RI 9283

REPORT OF INVESTIGATIONS/1989

Field Evaluation of Three Longwall Pillar Systems in a Kentucky Coal Mine

By Timothy M. Barton and Christopher Mark

BUREAU OF MINES

UNITED STATES DEPARTMENT OF THE INTERIOR

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

Report of Investigations 9283

Field Evaluation of Three Longwall Pillar Systems in a Kentucky Coal Mine

By Timothy M. Barton and Christopher Mark

UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel Lujan, Jr., Secretary

BUREAU OF MINES
T S Ary, Director

Library of Congress Cataloging in Publication Data:

Barton, T. M. (Timothy M.)
Field evaluation of three longwall pillar systems in a Kentucky coal mine / by Timothy M. Barton and Christopher Mark.

p. cm. – (Report of investigations / Bureau of Mines)

Bibliography: p. 13

Supt. of Docs. no.: I 28.23:9283.

1. Columns–Testing. 2. Ground control (Mining) 3. Longwall mining–Kentucky–Letcher County. I. Mark, Christopher. II. Title. III. Series: Report of investigations (United States. Bureau of Mines); 9283.

TN23.U43 [TN288] 622 s–dc20 [622'.334] 89-600199 CIP

CONTENTS

ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	m	meter
h	hour	pct	percent
in	inch	psi	pound per square inch
in/week	inch per week		

FIELD EVALUATION OF THREE LONGWALL PILLAR SYSTEMS IN A KENTUCKY COAL MINE

By Timothy M. Barton[1] and Christopher Mark[1]

ABSTRACT

The U.S. Bureau of Mines is conducting research to assess the effectiveness of different chain pillar designs in maintaining gate entry stability. A particular concern is ground control for deep-cover longwalls located at depths in excess of 1,000 ft. The study described in this report was performed in two experimental sections in one longwall headgate section which contained three different pillar designs. Two of the designs used conventional abutment pillars, while the third was a total-yielding pillar system. Both of the test areas were located under 1,800 ft of cover. The purpose of this study was to evaluate the effectiveness of these three pillar designs for gate road stability.

As the longwall mined passed the test areas, Bureau engineers monitored entry convergence, roof sag, and changes in roof quality. The study indicated that the all-yield system performed nearly as well as the better of the two abutment pillar systems; but all of the three designs would have failed to provide acceptable stability for second panel mining without considerable artificial support.

[1]Mining engineer, Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

Proper pillar design is essential to successful longwall mining. The most important function of longwall pillars, in conjunction with artificial support elements, is to protect the critical headgate and tailgate entries while the longwall panels are being mined. Pillar design can also directly impact overall extraction ratios, the rates at which gate entries can be developed, the degree and characteristics of surface subsidence, and indirectly impact the rates of longwall face advancement.

There are two basic approaches to longwall pillar design: conventional and yielding. In conventional design, the chain pillars are sized to carry all the abutment loads to which they will be subjected. Conventional designs may employ equal-sized pillars or combinations of large and small (sometimes called abutment and yielding) pillars. The other design philosophy, yielding, uses only very small pillars that transfer the abutment loads.

Nearly all of the longwall installations in the eastern United States use multientry, conventional pillar designs. Experience in relatively shallow mines, where the depth of cover is less than 1,000 ft, has indicated that moderately sized pillars (100 ft wide or less) can usually provide adequate entry stability. A method for sizing conventional longwall pillars, called analysis of longwall pillar stability (ALPS), has recently been developed by the U.S. Bureau of Mines (*1*)[2], and other design methods are also available (*2-3*).

As longwall mining progresses to greater depths, conventional pillar designs require larger and larger pillars. Some operators have reported that pillars in excess of 200 ft wide have been necessary to provide ground control under 2,000 ft of cover (*4*). The practical difficulties of developing such large pillars, together with uneconomical extraction ratios, present serious problems for operators of deep longwalls. Many operators have used pillars that were too small for their depth of operation and have found it necessary to install heavy artificial support (*5*). Others have cut down the total pillar width by combining very large abutment pillars with narrow yielding pillars. Most recently, a few Eastern Coal operators have begun to experiment with total-yielding pillar designs (*6*).

