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Single-Entry Development for Longwall Mining

Research Approach and Results at Sunnyside No. 2 Mine, Carbon County, Utah

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR
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SINGLE-ENTRY DEVELOPMENT FOR LONGWALL MINING

Research Approach and Results at Sunnyside No. 2 Mine, Carbon County, Utah

by

Melvin E. Poad,[1] Galen G. Waddell,[2] and Earl L. Phillips[3]

ABSTRACT

This Bureau of Mines report presents two phases of a research program to evaluate a single-entry system for longwall development. Organizations participating in the program, which began in July 1971, include the Bureau of Mines, the Mining Enforcement and Safety Administration, and the University of Utah, working under a cooperative agreement with Kaiser Steel Corp. at its Sunnyside mine in Utah. Part 1 of this report describes the present longwall mining practice, including a brief history, and discusses the advantages and disadvantages of a single-entry development system and its introduction in the United States. Part 2 of the report presents the research program, test design, instrumentation for ground and support evaluation, and the test results from the No. 2 mine. Subsequent reports will describe the research conducted in the No. 1 mine.

INTRODUCTION

The Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173) is designed to improve the health and safety of miners with new or improved standards, strict enforcement of those standards, and new or improved mining technology accomplished through research. Although single-entry development and longwall mining have never been used in the United States, their use in other parts of the world has resulted in improved safety records compared with conventional types of mining (room-and-pillar, etc.) (8).[4]

Because the single entry has been used with success in Europe and other parts of the world, there is sufficient reason to believe that it will succeed under the deep cover and geologic conditions found at Sunnyside. The Federal

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

Coal Mine Health and Safety Act of 1969 specifies that there must be an alternate escapeway within 100 feet of an area in which miners are working. The question that is proposed and requires the subject research is, "Will a single entry, divided along the centerline by a fire-resistant support-divider, provide an alternate escapeway?" Title V of the act provides for exemptions under the law if research is directed by the Bureau of Mines. After meetings of the groups involved, the Single-Entry Research Program was initiated.

This Bureau of Mines paper explains the use and advantages of a single-entry system in development for longwall coal mining, defines the problems anticipated with single entries, and presents the research approach needed to evaluate and solve the problems. Under study are problems associated with ground control, ventilation (methane and dust), and safety procedures. Described are crib and roof-bolt loads as the entry heading advances, stress determinations, and preliminary structural analysis of the double entry. Some of the mine operation problems and waivers of mining laws (for experimental purposes) are discussed.

Although the field results reported in this publication are minimal, this report provides the background and rationale for the single-entry program. Additional publications will address the ground-control, ventilation, and safety problems during driving of the single entries and during retreat of the longwall panels. One report will describe detailed geologic parameters, stratigraphic columns, and structural properties of the immediate roof and floor. Another report will analyze the failure of the wooden cribs as a centerline support system, describe the design of the concrete cribs, and analyze the structural properties of the cribs in the laboratory and in the field.

The research program has progressed approximately 5 years in an 8-year program. If successful, single-entry longwall development would improve both safety and production. Cooperators in the study include the Federal Bureau of Mines, the Mining Enforcement and Safety Administration (MESA), Kaiser Steel Corp., and the University of Utah.

PART 1.--THESIS OF SINGLE-ENTRY DEVELOPMENT

Background

Before describing the single-entry research project, a brief discussion of general coal mining practices will explain why single-entry development, together with longwall mining, constitutes a more efficient mining system.

Longwall Mining

Longwall mining was tried in the United States prior to 1900 but was abandoned in favor of room-and-pillar mining because of the labor costs involved with manually moving the supports. Following the advent of self-advancing props, longwall mining was again introduced in the United States in 1960. The first installations were in southern West Virginia mines with ground-control problems. These mines had mudstone or friable-shale roof, which was easily caved; cover was shallow and props were light. The system was next tried using the same-capacity jacks in seams overlaid with massive roof strata and shallow cover. Under such mining conditions, the support either failed or was operated with great difficulty. This discouraging experience stunted the growth of longwall mining for a considerable period of time.

In 1966 two longwall units were equipped with massive, heavy-duty supports. Both operations were under thick sandstone roof strata and one was in a deep mine. Both installations met with instant success and led to the first modest expansion of the longwall mining system (3). Although U.S. underground coal mine tonnage dropped from 347.1 to 302.4 million tons between 1969 and 1971, longwall mining increased from 6.3 to 8.4 million tons and accounted for about 4 percent of total underground production in coal mines. From August 1972 to June 1973, the number of longwalls increased from 30 to 43. As of January 1977, there were 72 operating longwall faces in the United States (4).

The fundamental principle of longwall mining is the complete removal of the entire seam in one operation by carrying a continuous working face, leaving no pillars, and allowing the roof to cave behind the face (8). Development consists of driving one or more gates or entries approximately 300 to 600 feet apart, providing an interconnection, and then mining the rib of the interconnection. Figure 1 shows multiple-entry, double-entry, and single-entry development.

The longwall mining system consists of three basic components: (1) a support system, (2) a coal-getting device, and (3) a haulage system. The support system comprises a series of hydraulically powered chocks that have a number of hydraulic legs (props or jacks), box-type steel canopy or canopies, single- or double-base plates, a push-pull cylinder, and a control valve that lowers, advances, and resets the unit (11). The trend is to heavier units; those used in this single-entry study are rated at 450 tons.

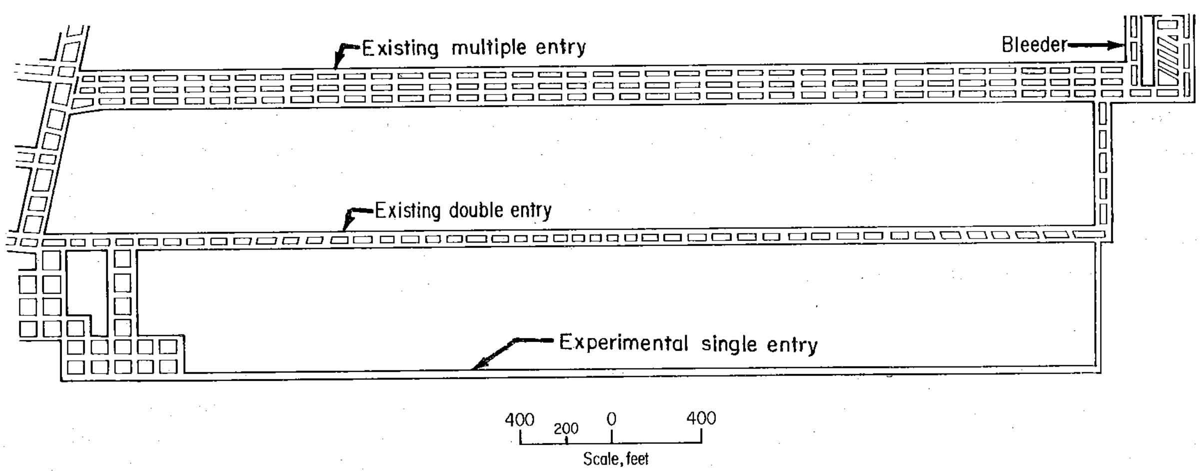

FIGURE 1. - Multiple-, double-, and single-entry longwall-development systems.

Two types of longwall mining are practiced--advance and retreat. In Europe and Japan where coal mining is at greater depths (down to 4,000 feet), it is almost impossible to drive and maintain entries for complete development of a longwall panel; thus, the advance type is used. Two entries are driven (headgate and tailgate) a short distance ahead of the advancing longwall face; hence, the term "advance longwall mining." In "retreat longwall mining," complete development of the longwall panel (entries and crosscut) takes place prior to mining. This system predominates in the United States where mining is conducted at lesser depths, except when an advancing tailgate is added to make a combination system.

Some advantages of advance longwall over retreat longwall mining include the following (11):

1. Development costs are reduced because coal is mined immediately.

2. An escapeway is provided immediately.

Some disadvantages are--

1. Air tends to short-circuit through the gob, causing ventilation problems.

2. Entries are subjected to increased ground pressure owing to caving of adjacent ground, and they must be constantly maintained.

3. Entries are subjected to heavy concentrations of methane from the gob.

Longwall Mining Versus Room-and-Pillar Mining

The longwall system provides several advantages over room-and-pillar operations.

1. Continuous support provides a safer environment. Only 2 fatalities occurred at longwall faces in 1972, compared with 121 for room-and-pillar mining; based on production, fatality rates were 1 per 7 million tons of coal mined by longwall, and 1 per 2 million tons by room-and-pillar mining (12). For the same period, there were 551 disabling injuries for longwall operations versus 14,237 for room-and-pillar; again, based on production, 25,000 tons per injury for longwall versus 18,000 tons per injury for room-and-pillar mining (13).

2. A high extraction ratio is possible. As the need for energy increases throughout the world, we can no longer afford to leave large amounts of our coal reserves underground because of out-dated and inefficient mining methods. Room-and-pillar methods extract an average of 55 percent of a minable seam, whereas conventional longwall methods average 75 percent recovery. From 90 to 95 percent is possible with single-entry development (6).

3. Supply, ventilation, supervision, and power are cheaper because activities are concentrated.

4. Supports are recovered.

5. Subsidence can be controlled. Visual subsidence is a primary concern of environmentalists. Europeans have been able to adjust their rate of advance to control subsidence, even under cities and harbors, with minimal effect. In most cases, delayed subsidence resulting from room-and-pillar operations may pose a greater problem (6).

6. There is no need to dust the face.

7. Coal extraction rates are higher. Faster and more economical methods of mining are required to insure the Nation of a dependable and reasonable resource. Development rates are relatively the same for both types of mining (200 tons per shift); however, longwall mining will average approximately 700 to 1,000 tons per shift during production versus 200 tons per shift for room-and-pillar operations (6).

Longwalling has been proven and is used almost exclusively in Europe for coal mining. Although European mines operate under more adverse conditions due to greater depth and poor roof conditions, their accident rate is relatively low and coal recovery high.

Longwall mining is not a panacea for all mining conditions. Problems that have to be considered in a longwall mining system include the following:

1. Where the floor is weak, supports may be driven in.

2. A strong roof may not cave properly, hanging up behind the chocks and making it necessary to induce caving.

3. Discontinuities in the seams (faults with significant displacement) are impossible for present mining systems to transverse.

4. Cutter and support systems can adapt to only a minimal variation in coal thickness.

5. A loss of production results from the time lost in changing locations.

6. The tailgate might be subjected to extensive ground pressures as the face abutment pressures from the active panel are superimposed on the existing abutment pressures from the adjacent mined panel.

7. If pillars are left in seams, they transfer their loads to lower seams, and mining of a lower seam may become impossible because of the danger of the pillars "punching" through the roof.

8. Equipment is moved with difficulty in inclined seams.

9. If one element of the longwall is inoperative, it closes the entire wall.

Some of these problems are being addressed at the present time. Solutions include introduction of shortwall mining, shield-type chocks that can adjust to the varying seam heights and navigate poor floor, and the advancing tailgate system.

