canister, roof-contact actuating arms, and mounting screws (fig. 15). Roof movement moves the actuating arms, which release the latching mechanism, which lets the reflective canister drop.

Installation

Step 1: Loosen the setscrew on the actuating arms and let the arms swing freely.

Step 2: Loosen the bolthead-connecting setscrews.

Step 3: Install the Spider on a roof bolt head and secure by tightening the setscrews. It is recommended that the Spider be installed on a bolt, minus the bearing plate, which is anchored 12 in above the existing bolts and extends 1 or 2 in below the roof line (fig. 16).

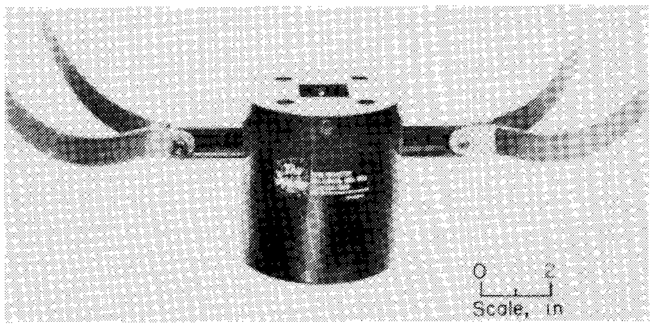

FIGURE 15. - The Spider roof monitor (13).

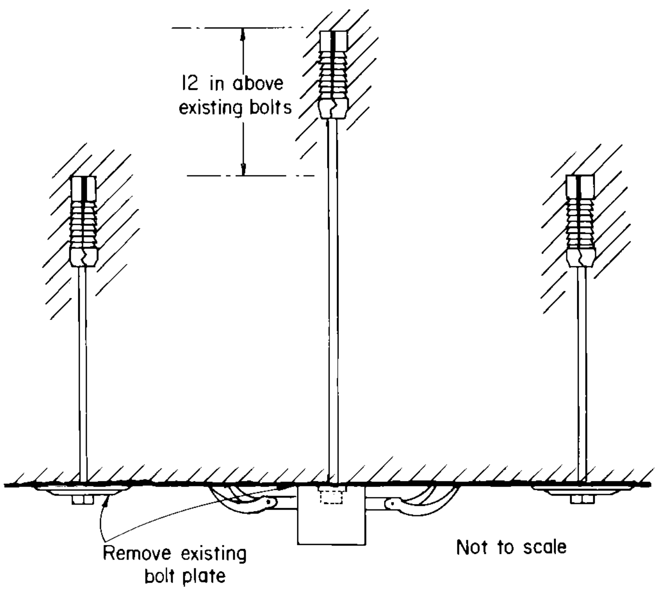

FIGURE 16. - Installation diagram for the Spider roof monitor (13).

Step 4: Set the actuating arms against the roof and secure them in position by tightening the setscrews. The amount of movement detected will vary according to the location of the actuating arms (the installation pressure against the roof).

Step 5: Latch the reflective drum by pushing it and the pin upward until they latch. If they will not latch, the actuating arms are applying too much pressure against the roof and must be readjusted.

Data Collection

If sufficient roof movement has occurred to trip the mechanism, the reflective canister can be seen. This instrument can be viewed on a regular basis (weekly, monthly, etc.) or during regular travel throughout the mine. If the instrument has tripped, it should be reported to the appropriate mine authority immediately.

The detection of movement must be individually analyzed for each mine, possibly for each specific installation. The amount of movement that indicates potentially hazardous roof will vary from site to site. Basically, this instrument detects movement only; it does not reveal the subsequent effect of the movement. Once the Spider has tripped, and the reflective canister is visible, it should be assumed that a hazardous roof condition has developed, until proven otherwise.

SRC Closure Rate Instrument

Principle and Application

The SRC closure rate instrument provides roof-to-floor closure rate measurements during underground mining, especially retreat mining of coal pillars (14). Change in resistance resulting from closure along a simple potentiometric extensometer is relayed to a readout box by means of a long cable. The instrument is designed to be pulled out of place and dragged to a safer location when closure reaches a predetermined rate.

Availability

This instrument can be purchased from Serata Geomechanics, Inc. Expected cost range is $1,000 to $2,000.

Description

The closure rate instrument system consists of a rugged telescoping potentiometric extensometer and a digital readout and control box. The extensometer is designed to accommodate a height of from 4.6 to 12.1 ft, with a measurement range of 6 in. It is spring loaded over this range. Long cables (98 to 125 ft) connect the extensometer to the readout box, permitting the operator to remain in a safe, supported area. A breakaway feature on each extensometer allows it to be pulled from the fall area by its electrical cable (15).

Installation

The instrument is placed between the roof and floor in the desired measurement area, while the readout box is kept in a safe area.

Data Collection

The operator watches the digital readout on the control box during pillar mining. When a predetermined, critical closure rate is reached, an alarm light and horn are activated, and the operator retrieves the extensometer and signals the miner operator to pull back.

Data Interpretation

Initially, the mine must determine a closure rate that indicates a roof fall is about to occur. This is the rate at which the alarms should be set to be activated. In many cases, a rate at which most falls will occur within 2 min of signalling can be determined.

Tape Extensometer

Principle and Application

The tape extensometer detects entry convergence or rib failure by measuring the change in distance between two permanent stations, either from rib to rib (closure) or roof to floor (convergence). The stations can be located as much as 100 ft apart, which is an advantage this instrument has over the tube extensometer.

Availability

Tape extensometers are available from the following suppliers: Geokon, Inc.; Irad Gage; Roctest, Inc.; Sinco, Slope Indicator Co.; and Soiltest, Inc. The approximate cost ranges from $550 to $1,500.

Description

A tape extensometer consists of a steel engineers' tape, a dial-tensioning mechanism, and two snaphooks (figs. 17-18). Anchoring stations are usually rods, grouted in place, with an eyebolt for connection to the instrument.

Installation

When measuring roof-to-floor convergence:

Step 1: Drill and tap roof bolt head. Screw the eyebolt into the roof bolt head.

Step 2: Directly below the roof station, drill a floor hole, and grout the floor station in place (eyebolt already attached).

When measuring rib-to-rib closure:

Step 1: At the desired location, drill a horizontal hole into the rib, then grout the anchor station in place.

Step 2: Repeat step 1 for the remaining rib anchor station.

Rib and floor stations should be made from a minimum 12-in rod, which should be completely grouted into the hole to ensure that the station is permanent.

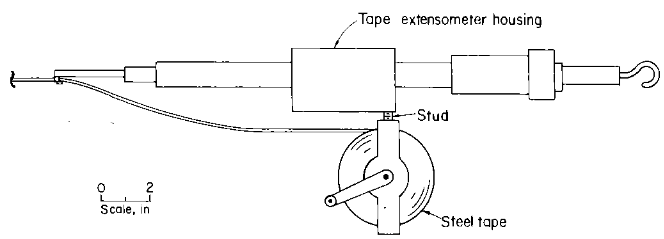

FIGURE 17. - Side view of tape extensometer (16).

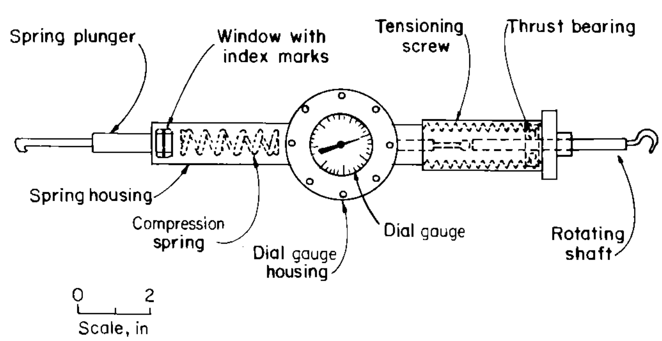

FIGURE 18. - Top view of tape extensometer (16).

Data Collection

Readings are taken as follows (fig. 19):

Step 1: Connect the free end of the tape to one of the stations.

Step 2: Connect extensometer (dial gauge) end to the remaining station. This should be the station at which the dial gauge is most easily read.

Step 3: Tension the tape by turning the handle, then connect the extensometer body to the tape by inserting the hook into one of the holes in the tape.

Step 4: Adjust the system to the zero mark on the extensometer spring plunger.

Step 5: Measurement is obtained by adding the tape distance (where the hook is in the hole) to the reading on the dial gauge.

Normally one reading per week is adequate, but large changes require more frequent readings, while small changes require less frequent readings. It should be noted that high air velocity will affect accuracy because of tape flutter (17).

Data Interpretation

The amount of measured movement indicating unstable conditions depends on the mine. Only through experimentation can this value be determined.

Tube Extensometer

Principle and Application

A tube extensometer detects entry convergence (roof sag and/or floor heave) by measuring the change in distance between pairs of permanent stations anchored in the roof and floor of a mine (18). The readout system is either a dial gauge, a sonic probe, or a continuous drum.

Availability

Tube extensometers are available from the following suppliers: Geokon, Inc.; Irad Gage; Sinco, Slope Indicator Co.; and Soiltest, Inc. The approximate cost of a tube extensometer and readout system is from $690 to $3,000.

Description

A tube extensometer consists of a series of telescoping tubes of Invar steel (19) (or other suitable metal alloy), an internal spring that provides tension against the reference stations, two reference stations, and a readout system (dial gauge, sonic probe, or continuous drum) (fig. 20). The sonic probe has an accompanying readout box and electrical connection cable. The continuous readout has a rotating-drum strip chart, and a lever arm and pen, which records all movements.

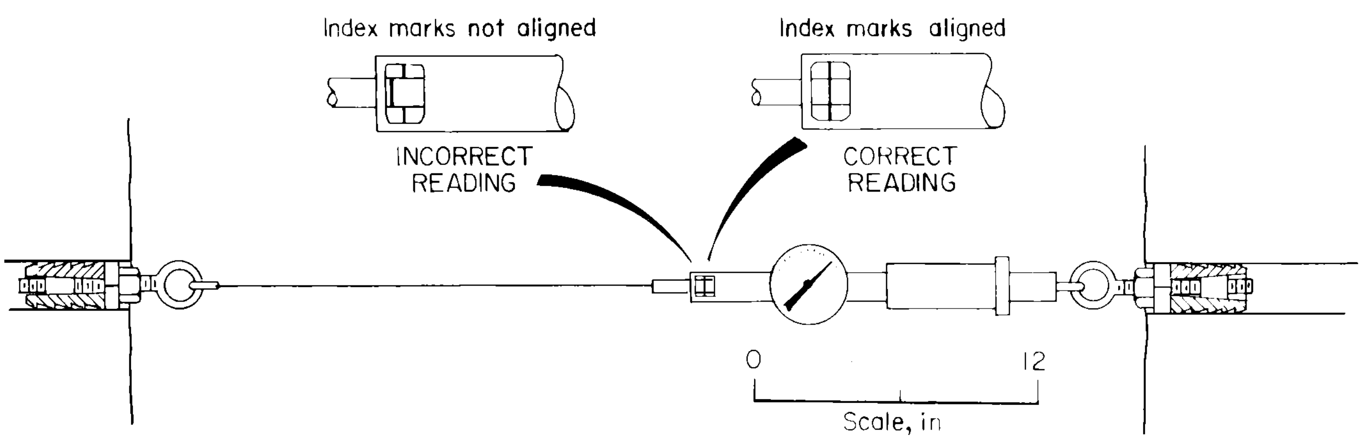

FIGURE 19. - Index mark alignment for correct reading of tape extensometer (16).

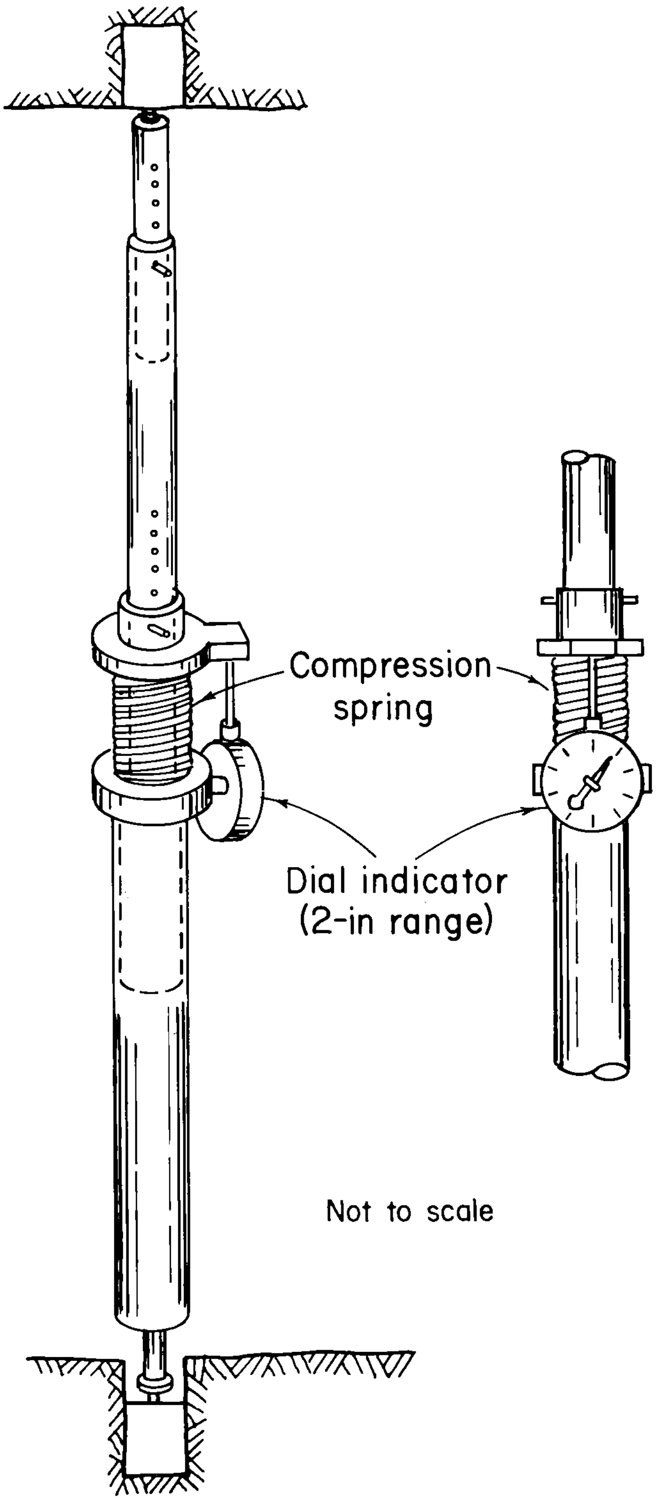

FIGURE 20. - Dial-gauge tube extensometer (20).

Installation

To anchor the reference stations:

Step 1: Drill and tap a roof bolt head to accept the roof reference pin.

Step 2: Use a plumb bob to mark the floor directly below the bolt, then drill a hole 12 in deep into the floor.

Step 3: Grout the floor reference station into the floor hole.

Step 4: Screw the roof station into the roof bolt head and tighten securely.

Step 5: When the grout has hardened, connect the appropriate number of tubes together, place the extensometer between the reference stations and record the first reading; this reading serves as the reference for all subsequent readings.

Data Collection

The collection procedure depends on the type of tube extensometer readout being used. For the continuous-recording type, all that is required is to observe the readings recorded on the strip chart and change the chart periodically. The dial gauge only needs to be read. The sonic probe readout requires connecting the readout box to the extensometer using the electrical cable, then reading the deflection as displayed. Data should be collected once a week unless conditions warrant otherwise.

Data Interpretation

Interpretation of data depends on the mine in which the data are collected. Unacceptable movement must be determined for each mine through continuing experimentation.

Visual Roof Sag Bolt

Principle and Application

As its name implies, the instrument displays roof movements visually, and gives no numerical data. This is not a precise measuring instrument, but it is useful for detecting impending roof failure, at minimal cost, in time to provide additional support (21). Visual roof sag bolts are intended for installation in the face area but can be installed minewide. They do not replace pattern bolts since they have no supporting capability.

Availability

Visual roof sag bolts are not commercially available, but the materials to fabricate them are. Since a standard roof bolt is used, the only material to be purchased is the reflective tape or paint. Total cost will range from $5 to $15.

Description

A visual roof sag bolt system consists of a standard mechanical anchor bolt, three bands of reflective tape or paint (green, yellow, and red), and a polystyrene foam (such as Styrofoam) plug (fig. 21). The roof bolt can have the head left on or cut off and should be at least as long as (preferably longer than) the pattern bolts in the area being monitored. The movement-indicating bands (approximately 0.5 in wide) are placed on the bolt with the green nearest the anchor, followed by the yellow and then the red, going toward the head of the bolt. A polystyrene foam plug, cut to slide over the bolt and into the hole, serves as the reference level indicator.

Installation

The bolts should be installed in the middle of the entry or at intersections where, theoretically, the most movement will occur.

Step 1: Drill a standard roof bolt hole the length of the visual roof sag bolt. The bolt should anchor above the anchorage horizon of the surrounding pattern bolts in a stable zone of rock.

Step 2: Remove the anchor and slide the foam plug down over the bolt to the bolt head.

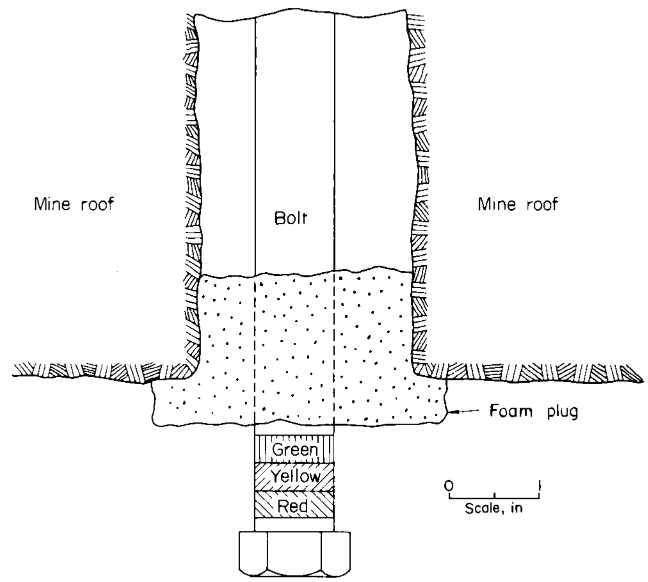

FIGURE 21. - Visual roof sag bolt at installation (19).

Step 3: Replace the anchor, slide the bolt into the hole, and seat the foam plug.

Step 4: Tighten the bolt so that all three color bands just show.

Data Collection

No numerical data are collected. A quick glance tells mine personnel if the roof has moved. The bolts can be checked either randomly in passing, or on a regular schedule. The frequency of observation depends on the amount of movement occurring. The appropriate mine personnel must be notified of any significant movements as soon as possible.

Data Interpretation

The amount of movement (indicated by the disappearance of the color bands) will vary from mine to mine. Each mine must determine the rate of movement that indicates unstable roof conditions. The color bands are interpreted as follows:

1. All three colors showing: No movement, stable roof conditions (fig. 21).

2. Green disappearing: Initial (slight) movement, caution, possible unstable roof conditions developing (fig. 22*A*).

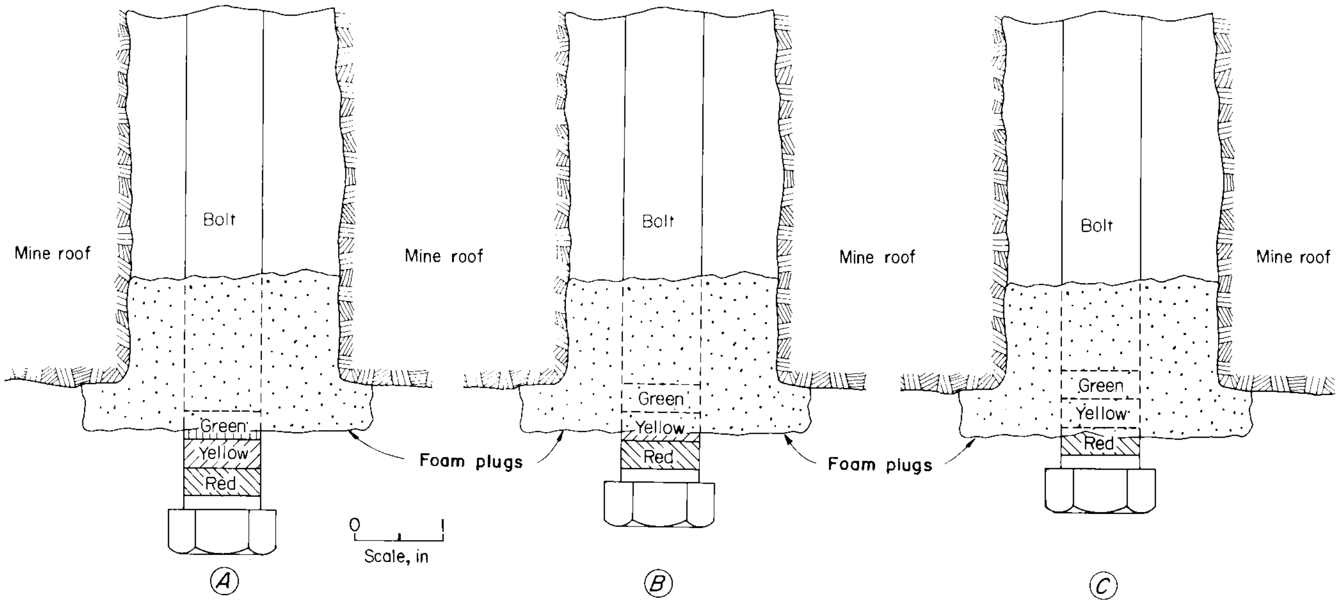

FIGURE 22. - Visual roof sag bolt after convergence movements. *A*, Initial (slight); *B*, moderate; *C*, substantial.

3. Yellow disappearing: Moderate movement, caution, unstable roof conditions developing (fig. 22*B*).
4. Red disappearing: Substantial movement, warning, unstable roof conditions (fig. 22*C*).

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CHAPTER 2.--STRATA SEPARATION MEASUREMENTS

INTRODUCTION

Strata separation is the differential downward separation of distinct roof strata layers. It results from a low coefficient of friction between roof strata layers and the weight of the immediate roof and overburden.

Strata separation measurements allow mine operators to detect movement before roof control problems occur, to analyze and prevent further occurrences, and to make changes in mine plans. Early detection of developing hazardous roof conditions can improve safety and production.