With yielding pillar designs, the pillars are purposely sized too small to carry the abutment loads, which are instead shifted to the unmined panel. Yielding pillar designs can greatly increase both extraction and development rates in deep longwalls. While western longwalls have used two-entry yielding pillar systems for many years, there is very little experience with multientry total-yielding designs. For example, some researchers have observed that when the number of entries in a yielding pillar system is increased to four or more, ground conditions can worsen (*4*). Others have observed that tailgate stability with yielding pillar systems can require heavy artificial support (*7*).

The study described in this report was designed to assess one multientry total-yielding pillar design and two conventional abutment pillar designs located in the same geologic environment. These designs were tested in two sites at a longwall gate road located under 1,800 ft of cover.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the cooperation of the Blue Diamond Coal Co., Knoxville, TN, who provided access to Scotia Mine, Ovenfork, KY, and the generous support provided by Blue Diamond and Scotia Mine personnel for providing assistance in conducting the actual study.

DESCRIPTION OF MINE

The study was conducted in Blue Diamond Coal Co.'s Scotia Mine, located in Letcher County, KY (fig. 1). Topography in the area is extremely mountainous, and the depth of cover over the mine ranges from near 0 to almost 2,000 ft. The seam being mined is the Imboden, which is typically 6 to 7 ft thick.

The immediate roof in the mine is predominantly sandstone and is generally quite stable during development. The sandstone can be massive, but it is more often crossbedded and interbedded with shale, silty shale, and some coal spars. In most areas the sandstone is underlain by 0 to 8 ft of weak shale locally known as drawrock. The drawrock is highly slickensided and of poor geotechnical quality. Where the drawrock is thin, it presents few stability problems and is often removed during mining. Where the drawrock is thicker, it tends to separate from the overlying sandstone, resulting in roof falls.

The Rock Mass Rating (RMR) (*8*) of the Scotia Mine roof was determined by back calculation. Several locations were observed in which 20-ft spans of thick-shale drawrock had collapsed within hours after they were mined. Using Bieniawski's chart (fig. 2), the RMR for the drawrock roof was estimated at 39. Few falls of the

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

sandstone roof occurred, but in one instance an intersection with a large effective span collapsed 6 months after it had been mined. Again using figure 2, the RMR of the sandstone may be estimated at 70.

The overburden above the immediate roof consists of more than 70 pct sandstone, including a number of massive beds. The floor is predominantly shale, which is prone to heaving at greater depths of cover.

Longwall mining was introduced at the mine in 1986. The first three longwall panels were developed in an older part of the mine, under approximately 1,000 ft of cover. A conventional three-entry, yield-abutment pillar design was used in the gates of these panels, with pillars on 48- and 120-ft centers. The stability factor predicted by the ALPS method for this design was 1.0. No significant ground control problems were encountered in these panels.

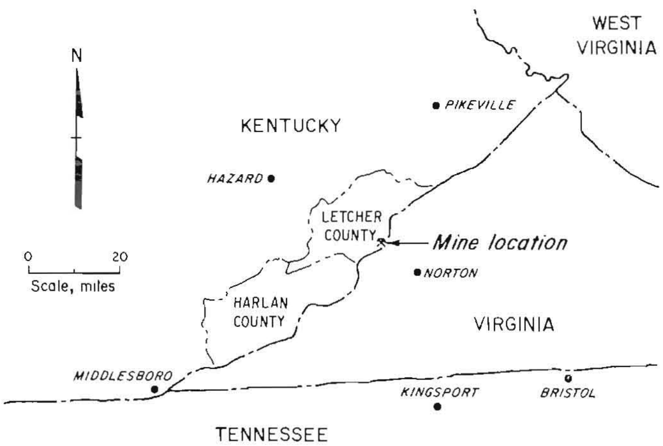

Figure 1.-Location of study site.

Longwall mining has now moved to a large area of reserves located under much greater cover. A series of panels, each measuring 700 ft wide by 7,000 ft long, will be mined in sequence. Initial plans called for the use of the same yield-abutment pillar design, with three entries on 48- and 120-ft centers, in the new panels. In addition, mine management decided to use the inby portion of the headgate of the first panel as a testing ground for two new pillar designs (fig. 3). Beginning 1,300 ft outby the setup room, a 400-ft length of the gate system was driven as an all-yield pillar system, with five entries on 48-, 40-, 40-, and 40-ft centers. Then one of the new entries was dropped for the remaining 900 ft, leaving a yield-yield-abutment pillar system with four entries on 48-, 40-, and 80-ft centers. The experimental section (site 1) that was monitored by the Bureau included the entire five-entry system and several breakthroughs of the adjacent three-entry and four-entry systems. In addition, a second site (site 2) consisting of 800 ft of the standard three-entry design was monitored approximately 4,000 ft outby the experimental section as seen in figure 3. The second site was chosen so that the three-entry system could be studied in an area free from possible interaction with the yield pillar area.