Single-Entry Development

Coal bounces, bumps, or bursts have been a continuing problem in the Sunnyside District of Utah since mining began in the 1890's (7). As mining progresses to great depths, bounces can be expected to increase, with associated larger outburst of methane and worsening support problems in the entries, particularly at intersections. Because of these problems, Kaiser Steel was granted a variance from section 317(f)(4) of the law by MESA in April 1970; this permitted the use of a two-entry system for longwall development. (Normally three or more entries are used in this country.) As a result, roof problems improved, and bounces in the entries were reduced. The company reasoned that additional improvement could be gained with a single-entry system that would accomplish the following:

1. Reduce overall disturbance of virgin coal areas.--This is a big factor in minimizing bounces.

2. Eliminate chain pillars.--Chain pillars have always created a bounce environment at Sunnyside.

3. Eliminate crosscuts and intersections.--This will enhance safety by reducing exposed roof area.

4. Reduce float-coal dust.--Because coal ribs are never stable in deep cover, sloughing and dribbling adds to the dust problem.

5. Improve ventilation.--The total amount of air required to dilute the methane across one exposed coal face will be less than that across several faces where a substantial amount of the air is lost in leakage through curtains and line brattice. Dust control will be improved as dust-laden air goes directly to the return. The greater amount of air in a single face will afford better gas dilution and reduce the concentration of airborne dust.

6. Improve roof support.--Straight-line advance eliminates crosscuts, a major source of support problems.

7. Reduce electrical trouble and cable damage.--Straight-line advance eliminates the necessity of moving equipment through crosscuts.

8. Reduce the number of openings.--This will reduce the required inspection and maintenance.

9. Improve extraction ratio.--Elimination of chain pillars will increase recovery of the minable seam from 75 percent to 80-95 percent and extend our energy reserve. Superimposed seams will be more easily mined because the punch-out effect of chain pillars is eliminated.

10. Increase development rates.--A faster return on capital investment will result from reducing the amount of development equipment and time required to bring a block into production. This in turn should provide a cheaper energy source to the public.

11. Controlled subsidence.--Owing to uniform extraction subsidence gradients should be significantly smaller than those associated with a multiple-entry system.

Of course, the single-entry system will not accomplish all of these things. Numerous unknowns must be evaluated before it can become a workable system. Maintenance of an adequate escapeway, for instance, brings up several problems. Will the wider entry needed for mining equipment, centerline cribs, and an escapeway cause a higher stress concentration in the ribs, extending the failure zone into the standing ribs? The failed material would increase the roof span and possibly aggravate floor and roof convergence or failure. Will a single entry increase or decrease the frequency of bounces or bumps, and if they do occur, will a crib line with partition be strong enough to adequately maintain the escapeway, as well as its integrity as a fire-resistant barrier? And finally, will mining equipment be capable of operating safely in such a confined space?

Some of the problems anticipated with the mining of adjacent longwall panels include whether or not a line of cribs will be able to withstand the side-abutment load produced by the mined-out panels and still maintain the tailgate. Also, will the standing ribs emit a higher percentage of methane because of the absence of pillars, which bleed off faster? If methane is a problem, will ventilation be capable of diluting it to prescribed safety limits, or will the greater volume of air needed increase the velocity because of the smaller cross section and cause dust problems? And again, will bounces and bumps be more prevalent in the rib of the single entry since there will be no pillar to act as a cushion between the active and mined-out panels? Some of these situations are highly unlikely, but will still have to be evaluated.

Problem Definition and Research Approach

The objective of this section is to present the problems confronting the project and the approach to their solution. Problems are in three areas; namely, ground control, ventilation, and safety procedures.

Ground Control

The Sunnyside coal mines are among the deepest in the United States. In mining a longwall panel, the main support problems occur at the intersections of the entries with the crosscuts and at the head of the gates. Pillars crush or burst, and chocks, cribs, and posts punch into the roof and floor. Future mining will be pursued at depths of 3,000 feet or more as the bed dips further beneath the mountainous topography, and support problems are expected to become more pronounced. To analyze the ground control of entries, we will look at three separate phases of panel development and extraction: (1) Driving of the entry, (2) mining of the longwall, and (3) long-term maintenance of bleeders.

Support During Development

A question with the single-entry drive is, "Will the single entry, divided by crib supports along the center, be stable enough to control the roof and, if a cave or burst occurs on one side of the split entry, will the other side be open for an escapeway?" With multiple entries, if one entry caves shut, miners can escape through another entry. Our approach is to compare the stability of the single and double entries by documenting the loads on supports (cribs, bolts, stulls) and measuring the rate of deformation as the entries advance. Microseismic stations installed during driving will monitor stress buildup in the ribs to identify possible burst conditions.

Structural analysis utilizing two- and three-dimensional finite-element techniques will (1) show the difference in stress between intersection and nonintersection, (2) show why the difference in geologic and structural properties of the roof might cause support problems at one place and not another, (3) determine what amount of support would allow a reasonable safety factor, and (4) determine the role of the pillar in roof support.

Support During Longwall Retreating Operation

The biggest question regarding the retreat operation is, "Will the entry, which becomes the tailgate adjacent to the old cave area, be adequately supported to prevent premature failure?" This entry must be maintained as an escapeway and also as an outby to supplement the bleeder ventilation. Our approach to this problem is to (1) study cases where the support system successfully and unsuccessfully limited the cave-line advance of the longwall, and (2) structurally analyze the ground and supports to determine the support rigidity and load-bearing capability needed to control the ground.

Experience and statistics show the tailgate entry presents a difficult support situation in multiple entries where chain pillars are left between the mined-out panel and the active longwall (7). The pillars are prone to bumps and the tailgate is difficult and dangerous to support. Eliminating the pillar by using the single-entry system may eliminate pillar bumps in both headgates and tailgates.

Our main approach to analyzing the structural competence of the tailgate will be structural analysis by means of complex two- and three-dimensional finite-element programs using data generated by the instrumentation described later in this report. The effectiveness of the wood cribs will be evaluated. Determinations will be made as to whether a more rigid crib would be beneficial or would create other problems, such as cracking of the roof and sill, causing more rock-fall problems in the immediate vicinity. Both field data analyses and finite-element studies will be used for evaluation.

Support of Bleeder Entry

Bleeders must be maintained during the life of that section of the mine. Since the bleeder's purpose is to drain methane from the gob area, the flow of air must be unobstructed. Longwall equipment is installed in the bleeder, which becomes the first cut area of the longwall advance. Therefore, it could be made as wide as desired if the cave line could be controlled with artificial supports. Plans call for single-entry development. Again, our approach will be data collection and structural and field analysis.

Ventilation

One of the most important questions about the single-entry feasibility is, "Will the ventilation be good enough to meet standards for methane control during the driving of the single entry and subsequent longwall mining?" Dust control, particularly along the longwall cutting face, is critical with all longwall operations, and conditions may become worse with single entries.

Methane

Methane concentrations below 1.0 volume-percent must be maintained, and if 1.5 volume-percent or greater is detected, miners must be withdrawn from the area. Cutting equipment automatically shuts down when methane concentrations reach 1.0 volume-percent methane. An explosive mixture exists within the range of 5 to 15 volume-percent methane. The Sunnyside mines are considered gassy mines; according to the company, 2,500 cubic feet of methane was liberated per ton of coal in the No. 1 mine, 16 left, during driving. With a two-entry system, there are separate entries for the inby and outby air. However, with the single entry, both air courses are restricted to one divided entry. Less coal is mined during single-entry development, which reduces the amount of methane liberated and the need for a large volume of air. Methane and air will be measured in both the single-entry portion and the double-entry portion as the entries are driven. This will define the amount of air needed to maintain safe methane dilution when one and two entries are being driven.

Another question is, "How far can a single entry be driven and proper methane drainage maintained without increasing the air velocity to the point where it causes a dust problem?" This will be resolved by regular measurements of methane and air velocity along the entries.

Will there be enough air flowing through the single entry during the longwall operation to maintain the minimum airflow across the longwall face and to keep the air flowing from the entry toward the bleeders? To determine this, methane and air volume will be monitored using portable and automatic recorders placed in the single entry, in the bleeders, and in the tailgate entry.

Dust

The Mine Safety Act establishes a maximum airborne dust concentration of 5 milligrams per cubic meter, and as little as 0.5 milligram per cubic meter if all the dust is silica. As previously stated, the biggest dust problem with all longwalls, regardless of the entry system used, is the concentration of dust along the longwall face during cutting.

The company is interested in cutting down the airborne dust along the longwall face and has been working with the Bureau in demonstrating dust suppressants. Regular dust samples will be taken by MESA inspectors and company personnel.

Safety Procedures

Normal preventative methods employed by the mine will be followed. Dusting will be done regularly. All potential causes of fires such as belts, power cables, etc., will be on the outby side of the single-entry divider. Flammable materials such as cribs, will be located on the outby, and the cribs will be treated with a fire-resistant material.

Metal brattice used to line the inby side of the entry will be fireproofed and sealed. Escape doors will be located every 100 feet along the entry divider.

PART 2.--FIELD INVESTIGATIONS AT THE SUNNYSIDE NO. 2 MINE

The Sunnyside Mining District of Kaiser Steel Corp. is located 27 miles northeast of Price, Utah, in Carbon County and consists of three mines, Nos. 1, 2, and 3 (fig. 2) The coal is mined from the lower and upper Sunnyside seams in the Blackhawk Formation (a part of the Mesaverde group of late Cretaceous Age). It is a high-volatile-bituminous, marginal-coking coal ranging in rank from A to B (fig. 3).

The test site selected was in the lower seam of the No. 2 mine and was to consist of three parallel entries, 3,500 feet long and 500 feet apart. The first of these was a 1,850-foot section of double entry to be followed by 1,500 feet of single entry. Instrumentation was to be placed at predetermined intervals in both sections (fig. 4); however, only part of the double entry section was driven and instrumented as a test site, and none of the single entry was driven in the No. 2 mine. The test was stopped because a minable seam was defined above the initial test site that previously was believed to be too thin and too close to the lower seam to be minable. This discovery made it necessary to mine the upper seam first or it would be lost. Consequently, a new test site was selected at the No. 1 mine. Although this move delayed the program somewhat, considerable knowledge (instrument design, layout and evaluation, installation procedure, training of personnel, and evaluation of an intersection) was gained, which is the subject of this report. Additional results will be published in succeeding reports.