GROUND MOVEMENT INDICATORS

Each ground movement is characterized by specific indicators. However, since some indicators are common to several types of movement, recognizing the movement that is occurring can be difficult, and at times may be just an educated estimate. The following indicators of strata separation can help to identify this movement:

- Cracks developing in middle of roof span.
- Distinct layers of roof falling.
- Succession of falls of distinct layers in the same area.
- Increase in dripping of water from roof.
- Visible entry closure or convergence.

INSTRUMENT SELECTION

As requirements and parameters are defined, they should be listed on an instrument selection worksheet (fig. 1). In this case, the user should list strata separation in the "movement occurring" column. The controlling parameters, as defined in the section "Instrument Selection Guidelines," should be listed in the "desired elements" column.

Next, the user should refer to figures 23 through 25 and follow steps 1 through 6 to make a preliminary choice as to which instrument(s) best suits the ground control problem being investigated.

Step 1: List the instruments available for monitoring strata separation on the worksheet under "instruments available" across from "movement occurring." All three instruments described in this chapter will monitor strata separation.

Step 2: From figure 23, choose the instruments that satisfy the cost parameter selected and list them under "instruments available," across from the cost parameter.

Step 3: From figure 24, choose the instruments that satisfy the technical aspects parameter and list them under "instruments available," across from the technical aspects parameter.

Step 4: From figure 25, choose the instruments that satisfy the data requirement parameter and list them under "instruments available," across from the data requirement parameter.

Step 5: Examine the "instruments available" column of the worksheet to find the instruments that satisfy all requirements and parameters, and list them at the bottom of the worksheet. If no instruments satisfy all the requirements and parameters, it may be necessary to change the parameters or to choose the instrument that satisfies the most requirements and parameters.

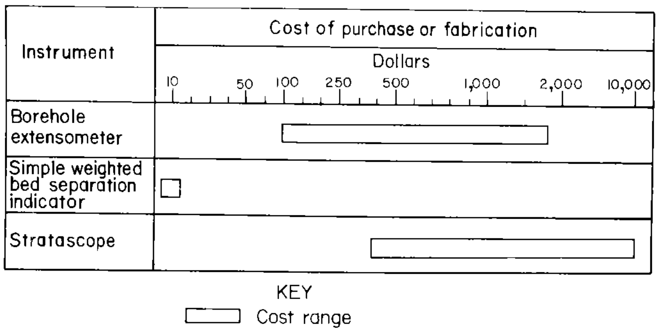

FIGURE 23. - Cost range of purchase or fabrication of strata separation measuring instruments.

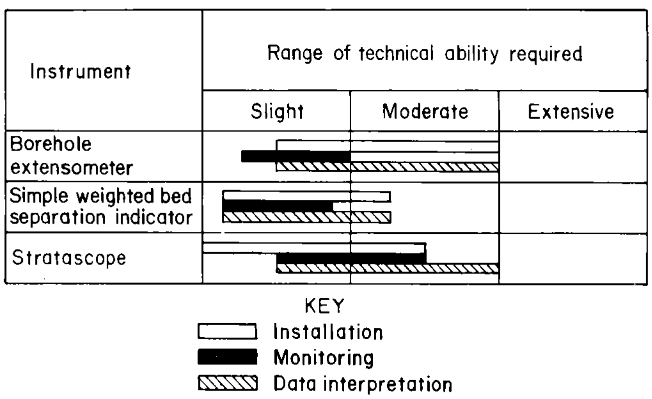

FIGURE 24. - Range of technical ability required for installation, monitoring, and data interpretation of strata separation measuring instruments.

Instrument	Type of measured data obtained		
	Visual	Simple numerical	Detailed numerical
Borehole extensometer		○	○
Simple weighted bed separation indicator		○	
Stratascope	○	○	

KEY
○ Data obtainable

FIGURE 25. - Type of measured data obtained from strata separation measuring instruments.

Step 6: At this point, the user must make a decision as to the instrument or instruments to be used, based on the following detailed descriptions.

DESCRIPTION OF INDIVIDUAL INSTRUMENTS

Borehole Extensometer

Principle and Application

Borehole extensometers are in-hole measuring devices that detect strata separation movements at various horizons of the roof. Movement is detected by the change in distance between anchors at various depths and the reference head at the roof line (1).[6] Anchors are connected to the reference head by rod or wire connection systems. Borehole extensometers are available as single-position (one horizon detection) (fig. 26*A*) and

[6]Underlined numbers in parentheses refer to items in the list of references at the end of this chapter.

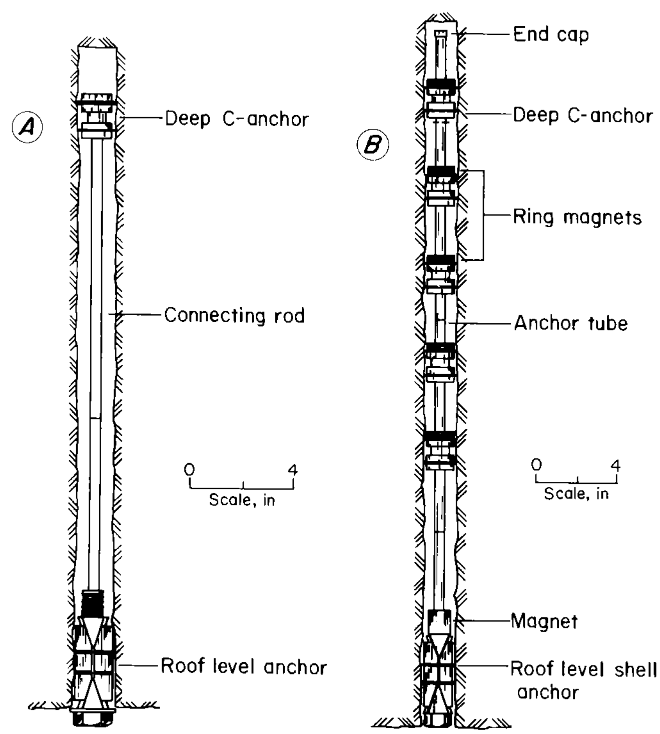

FIGURE 26. - Borehole extensometer. *A*, Single point; *B*, multipoint (2).

multiple-position (multiple horizon detection) instruments (fig. 26*B*). Readout systems include flexible and rigid sonic probes, dial gauge, and spring cantilever.

Availability

Borehole extensometers can be purchased from the following suppliers: Geokon, Inc.; Irad Gage; Roctest, Inc.; Sinco, Slope Indicator Co.; and Soiltest, Inc.

Approximate cost for the extensometer and readout system ranges from $100 to $1,800.

Description

Borehole extensometers consist of anchors, a reference head, wire or rod connecting assemblies, and a readout system. Anchors are of many different types: rock bolt expansion shell, double-wedge expansion shell, flat sliding wedge, wedge-split ring, screw-activated shoe, hydraulic anchor, cement-grouted anchor, C-anchor, cam anchor, and expansion shoe anchor. The readout system can be a dial gauge, depth gauge, dial micrometer, continuous-drive mechanical chart, spring cantilever, potentiometer, or sonic probe.

Installation

Installation procedures are very general, because each type of anchor has a specific installation sequence that cannot be adequately described here. Information on special tools or methods needed to install the connecting rods or wires can be obtained from the instrument suppliers.

Step 1: Drill anchor holes to appropriate diameter and depth (just past the last horizon of desired monitoring).

Step 2: Set anchors in the hole at desired horizons.

Step 3: Install reference head in the hole at the roof line.

Step 4: Connect anchors to reference head with wires or rods (depending on the type of extensometer being installed).

Step 5: Connect the readout system to reference head and take the initial readings, which will serve as the baseline for all subsequent readings.

Data Collection

Data are collected using the readout system appropriate to the extensometer selected.

A total of eight horizons in 15 ft of strata can be monitored for their change of location, to determine bed separation. Borehole extensometers should be read once a week unless (1) no movement is occurring (readings can be stopped) or (2) large movements are occurring (frequency of readings should increase).

Data Interpretation

The critical factor is the amount of bed separation at each horizon monitored and the total roof sag created. The strata will sag differently from mine to mine; therefore, there is no degree of deflection that can be taken as an industry-wide warning of developing unstable roof conditions. Each mine must determine allowable separation for the roof strata being supported.

Simple Weighted Bed Separation Indicator

Principle and Application

The simple weighted bed separation indicator (also known as a vertical displacement gauge) can be adapted to measure one or several horizons of separation within the same hole. Movement is measured by the change in length of wires with reference to a brass plug at the roof line.

Availability

This instrument is not commercially available. It can be fabricated in-house or by a local machine shop. Cost for each installation is approximately $5 to $15.

Description

Components include spring clip anchors, lightweight steel wires, ring-tongue solderless terminals, a brass reference plug, and a weight. Measurements are made with a vernier caliper or graduated scale, depending on the precision required.

Installation

Step 1: Braze wires to anchors before installation, attaching the wires to center or sides of anchors as needed.

Step 2: Drill 3-in-diam hole into roof to a depth greater than the zones of suspected separation.

Step 3: Install anchors one at a time, making sure not to tangle the wires. To do this, compress the anchor in a hollow cylinder, position it at the desired depth, then eject it from the cylinder by pushing a rod through the cylinder.

Step 4: Slide wires through appropriate holes in the brass plug, then secure the plug in the hole opening.

Step 5: Clip wires and install ring-tongue solderless terminals (fig. 27), to which the weight will be attached.

Step 6: Attach the weight to one wire at a time and take an initial reading to serve as the reference for all subsequent readings.

Data Collection

Readings are taken by hanging the weight on the wire, then measuring the distance from the solderless terminal to the reference plug. A vernier caliper works well, but a graduated scale will also work. A change in wire length indicates a separation of strata.

Data Interpretation

How much each zone has moved is shown by the amount of movement recorded in comparison with the reference reading. Subtracting the movement measured from the reference reading will give the total movement from the time of installation.

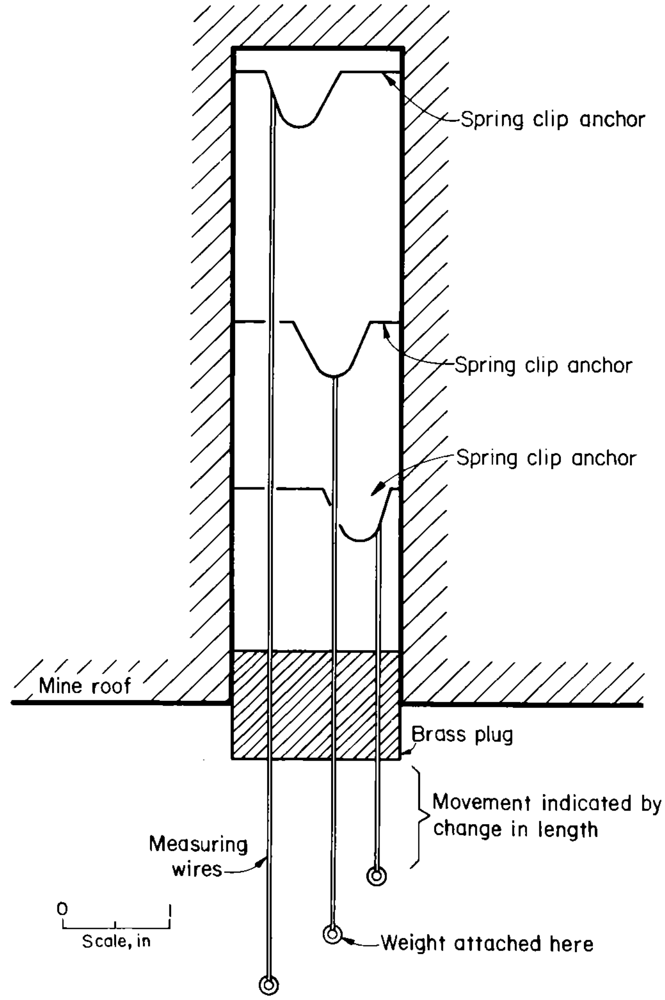

FIGURE 27. - Simple weighted bed separation indicator.

Interpretation of the data will depend on the mine or area being monitored. The amount of movement that indicates unstable roof conditions must be determined for each mine.

Stratascope

Principle and Application

The stratascope (borescope) is an optical viewing instrument designed to permit visual or photographic observations within a drilled hole. It is used to detect cracks, separations, geologic makeup of mine strata, and lateral roof movements. Recently developed models use flexible fiberoptics.

Availability

Stratascopes can be purchased from the following suppliers: American Optical Corp.; Baltimore Instrument Co., Inc.; Eder Instrument Co., Inc.; Expanded Optics Co., Inc.; Instrument Technology, Inc.; Lenox Instrument Co., Inc.; Olympus Corp of America; Soiltest, Inc.; and Welch Allyn, Inc. Approximate cost ranges from $390 to $10,000.

Description

The stratascope is basically a periscope, either handheld or tripod mounted. It consists of a light, a protective outer housing, a lense, and mirrors or fiberoptics (fig. 28). The light is powered by a battery pack. If pictures are to be taken, tripods are needed for both the stratascope and camera (fig. 29).

Installation

Step 1: Drill a hole to the desired depth (the diameter depends on the stratascope used).

Step 2: Assemble necessary extensions for viewing at the desired depth.

Step 3: Connect the battery pack to the stratascope using electrical cable.

Step 4: If photographs are to be taken, assemble the stratascope tripod directly below the hole.

Data Collection

Visual observation: Slowly slide the stratascope into the hole, stopping to view the hole where desired, by looking through the eyepiece. By rotating the stratascope, the entire circumference of the hole can be observed.

Photographic observation: Slide the stratascope into the hole, then clamp it to the tripod. Move the tripod-stratascope assembly until the stratascope is centered in the hole. Set up the camera tripod and attach the camera to tripod and to stratascope. Set the stratascope to the borehole area to be photographed and take the picture.

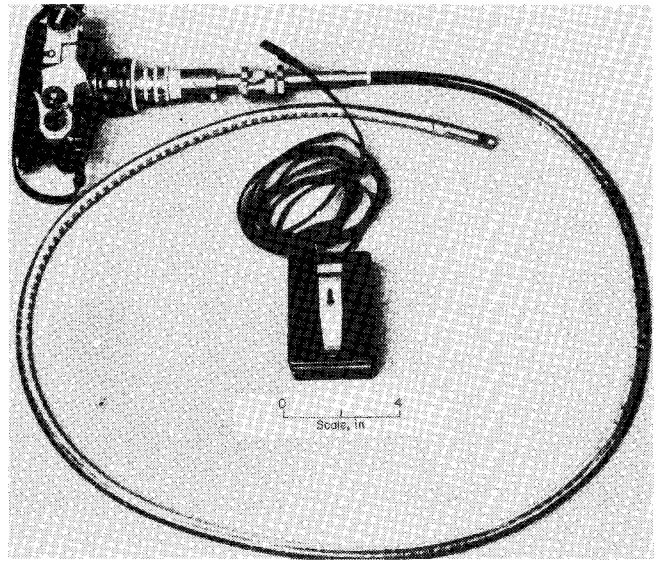

FIGURE 28. - Fiberoptic stratascope, battery pack, camera, and attachment (3).

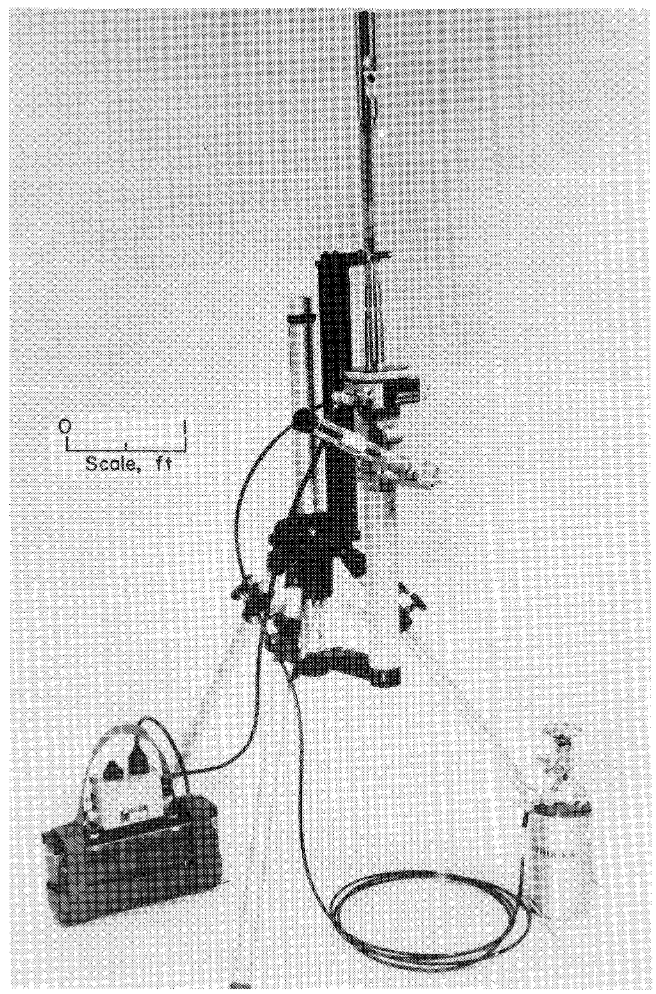

FIGURE 29. - Stratascope setup for roof observation.

There are no specific guidelines as to how often a hole should be viewed. Using the stratascope in newly mined areas to determine if the roof strata characteristics have changed or in previously mined areas to check for developing cracks and separations will determine the frequency of viewing.

Data Interpretation

Since no two mines are the same, the significance of any irregularities observed will depend on the particular mine. Irregularities such as clay veins, mud seams, cracks, fractured zones, and slips will create different problems for each mine. The important fact is that early detection of these ground conditions will enable mine personnel to initiate the appropriate action to control them.

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CHAPTER 3.--LATERAL ROOF MOVEMENT MEASUREMENTS

INTRODUCTION

Lateral roof movement is the differential horizontal displacement (sliding) of distinct roof layers. It is a result of a low coefficient of friction between roof layers and a high horizontal stress within the roof.

Lateral roof movement measurements provide mine operators with a means of detecting such movements before roof control problems occur, analyzing their cause and preventing further occurrences, and making necessary changes in mine design. Early detection of developing hazardous roof conditions can result in increased safety and production.

GROUND MOVEMENT INDICATORS

Like other ground movements, lateral roof movement has specific indicators that characterize it. Unfortunately, some indicators are common to several movements. Therefore, differentiating among movements and determining which movement is occurring can be difficult, and at times may be just an educated estimate. The following indicators of lateral roof movement should help in recognizing its occurrence:

- Offsets developing in holes drilled in the roof.
- Falls where many bolts are bent in in the same direction.
- Bolts shearing and falling out of holes.
- Tension cracks in roof at one rib line, compression cracks in roof at opposite rib line.

INSTRUMENT SELECTION

As requirements and parameters are defined, they should be listed on an instrument selection worksheet (fig. 1). Since this chapter deals with lateral roof movement only, "lateral roof movement" should be written in the "movement occurring" column. The controlling parameters as defined in the section "Instrument Selection Guidelines," should be listed in the "desired elements" column.

Next, the user should refer to figures 30 through 32 and follow steps 1 through 6 to make a preliminary choice as to the most suitable instrument(s) for the ground control problem being investigated.

Step 1: Both of the instruments in this chapter satisfy the "movement occurring" requirement previously entered on the worksheet. List them under "instruments available," across from the "movement occurring" parameter.

Step 2: From figure 30, choose the instrument that satisfies the cost parameter selected and list it under "instruments available," across from the cost parameter.

Step 3: From figure 31, choose the instrument that satisfies the technical aspects selected and list it under "instruments available," across from the technical aspects parameter.

Step 4: Figure 32 shows that both instruments provide visual and simple numerical data. Neither provides detailed data. List both or neither on the worksheet depending on the type of data required.

Step 5: From the "instruments available" column, determine which instrument satisfies all requirements and parameters. Enter this instrument at the bottom of the worksheet. If neither instrument satisfies all the requirements and parameters, it may be necessary to change the parameters or to choose the instrument that satisfies the most requirements and parameters.

Step 6: At this point, the user must decide which instrument should be selected, based on the following detailed descriptions.

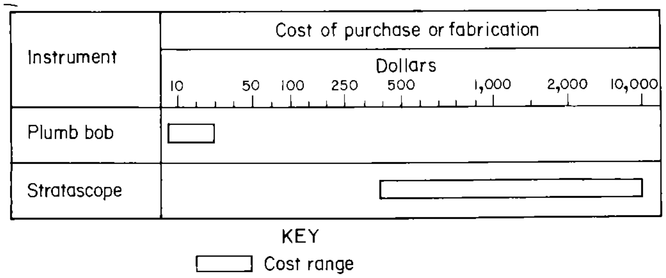

FIGURE 30. - Cost range of purchase or fabrication of lateral roof movement measuring instruments.

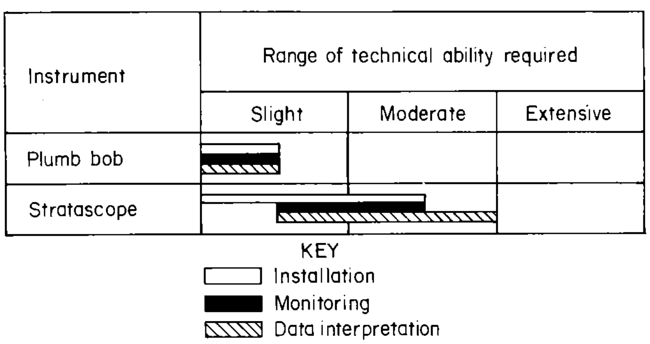

FIGURE 31. - Range of technical ability required for installation, monitoring, and data interpretation of lateral roof movement measuring instruments.

Instrument	Type of measured data obtained		
	Visual	Simple numerical	Detailed numerical
Plumb bob	○	○	
Stratascope	○	○	

KEY
○ Data obtainable

FIGURE 32. - Type of measured data obtained from lateral roof movement measuring instruments.

DESCRIPTION OF INDIVIDUAL INSTRUMENTS

Plumb Bob

Principle and Application

A plumb bob is a pointed weight suspended by a string. It can be used for imprecise measurement of lateral roof movement, by being suspended from a point on or in the roof and its movement measured with respect to a reference pin in the floor.[7] Observed plumb bob movements, coupled with visual observation of the holes drilled into the roof will be sufficient for detection of lateral movement of roof strata.

Availability

Plumb bobs and associated materials are available from most hardware stores. The approximate cost ranges from $10 to $20.

Description

The assembly consists of a plumb bob, string, a spring clip anchor, and a reference pin grouted into the mine floor (fig. 33).

[7] Shepherd, R., and D. P. Ashwin. Measurement and Interpretation of Strata Behavior on Mechanized Faces. Colliery Guardian, v. 216, No. 12, 1968, pp. 795.

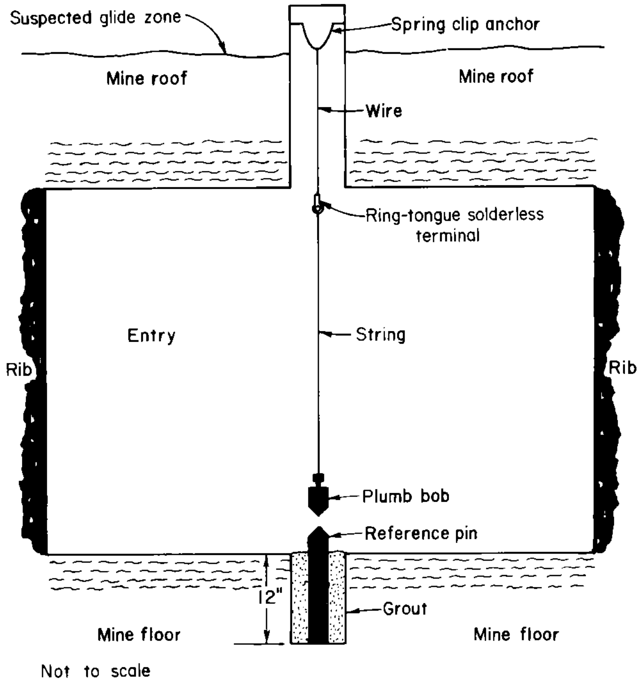

FIGURE 33. - Plumb bob setup for detecting lateral roof movement.

Installation

Step 1: Braze a long piece of steel wire (longer than depth of hole) to the center of a spring clip anchor.

Step 2: Drill a minimum 2-in-diam hole into the roof strata layer that is thought to be moving.

Step 3: Install the spring clip anchor in the hole by compressing the anchor in a hollow cylinder, pushing this cylinder and anchor to the desired location, and then pushing the anchor out of the cylinder and against the strata using a rod slid up through the cylinder.

Step 4: Remove the cylinder and rod from the hole.

Step 5: Clip the wire several inches below the hole, then clamp a ring-tongue solderless terminal to the end of the wire.

Step 6: Using the suspended plumb bob as a guide, drill or chip a hole into the mine floor directly below the plumb bob.

Step 7: Grout the reference pin in the floor so that its point is directly under the plumb bob point.

Step 8: When the grout has hardened, adjust the plumb bob so that it is just barely above the reference pin.

Data Collection

Any roof movement will be indicated by a change in horizontal distance between the reference pin and the plumb bob.

A plumb bob installation should be checked as often as experience indicates is necessary. The frequency of observations should increase if substantial movement is detected.

Data Interpretation

The amount of movement that indicates unstable roof conditions will vary from mine to mine. Only by experience and continuing measurements can this movement be determined. Once this is known, developing unstable roof can be detected in time for corrective action.

Stratascope

See chapter 2 for a complete description of this instrument.

CHAPTER 4.--STRESS MEASUREMENTS

INTRODUCTION

Ground stress is the force per unit area distributed about an excavation. There are two types of stress, either in situ (produced by nature) or extraction (resulting from mining). Ground stress measurements are used for mine design. Based on the distribution of stress around an excavation, the best orientation of entries and the optimum pillar size can be determined, thus reducing or eliminating ground control problems.

Stress measurements provide mine operators with a means of detecting ground (roof, rib, and floor) control problems before and after they occur, analyzing their causes and preventing further occurrences, and making necessary changes in mine design.

GROUND MOVEMENT INDICATORS

Like other ground movements, ground stress has specific indicators that characterize it. Unfortunately, some indicators are common to several movements. Therefore, differentiating among several movements can be difficult, and at times may be just an educated estimate. The following indicators of excessive stress can help miners to recognize its occurrence:

- Excessive number of roof falls.
- Numerous roof falls with same orientation.
- Excessive rib sloughing.
- Floor heave.
- Roof sag.
- Entry closure (squeeze).

INSTRUMENT SELECTION

As requirements and parameters are defined they should be listed on an instrument selection worksheet (fig. 1). Since this chapter deals with stress measurements only, stress should be listed under the "measurement desired" column. The controlling parameters, as defined in the section "Instrument Selection Guidelines," should be listed in the "desired elements" column.

Next, the user should refer to figures 34 through 36 and follow steps 1 through 6 to make a preliminary choice as to the most suitable instrument(s) for the ground control problem being investigated.

Step 1: All of the instruments in this chapter satisfy the "measurement desired" requirement (stress) previously listed on the worksheet. List these instruments under "instruments available," across from the "movement occurring" parameter.

Step 2: From figure 34, choose the instruments that satisfy the cost parameter previously selected and list them under "instruments available," across from the cost parameter.

Step 3: From figure 35, choose the instruments that satisfy the technical aspects parameter and list them under

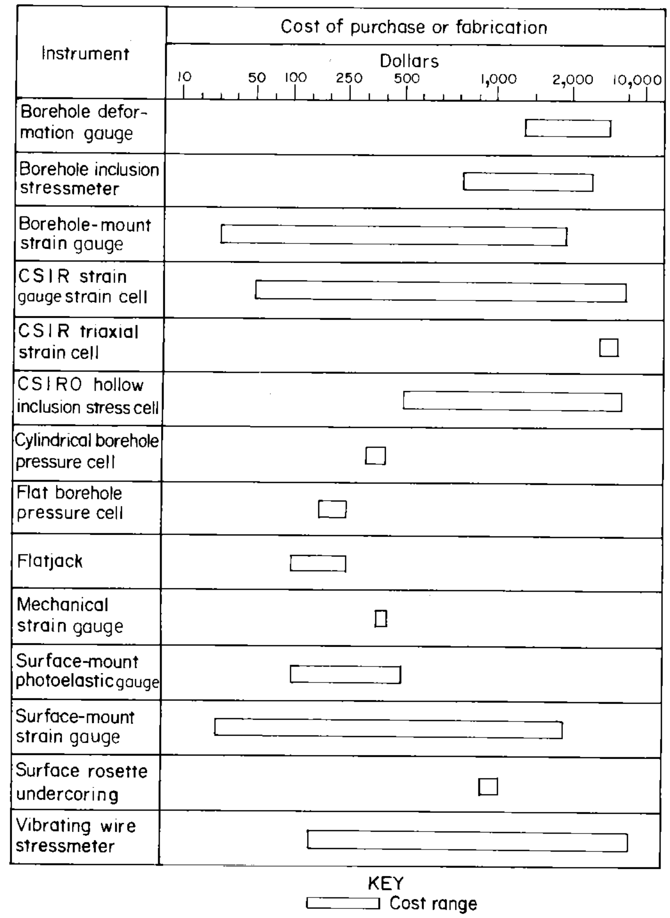

FIGURE 34. - Cost range of purchase or fabrication of stress measuring instruments.

"instruments available," across from the technical aspects parameter.

Step 4: From figure 36, choose the instruments that satisfy the data requirement parameter and list them under "instruments available," across from the data requirement parameter.

Step 5: From the "instruments available" column, determine the instruments that satisfy all requirements and parameters. List these at the bottom of the worksheet. If no instruments satisfy all of the requirements and parameters, it may be necessary to change the parameters or to choose the instruments that satisfy the most requirements and parameters.

Step 6: At this point, the user must select the most suitable instrument(s). The final decision can be made from the following detailed descriptions.

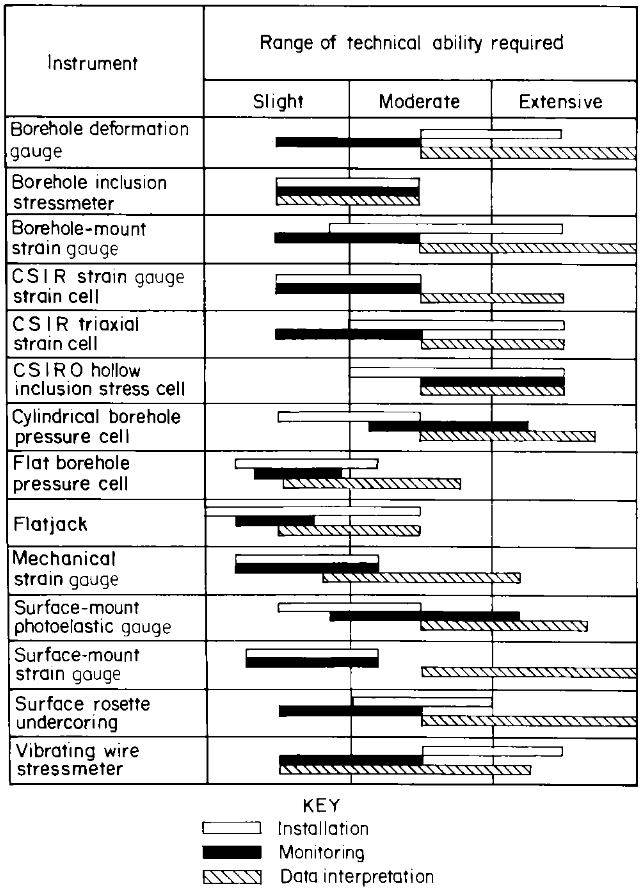

FIGURE 35. - Range of technical ability required for installation, monitoring, and data interpretation of stress measuring instruments.

Instrument	Type of measured data obtained		
	Visual	Simple numerical	Detailed numerical
Borehole deformation gauge			○
Borehole inclusion stressmeter		○	
Borehole-mount strain gauge			○
CSIR strain gauge strain cell			○
CSIR triaxial strain cell			○
CSIRO hollow inclusion stress cell			○
Cylindrical borehole pressure cell			○
Flat borehole pressure cell		○	
Flatjack		○	
Mechanical strain gauge		○	○
Surface-mount photoelastic gauge		○	○
Surface-mount strain gauge			○
Surface rosette undercoring			○
Vibrating wire stressmeter		○	○

KEY
○ Data obtainable

FIGURE 36. - Type of measured data obtained from stress measuring instruments.

DESCRIPTION OF INDIVIDUAL INSTRUMENTS

Borehole Deformation Gauge

Principle and Application

Borehole deformation gauges are designed to measure diametral deformations of a borehole during the overcoring process of stress relief (1).[8] These deformation measurements provide information to calculate the state of stress in the plane normal to the borehole. This technique determines the absolute field stress and is not easy to use, especially in coal measure rocks. The gauges are either single component (one point of contact and one direction of measurement) or three component (three points of contact and three directions of measurement).

Availability

Borehole deformation gauges are available from the following suppliers: Geokon, Inc.; Irad Gage; Rogers Arms and Machine Co.; Sinco, Slope Indicator Co.; and Soiltest, Inc. The approximate cost for the gauge and readout system ranges from $1,300 to $3,600.

[8] Underlined numbers in parentheses refer to items in the list of references at the end of this chapter.

Description

Borehole deformation gauges are round cylinders, 1.4 by 12 in, that house cantilever strain transducers to which matched pairs of strain gauges are attached (fig. 37). The single-component gauge has one pair of oppositely placed cantilevers; the three-component gauge has three pairs of such cantilevers. These gauges are designed for a 1.5-in-diam hole and overcoring by a 6-in-diam core drill (fig. 38). A standard electronic strain gauge readout is needed for data collection.

Installation and Data Collection

The installation procedure is basically the same for the single- and three-component gauges, but the single-component gauge must be overcored three times within the same hole at 120° orientations.

Step 1: Drill a 1.5-in-diam hole to the desired depth.

Step 2: Position the gauge in the hole.

Step 3: Connect the gauge lead wire to the strain readout box.

Step 4: Read the instrument. Be sure to read out all three components when a three-component gauge is used.

Step 5: Overcore the gauge with the 6-in overcore drill while simultaneously recording the deformations and depth of overcore.

Step 6: When the gauge is completely overcored, remove the core drill, and read and remove the gauge.

(For single-component gauges, repeat above installation and data collection steps two more times, rotating the gauge 120° each time.)

Step 7: Remove the core and store securely if the core is to be tested in the laboratory.

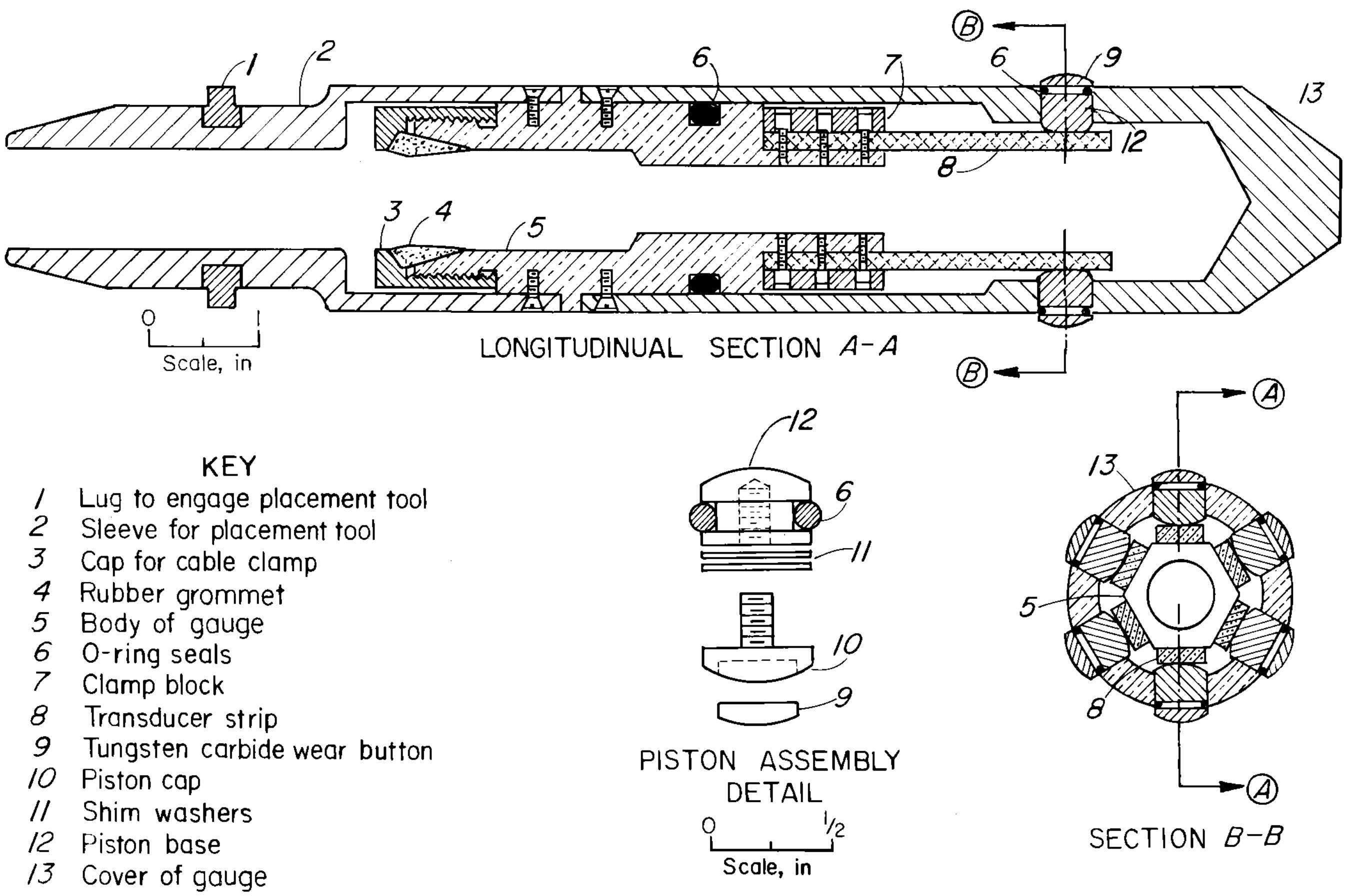

FIGURE 37. - Three-component borehole deformation gauge (1).

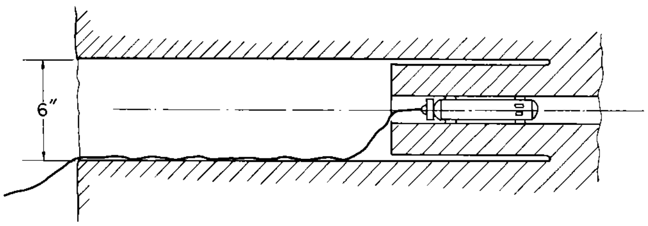

FIGURE 38. - Cross section through a borehole showing borehole deformation gauge after overcoring (2).

Data Interpretation

Stress in the plane normal to the borehole can be calculated using the following equations (1):

$$P + Q = \frac{E}{3d\ (1 - \mu^2)}\ (U_1 + U_2 + U_3),$$

$$P - Q = \frac{E\ \sqrt{2}}{6d\ (1 - \mu^2)}\ [(U_1 - U_2)^2 + (U_2 - U_3)^2 + (U_1 - U_3)^2]^{1/2},$$

and $$\text{Tan}\ 2\Theta = - \frac{\sqrt{3}\ (U_2 - U_3),}{2U_1 - U_2 - U_3},$$

where U_1, U_2, and U_3 = the three borehole deformation measurements, µin/in,

E = Young's modulus of rock, psi,

µ = Poisson ratio of rock,

d = diameter of the pilot borehole, in,

P = maximum secondary principal stress, psi,

Q = minimum secondary principal stress, psi,

and Θ = angle from U_1 to P.

If a three-dimensional state of stress is desired, deformation measurements must be made in three nonparallel boreholes. Some of the recommended borehole configurations are shown in figure 39.

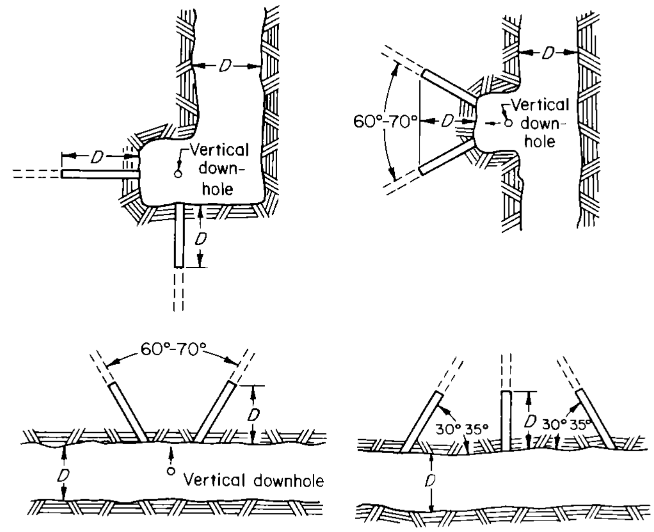

FIGURE 39. - Recommended borehole configurations for complete, three-dimensional, state-of-stress determination. These various configurations will all reveal the same state of stress (1). (*D* is diameter of mine opening.)

Borehole Inclusion Stressmeter

Principle and Application

Borehole inclusion stressmeters are rigid devices with an elastic modulus greater than that of the material to be tested (2, pp. 363-383). When inserted into a borehole, a stressmeter measures directly the stress changes of the surrounding rock. It is secured in the borehole by hydraulic pressure or with grout and can be left in place for long-term stress monitoring. Stress is detected by pressure changes on a diaphragm, which are transformed by a transducer. The transducer can be an electrical or foil resistance strain gauge or an electrical coil impedance, photoelastic, or magnetostriction device.

Availability

The availability of this instrument is limited. The cost ranges from $800 to $3,000.

Description

The borehole inclusion stressmeter consists of a rigid outer shell, fluid-filled diaphragm or magnetic coil, transducer, and readout box. Stressmeters have been developed by many individuals and organizations (3) (figs. 40-42).

Installation

Step 1: Drill a 1.5-in-diam hole to the desired depth.

Step 2: Install the stressmeter in the hole. If a hydraulic stressmeter is used, pump pressure up to that specified by the manufacturer. If a grouted stressmeter is used, fill the hole with grout, then slide the stressmeter to the desired depth.

Step 3: After the stressmeter is set, take an initial reading, which will serve as reference for all subsequent readings.

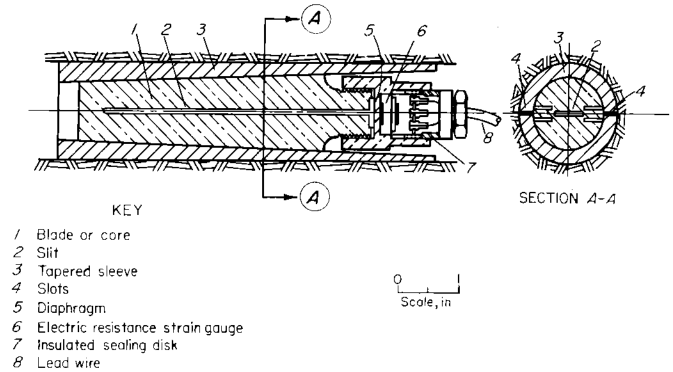

FIGURE 40. - Cross section of stressmeter (3).

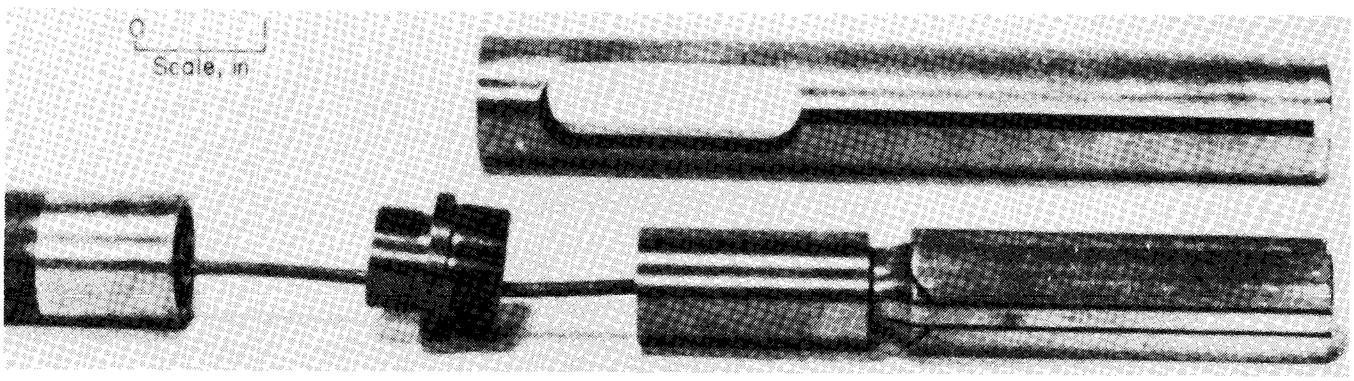

FIGURE 41. - Stressmeter and tapered sleeve into which it fits (3).