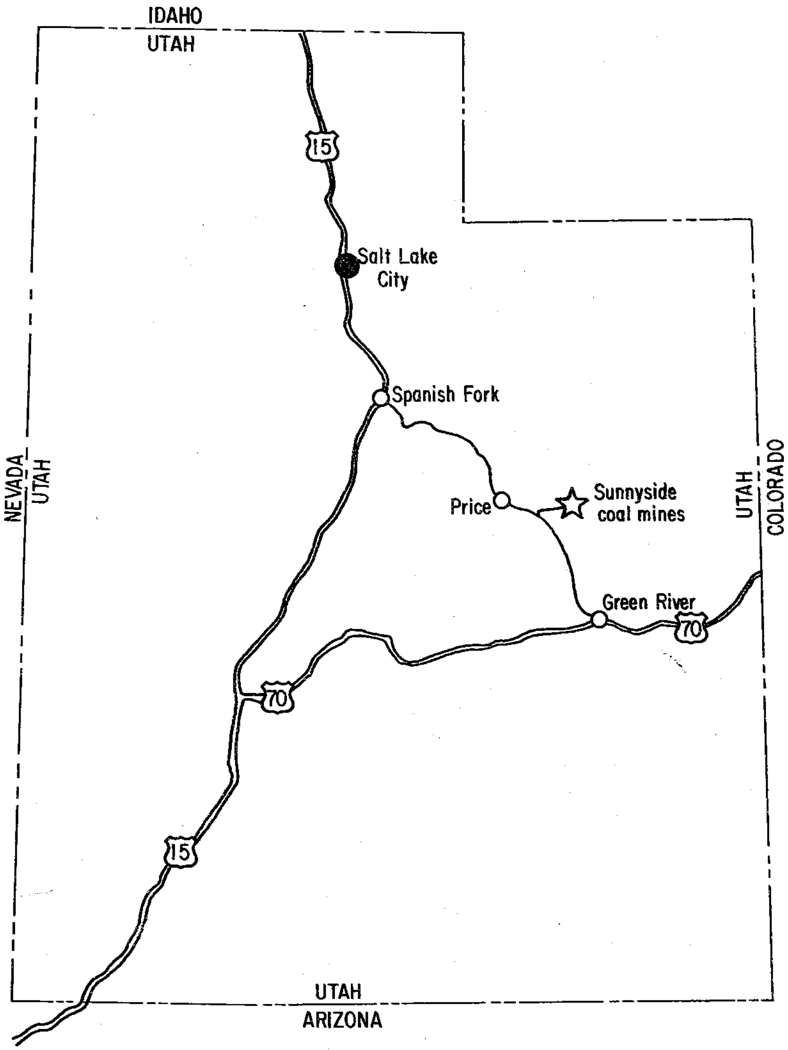

FIGURE 2. - Location map of the Sunnyside mines.

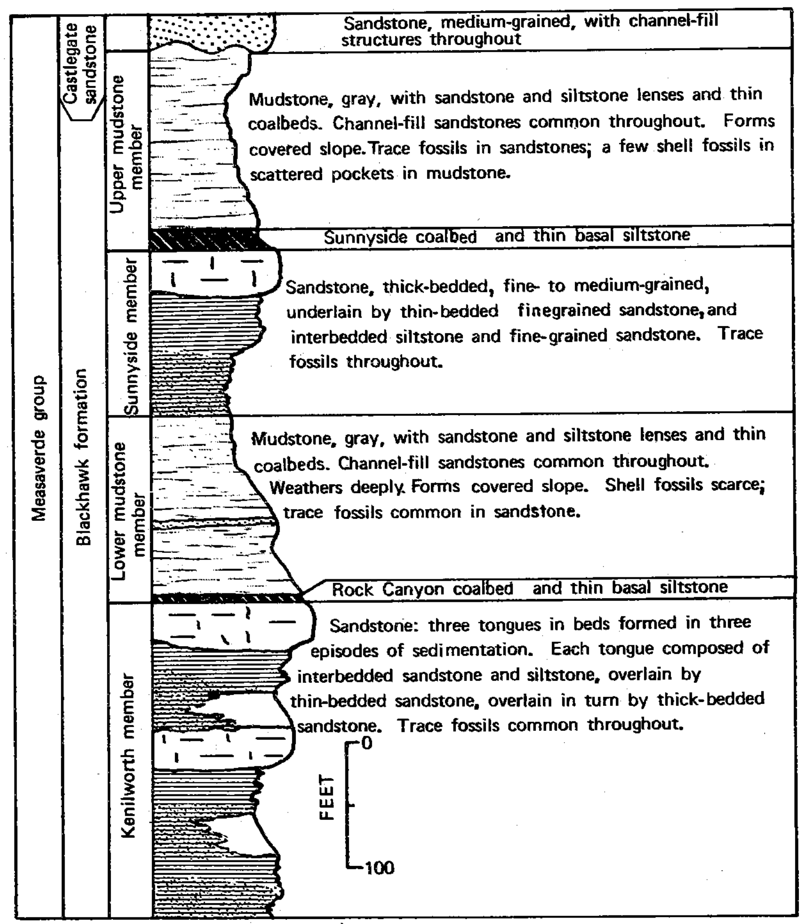

FIGURE 3. - Stratigraphic section of the Mesaverde group.

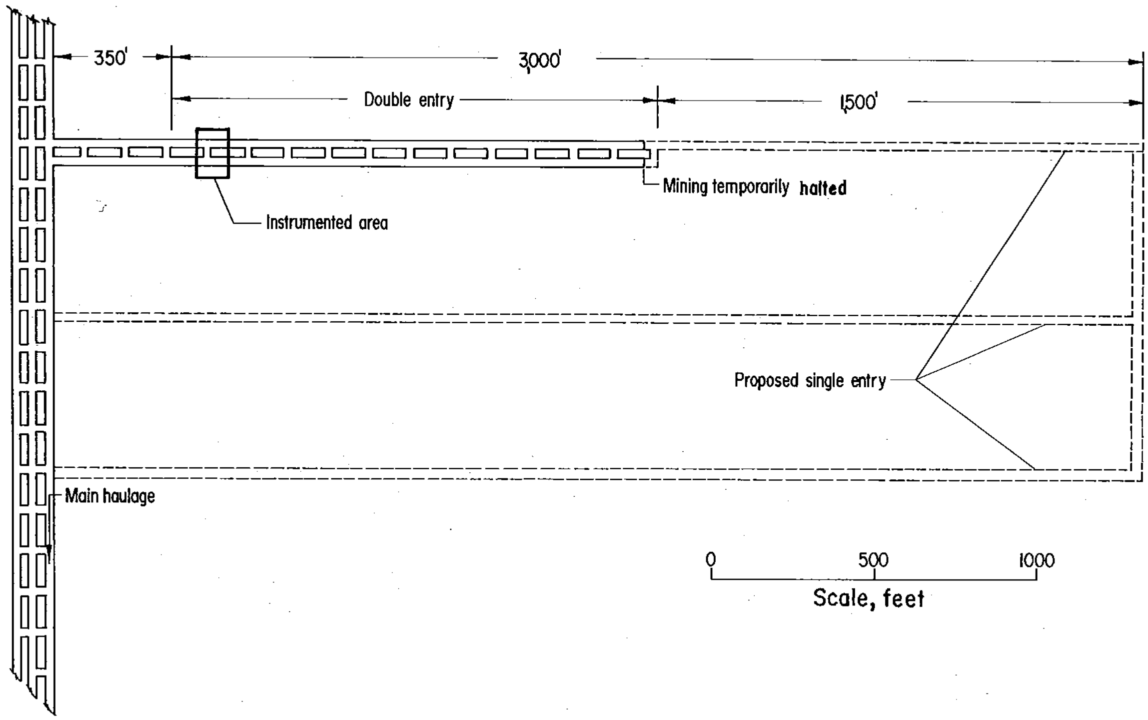

FIGURE 4. - Plan map of Sunnyside mine No. 2.

Geologic Investigations

The roof at test site 1 in mine No. 2 was described by mine management as treacherous. Miners working daily in this area agreed. Two roof falls, one in the test room adjacent to several load and deformation instruments, and another approximately 120 feet along the entry, confirmed the opinions. Because of the adverse conditions, various geologic phenomena were observed and mapped. These include fractured roof, separations, joints with and without slickensides, bedding-plane shears, faults, joints, and roof falls. Major geologic structures, geologic section, and roof-fall zones are depicted in figure 5. A full discussion of the geology of the area and physical properties of the strata will follow in a later report.

Numerous factors can contribute to roof falls. These include (1) lateral stress or movement in the roof, (2) horizontal separations in the roof strata, (3) highly fractured roof rock, and (4) possibly closed joints running across the entries.

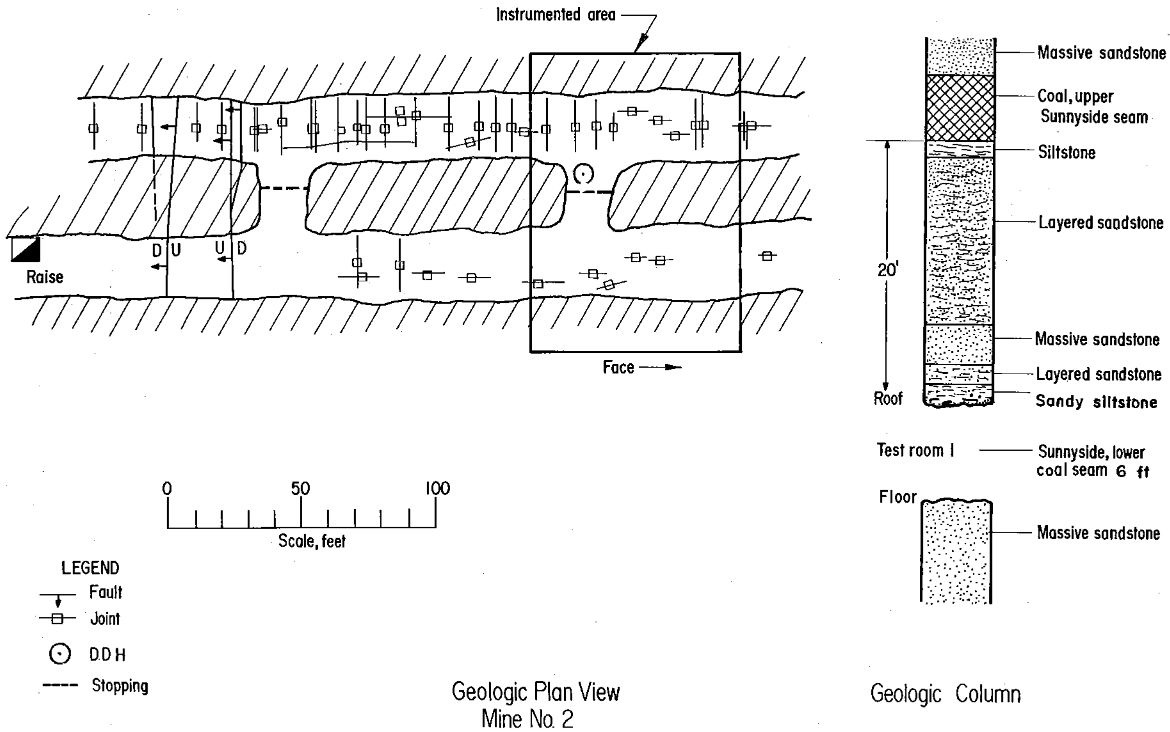

FIGURE 5. - Major geologic structures, geologic section, and roof-fall zones.