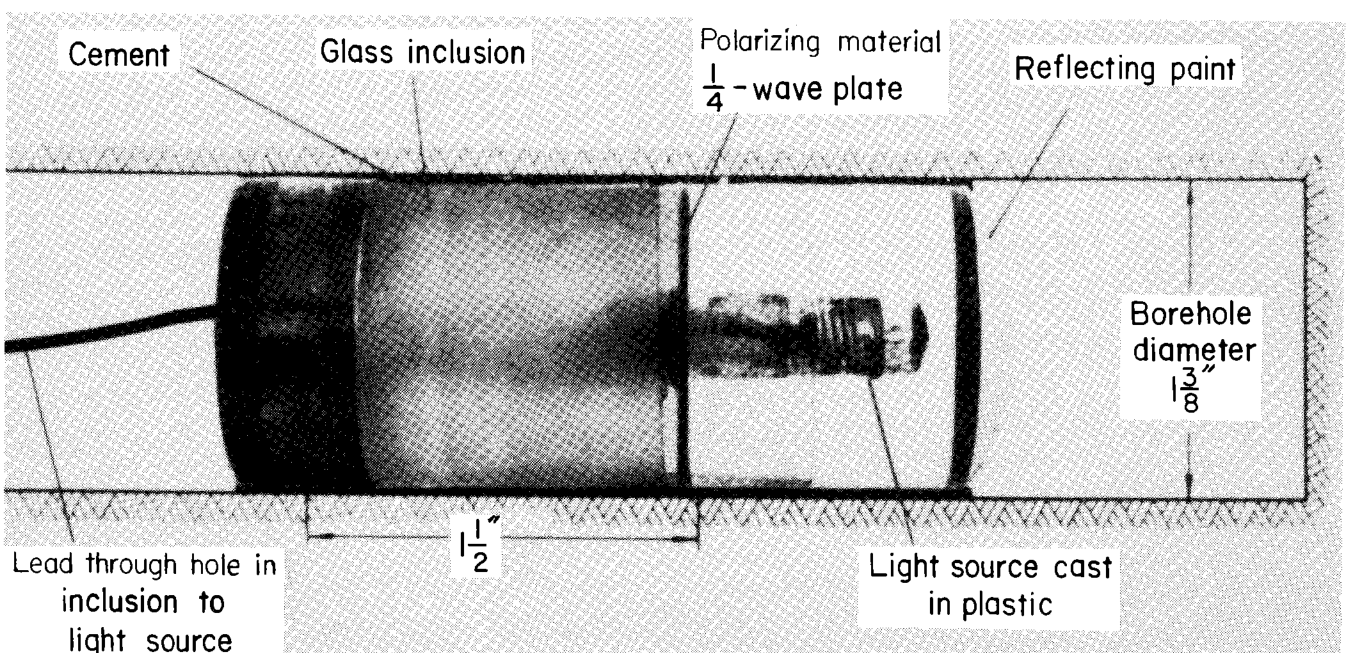

FIGURE 42. - Cross-sectional view of a borehole showing installed photoelastic stressmeter (3).

Data Collection

For nonphotoelastic stressmeters, readings are taken by connecting the lead wires from the stressmeter to a read-out box. The photoelastic type of stressmeter is read with a polarizer light, which illuminates the stress fringe patterns. Data should be collected on a regular basis, preferably once a week.

Data Interpretation

Stress can be determined from the recorded strain, using Hooke's law:

$$\delta = eE,$$

where δ = stress, psi,

e = strain, in/in,

and E = Young's modulus of rock being tested, psi.[9]

This stress value can be compared with the laboratory experimental stress determined from a sample of the material to see if the material is near failure.

Borehole-Mount Strain Gauge

Principle and Application

This instrument is mounted to the flat end of a borehole, then overcored and removed to relieve the strain (stress). It can be of the electric-resistance or photoelastic type. This gauge is used primarily to measure strain in pillars but can also be used in mine roof and floor.

Availability

This gauge can be purchased from many suppliers, including Micro-Measurements. The approximate cost of the gauge and readout system ranges from \$30 to \$1,900.

[9]Average values for E are
Coal: $0.1\times10^6 < E < 1.5\times10^6$ psi.
Rock: $2.0\times10^6 < E < 15\times10^6$ psi.
Steel: $E \approx 30\times10^6$ psi.

Description

This instrument is simply a single strain gauge or rosette that is glued to the flattened end of a borehole. In addition to the gauge, the user needs setting glue, setting tools, overcore drill, flat-grinding drill, and readout equipment.

Installation

Step 1: Drill a 1.75-in-diam hole to the desired measuring depth (usually in a pillar).
Step 2: Grind the bottom end of the hole flat.
Step 3: Read the gauge before installation.
Step 4: Glue gauge to the flat surface of the hole. Orient gauge so that one component is axially lined up with the suspected direction of principal stress (strain).
Step 5: Overcore gauge 6 to 12 in, then remove core drill and core.
Step 6: Read the gauge.

Data Collection

Data are collected twice during the installation process: The gauge is read just prior to being overcored and after it has been overcored and the core and gauge have been removed from the hole. These readings, as well as the date, time, installation location, depth of gauge in hole, and person(s) taking the readings and involved in the installation process should be recorded in a field book.

Data Interpretation

The strain in the pillar is found by subtracting the original reading from the overcored reading. Stress is calculated using Hooke's law:

$$\delta = eE.$$

Since stress is measured inside the pillar, it can be compared with the yield strength of the pillar to determine if the pillar is near failure.

The pillar strength is determined as follows:

$$S = \frac{K\sqrt{L}}{T},$$

where S = estimated strength of pillar, psi,

T = seam thickness, in,

L = least lateral pillar dimension, in,

$K = S_L \sqrt{W_L}$, psi,

W_L = cubic size of lab specimen, in^3,

and S_L = strength of lab specimen, psi.

CSIR Strain Gauge Strain Cell (Doorstopper)

Principle and Application

The Doorstopper Cell, developed by the Council for Scientific and Industrial Research (CSIR), is designed to determine the absolute stress in rock using an overcoring stress-relieving technique. It may, however, be used to measure changes in stress, provided the glue used to bond the cell possesses sufficiently stable characteristics. The cell measures the major principal stress where its direction and those of the two other principal stresses are known or can be assumed. It is also possible to determine the complete state of stress using Doorstoppers by taking measurements in three boreholes drilled in any three different and known directions (4).

Availability

The Doorstopper Cell is available from Roctest, Inc., at a cost of approximately $56 per cell. A complete system will cost approximately $7,500.

Description

The Doorstopper consists of four strain gauges at -45°, 0°, +45°, and +90° angles, molded into a rubber casting that fills a plastic shell. The gauges are connected by lead wires to a strain-indicating instrument. The cell can be used in either a BW (2.4-in nominal diam) or NW (3.0-in nominal diam) diamond-drilled borehole. The rubber and plastic shell serve to protect the strain gauges from damage and from water during the overcoring operations (4).

Installation and Data Collection

Step 1: A temperature compensation dummy cell with a 1/2-in length of BX (1.5-in nominal diam) core attached must be installed in the installation tool prior to use in the mine.

Step 2: Drill a borehole to the desired measurement zone. Grind flat and polish the end of the borehole.

Step 3: Plug a Doorstopper Cell into the installation tool, cover cell with glue, then push cell to back of the borehole and orient cell as indicated by orientation device.

Step 4: Push cell against rock until correct pressure is obtained. Wedge the rods in place to maintain this pressure until glue hardens.

Step 5: After the glue has hardened, read out the strain in the cell, using a standard strain gauge indicator unit, and then remove the installation tool from the borehole.

Step 6: Overcore cell with the same size core barrel to a minimum depth of 6 in. Break off core and remove from the borehole.

Step 7: Plug cell back into the installation tool and take the stress-relieved readings. Save the core for laboratory testing.

Data Interpretation

The magnitude and direction of stress can be calculated from the data using the following equations (4):

Magnitude:

$$\sigma_1' = \frac{E}{1-\mu^2}(e_1 + \mu e_2)$$

and $$\sigma_2' = \frac{E}{1 - \mu^2} (e_2 + \mu e_1),$$

where

σ_1' = magnitude of maximum horizontal stress at end of borehole, psi,

σ_2' = magnitude of minimum horizontal stress at end of borehole, psi,

E = Young's modulus of rock, psi,

μ = Poisson ratio of rock,

e_1 = maximum principal strain, μin/in,

e_2 = minimum principal strain, μin/in,

$$e_{1,2} = 1/2 \left\{ (e_H + e_V) \pm\sqrt{[2e_{45} - (e_H + e_V)]^2 + (e_H - e_V)^2} \right\},$$

and

e_H, e_{45}, e_V = difference in strain readings in the horizontal, 45°, and vertical directions before and after overcoring, respectively, μin/in.

$$\sigma_1 = 1/1.53\ \sigma_1'$$

and $$\sigma_2 = 1/1.53\ \sigma_2',$$

where σ_1 = magnitude of maximum horizontal stress, psi,

and σ_2 = magnitude of minimum horizontal stress, psi.

Direction:

$$\text{Tan}\ \Theta_1 = \frac{2\ (e_1 - e_H)}{2e_{45} - (e_H + e_V)},$$

$$\Theta_2 = \frac{2\ (e_2 - e_H)}{2e_{45} - (e_H + e_V)},$$

where Θ_1 is the angle measured anticlockwise from the horizontal (e_H) direction. The determination of the stress is important in planning of mine design, layout of panels, and analysis of probable areas of ground control problems.

CSIR Triaxial Strain Cell

Principle and Application

The CSIR triaxial strain cell is designed to obtain the complete state of stress in rock in a single borehole (5). The change in strain associated with the overcoring stress-relief method is detected by the strain gauges mounted in the instrument body.

Availability

This instrument is available from Roctest, Inc. Cost of the cell, installation equipment, and readout boxes is approximately $6,000.

Description

The cell consists of a plastic housing containing three strain gauge rosettes mounted on pistons, which are subsequently glued to the borehole walls. The pistons are actuated by air pressure. Strain changes are read using a standard strain gauge indicator unit.

Installation and Data Collection

Step 1: Drill a 3.5-in-diam hole to the depth at which the stress is to be determined.

Step 2: Drill a 1.5-in-diam hole for 18 in into the end of the borehole.

Step 3: Cover the three strain gauge rosettes with glue, insert the cell into the hole, then turn on the air pressure to actuate the pistons.

Step 4: After the glue has set, turn off the air pressure and take the inital strain readings using a standard strain gauge indictor.

Step 5: Overcore the cell with a 3.5-in-diam core barrel.

Step 6: Remove the core, plug back into the installation tool, then take a second set of strain readings.

Data Interpretation

The complete state of stress is determined from the strain readings using the following equations:

Magnitude:

$$\sigma_A = \frac{E}{2}\left[\frac{e_A + e_B}{1 - \mu} + \frac{e_A - e_B}{1 + \mu}\right],$$

$$\sigma_B = \frac{E}{2}\left[\frac{e_A + e_B}{1 - \mu} - \frac{e_A - e_B}{1 + \mu}\right],$$

and $$\tau_{AB} = \frac{E}{2}\left[\frac{2e_C - (e_A + e_B)}{1 + \mu}\right],$$

where σ_A = normal stress in A direction, psi,

σ_B = normal stress in B direction, psi,

τ_{AB} = tangential stress, psi,

E = Young's modulus of rock, psi,

μ = Poisson ratio of rock,

e_A = measured strain in A direction (X-axis), μin/in,

e_B = measured strain in B direction (Y-axis), μin/in,

and e_C = measured strain in C direction (45° to A and B), μin/in.

Direction:

$$\text{Tan}\ \Theta_A = \frac{2(e_1 - e_A)}{2e_C - (e_A + e_B)}$$

and $$\text{Tan}\ \Theta_B = \frac{2(e_2 - e_A)}{2e_C - (e_A + e_B)},$$

where Θ_A is the angle measured anticlockwise from the horizontal direction (X-axis),

and $$e_{1,2} = 1/2\left\{(e_A + e_B) \pm \sqrt{(e_A - e_B)^2 + [2e_C - (e_A + e_B)]^2}\right\}.$$

CSIRO Hollow Inclusion Stress Cell

Principle and Application

The CSIRO cell, developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO), provides a method of determining the three-dimensional stress state in rock or coal (6). Strain gauges mounted in the instrument measure the change in strain as the rock "relaxes" after overcoring. The cell can also be left in place for long-term monitoring of stress changes.

Availability

This instrument is available from Geokon, Inc., at a cost of approximately $500 per cell, $6,000 for a complete system.

Description

The CSIRO cell consists of a fully encapsulated array of nine strain gauges mounted in the instrument body. The cell is 0.4 in long and is grouted into a 1.5-in-diam hole. It is constructed from epoxy pipe with the gauges precisely oriented at 120° angles along the circumference.

Installation and Data Collection

Step 1: Drill a 1.5-in-diam hole to the desired measurement zone.

Step 2: Fill the hole with grout, then insert cell and push to back of hole, extruding the grout.

Step 3: Allow the grout sufficient time to harden.

Step 4: Readout the strain on all the gauges.

Step 5: Overcore the cell with a 6-in-diam core barrel. Monitor the strain response during overcoring.

Step 6: Read out the new strain on all the gauges.

Data on the strain in the rock as indicated by cell readings are obtained using a nine-channel switch box and quarter bridge strain indicator.

Data Interpretation

A data reduction program supplied by the manufacturer analyzes the stress tensor using the overcore strain data and biaxial pressurization results, giving the stress state in both principal form and oriented along coordinate axes (6). The stress information can be used in mine design studies and geotectonic studies.

Cylindrical Borehole Pressure Cell

Principle and Application

This device determines the modulus of rigidity of rock or coal by direct measurement inside a small-diameter borehole. It measures the change in volume of the borehole with respect to the applied pressure, which is interpreted by thick-wall cylinder equations for an elastic body (7).

Availability

Cylindrical borehole pressure cells can be made in-house, or purchased from Sinco, Slope Indicator Co. The approximate cost is $350.

Description

The cylindrical borehole pressure cell consists of a steel core and copper jacket. Overall length is 8 in. The cell is installed in a 1.5-in-diam hole without grout. In-mine tests require a hydraulic pump, fluid reservoir, and gauge. A calibration cylinder is needed to calibrate the cell before installation.

Installation and Data Collection

Step 1: Drill a hole to the desired depth. The hole must be 1.5 in, at the measuring zone, and must not have open joints or cracks wide enough for the copper shell to extrude into them.

Step 2: Slide cell into hole. No specific orientation is required because cell is equally sensitive to changes in all directions.

Step 3: Connect pressure gauge and fluid pump to cell and fluid reservoir (fig. 43).

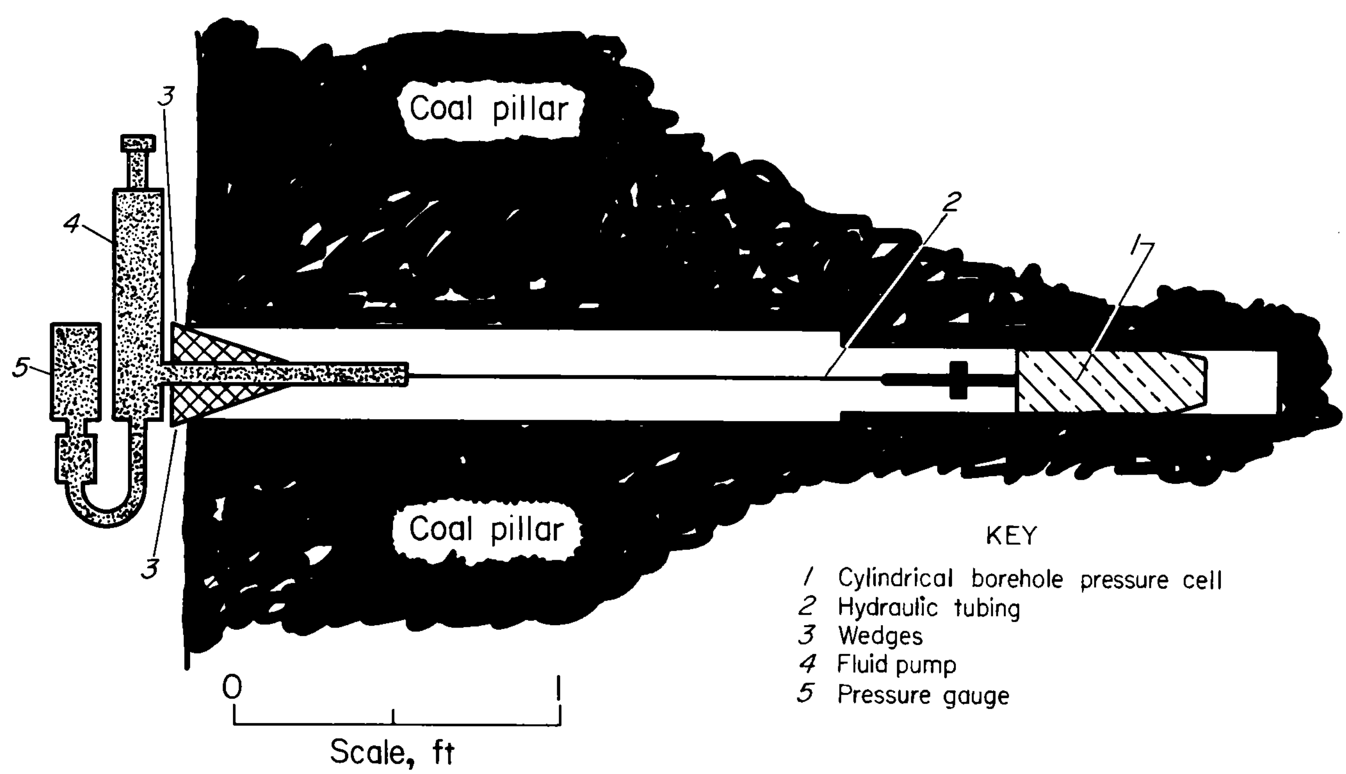

FIGURE 43. - Typical installation of a cylindrical borehole pressure cell (1).

Step 4: Completely fill cell with fluid, then bleed off any air in the system. Only slight pressure is needed.

Step 5: Cell is ready for pressure cycling, consisting of loading, unloading, and reloading at a rate of 200 psi/min, with readings taken at 1-min intervals. The measurements taken are the volume of fluid injected into the cell versus the cell pressure reading. The test for the modulus of rigidity is complete after the second loading. Maximum pressure per loading is 3,500 psi.

Step 6: Cell can now be removed by releasing pressure. Measurements can be repeated at another horizon within the hole. Cell can also be left in place to continue monitoring. In this case, pressure in cell must be continued by closing valve located between cell and hydraulic pump. Pump and fluid reservoir can now be removed (1).

Readings need to be taken only during the test procedure described in step 5 above. If the cell is left in place, it should be checked once a week.

Data Interpretation

The modulus of rigidity (G_r) can be determined as follows (1):

1. Calculate M_c for a calibration cylinder of known properties using

$$M_c = \frac{vG}{\pi \ell r_i^2 \left[\frac{1 + B - 2\,vB}{1 - B}\right]},$$

where v = volume per turn of pressure generator, in^3,

ℓ = effective length of pressure cell, in,

$B = \left[\frac{r_i}{r_o}\right]^2$, where r_i and r_o are the inner and outer radii of the cylinder,

and G = modulus of rigidity of calibration cylinder, psi.

2. Insert the cell into the calibration cylinder and determine the slope of the experimental pressure-volume curve (M_m). This is done by pressure cycling as described in the installation procedures, step 5. The system stiffness (M_s) is calculated by

$$M_s = \frac{M_c M_m}{M_c - M_m}.$$

3. Perform pressure cycling with the cell in the borehole and determine the pressure-volume curve (M_t). Calculate the pressure-volume relationship (M_r) from the test data:

$$M_r = \frac{M_t M_s}{M_t - M_s}.$$

4. The modulus of rigidity for the rock is calculated from

$$G_r = \frac{M_r\, \pi\, \ell r_i^2}{v}.$$

Flat Borehole Pressure Cell

Principle and Application

A flat borehole pressure cell is a flatjack, 2 in wide, 8 to 10 in long, and 0.125 to 0.25 in thick (7), designed for permanent (long-term) installation. It measures the changes in pressure from continued mining. It can be installed in the roof, floor, and ribs and is either grouted in place or preencapsulated.

Availability

This instrument can be made in-house or purchased from Geokon, Inc., or Sinco, Slope Indicator Co. The approximate cost ranges from \$195 to \$230.