Support System

The mine-approved support plan consisted of 3/4-inch roof bolts and mats installed on a 4-foot grid pattern. Seven- to ten-inch wooden stulls and 3-foot-square wooden cribs were installed alongside each rib according to localized ground conditions. Temporary hydraulic props were installed after each cut to provide support to the face until roof bolts, cribs, and stulls are installed. Figure 6 depicts the methods used for roof control, support types, and density pattern.

Instrumentation

As in any field project, rugged, cheap, and reliable instrumentation was required. After an extensive search for "off-the-shelf" items for determining roof bolt and crib loads, it was determined that those available were not sensitive enough to identify initial load parameters. Therefore, an in-house task was undertaken to develop load-measuring devices for roof bolts, cribs, and stulls. Essentially, the instrumentation consisted of weldable strain gages on a titanium housing. The roof-bolt cells had a range of 32,000 pounds and a sensitivity of 5 pounds (2) (fig. 7). The crib and stull cells had a range of 250,000 pounds and a sensitivity of 20 pounds (2) (fig. 8). The electrical readout from both cells was obtained from a strain indicator.

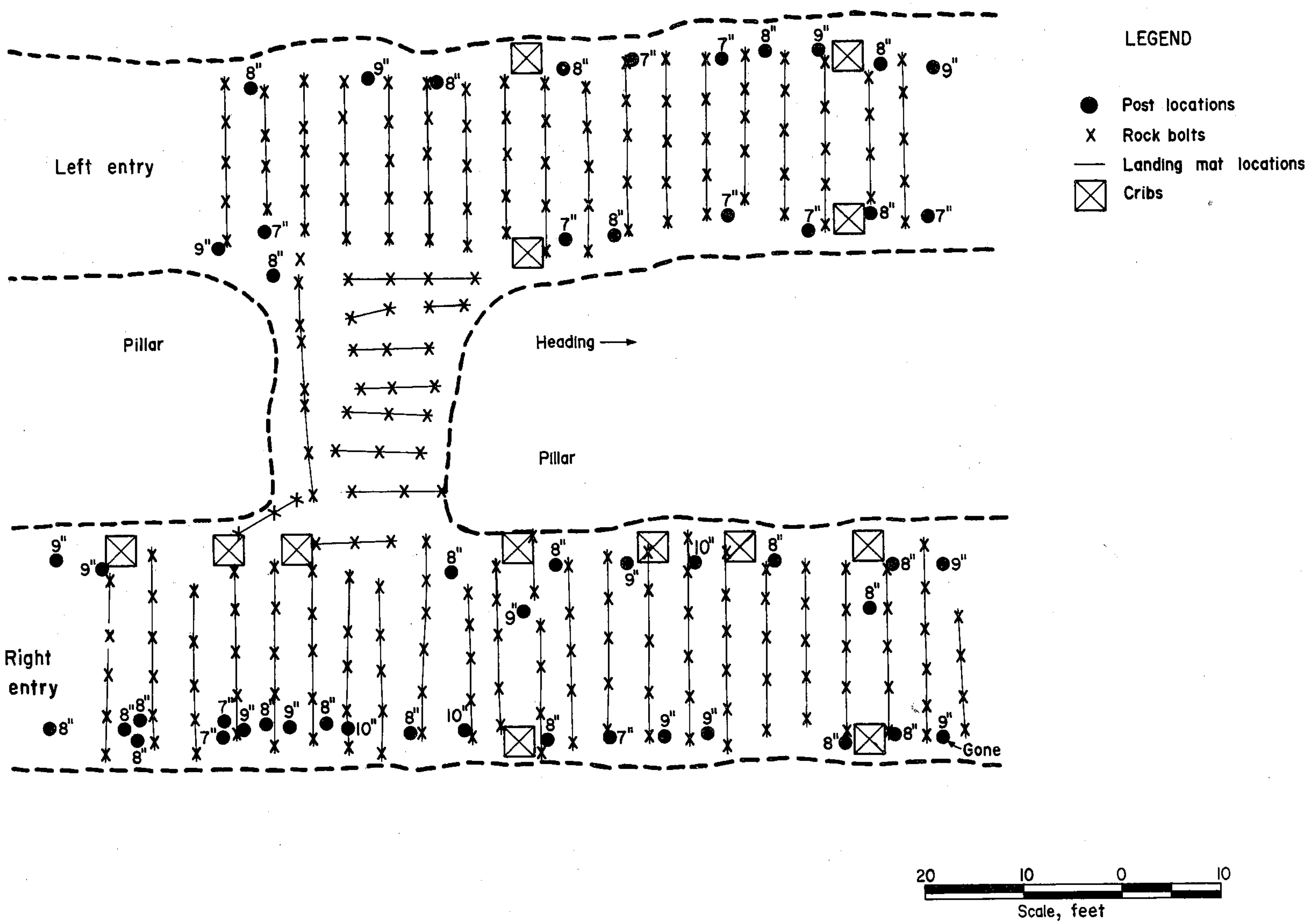

FIGURE 6. - Support layout for room No. 1. Post diameters are indicated in inches (").

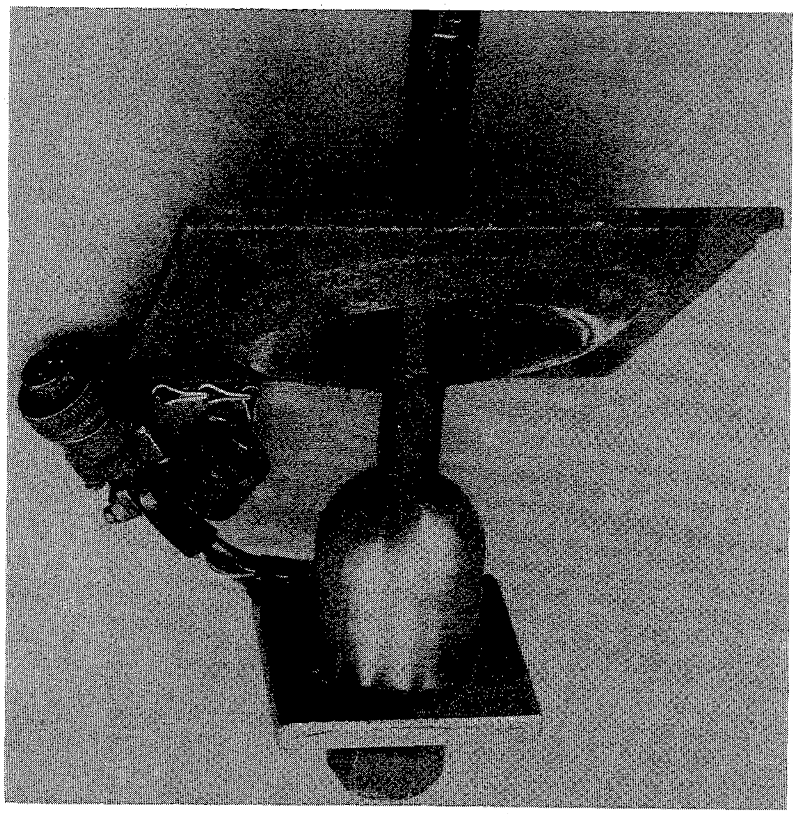

FIGURE 7. - Modified full-bridge rock-bolt-load cell.

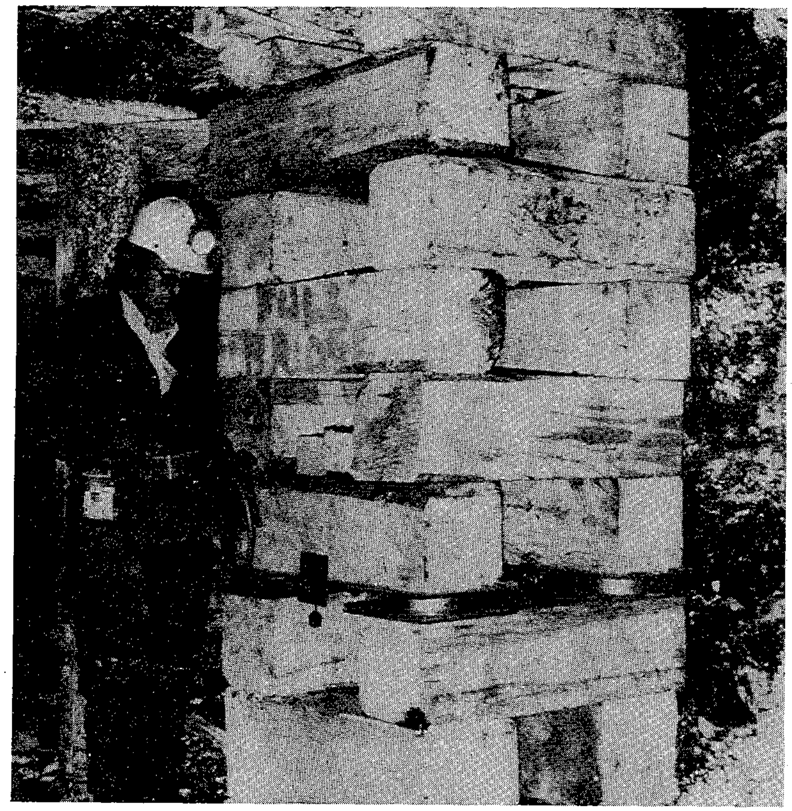

FIGURE 8. - Strain crib cell.

Hydraulic roof-bolt (fig. 9) and crib cells (fig. 10) were used although they were not sensitive enough for initial deformation. These cells (fabricated by MESA) had the advantage of direct dial readout, which the miner could use in evaluating roof-control problems.

Vertical deformation was measured with a telescoping, stainless-steel extensometer that gave a definition of 0.001 inch (fig. 11). To differentiate between roof and floor movement, precise level measurements were taken on selected points.

To record initial deformation and roof-bolt loads, closure points and roof-bolt-load cells were installed within 1 foot of each other. All instrumented roof-bolt cells were placed on standard mine bolts and installed as part of the normal mine support plan. Each of the bolts was itself a closure point and had an associated surface closure point alongside. Both of these points were referenced to a common down point, which was a 3-foot roof bolt imbedded 18 inches into the floor. The down points were countersunk 2 inches to prevent damage from mining equipment--even so, problems occurred where seam thickness varied or there was considerable floor or roof deformation. Inevitably, the floor had to be remined to regain sufficient clearance, and points had to be replaced.

Wooden cribs were normally placed approximately 100 to 150 feet from the face because no heavy loads were expected on the cribs until the longwall face approached. If heavy ground was encountered, they were placed as close to the

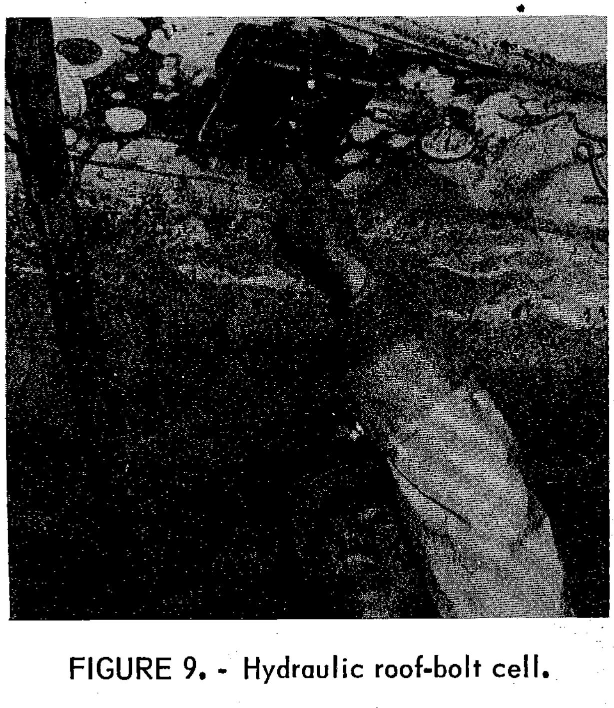

FIGURE 9. - Hydraulic roof-bolt cell.

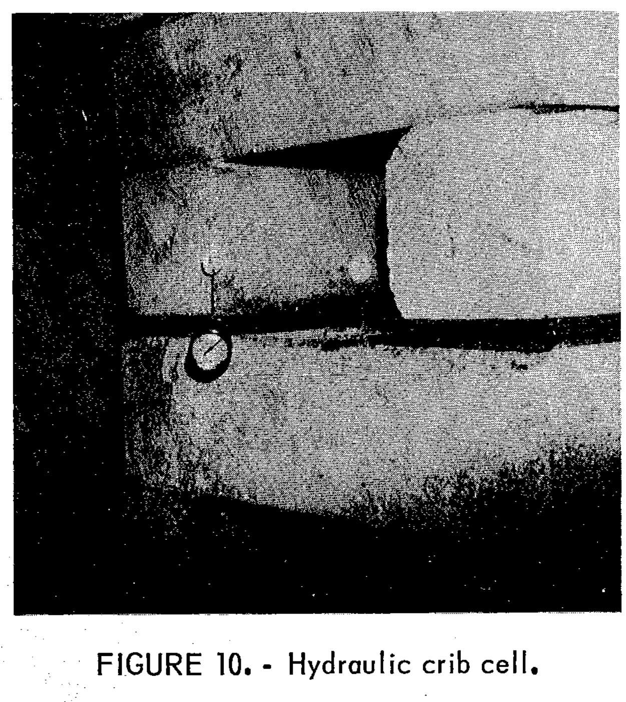

FIGURE 10. - Hydraulic crib cell.

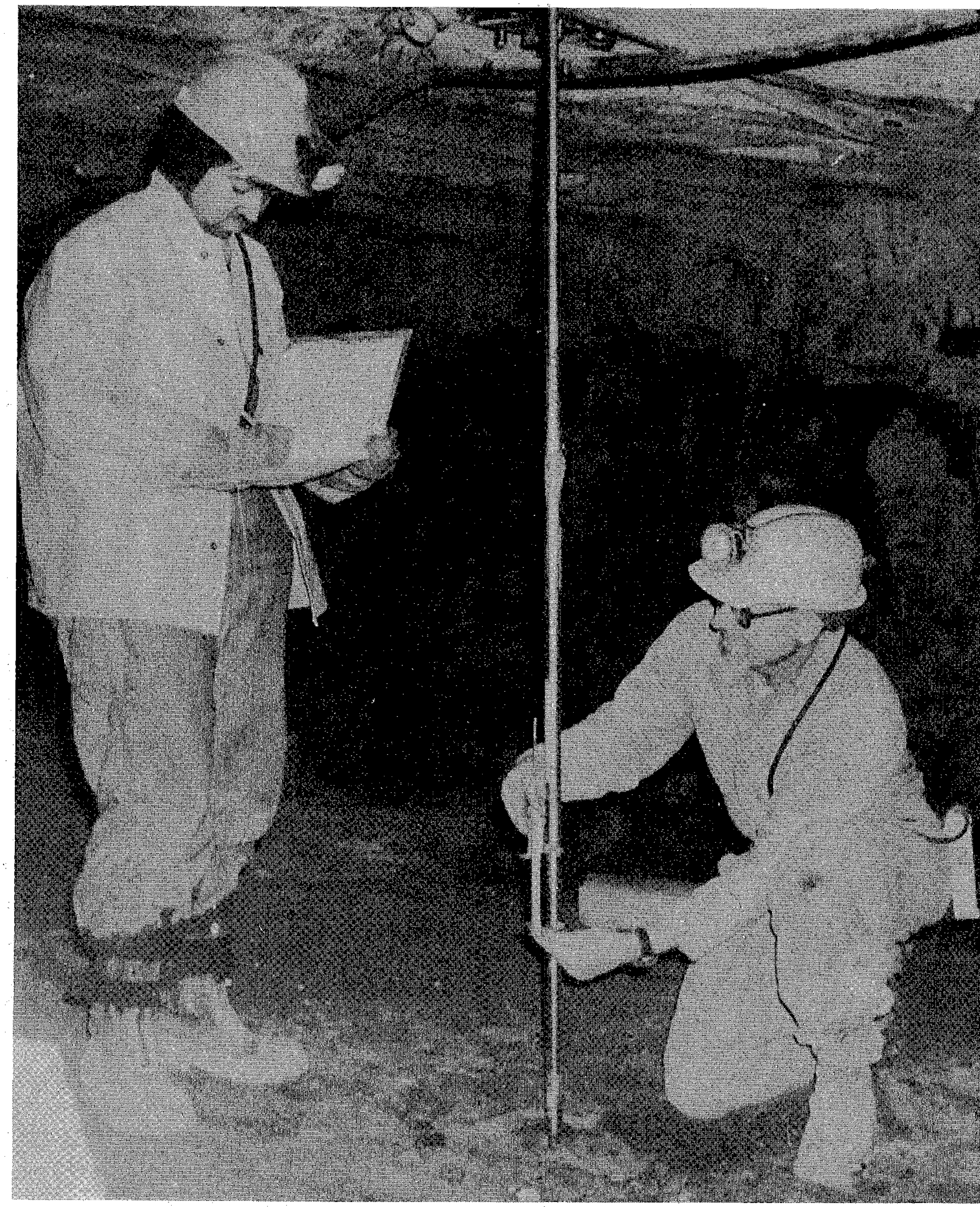

FIGURE 11. - Stainless steel extensometer.

face as possible (fig. 12). The cribs were built halfway up, and then cells were placed on each corner. After a zero was recorded for each cell, the crib was completed and blocked in. Another reading was taken to record the pre-loading pressure against the roof.

Horizontal closure points consisted of 3-foot bolts installed directly opposite each other in the rib and pillar. The hole was drilled with an air-operated auger, and the expansion anchor was coated with epoxy. A pulley arrangement on one bolt allowed the tape to ride over it. A weight was

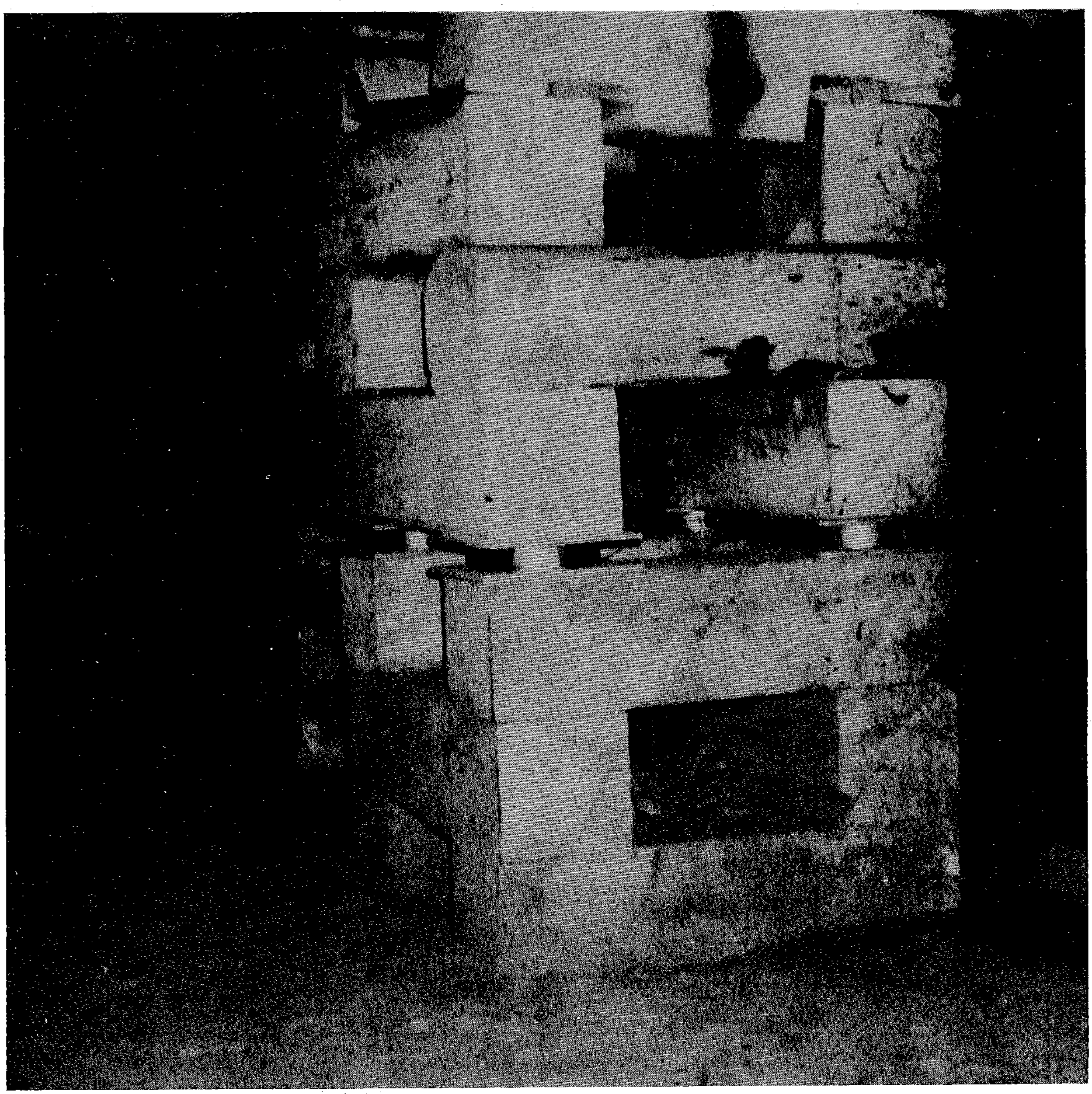

FIGURE 12. - Wooden crib.

FIGURE 13. - Horizontal closure-measurement device.

attached to maintain a uniform tension (fig. 13).