Description

The flat borehole pressure cell consists of a thin-walled, fluid-filled metal bladder, hydraulic connection lines, and a pressure gauge (fig. 44). It is

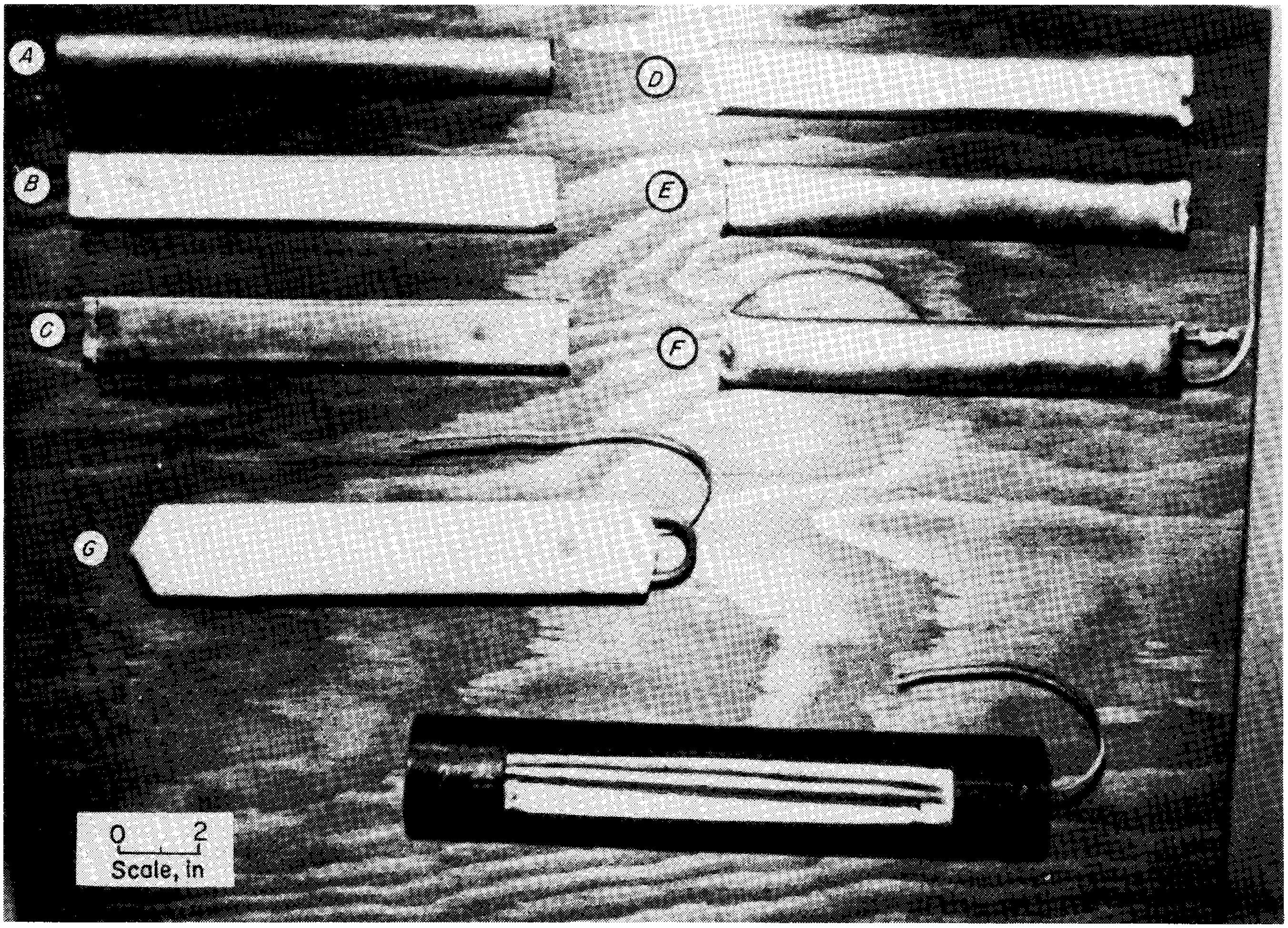

FIGURE 44. - Steps in fabrication of an encapsulated flat borehole pressure cell. *A*, Copper tube cut to length; *B*, tube flattened to 1/4-in opening; *C*, top half of ends cut; *D*, top half of ends removed; *E*, bottom of ends folded up and brazed to top; *F*, fluid-filling and pressuring and gauge tubes attached; *G*, cell encapsulated in plaster.

either preencapsulated with a cement mixture or grouted in place. A hydraulic hand-operated pump is required to set the instrument at the correct insertion pressure.

Installation

The procedure depends on the type of cell used. Preencapsulated cells require a precise hole but can be installed, pressurized, and read within 30 to 60 min. Grouted cells do not require a precise hole, but pressurization and monitoring cannot begin until the grout has set.

Step 1: Drill a hole to desired depth. Hole diameter is about 2.25 in.

Step 2: Insert cell and orient it within the hole. Grout in place if necessary. Cell measures pressure perpendicular to its flat side.

Step 3: Attach pressure gauge and pump to cell. A shutoff valve must be located between the pressure gauge and pump. Create a pressure in the cell equal to the known or estimated pressure of the surroundings. Hold this pressure by closing the shutoff valve.

Step 4: Record this pressure as read from the gauge.

Step 5: Take readings every few minutes for the first hour to check for pressure leaks or other problems.

Data Collection

The amount of pressure, as indicated on the gauge, should be recorded once a week. Any drastic changes should be investigated and reported to the appropriate authorities.

Data Interpretation

The information obtained from flat borehole pressure cells is the pressure induced by mining. To obtain the change in pressure, the original (installation) pressure must be subtracted from the subsequent readings. Various ground control problems are associated with increased pressure. Knowing the allowable pressure limits could help eliminate hazards associated with squeezing, floor heave, bursts, etc.

Flatjack

Principle and Application

A flatjack is a thin-walled fluid-filled metal bladder designed to withstand several thousand pounds per square inch when confined in a slot in rock strata (7). It records the pressure within the slot. The pressure needed to bring the rock back to equilibrium is the stress in the rock before the stress is relieved. The flatjack method can measure rock stress directly.

Availability

Flatjacks are usually manufactured in-house, but can be purchased from Geokon, Inc., or Sinco, Slope Indicator Co. The approximate cost of this instrument ranges from \$100 to \$250.

Description

A flatjack consists of a metal bladder, hydraulic connection line, and pressure gauge (fig. 45). For measurement purposes, a hydraulic pump and two reference pins are needed. The flatjack should be sandwiched between flat steel plates or encapsulated to ensure uniform pressure distribution.

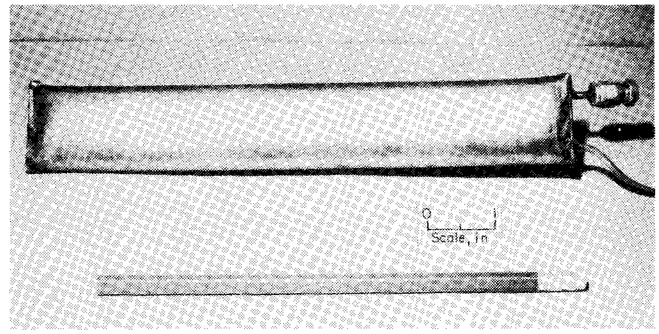

FIGURE 45. - Flatjack pressure cell.

Installation and Data Collection

Step 1: Cement two measurement pins to rock surface or grout them in holes drilled into the rock. Spacing should be 1 to 12 in from the slot (2 to 24 in apart). Pins should be perpendicular to the flatjack when installed.

Step 2: Measure the distance between pins with as precise a measuring instrument as is available. Record this measurement.

Step 3: Cut a slot into the rock surface perpendicular to pins by drilling a series of overlapping holes. This relieves stress perpendicular to the slot.

Step 4: Take and record another reading across the pins.

Step 5: Embed flatjack in slot. The flatjack can be grouted in the slot if desired. Use hand pump to steadily increase pressure within flatjack until displacement (stress relieved) by the cut slot is cancelled. This requires frequent measurements across the pins to determine when they are the original distance apart. This cancellation pressure is equal to the original stress in the area monitored.

The information obtained is the cancellation pressure needed to restore the area to its original position, which represents the original stress in the area. Usually, no additional readings are taken since the flatjack is removed when the process is completed. However, if desired, the flatjack can be left in place to continue monitoring rock stresses.

Data Interpretation

Cancellation pressures (original stress) can be analyzed to determine several possible situations, all dealing with excessive pillar pressures. Excessive pressures (stress) can be the result of inadequate pillar size, pillar orientation, insufficient barrier pillars, etc. If it is known what pressures are acceptable, mine design can be modified, resulting in safer and more stable roof and pillars.

Mechanical Strain Gauge

Principle and Application

A mechanical strain gauge determines rock stress by the stress relief method. It measures the strain between three reference points, set in the surface of the rock, after a series of relief holes are drilled. This gives surface strain only. Hooke's law is used to convert the strain to the maximum and minimum principal stresses.

Availability

Mechanical strain gauges are available from Soiltest, Inc. The approximate cost is $425.

Description

This system consists of a mechanical strain gauge (fig. 46) with an attached dial gauge and three reference (measurement) pins. A suitable drilling apparatus is also required.

Installation

Step 1: Grout three pins into or on the rock surface, in a triangular layout.

Step 2: Measure the strain between the pins with the mechanical strain gauge. Record the readings.

Step 3: Drill a series of adjacent holes, 12 to 30 in deep and 1.5 to 3 in. in diam, completely around the pins. This relieves stress and allows the pins to move in any direction (fig. 47).

Step 4: Remeasure and record strain between pins using mechanical strain gauge.

Data Collection

Strain is measured and recorded twice during the instrumentation process: (1) just after pins are installed and (2) after the stress relief holes have been drilled.

Data Interpretation

Hooke's law is used to derive the principal stress. The strain used in the equations is the change in strain (the second measurement minus the first measurement). The allowable stresses before failure occurs must be determined through observations such as this. These stresses will help determine the proper entry orientation, pillar size, etc.

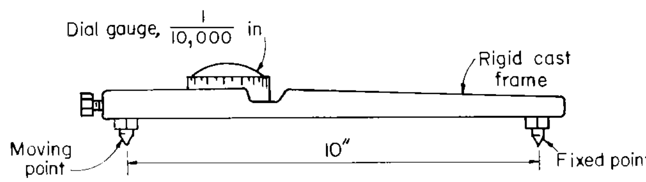

FIGURE 46. - Mechanical strain gauge. (8).

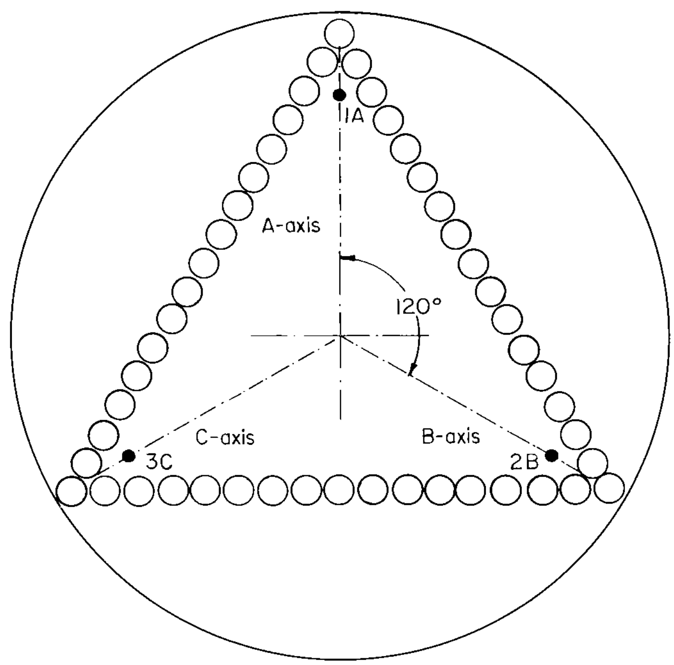

FIGURE 47. - Typical measurement setup for mechanical strain gauge showing measuring points (1A, 2B, and 3C) and stress relief holes (8).

Hooke's law (9):

$$S = E\left[\frac{e_A + e_B + e_C}{3\,(1 - \mu)} + \frac{1}{1 + \mu}\sqrt{\left(e_A - \frac{e_A + e_B + e_C}{3}\right)^2 + \left(\frac{e_C - e_B}{\sqrt{3}}\right)^2}\right],$$

$$T = E\left[\frac{e_A + e_B + e_C}{3\,(1 - \mu)} - \frac{1}{1 + \mu}\sqrt{\left(e_A - \frac{e_A + e_B + e_C}{3}\right)^2 + \left(\frac{e_C - e_B}{\sqrt{3}}\right)^2}\right],$$

$$\phi = 1/2\ \tan^{-1}\left[\frac{\frac{1}{\sqrt{3}}\,(e_C - e_B)}{e_A - \frac{e_A + e_B + e_C}{3}}\right],$$

where e_A, e_B, e_C = strain at 60° orientations, µin/in,

S = maximum principal stress, psi,

T = minimum principal stress, psi,

E = Young's modulus of rock, psi,

μ = Poisson ratio of rock,

and ϕ = angle from maximum principal stress to A-axis.

Surface-Mount Photoelastic Gauge

Principle and Application

Surface-mount photoelastic gauge measurements are taken by mounting thin sheets of photoelastic material to the rock, coal, or prop surface. This photoelastic coating reacts exactly as the surface does, and by its photosensitive nature reveals stress changes on the material surface (10). The stress patterns that develop can be interpreted using a polarizer.

Availability

Surface-mount photoelastic gauges are available from Micro-Measurements. The approximate cost of the gauge and readout system ranges from $100 to $500.

Description

Photoelastic gauges are of two types: (1) sheets of materials that are glued to the surface and (2) sprayon or brushon paint (these may be extremely difficult to use in the underground environment). Fringe patterns develop that reveal the stress changes on the surface of the material. A polarizer and viewer are used to detect the fringe patterns.

Installation

Step 1: Prepare the surface by chipping or grinding it as smooth and flat as possible. Surface preparation is critical for a good installation.

Step 2: Glue the sheet-type gauge or paint the photoelastic coating on the surface. The glue or coating dries in a few minutes. Stress changes are now being detected and displayed as fringe patterns in the photoelastic material.

Data Collection

Data can be collected as often as desired and for as long as desired. The polarizer and viewer are used to take readings from the photoelastic gauge in the following manner. First, the polarizer is used to illuminate and define the fringes. The handle of the handheld viewer is held in line with the loading axis of the gauge. The aperture on the viewer has a rotating compensation scale. With the scale initially set at zero, the number of visible photoelastic fringes (fig. 48) in one-half of the glass cylinder is counted. An exact count is made when the fringe at the center forms a cross (X). Where this is not the case, the full fringes are counted, and then the compensation scale is rotated clockwise until the last fringe counted (nearest the center) has moved back to form a cross. In this case, the scale reading is added to the initial full fringe count. The fringe count is multiplied by the appropriate cell sensitivity factor to obtain the change of stress (11).

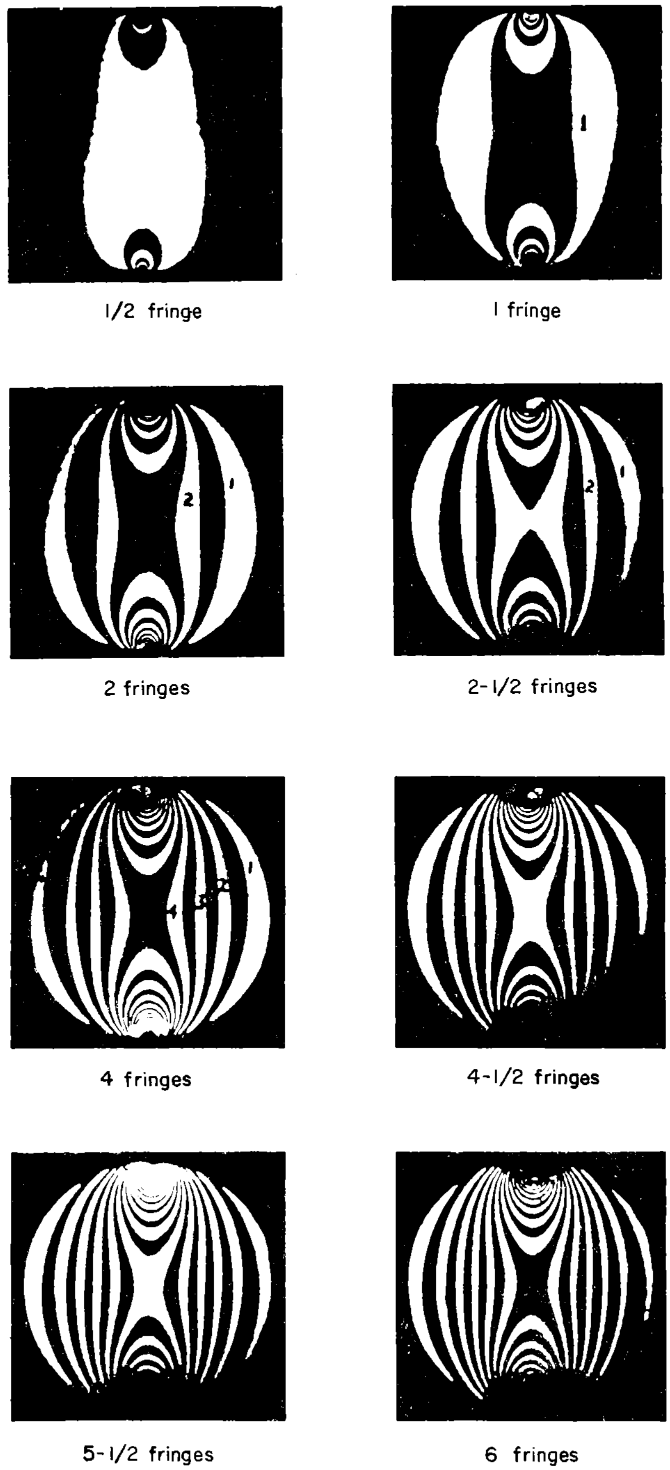

FIGURE 48. - Example of photoelastic fringe patterns displayed by a surface-mount photoelastic gauge (11).

Data Interpretation

The stress changes shown depend on the type of photoelastic material used, as well as on the object monitored. Each material has its own analysis graph, which will convert fringe patterns to stress values. Each material monitored has specific stress limits that must not be reached, or failure will occur.

Surface-Mount Strain Gauge

Principle and Application

Surface-mount strain gauges are mounted on the flat surface of rock, coal, or props and detect the strain or stress changes on the surface of the material (12). The overcoring stress relief method can be used, or the gauges can be left in place for long-term monitoring. There are three types of gauges: electric resistance, vibrating wire, and photoelastic.

Availability

Strain gauges can be purchased from the following suppliers: BLH Electronics;

Budd Co.; Geokon, Inc.; Hitec Corp.; Irad Gage; Kulite Semiconductor Products, Inc.; Microdot, Inc.; Micro-Measurements; Sinco, Slope Indicator Co.; and Soiltest, Inc. The approximate cost of the gauge and readout system ranges from $25 to $1,850.

Description

The electric-resistance gauge measures resistance changes in wires of the gauge as wire length changes. The vibrating-wire gauge measures vibration frequency as wire length changes (fig. 49). The photoelastic gauge measures stress by showing fringe patterns. All three types are attached to the flat surface of rock, coal, or props. They can be glued, grouted, or welded on (steel props only). If the stress relief method is used, an overcoring drill is needed. Each system has a matching readout system.

Installation

Installation is the same for the three types of gauges. The following procedure is for the overcoring method (fig. 50):

Step 1: Pick desired location, then make the surface as smooth and flat as possible.

Step 2: Glue, grout, or weld the gauge to the flat surface.

Step 3: After the gauge is set, take a reading.

Step 4: Overcore the gauge using a core drill that is larger than the gauge. Drill 6 to 12 in deep into material.

Step 5: Remove core drill. Break off core at back of hole and remove.

Step 6: Read the gauge. Subtract this reading from the original reading to determine strain in the material before it was relieved by overcoring.

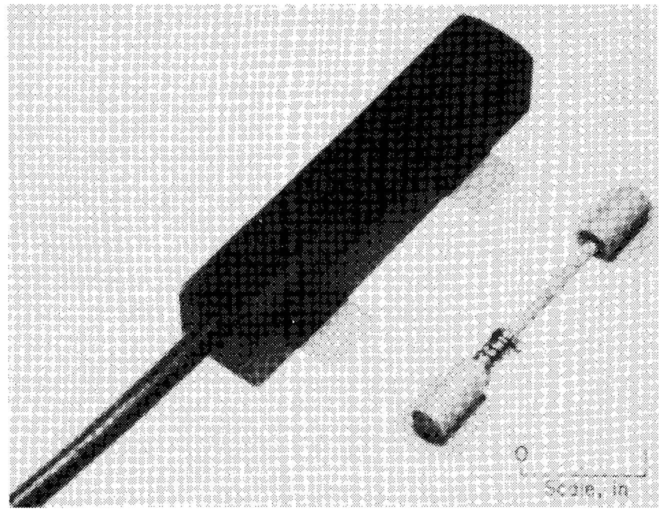

FIGURE 49. - Vibrating wire surface-mount strain gauge (13).

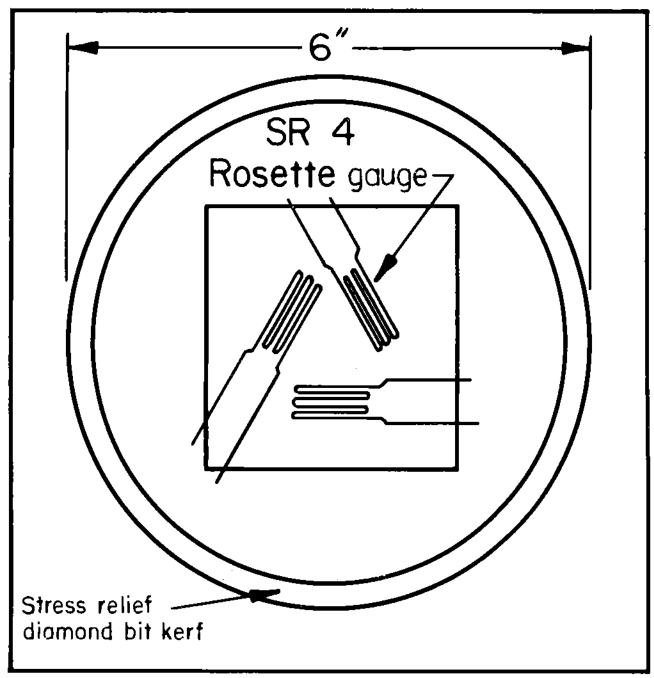

FIGURE 50. - Surface-mount strain gauges showing stress relief using large overcoring bit (9).

For a permanent gauge installation (no overcoring), the procedure is as follows:

Steps 1 through 3: Same as above.

Step 4: Coat gauges with sealer.

Step 5: Take readings at predetermined intervals to determine change in strain as mining continues.

Data Collection

Electrical-resistance gauges and vibrating-wire gauges are read by connecting the readout box to the gauge with a cable, then recording the reading that is displayed. Reading the photoelastic gauge requires a polarizer light and viewer to detect the stress fringe pattern (see the section "Data Collection" for the surface-mount photoelastic gauge). Readings are taken twice during the overcoring process, and at desired intervals (usually once a week) during long-term monitoring.

Data Interpretation

The overcoring process reveals the total strain in the medium (pillars, roof, etc.), whereas leaving the gauges in place reveals the change in strain induced by mining activity. The total strain indicates if the medium is near failure. The change in strain indicates the rate of loading leading to failure. This information is valuable in achieving optimum safety through efficient mine design.

Surface Rosette Undercoring

Principle and Application

Surface rosette undercoring determines the two-dimensional state of stress about the collar of a borehole. The strain between three sets of pins set in the surface of the rock is measured before and after a large relief hole is drilled. Hooke's law is used to convert the strain measurements to the two-dimensional principal stresses.

Availability

A mechanical strain gauge or Whitmore gauge for making the measurements is available from Soiltest, Inc., and costs approximately $1,000. The reference pins, template, and masonry bits can be purchased for under $100 per setup.

Description

The system consists of a mechanical strain gauge, reference pins, and template. A suitable drilling apparatus is also required.

Installation

Step 1: Use the template to mark positions of reference pins. Drill holes, and grout pins in place.

Step 2: Take a strain reading across the pins.

Step 3: Drill a 24-in-deep hole with a 6-in-diam core barrel. Remove and save core for laboratory testing of rock properties.

Step 4: Take another strain reading across the pins (14).

Data Collection

Readings are taken just prior to undercoring and just after stress relieving by undercoring.

Data Interpretation

Hooke's law is used to derive the principal stress. The strain used in the equations is the change in strain (the second measurement minus the first measurement). The allowable stresses before failure occurs must be determined through observations such as this. These stresses will help determine the proper entry orientation, pillar size, etc.

Hooke's law (9):

$$S = E\left[\frac{e_A + e_B + e_C}{3\ (1 - \mu)} + \frac{1}{1 + \mu}\sqrt{\left(e_A - \frac{e_A + e_B + e_C}{3}\right)^2 + \left(\frac{e_C - e_B}{\sqrt{3}}\right)^2}\right],$$

$$T = E\left[\frac{e_A + e_B + e_C}{3\ (1 - \mu)} - \frac{1}{1 + \mu}\sqrt{\left(e_A - \frac{e_A + e_B + e_C}{3}\right)^2 + \left(\frac{e_C - e_B}{\sqrt{3}}\right)^2}\right],$$

$$\phi = 1/2 \tan^{-1}\left[\frac{\frac{1}{\sqrt{3}}\ (e_C - e_B)}{e_A - \frac{e_A + e_B + e_C}{3}}\right],$$

where e_A, e_B, e_C = strain at 60° orientations, µin/in,

S = maximum principal stress, psi,

T = minimum principal stress, psi,

E = Young's modulus of rock, psi,

μ = Poisson ratio of rock,

and ϕ = angle from maximum principal stress to A-axis.

Vibrating Wire Stressmeter

Principle and Application

A vibrating wire stressmeter is an instrument designed to monitor stress changes within mine rocks. It measures the altering period of the resonant frequency of a highly tensioned steel wire clamped diametrically across the gauge (13, 15). This reading is converted to pressure (pounds per square inch) using the appropriate calibration graph.

Availability

This instrument is available from Geokon, Inc., or Irad Gage. The approximate cost of the stressmeter and readout system ranges from $150 to $6,000.

Description

The vibrating wire stressmeter consists of a highly tensioned steel wire surrounded by a metal housing, anchorage platen, anchorage wedge, and electrical wire (fig. 51). A readout box is used to collect data.

Special setting tools and rods (manual or hydraulic) are needed for installation.

Installation

Step 1: Drill a 1.5-in-diam hole to desired depth. Diameter range is 1.475 to 1.525 in for hard rock and 1.450 to 1.545 in for soft rock and coal.

Step 2: Thread the loose end of wire from the stressmeter through the hole in setting tool. Place the stressmeter and platen in place on the end of the setting tool. Using a hydraulic pump, slowly apply pressure until the stressmeter is held in place. Take initial reading.

Step 3: Slide the stressmeter and setting tool into hole. Align the stressmeter to desired measuring plane in hole. Connect needed setting rods onto assembly as it is slid into hole.

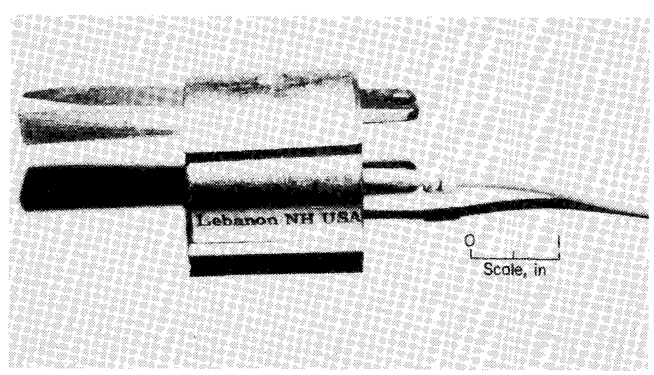

FIGURE 51. - Vibrating wire stressmeter.

Step 4: When the stressmeter is at the desired depth, pump pressure into the system until the stressmeter readout is 300 units above the original reading. Once this reading is reached, the stressmeter is securely anchored.

Step 5: Slowly let the pump pressure off. The rods should be left free so that they can move slightly back out of the hole. When the pressure has reached zero and the rods have stopped moving (approximately 1 min), the assembly can be slowly pulled out of the hole and disassembled.

An additional two stressmeters can be installed in this hole. To avoid damage, care must be taken to properly route the previously installed stressmeter wires, as well as the wire of the stressmeter being installed, through the setting tool guide slots. More specific instructions can be obtained from the instrument supplier.

Data Collection

Vibrating wire stressmeters are read twice during installation, then at desired intervals thereafter. For a detailed account of pressure changes, a data logger can be used. It will provide a continuous tape readout and can be set to read as often as desired.

Data Interpretation

Readout data are numbers that indicate the frequency of vibration of the wire. A calibration chart is needed to change these data into pounds per square inch. When the pressure is known, such parameters as roof or rib stability can be analyzed and used for design modifications, such as orientation and pillar size.

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CHAPTER 5.--SUPPORT LOAD MEASUREMENTS

INTRODUCTION

Support load is the weight exerted on a roof support (post, crib, roof bolt, etc.) by the roof and overburden. Measurement of support loads can reveal possible support and/or roof failures.

Support load measurements provide mine operators with the means of detecting ground (roof, rib, and floor) control problems before they occur, analyzing their cause and preventing further occurrences, and making necessary changes in mine design.

GROUND MOVEMENT INDICATORS

Like other ground movements, support load has specific indicators that characterize it. Unfortunately, some indicators are common to several movements. Therefore, differentiating among several movements can be difficult and at times may be just an educated estimate. The following is a list of support load indicators:

- Excessive number of roof falls.
- Extreme or continual torque loss on roof bolts.
- Broken posts.
- Roof bolts shearing and then falling out of hole.
- Loss of bolt anchorage.
- No bolt anchorage when installing.
- Inability to torque bolts at installation.
- Squeezing cribs.
- Downward-bending roof support beams.

INSTRUMENT SELECTION

As requirements and parameters are defined, they should be listed on an instrument selection worksheet (fig. 1). Since this chapter deals with support load measurements only, support load should be listed in the "measurement desired" column. The controlling parameters, as defined in the section "Instrument Selection Guidelines" should be listed in the "desired elements" column.

Next, the user should refer to figures 52 through 54 and follow steps 1 through 6 to make a preliminary choice of the most suitable instrument(s) for the ground control problem being investigated.

Step 1: All of the instruments in this chapter satisfy the "measurement desired" requirement (support load) previously listed on the worksheet. List these instruments under "instruments available," across from "measurement desired."

Step 2: From figure 52, choose the instruments that satisfy the cost parameter previously selected and list them under "instruments available," across from the cost parameter.

Step 3: From figure 53, choose the instruments that satisfy the technical aspects parameter selected and list them under "instruments available," across from the technical aspects parameter.

Step 4: From figure 54, choose the instruments that satisfy the data requirement parameter and list them under "instruments available," across from the data requirement parameter.

Step 5: From the "instruments available" column, determine the instruments that satisfy all requirements and parameters. List these at the bottom of the

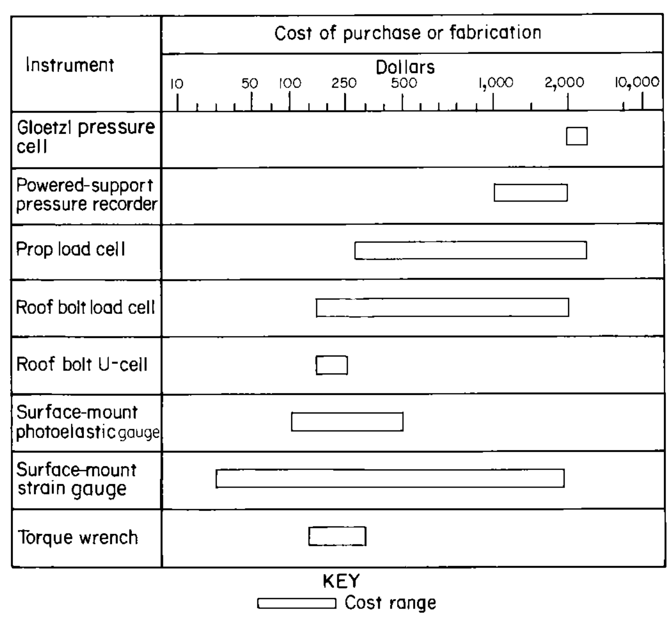

FIGURE 52. - Cost range of purchase or fabrication of support load measuring instruments.

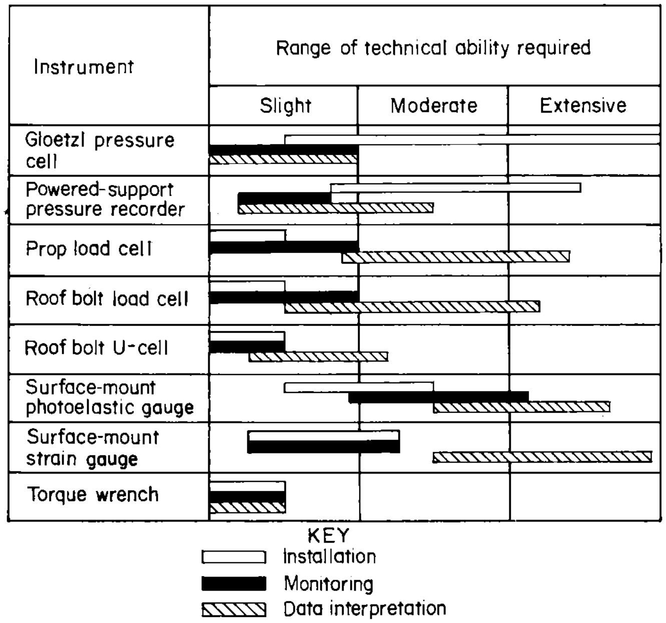

FIGURE 53. - Range of technical ability required for installation, monitoring, and data interpretation of support load measuring instruments.

Instrument	Type of measured data obtained		
	Visual	Simple numerical	Detailed numerical
Gloetzyl pressure cell		○	
Powered-support pressure recorder		○	○
Prop load cell		○	
Roof bolt load cell		○	○
Roof bolt U-cell		○	
Surface-mount photoelastic gauge		○	○
Surface-mount strain gauge			○
Torque wrench	○	○	

KEY
○ Data obtainable

FIGURE 54. - Type of measured data obtained from support load measuring instruments.

worksheet. If no instruments satisfy all of the requirements and parameters, it may be necessary to change the parameters or to choose the instruments that satisfy the most requirements and parameters.

Step 6: At this point, the user must select the most suitable instrument(s), based on the instrument descriptions following.

DESCRIPTION OF INDIVIDUAL INSTRUMENTS

Gloetzl Pressure Cell

Principle and Application

Gloetzl pressure cells are used for measuring the pressure in tunnel linings, rock formations, earth fills, and supports. Pressure is measured by a fluid-filled diaphragm (1).[10]

Availability

The cell is available from Roctest, Inc., or Sinco, Slope Indicator Co. at a cost of approximately $2,500. This includes the cell, installation equipment, and readout gauges.

Description

The cell is basically a flat, fluid-filled diaphragm made of stainless steel or copper. A unique feature of this cell is a hydraulic bypass valve, which isolates the cell fluid from the line fluid, resulting in a stiffer and more accurate device.

Installation

For monitoring pressures in rock:

Step 1: Drill a series of horizontal holes to create a slot in the rock. The slot should be at least 8 in wide and 0.5 in high.

Step 2: Insert the cell into the slot. It will be necessary to use steel plates on each side of the cell to make the cell the appropriate thickness.

[10] Underlined numbers in parentheses refer to items in the list of references at the end of this chapter.

For monitoring support load: Install the cell between the prop and mine roof or between the blocks of a crib, then wedge the support tight.

Data Collection

Oil is pumped into the cell until the bypass valve opens. At this point, continued pumping produces no further increase in the input pressure. This bypass pressure is read and is equivalent to the external pressure acting on the cell or to the load on the support.

Data Interpretation

The reading obtained is the pressure acting on the cell at the cell location, which may not be the true pressure in the rock. Many pressure measurements taken at various locations should reveal a more precise picture of the total rock pressure.

Powered-Support Pressure Recorder

Principle and Application

A powered-support pressure recorder is a clockwork-operated recorder, connected to the hydraulic support systems of powered supports (longwall chocks and shields or automated temporary roof supports (ATRS)) (2). It measures and records pressure changes that reflect load changes on the support.

Availability

This instrument is available from Bristol Division, Acco Industries Inc., and Weksler Instruments Corp. The approximate cost of this instrument ranges from $1,000 to $2,000.

Description

A powered-support pressure recorder consists of a clockwork mechanism, paper chart, ink pen, hydraulic hoses and fittings, and protective case (fig. 55). It is connected to the hydraulics of the support and measures all pressure changes. The charts are of 1-week duration and are either mechanically (spring) or electrically driven.

Installation

Step 1: Select a mounting location as free as possible from dust, grime, vibration, and extremes of temperature.

Step 2: Mount instrument and case as securely as possible.

Step 3: If chart is electrically driven, wire instrument to voltage shown on instrument (120 or 240 V).

Step 4: Connect hydraulic connections on back of case to hydraulics of support jacks. Detailed hydraulic hookup instructions can be obtained from instrument suppliers (3).

Data Collection

The pressures are recorded on the chart, which can be read as often as desired and will reveal any substantial increase or decrease that occurs (fig. 56). The chart should be changed once a week, usually on the day when it will expire.

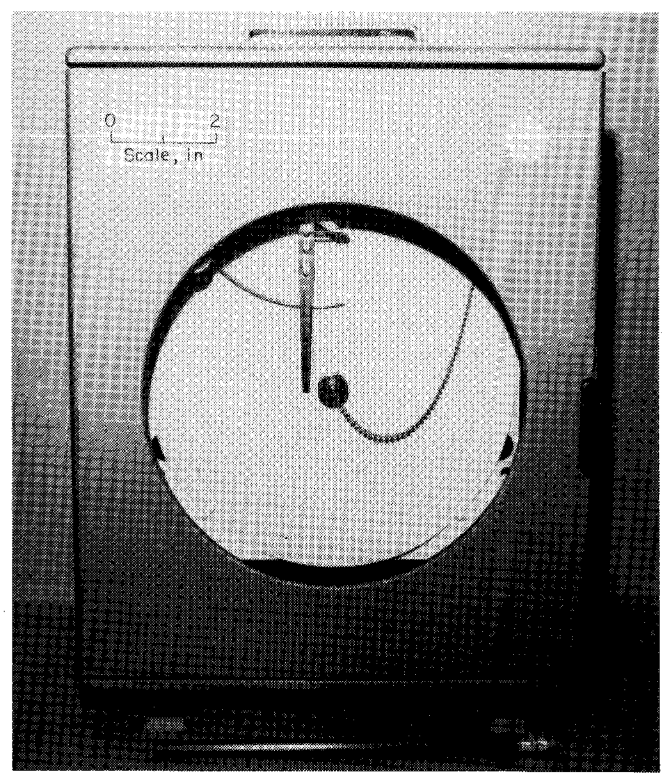

FIGURE 55. - Powered-support pressure recorder.

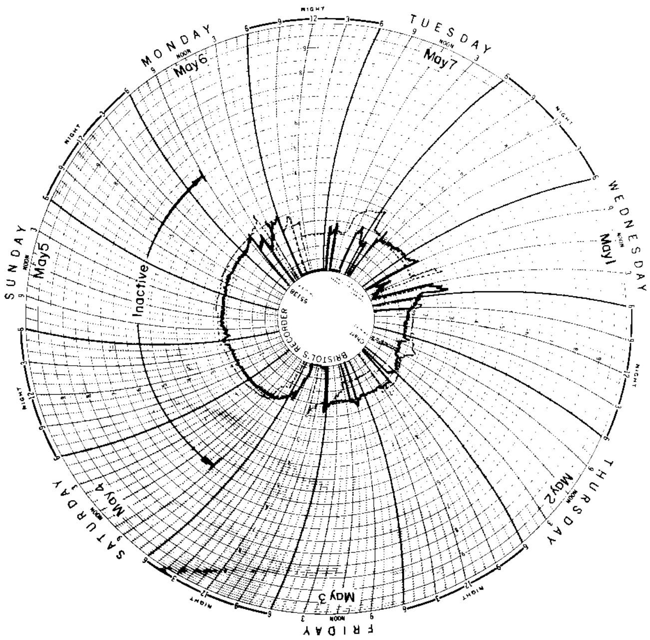

FIGURE 56. - Chart of hydraulic pressures in longwall roof supports during normal operation (4).

Data Interpretation

Most installations are designed to monitor the pressures to see if the support system is nearing its yield point. Large increases in pressure indicate loading from the roof that could lead to increased difficulty repositioning the support. It could also mean that the roof could fall when supports are lowered; that is, the fall line has overridden the supports and is now at the coal face. It is important to match the pressure recorded to the corresponding physical conditions observed. This will reveal which pressures are acceptable, which are not acceptable, and what types of adverse roof conditions and/or support problems can be expected from a particular pressure.

Prop Load Cell

Principle and Application

A prop load cell is a device that measures the load on a roof support prop (steel jack, timber, post, crib, rail bar, etc.). Prop load cells are inserted between the prop and the mine roof. The load measured is the result of a roof movement (roof sag) and is generally attributed to poor pillar design, mine design, entry orientation, or support capabilities.

There are three types of prop load cells: Multiple strain gauge (electronic strain readout), hydraulic-pneumatic (pound-per-square-inch readout), and photoelastic (photoelastic readout).

Availability

Prop load cells are available from the following suppliers: BLH Electronics; Enerpac; Geokon, Inc.; Irad Gage; Roctest, Inc.; Sensotec, Inc.; Sinco, Slope Indicator Co.; and Strainsert Co. The approximate cost for a load cell and readout system ranges from $250 to $2,000.

Description

Electrical strain gauge readout cells are constructed from high-strength steel, stainless steel, or titanium, to which several sets of matched strain gauges are bonded (fig. 57) (5). The cell is connected to the readout box by an electrical cable.

Hydraulic-pneumatic readout cells are constructed of two plates welded together at their outer circumference and filled with antifreeze (6-7). They have either a pressure gauge or pressure transducer readout.

Photoelastic readout cells consist of a high-tensile-steel cylinder that houses a cylindrical glass transducer within a diametrical hole (fig. 58) (8). The glass cylinder is illuminated with a polarizer light and viewed through a hand viewer.

Installation

No special tools or training are needed to install prop load cells. They are simply inserted between the prop and a header board (which is against the mine roof) then wedged down in the normal prop installation method. Care must be taken to install the prop and cell as nearly perpendicular to the roof as possible to ensure accurate load measuring. Also,

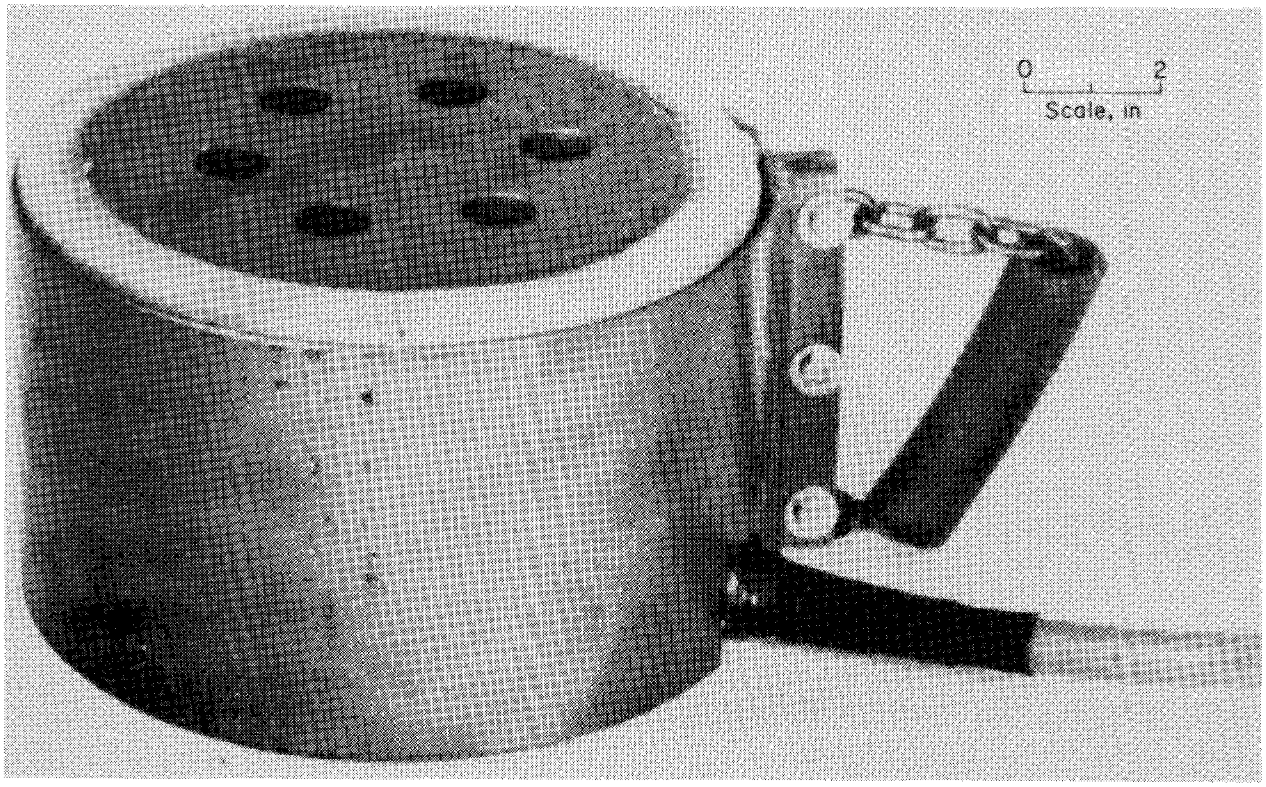

FIGURE 57. - Prop load cell (strain gauge design) (5).

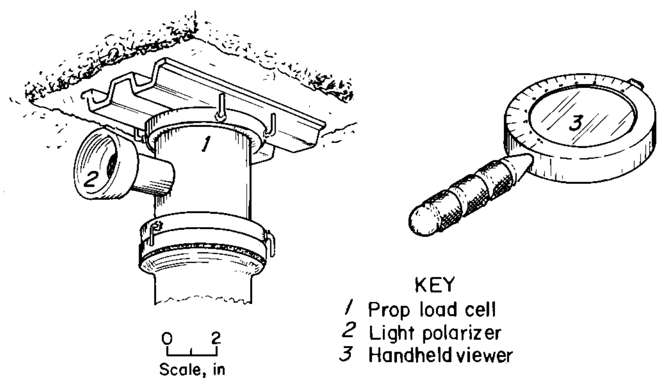

FIGURE 58. - Photoelastic prop load cell and readout equipment (8).

all load cells should be calibrated prior to installation.