Other instruments that were tried in the first test included the brass-rod extensometer installed in the ribs, hydraulic-jack rock-bolt-load cells, and Davis-Derby[5] deformation gages. The brass-rod extensometers were discarded because the rib coal sloughed away from the head, making it impossible to obtain a stable datum point. Hydraulic-jack rock-bolt-load cells were discontinued because an improper seal allowed the fluid to leak and bleed off the tension in the bolt. David-Derby motors were discarded due to the insensitivity, having only a one-to-one direct readout.

Instrumentation Layout

The instruments designed to document the loads and deformation were located at three different locations in each "room," which was designated as that location where banks or series of instrumentations were installed. Banks of instrumentation were placed across the entries at the midpoint of the pillars, at various points around the pillar, and through the intersection (crosscut). Figure 14 displays the instrument layout for room 1 in mine No. 2. Since hydraulic gages were cheaper than strain gages, they were generally installed in the entry that would cave as the longwall passed.

Data Collection and Storage

All data were recorded directly in the field onto preprinted sheets, which correspond to a computer data card. Field data sheets were shipped directly to data processing for key punching and computer storage, thus

[5]Reference to specific trade names is made for information only and does not imply endorsement by the Bureau of Mines.

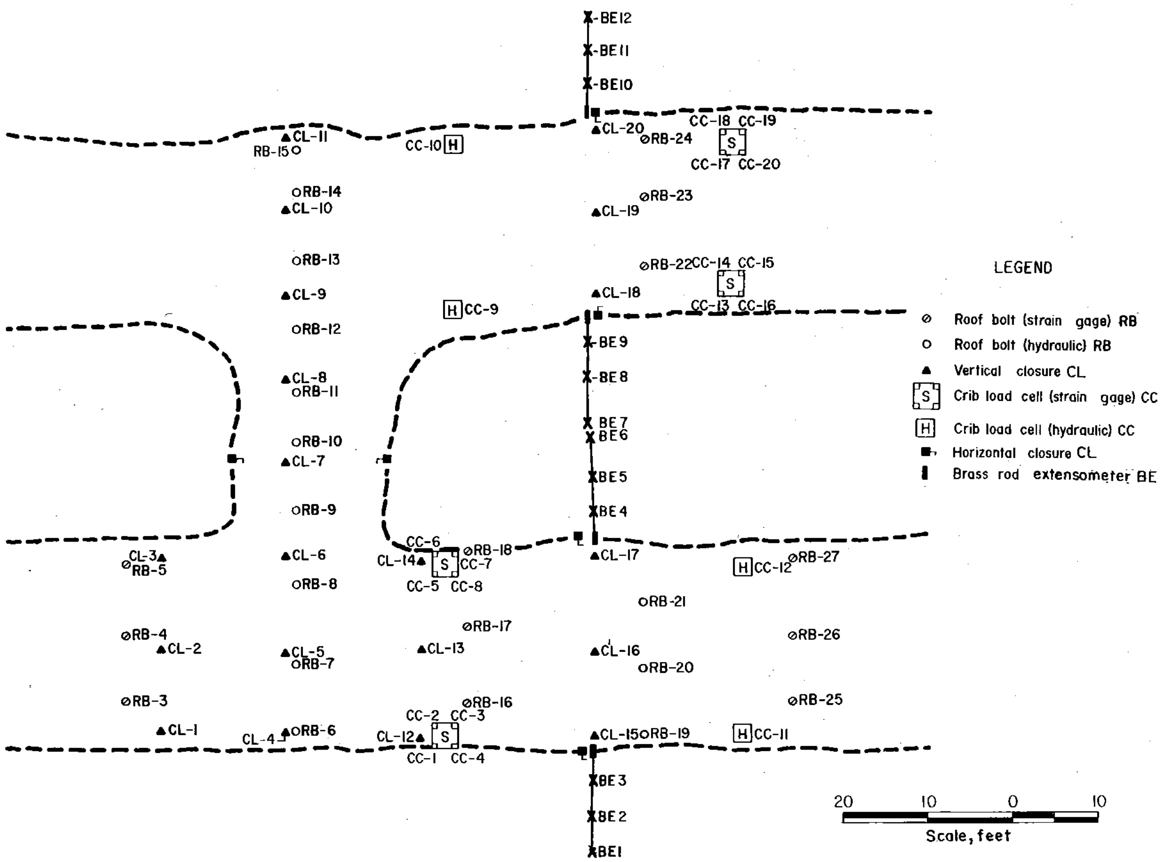

FIGURE 14. - Instrumentation layout for room No. 1.

eliminating any error of transposing data (fig. 15). Data were placed on disk storage for subsequent retrieval, plotting, and analysis. The computer program corrected the data for temperature variations and established the zero point on the calibration curve for each instrument. Support loads and roof deformation could then be plotted with reference to time, entry advance, or longwall retreat.

Field Results

Results of our first test room in Sunnyside mine No. 2, supported with 5-foot, 3/4-inch bolts on 4-foot centers, showed that even as the entries were being driven, support at the intersections was a problem. The greatest

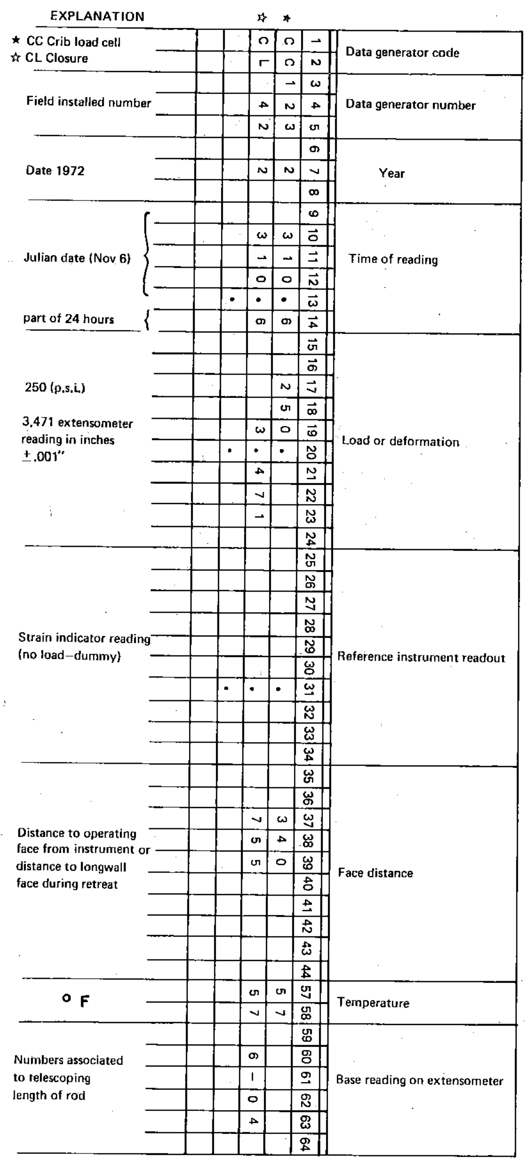

FIGURE 15. - Sample of underground recording sheet and associated data-processing card.

deformation occurred close to the intersection. Figures 16 and 17 show the deformation history through the centerline of the crosscut, and across the entries at the centerline of the coal pillar, respectively, as the entry faces advanced. A composite deformation profile is shown in figure 18. Figures 19 and 20 depict the rock-bolt-load profiles of the same areas. A composite roof-bolt-load profile at the test site is shown in figure 21. The load on a wooden crib located near a fall area is shown in figure 22. The greatest roof-bolt loads occurred along the centerline of the entries, as illustrated in the load profile of figure 21. Maximum deformation occurred close to the intersection around the corner where a roof fall did occur. Roof falls were experienced in the area of greatest closure rate, at the pillar corners where bolt anchor slippage is apparent (fig. 23). Figure 21 shows the roof bolts along the centerline were already taxed to their limit (greater than 20,000),

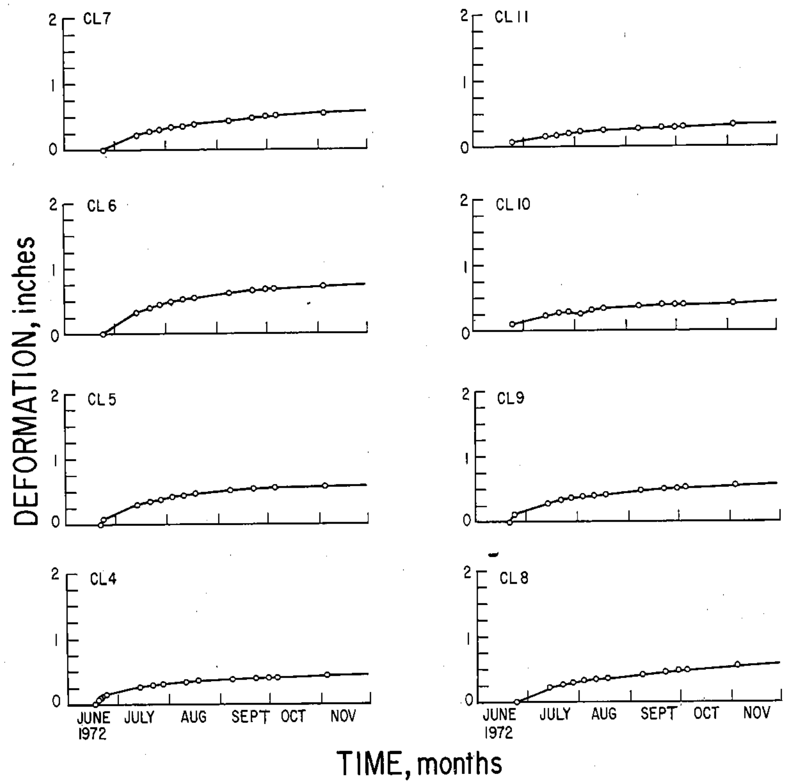

FIGURE 16. - Deformation profile through the centerline of the crosscut. Closure-measurement-location (CL) numbers are shown.

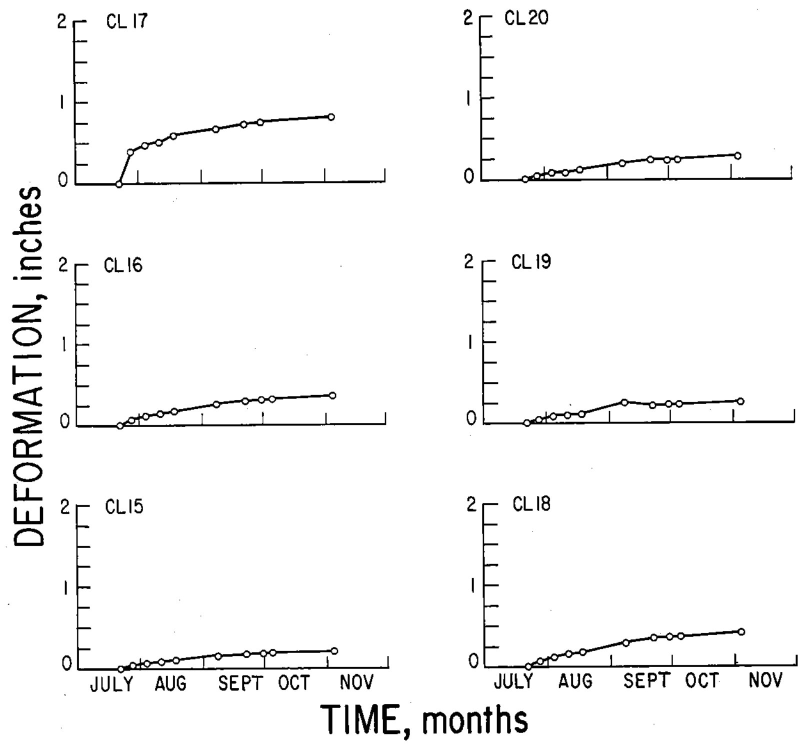

FIGURE 17. - Deformation profile across the entries at the centerline of the pillar. Closure-measurement-location (CL) numbers are shown.