A reading should be taken immediately after installation. This reading serves as a reference for all additional readings.

Data Collection

Readings from an electrical strain gauge cell are taken by connecting the cell to the readout box, using an electrical cable. The reading will appear on the screen of the readout box.

Readings from the hydraulic-pneumatic cell are taken either by reading the dial gauge, or for some models, by connecting the pressure transducer between the cell and readout box.

Readings for the photoelastic cell are slightly more difficult. First, the polarizer is inserted into the opposite side of the cell. The handle of the handheld viewer is held in line with the loading axis of the cell. The aperture on the viewer has a rotating compensation scale. With the scale initially set at zero, the number of visible photoelastic fringes (see fig. 50) in one-half of the glass cylinder is counted. An exact count is made when the fringe at the center forms a cross (X). Where this is not the case, the full fringes are counted, and then the compensation scale is rotated clockwise until the last fringe counted (nearest the center) has moved back to form a cross. In this case, the scale reading is added to the initial full fringe count. The fringe count is multiplied by the appropriate cell sensitivity factor to obtain the load (9).

This instrument should be read once a week. However, the frequency of readings depends on roof conditions and the amount of load detected. Large load changes or visible roof changes require frequent readings.

Data Interpretation

Each mine must establish how much load is acceptable. The strength of the props can be determined that corresponds to the maximum load they can support. When the maximum load is reached, the props, and possibly the roof, will fail. Therefore, additional props should be installed before this maximum load is reached.

Roof Bolt Load Cell

Principle and Application

A roof bolt load cell is designed to measure the load on mechanical anchor bolts. It has a hole through the center so that it can be slid onto a roof bolt. Final position is between the roof and bolt plate. If the roof is uneven, it may be necessary to put a steel plate between the load cell and roof.

A roof bolt load cell measures load by one of three methods: (1) sets of matched strain gauges within the load cell, (2) springs and two metal disks, or (3) a rubber pad compressed between two metal plates.

Availability

Roof bolt load cells can be purchased from the following suppliers: Ailtech; Geokon, Inc.; Goodyear Tire and Rubber Co.; Irad Gage; Roctest, Inc.; Sensotec, Inc.; Sinco, Slope Indicator Co.; and Strainsert Co. The approximate cost of the cell and readout system ranges from $150 to $2,000.

Description

The electronic readout load cells are constructed of steel to which several sets of matched strain gauges are bonded (fig. 59) (5). Load on the bolt is measured as a change in strain, as measured by the strain gauges. These cells are read by a strain indicator box connected to the cell by an electrical cable.

The spring-and-disk load cell measures the load by a change in distance between the two disks (fig. 60). The springs determine the load-detecting ability of the cell. A depth-measuring dial gauge is used to take readings.

The rubber compression pad cell measures the load by a change in thickness of the pad as measured by the distance between the two metal plates.

Installation

Step 1: Drill a standard roof bolt hole at the desired location.

Step 2: Remove anchor assembly from a roof bolt.

Step 3: Slide roof bolt plate onto the bolt, followed by the load cell.

Step 4: Replace anchor assembly on the bolt. Take an initial, unloaded measurement of the cell.

Step 5: Install the bolt in the hole, and tighten to torque specified by mine roof control plan. Take care to install the load cell perpendicular to the axis of the roof bolt.

Step 6: Take an initial reading to serve as the reference for subsequent readings.

Data Collection

When first installed, these load cells should be read each day until the readings have stabilized (when little or no change occurs). The frequency should then be decreased to once a week. If the readings do not stabilize, daily readings should continue until stabilization occurs or unsafe roof conditions develop.

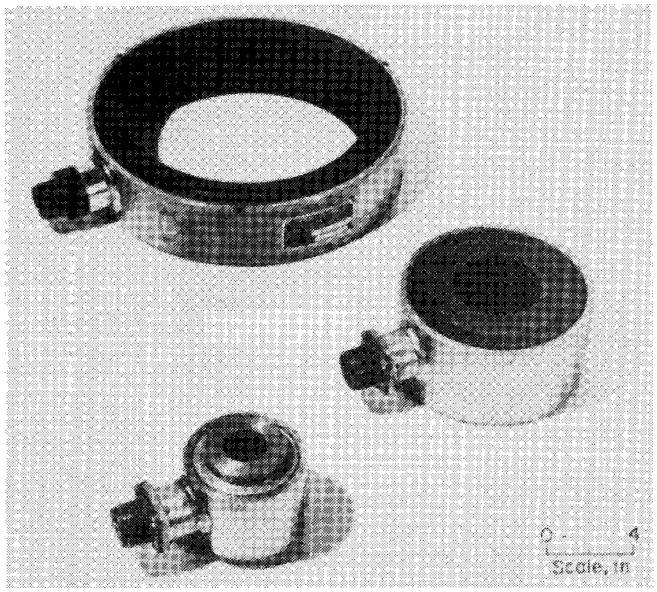

FIGURE 59. - Typical roof bolt load cells (strain gauge design) (5).

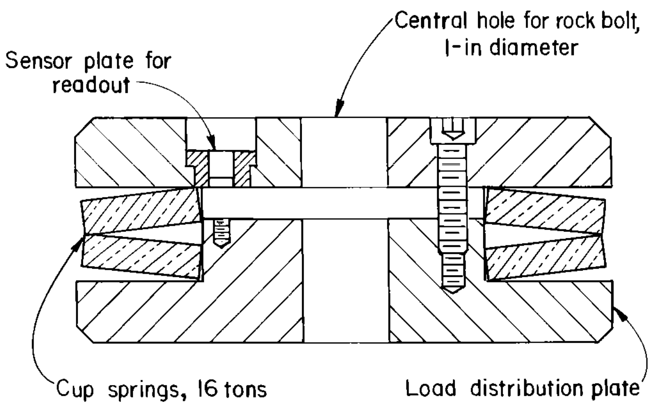

FIGURE 60. - Cross-sectional view of a spring-and-disk roof bolt load cell (10).

Data Interpretation

The suppliers of load cells will furnish the information (cell spring rate, deflection analysis, graphs, charts, equations, etc.) needed to convert the readings (strain or inches of deflection) to the actual load on the bolt. Bolt load is needed to determine if bolt failure or anchorage failure will occur. The amount of load that will cause these failures depends on the type of bolt, the geology of the roof strata, the yield and barrier pillar dimensions, and the amount of overburden.

Roof Bolt U-Cell

Principle and Application

Roof bolt U-cells are designed to measure the load on roof bolts due to roof sag, strata separation, or continued area mining (11). They can also measure applied bolt load when a bolt is torqued. U-cells do not allow mine personnel to identify the origin of the load exactly, but the measurements are used for design modification or to determine support load capability.

Availability

U-cells can be purchased or fabricated in-house. U-cells can be purchased from Sinco, Slope Indicator Co., for approximately $250 each. At present, the in-house fabrication cost is approximately $175 each, including labor and material.

Description

U-cells are U-shaped, thin-walled, fluid-filled metal bladders with an attached pressure gauge (6). They are constructed from copper pipe and tubing with brass fittings. They are sandwiched between steel plates, held together by split-ring keys, to ensure uniform pressure on the cell during loading (fig. 61).

Installation

U-cells are installed on pattern bolts during the mining cycle or on additional bolts in previously mined workings.

Step 1: Drill a standard roof bolt hole at the installation site.

Step 2: Insert the roof bolt into the hole until only 3 in protrudes.

Step 3: Slide the U-cell between roof and bolt plate with the bolt in U part of cell. Be sure the gauge is facing the entry to facilitate data collection.

Step 4: Push the bolt against the roof and tighten to torque specified in mine roof control plan.

Step 5: Take the first reading immediately after installation to serve as a reference for all additional readings.

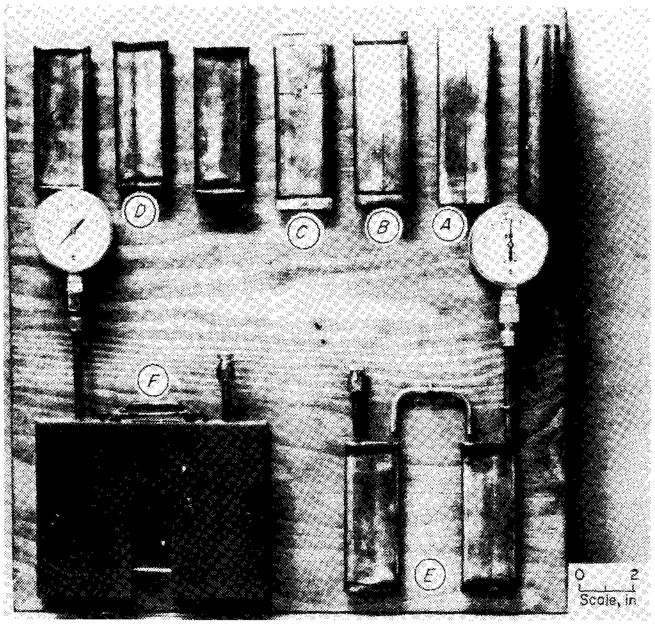

FIGURE 61. - Steps in fabrication of a roof bolt U-cell. *A*, Copper tube cut to length and flattened to 1/4 in; *B*, top half of ends cut; *C*, top half of ends removed; *D*, bottom of ends folded up and brazed to top; *E*, cells drilled and ready for connection of gauge, crossover tubing, and relief valve; *F*, completed cell.

Data Collection

U-cells should be read once a week, more often if large changes in pressure occur.

Data Interpretation

The readout data, in pounds per square inch, must be converted to pounds of load before they are useful for determining support load capabilities. The equation

Gauge reading (psi)

× area of U-cell (in^2)

= bolt load (lb)

converts the gauge reading to bolt load, which when compared with the bolt specifications, will indicate when the bolt could fail.

Surface-Mount Photoelastic Gauge

See chapter 4 for a complete description of this instrument.

Surface-Mount Strain Gauge

See chapter 4 for a complete description of this instrument.

Torque Wrench

Principle and Application

A torque wrench is a mechanical gauge that measures the torque (foot pounds) on an installed roof bolt. It is used primarily to test mechanical anchor bolts immediately after installation. Torque measurements are useful for determining the effectiveness of a bolting pattern, the structural integrity of the bolt, and anchorage conditions (12).

Availability

Torque wrenches are available from tool manufacturers and from suppliers of mine hand tools and safety equipment. A partial list of torque wrench suppliers includes Armstrong Bros. Tool Co.; Klein Tools, Inc.; and Snap-on Tools Corp. The approximate cost of a torque wrench ranges from $150 to $350.

Description

The system consists of a long-handled wrench, dial gauge, coupler mechanism, and socket that fits on the roof bolt head (fig. 62). Most dial gauges have double pointers, one of which stays at the maximum reading until reset.

Installation

No installation is required. Before using the wrench, set both dial gauge pointers to zero by rotating the dial or pointers.

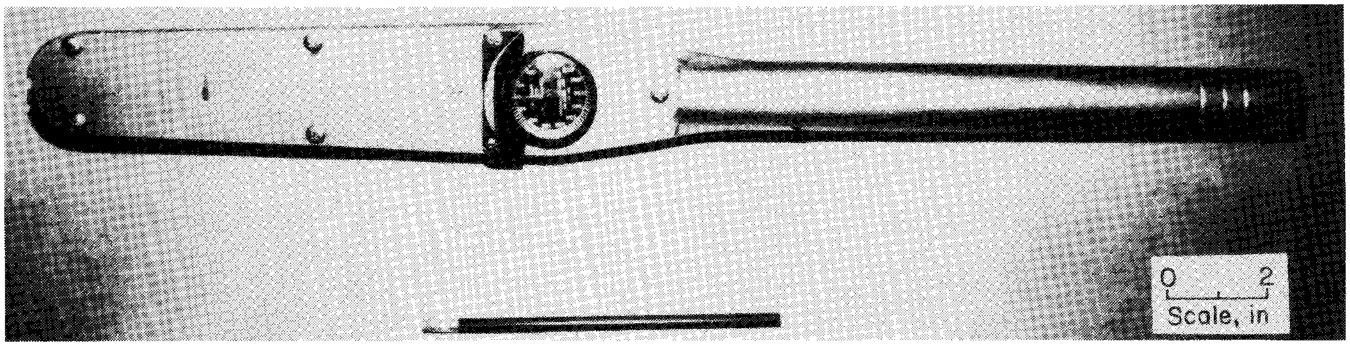

FIGURE 62. - Torque wrench.

Data Collection

Step 1: Fit socket and wrench onto the bolthead.

Step 2: Apply constant pressure to the bolt until it just moves.

Step 3: Remove the wrench from the bolt. Read the dial gauge and record the reading.

Step 4: If a second reading is desired, reset the gauge to zero, then follow steps 1 through 3.

Federal regulations require that 10 pct of all bolts inby the last open cross-cut be torque tested each shift. This reveals unfavorable bolt conditions relatively soon after installation. Roof bolts outby can also be checked if necessary.

Data Interpretation

Data are limited to the loss or gain of torque by the roof bolts. Torque loss can result from bad bolts, improper installation, or anchorage failure. Torque gain indicates loading of the bolt by the roof.

Torque in foot pounds (T) can be expressed as pounds of tension (P) by the following equation:

$$P = 42.5T - 1,000.$$

P will be within 2,700 lb of the torque value predicted by this equation 90 pct of the time. For example, a torque measurement of 260 ft•lbf indicates a bolt load of 10,000 ±2,700 lb. For a quick approximation, 1 ft•lbf torque corresponds to a bolt load of 40 lb (12). The above equation is general and may need to be modified if the bolts are installed with hardened washers and lubricated threads.

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DISCUSSION

This manual is intended not as an exhaustive instrument catalog but as a basic guide for selecting ground movement measuring instruments. Additional information can be obtained from the instrument suppliers and/or the author of this guidebook.

A ground control program can be developed in two ways. The first is the unlimited dollars and unlimited personnel approach. The second works with limited dollars and limited personnel. It is generally felt that the second approach is better for a company that is new to ground control instrumentation. The appointment of one or two mine engineers as ground control specialists to conduct tests, evaluate data, etc., will result in instrumentation programs that are better managed and more cost effective, and produce more reliable (useful) data and solutions.

Mine operators may encounter certain problems when introducing ground control instrumentation. One is that accidental or deliberate damage to the instrument can result in false and inaccurate readings. Another is that workers may misinterpret instrument outputs and be reluctant to work in an area they interpret to be unsafe. These problems can be largely eliminated by explaining to all employees (1) the reasons for instrumenting the area, (2) the extent to which movement actually indicates unstable conditions, and (3) the added margin of safety that such instrumentation gives them. Labor as well as management must realize that an efficient ground control program is the cornerstone to a safe and productive work environment.

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APPENDIX A.--CASE STUDIES

Case Study 1: Convergence Stations and Dial Gauge Tube Extensometer (1)[1]

This study was conducted by Bureau personnel and mine engineers at an underground coal mine in southwestern Pennsylvania. It involved measuring the magnitude and rate of advance of a squeeze. The squeeze, starting as a slow increase in weight on the pillars and continuing to total entry closure, was probably due to leaving undersized pillars to support the main roof.

Fifteen pairs of convergence stations were installed in the roof and floor outby the advancing squeeze. Measurements from these stations would reveal accelerated squeeze movement. Early warning was desired so that barrier support structures could be built to stop the squeeze. A tube extensometer with a dial gauge readout was used to make initial convergence measurements at the time of station installation, as well as subsequent measurements. At first, measurements were made once a week, but since convergence was slight, the time interval was increased to 2 weeks.

Convergence at each station was graphed to show its movement with respect to time, and contour maps of total convergence for each station were drawn to show the direction of squeeze movement. Maximum convergence for the first 8 months was 1.889 in; average convergence was 0.397 in. Underground observations just inby the stations revealed squeezing of cribs, floor heave, rib spalling, and small, scattered roof falls.

The analysis of the convergence data through maps, graphs, and underground observations indicated that after 6 months the squeeze had decelerated significantly, owing to a large block of solid coal that had been left to protect a gas well. Measurements were continued, to serve as an alarm in case of further squeeze movement.

[1]Underlined numbers in parentheses refer to items in the list of references at the end of this appendix.

Case Study 2: Simple Weighted Bed Separation Indicators, Horizontal Roof Strain Indicators, and Stratascope (2)

This investigation was conducted by Bureau personnel at an underground coal mine near Somerset, CO. Various instruments were installed in the roof of a room-and-pillar section in an attempt to determine the effects of length of time between exposure and support on mine roof stability. Simple weighted bed separation indicators were installed to measure differential roof displacement during and after mining. Horizontal roof strain indicators (HORSI) were used to determine the existence of horizontal stress fields that might influence roof stability. In addition, a drill hole was provided at each location for use with a stratascope to determine the locations and widths of roof separations.

Typical instrumentation stations consisted of three simple weighted bed separation indicators, one or two horizontal strain indicators, and a stratascope hole (fig. A-1). A total of 21 gauge stations were instrumented. A hole depth of 7 ft was used for the bed separation indicators. This depth was determined by the maximum heights of roof falls near the test area. The spring clip anchors were placed at 84, 54, 36, and 18 in into the roof. The first bed separation indicator was installed immediately after bolting of the first cut mined. The remaining bed separation indicators and the horizontal strain indicator were installed after the next cut was bolted, but with varying time intervals between mining and supporting.

Readings were taken daily over the first 5 weeks, then intermittently for approximately 3 months. Values of total change in vertical roof displacement ranged from 0.023 to 1.325 in, with an average maximum deflection of 0.257 in. Horizontal strain indicators showed changes of from 5 to 125 μin (1 μin equals 1×10^{-6} in). The average value was 84 μin/in of roof surface. Because of these low values, it was determined

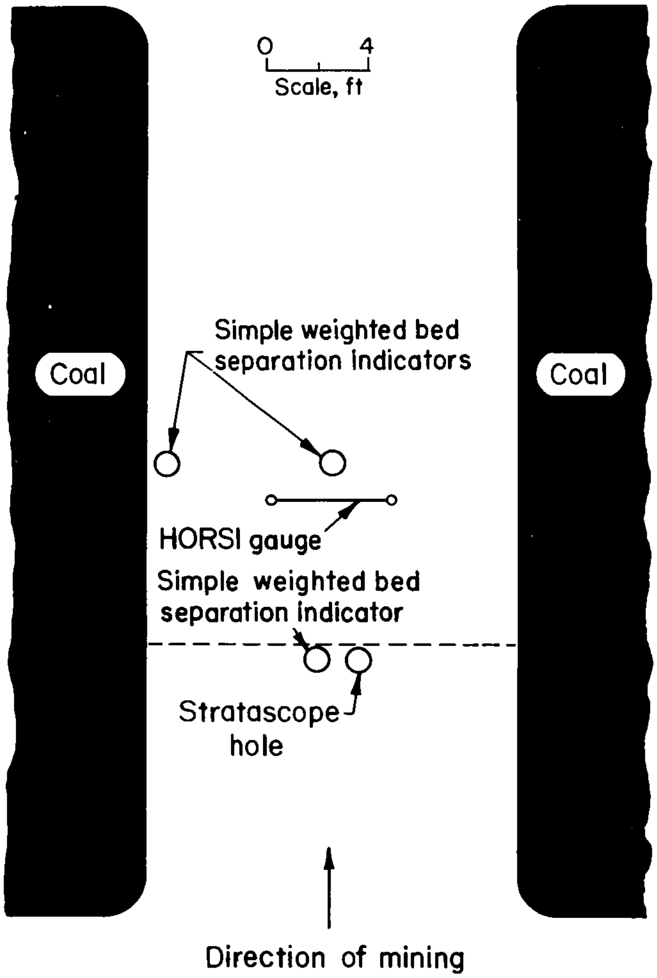

FIGURE A-1. - Typical gauge station. Dashed line indicates face location when first gauge was installed.

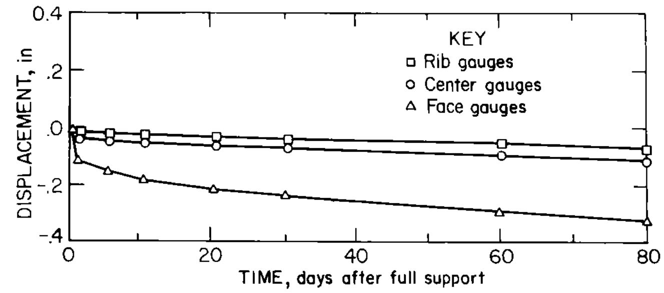

FIGURE A-2. - Average deflection, by location.

that horizontal movement was too small to influence roof stability in the test area.

Analysis of displacement values measured by the different gauges yielded a similarity in overall trends. In general, the displacement per unit time (rate of sag) was high immediately after mining and before bolting took place. After bolting operations, the rate of sag fell to a much lower value and eventually reached a stabilized rate of very little or no increase in displacement. As expected, the average amount of total displacement during unsupported time was greater for the longer time lapses. The rate of sag leveled off to essentially zero in all time lapse groups within 10 to 20 days after full support (fig. A-2).

The largest differential sag measured was between the 18- and 36-in roof levels. Stratascope observations indicated that differential roof movements were consistent with gauge readings. A hairline fracture was noted at the 33-in level, and a larger separation of 0.06 to 0.25 in was observed at the 19-in level.

Case Study 3: Roof Bolt U-Cells, Vibrating Wire Stressmeters, Tube Extensometer Convergence Stations, Multipoint Borehole Extensometer Stations (3)

This investigation was conducted by the Bureau at an underground coal mine in southeastern Ohio. Various ground control instruments were used to measure pillar stresses, bolt loadings, and strata separation movements of two longwall gateroads.[2] Measurements were made by means of roof bolt U-cells, vibrating wire stressmeters, convergence stations (dial-gauge tube extensometer), and multipoint borehole extensometer stations (fig. A-3). The purpose was to gather data on gateroad loadings during development and longwall panel mining in order to determine the optimum design of gateroad pillars and entries, and artificial support requirements.

Four groups of twelve roof bolt U-cells installed in the crosscuts and entries measured the change in roof bolt loads as different longwall loading situations occurred.

[2]At the time of publication, very few data were available, owing to recent installation of instruments.