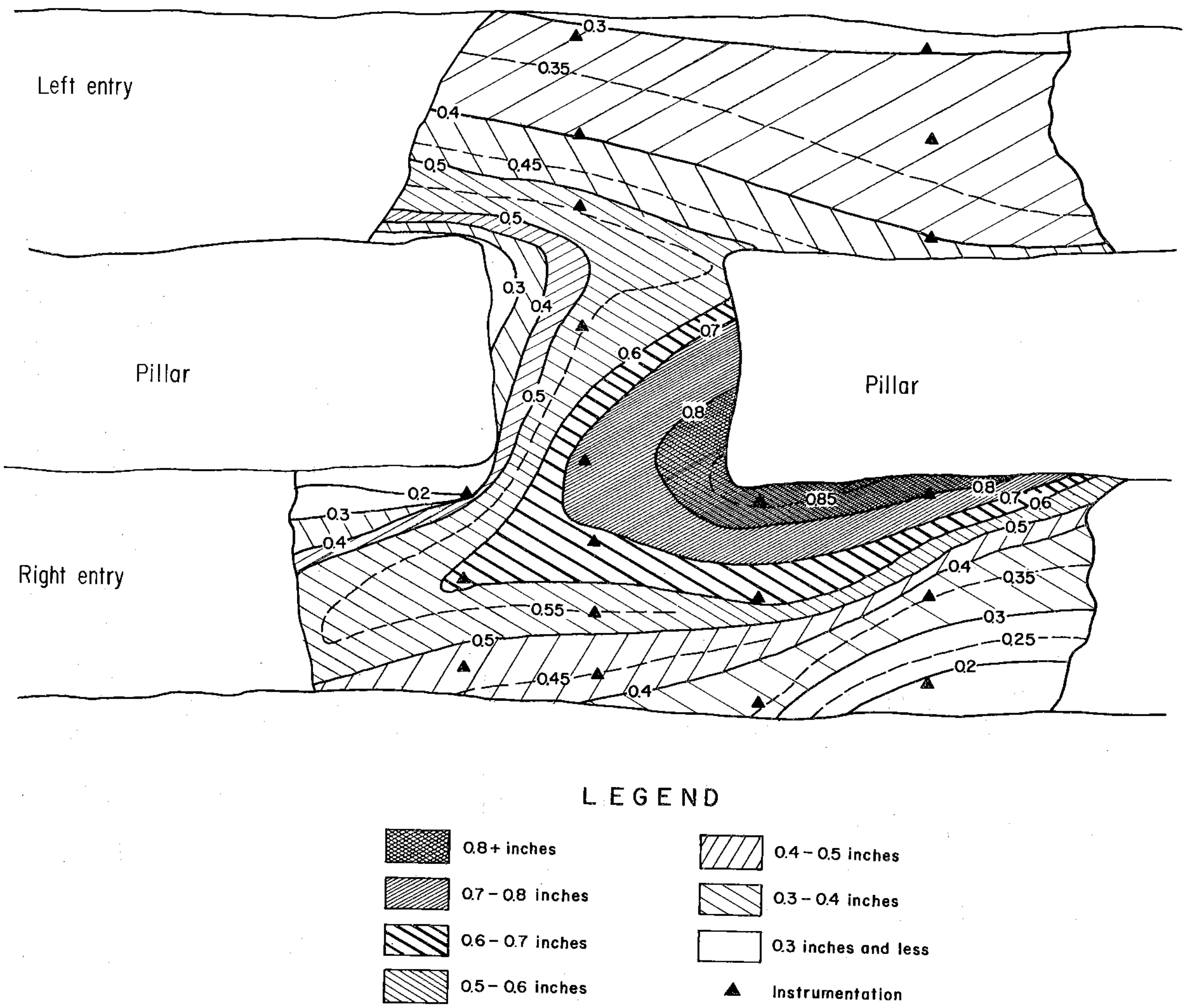

FIGURE 18. - Composite deformation profile at the test site.

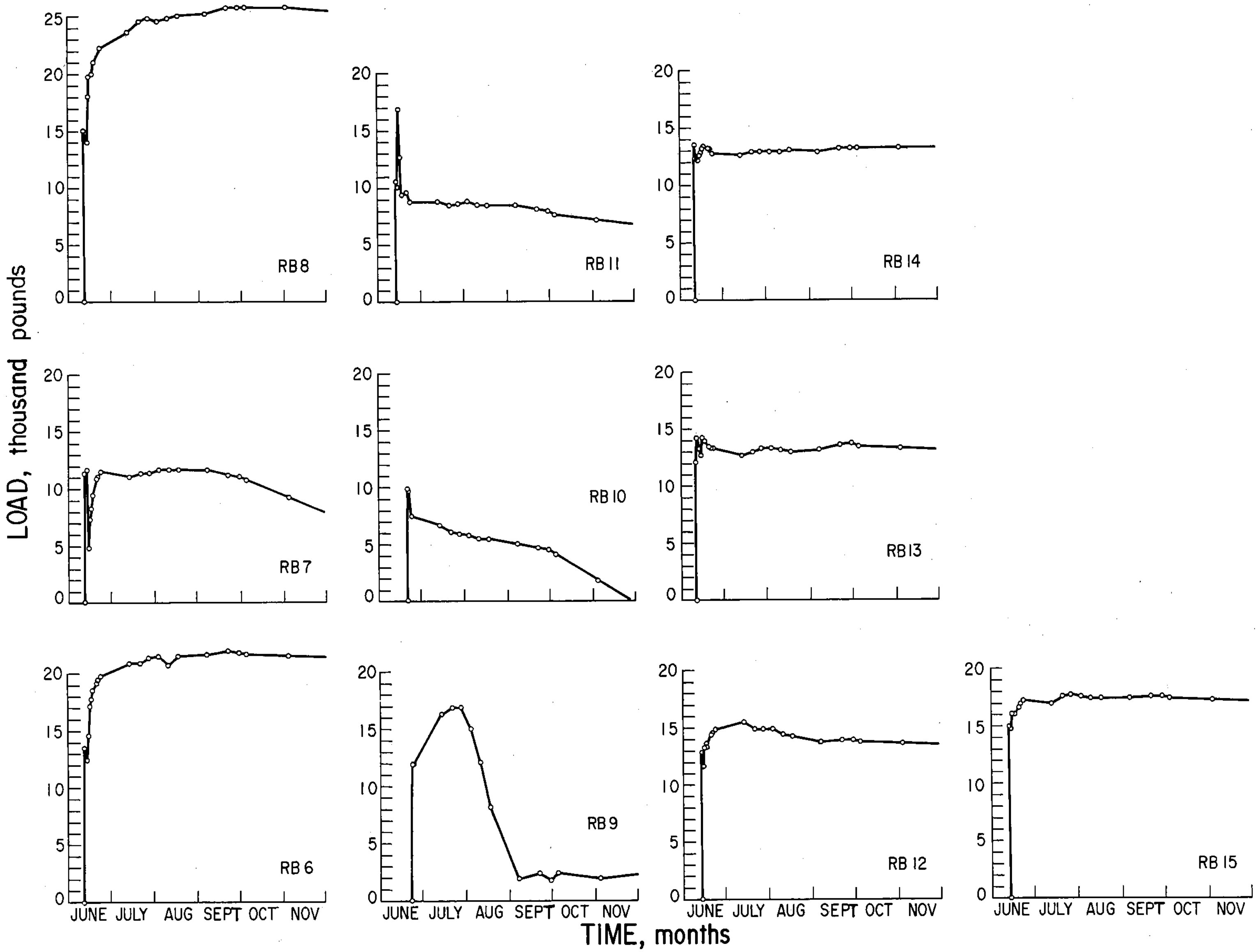

FIGURE 19. - Roof-bolt-load profile through the centerline of the crosscut. Roof-bolt (RB) location numbers are shown.

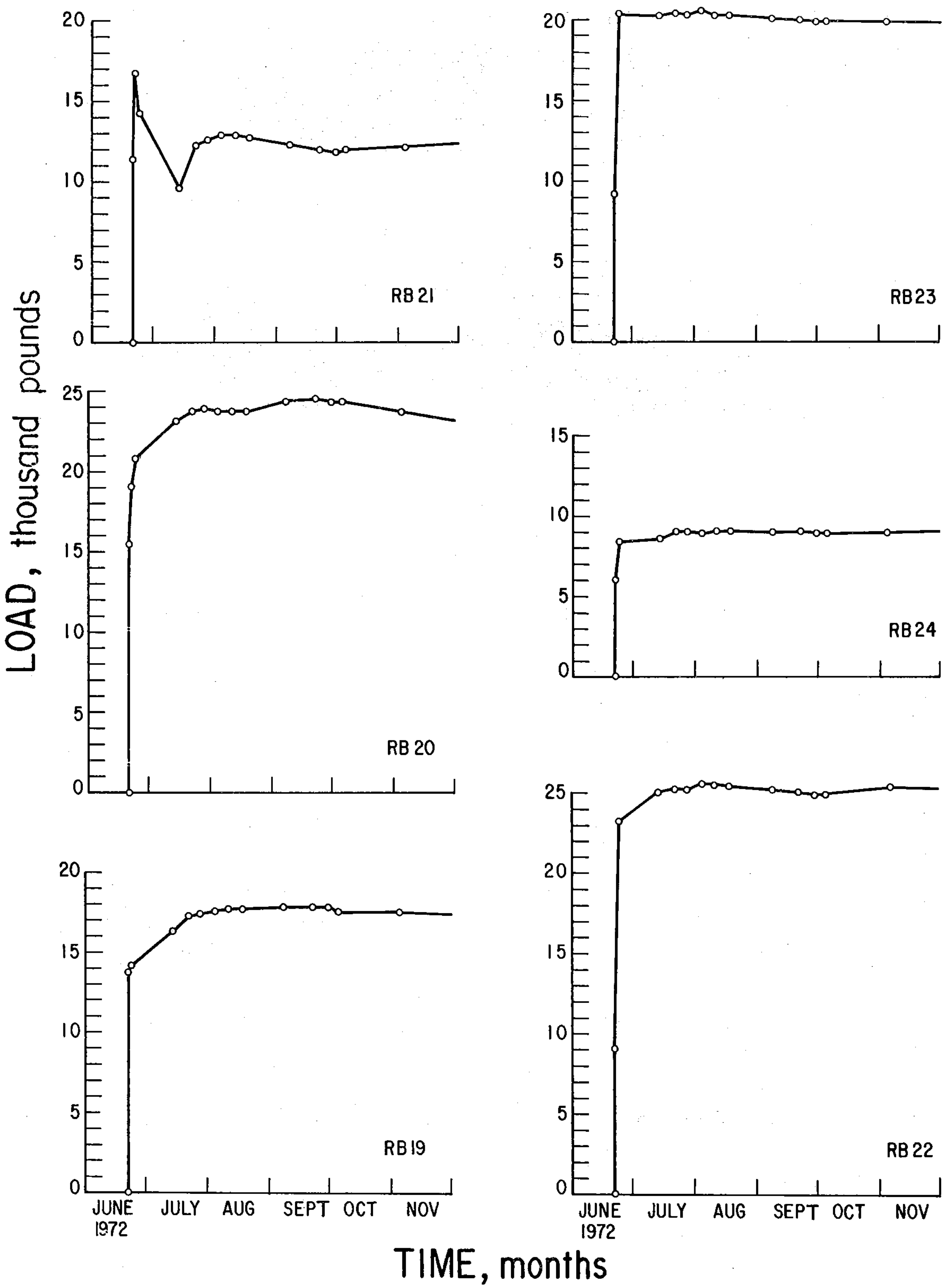

FIGURE 20. - Roof-bolt-load profile across the entries at the centerline of the pillar. Roof-bolt (RB) location numbers are shown.

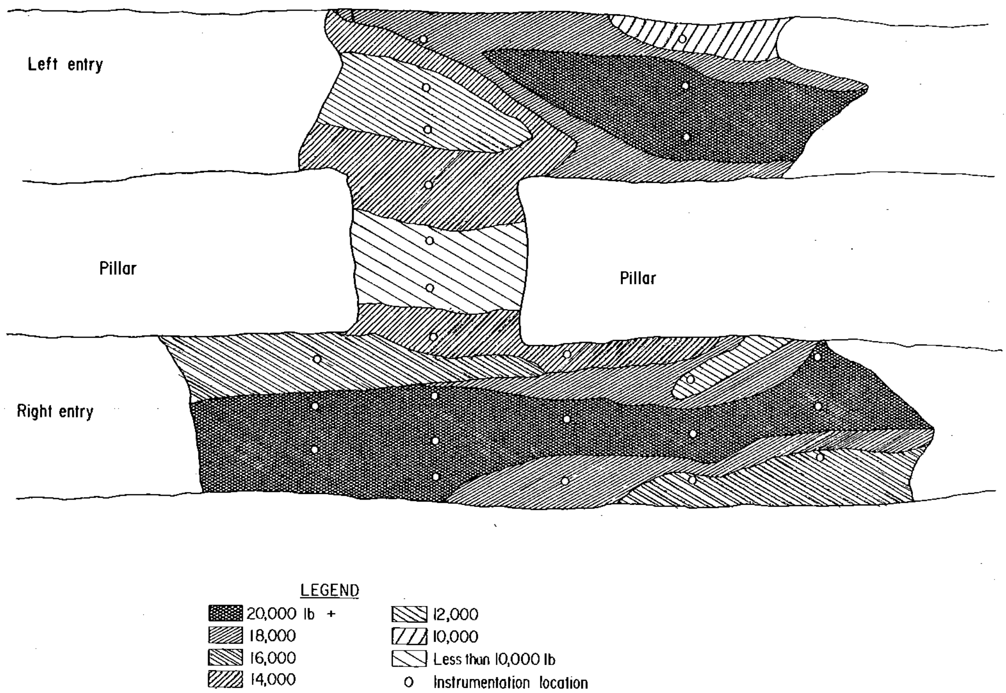

FIGURE 21. - Composite roof-bolt-load profile at the test site.

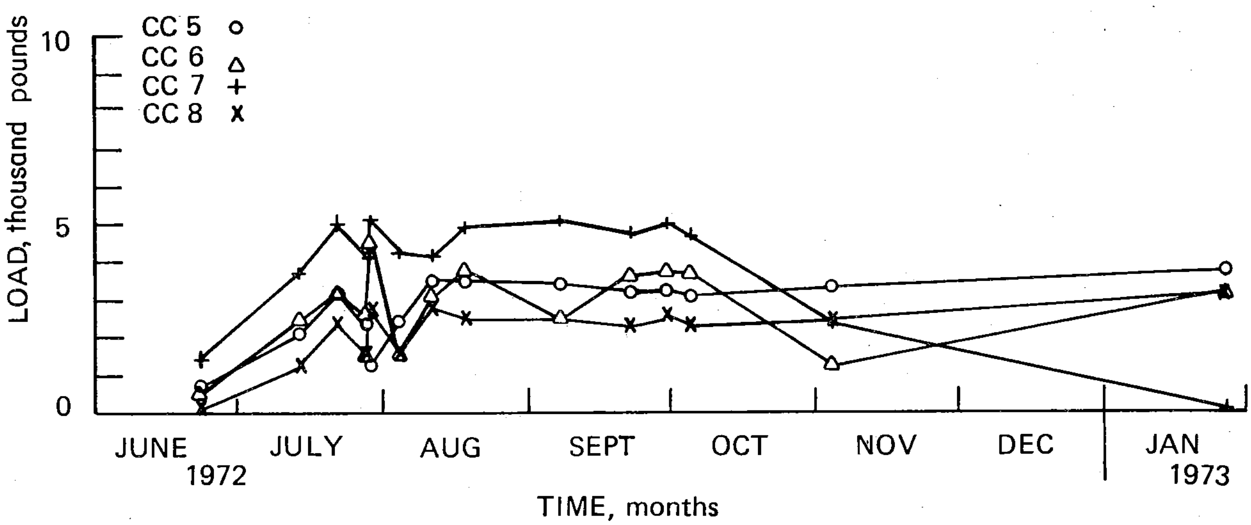

FIGURE 22. - Load profile of a wooden crib near the fall. Crib-load cell (CC) numbers are shown.

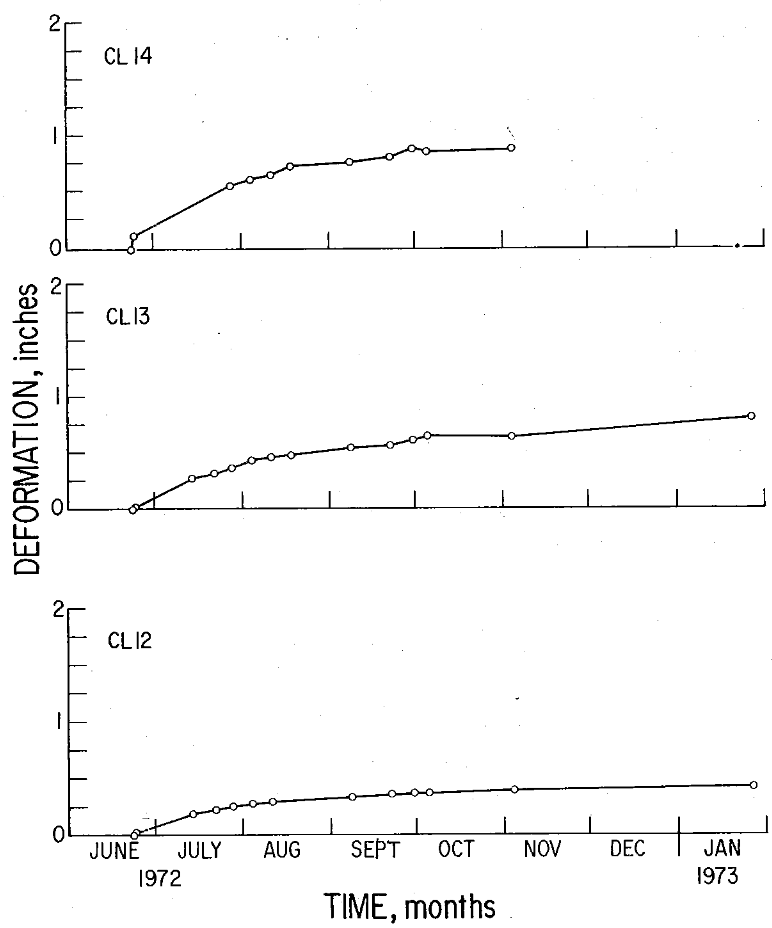

FIGURE 23. - Deformation profile across the entry where the fall occurred.

and they would be unable to withstand the abutment load as the longwall face approached. Several bolts failed along the centerline soon after being installed, including one that was instrumented. Bolt-load and roof-deformation measurements in the immediate vicinity of the caves along the pillar corners showed low bolt loads and high roof closures, indicating anchor slippage or separation above the anchor (figs. 21-22). The pillar corner (filet) has a high differential stress with associated high stresses in the roof rock. The rock probably broke around the anchor, loosening it. Longer bolts, resin bolts, angled bolts at the corners, and pillar softening are areas in which research is being conducted that may alleviate the problem. The single entry, of course, eliminates the intersection corners. In the double entry of the No. 2 mine, cribs were installed adjacent to the ribs. Because the wood cribs have high yield characteristics, they showed very little load during driving of the entry. They are not expected to bear much load until they become influenced by retreat of longwall.

Owing to the limited length of the test, no significant work was done on ventilation. The only comment that can be made is that no problems were encounted.

Fine-Element Analysis

The Bureau of Mines awarded a contract to Agbabian Associates to conduct a three-dimensional finite-element structural analysis of the intersection of a crosscut and entry at the Sunnyside No. 2 mine. Work was begun in June 1973 and completed June 1976 (1). The region of the mine considered in the analysis is part of a double entry instrumented under the Single Entry Project.

The calculation was performed using the computer code BMINES developed under an earlier contract with the Bureau. This code is a static, three-dimensional code with an extensive library of nonlinear, inelastic material behavior and is equipped with specially designed capabilities for simulating mining situations. In particular, excavation and installation of structural support systems during mining can be modeled.

CONCLUSION

Field evaluation verified the fact that the rock bolts in use were not satisfactory; some failed during entry development. The bolts were taxed to their limit and would not be able to take additional loading. Higher strength bolts, angled bolts, or fully grouted resin bolts may provide the needed support capacity to maintain the integrity of the entry as the longwall retreats.

It appears that roof-bolt-load profiles are not good indicators of roof falls; however, amount and/or rate of closure may provide advance warning of impending roof failure.

Although the test area had to be moved, valuable information was gained. Instruments were evaluated, with some being discarded as unsuitable. Installation procedure was perfected, good working relationships were developed with the mine personnel, and project personnel were in training. In addition, the computer program was rewritten to permit more selectivity in retrieval of stored data, more efficient coding of the instrumentation, and easier instrumentation.

Since this report, two single entries have been successfully driven at the second test site in mine No. 1 at Sunnyside. Results of these documentations will be published in subsequent reports. Reference 9 is a brief article covering some of the later work.

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