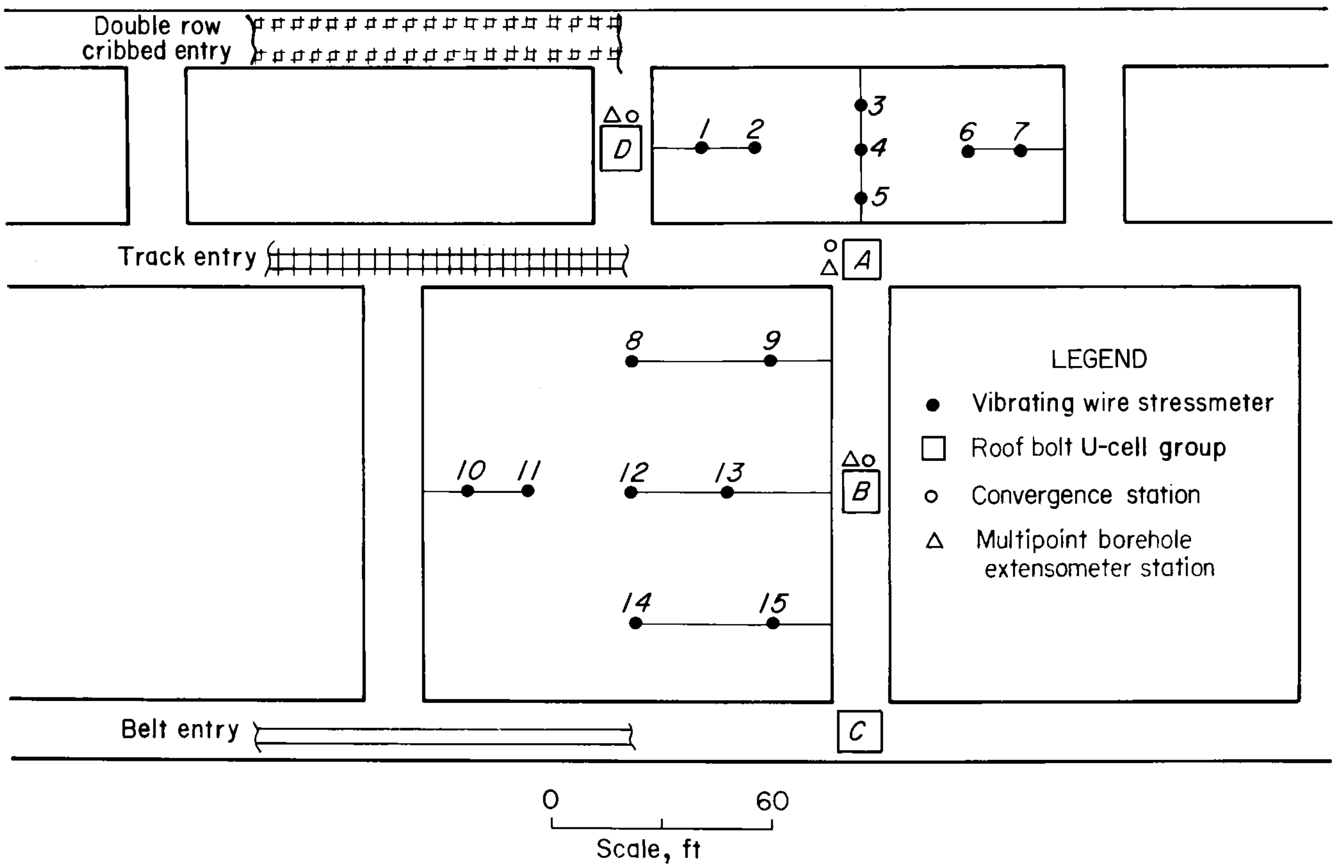

FIGURE A-3. - Instrumentation plan for each array.

Vibrating wire stressmeters installed in the abutment and yield pillars measured vertical, uniaxial stress changes. They were installed at varying distances into the pillars. This positioning will reveal the general stress distributions both lengthwise and widthwise across the pillars. Stress differences between the core and outer layer of the pillars will also be detected.

Convergence stations have been installed so that a dial-gauge tube extensometer can be used to measure roof-to-floor convergence. Multipoint extensometer stations, employing a sonic readout borehole extensometer, measure roof strata separations. The anchors were placed at the 2.5-, 4-, 5.5-, 7.5-, and 11-ft levels in the roof. These locations were just below the interfaces between the various roof rock layers. Floor heave is determined by comparing the measurements from these two instruments.

Case Study 4: Plumb Bobs

This study was conducted by the Bureau at an underground coal mine located in south-central Pennsylvania. The mine roof was monitored to determine the direction and amount of lateral movement. Plumb bobs were used to measure movements.

Lateral roof movement was suspected for the following reasons: (1) seam dips averaging 10°, (2) deteriorating roof conditions beginning updip and progressing downdip, (3) shearing of roof bolts, and (4) empty roof bolt holes with visible offsets. The general opinion of the mine employees was that all movement was downdip. In the attempt to prove or disprove this, six areas were monitored with plumb bobs. The plumb bobs were located in a main travelway that had shown only slight indications of movement or adverse roof conditions. Observations were made weekly to determine if the roof and floor were experiencing differential movement. No distinct direction of movement was found, primarily because of the lack of precision of the plumb bob measurements.

To supplement these findings, approximately 40 empty roof bolt holes were investigated. Nearly all showed a different direction and amount of movement. This movement occurred at the same strata interface within each hole (fig. A-4).

Case Study 5: Borehole Deformation Gauge (4)

This investigation was conducted by the Bureau at an underground lead-zinc mine near Bunker, MO. In situ stress was measured in one pillar to establish the pillar loading conditions and to evaluate the stability of the pillar. Laboratory tests were run on drill cores to determine the compressive strength, Young's modulus, shear strength, and the angle and coefficient of friction of the mine rock.

Tests on 280 NX (2.125-in-diam) core samples collected from 16 locations produced the following values:

Average strength = 11,900±2,554 psi,
Young's modulus = $9.27 \pm 0.98 \times 10^6$ psi,
Specific gravity = 2.75.

In situ rock stress mesurements were obtained using a three-component borehole deformation gauge. Overcoring was conducted in a borehole drilled horizontally at midheight of the pillar, to more than half the width of the pillar. Owing to poor core recovery during overcoring, only two sets of usable borehole deformation data were obtained. Secondary principal stresses in the plane normal to the borehole were calculated to be -10,048 psi for the vertical stress and -3,701 psi for the horizontal stress (negative sign denotes compressive stresses).

The measured vertical stress of -10,048 psi in the pillar is within the average compressive strength of 11,900±2,554 psi. This indicates that continual spalling and pillar deterioration may occur, which will increase the vertical stress in the pillar, resulting in more pillar deterioration. Since the pillar stress is

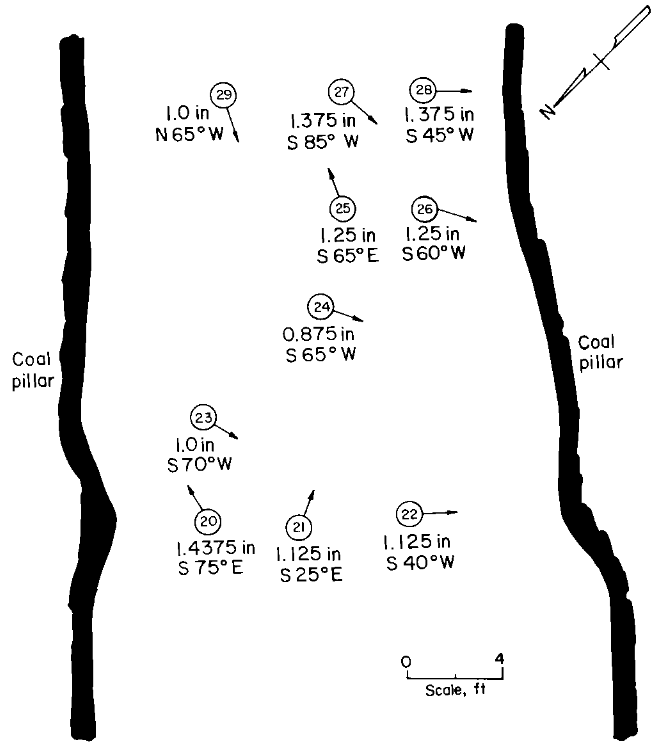

FIGURE A-4. - Amount and direction of lateral roof movement found in holes 20 through 29.

nearly equal to the average compressive strength of the rock samples tested, the strength of the pillar may be exceeded by the vertical stress. The possibility exists that the pillar stress has already exceeded the pillar strength and that the pillar is in a postfailure state. A method of pillar stabilization would be warranted in this situation.

Case Study 6: Flat Borehole Pressure Cells and Powered-Support Pressure Recorders (5)

This study was conducted by the Bureau at a mine located in the Ohio Valley area of southwestern Pennsylvania. Experimental shortwall sections were monitored by measuring the relative pressure changes in chain pillars and shortwall panels with flat borehole pressure cells (encapsulated type) to determine the effect of mining, and by recording hydraulic pressure on some roof support units to determine whether or not they approached the yield pressure. Chain pillars were monitored because of the concern that inadequate caving of the limestone roof would shift excessive load to the chain pillars. Pressure cells were installed in selected chain pillars and in shortwall panels to determine pressure changes due to increased loading, although the relationship between the relative pressures measured and the actual load or pressures was not fully understood (fig. A-5). The cells were installed from 4 to 14 ft deep, oriented to indicate vertical loading only, and were initially pressurized to about 800 psi (the estimated mean load exerted by the overburden). Measured pressure changes revealed no large increases in vertical pressures in any of the chain pillars during or after panel extraction (fig. A-6). The entries were generally stable, and there was a notable absence of pillar sloughing.

In addition to measuring relative pressure changes in the coal, recorders were connected into the hydraulic system of the powered roof supports to monitor fluid pressures in the front and rear leg assemblies. The purpose was to detect pressure surges under adverse roof conditions and to warn of excessive loading on the chocks. The recorders were placed on chocks near the center and near the tail end of the chock line. Both of these locations yielded recorder charts indicating similar pressure characteristics. During normal operation, potential roof falls are indicated by slow increases in pressure until the failure occurs, immediately followed by a substantial pressure jump. None of the chocks monitored reached more than 82 pct of its yield pressure.

Case Study 7: Roof Bolt U-Cells and Hydraulic Prop Load Cells (6)

This study was conducted by the Bureau at a central Pennsylvania coal mine. The mine roof, ribs, and bolts were monitored to determine the roof movement and pressures generated during the formation of cutter roof failure. U-cells were used to detect bolt loadings while flat, hydraulic prop load cells were used to monitor loading of fiber cribs.

Measured bolt loadings indicated that the roof was acting as a cantilever beam with the most sag on the side where the cutter was forming. Bolts near the cutter had greater load increases (500 to 600 psi) than those distant from the cutter (50 to 100 psi).

Measurements of crib loadings revealed that the cribs were able to support a considerable amount of fractured roof without failing. The average load increase was 1,000 psi.

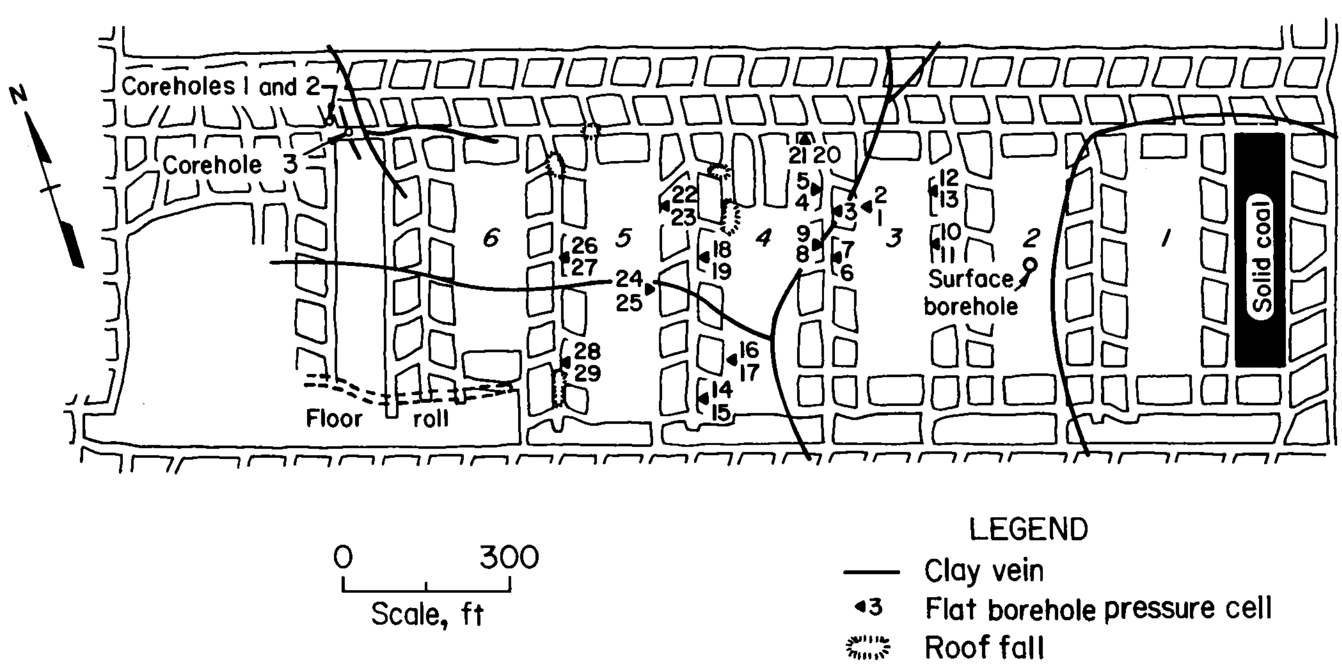

FIGURE A-5. - Shortwall section 7 right.

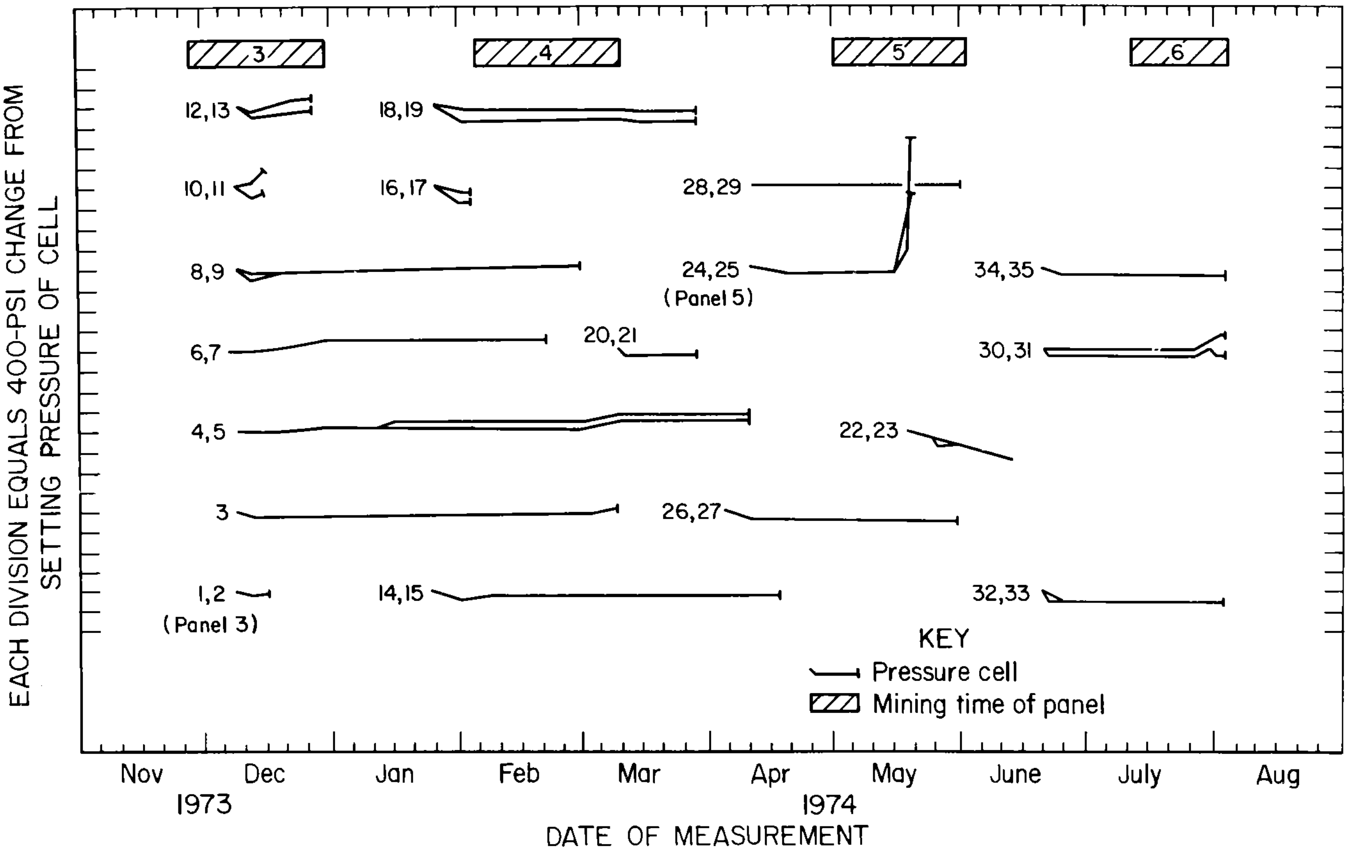

FIGURE A-6. - Pressure changes recorded in pillars and shortwall panels during mining.

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4. Horino, F. G., and J. R. Aggson. Pillar Failure Analysis and In Situ Stress Determinations at the Fletcher Mine Near Bunker, Mo. BuMines RI 8278, 1978, 19 pp.

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APPENDIX B.--INSTRUMENT SUPPLIERS[1]

Ailtech
19535 East Walnut Dr.
City of Industry, CA 91748
(213) 965-4911

American Optical Corp.
14 Mechanic St.
Southbridge, MA 01550
(617) 765-9711

Armstrong Bros. Tool Co.
5273 W. Armstrong Ave.
Chicago, IL 60646
(312) 763-3333

Baltimore Instrument Co., Inc.
4610 Harford Rd.
Baltimore, MD 21214
(301) 426-3656

Barnes Engineering Co.
30 Commerce Rd.
Stamford, CT 06902
(203) 348-5381

BLH Electronics
42 Fourth Ave.
Waltham, MA 02154
(617) 890-6700

Bristol Division, Acco Industries Inc.
40 Bristol St.
Waterbury, CT 06708
(203) 756-4451

Budd Co.
Grant and Franklin Sts.
Phoenixville, PA 19460
(717) 935-0225

Conkle Inc.
P.O. Box 190
Paonia, CO 81428
(303) 527-4848

Eder Instrument Co., Inc.
5115 N. Ravenswood Ave.
Chicago, IL 60640
(312) 769-1944

Enerpac
13000 W. Silver Spring Dr.
Butler, WI 53007
(414) 781-6600

Expanded Optics Co., Inc.
14102 Willow Lane
Westminster, CA 92683
(714) 894-1388

Extech International Corp.
114 State St.
Boston, MA 02109
(617) 227-7090

Geokon, Inc.
7 Central Ave.
West Lebanon, NH 03784
(603) 298-5064

Geophysical Instrument and Supply Co., Inc.
4665 Joliet St.
Denver, CO 80239
(303) 371-1940

Glowlarm Rock Fall Warning Devices
P.O. Box 465
White Pine, MI 49971

Handy Geotechnical Instruments, Inc.
P.O. Box 1200, Welch Ave. Station
Ames, IA 50010

Hitec Corp.
Nardone Industrial Park
Westford, MA 01886
(617) 692-4793

Hughes Aircraft Co.
Industrial Products Division
6155 El Camino Real
Carlsbad, CA 92008
(714) 438-9191

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[1]This list may not include all possible suppliers of ground control measuring instruments.

Industrial Products Co.
7445 North Oak Park Ave.
P.O. Box 48022
Chicago, IL 60648
(312) 647-7855

Instrument Technology, Inc.
Box 381, Mainline Dr.
Westfield, MA 01085
(413) 562-5132

Irad Gage
Etna Rd.
Lebanon, NH 03766
(603) 448-4445

Klein Tools, Inc.
7200 McCormick Blvd.
Chicago, IL 60645
(312) 677-9500

Kulite Semiconductor Products, Inc.
1039 Hoyt Ave.
Ridgefield, NJ 07657
(201) 945-3000

Lenox Instrument Co., Inc.
111 E. Luray St.
Philadelphia, PA 19120
(215) 324-4543

Microdot, Inc.
475 Steamboat Rd.
Greenwich, CT 06830
(203) 661-1200

Micro-Measurements, Measurements Group,
Vishay Intertechnology, Inc.
P.O. Box 27777
Raleigh, NC 27611
(919) 365-3800

Mikron Instrument Co., Inc.
P.O. Box 211
Ridgewood, NJ 07451
(201) 891-7330

Olympus Corp. of America
4 Nevada Drive
New Hyde Park, NY 11040
(516) 488-3880

Raytek, Inc.
325 E. Middlefield at Whisman
Mountain View, CA 94043
(415) 961-1650

Revere Corp. of America
845 N. Colony Rd.
Wallingford, CT 06492
(203) 269-7701

Roctest, Inc.
7 Pond St.
Plattsburgh, NY 12901
(518) 561-3300

Rogers Arms and Machine Co.
1426 Ute Ave.
Grand Junction, CO 81501
(303) 245-3729

Seco, Standard Equipment Co.
9240 N. 107th St.
P.O. Box 23060
Milwaukee, WI 53224
(414) 355-9730

Sensotec, Inc.
1200 Chesapeake Ave.
Columbus, OH 43212
(614) 486-7723

Serata Geomechanics, Inc.
1229 Eighth St.
Berkeley, CA 94710
(415) 527-6652

Sinco, Slope Indicator Co.
3668 Albion Place North
Seattle, WA 98103
(206) 633-3073

Snap-on Tools Corp.
8030 E. 28th Ave.
Kenosha, WI 53140
(414) 654-8681

Soiltest, Inc.
2205 Lee Street
Evanston, IL 60202
(312) 869-5500

Spider Inc.
4001 Gratiot
St. Louis, MO 63110
(314) 535-7868

Strainsert Co.
100 Union Hill Rd.
Union Hill Industrial Park
West Conshohocken, PA 19428
(215) 825-3310

Terra Technology Corp.
3862-T 148th Ave., NE.
Redmond, WA 98052
(206) 883-7300

Wahl Instruments, Inc.
5750A Hannum Ave.
Culver City, CA 90230
(213) 641-6931

Weksler Instruments Corp.
80 Mill Road
Freeport, NY 11520
(516) 623-0100

Welch Allyn, Inc.
99 Jordan Rd.
Skaneateles Falls, NY 13153
(315) 685-5788

Westinghouse Electric Corp.
Industrial and Govt. Tube Div.
Westinghouse Circle
Horseheads, NY 14845
(607) 796-3211

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