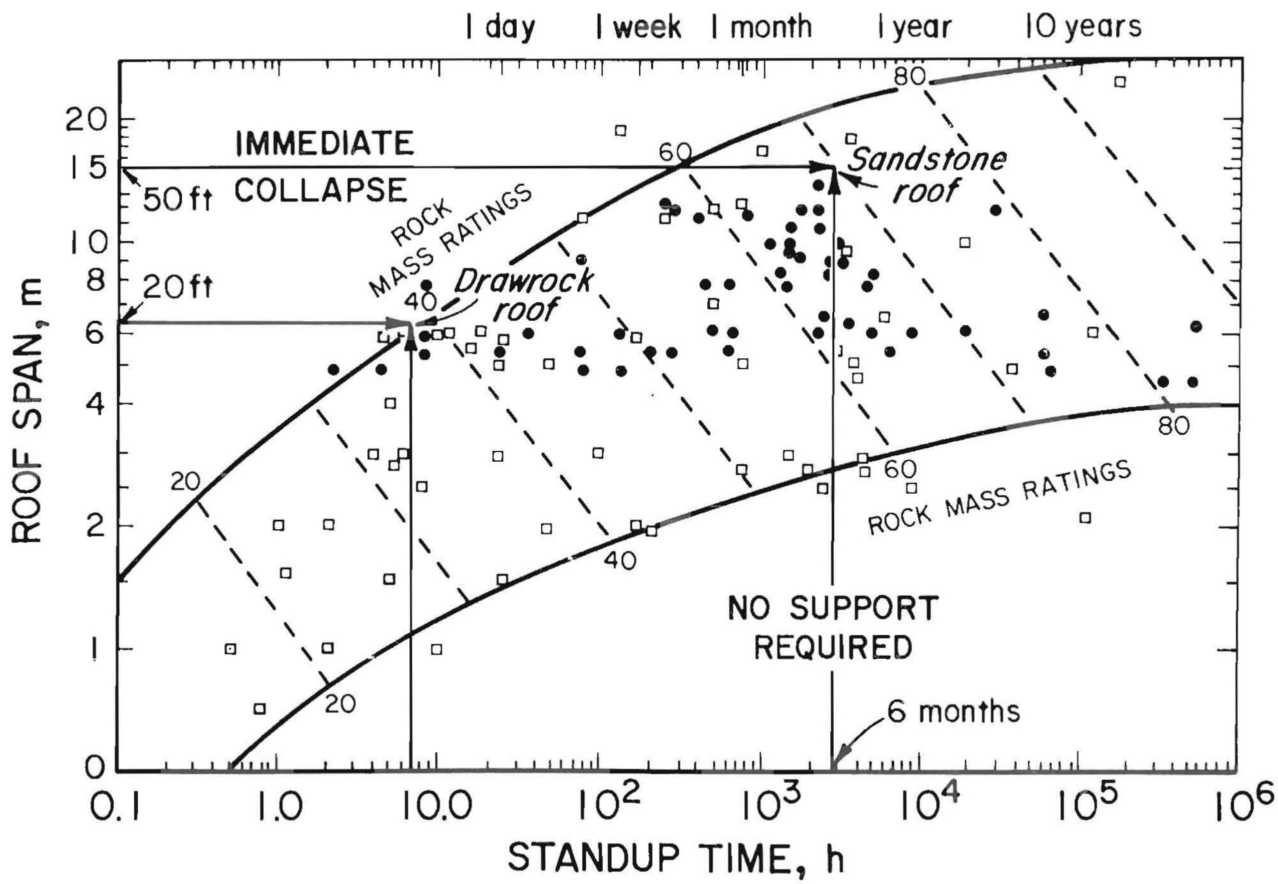

Figure 2.-Back calculation of RMR for drawrock and sandstone roof of Scotia Mine using chart presented by Bieniawski.

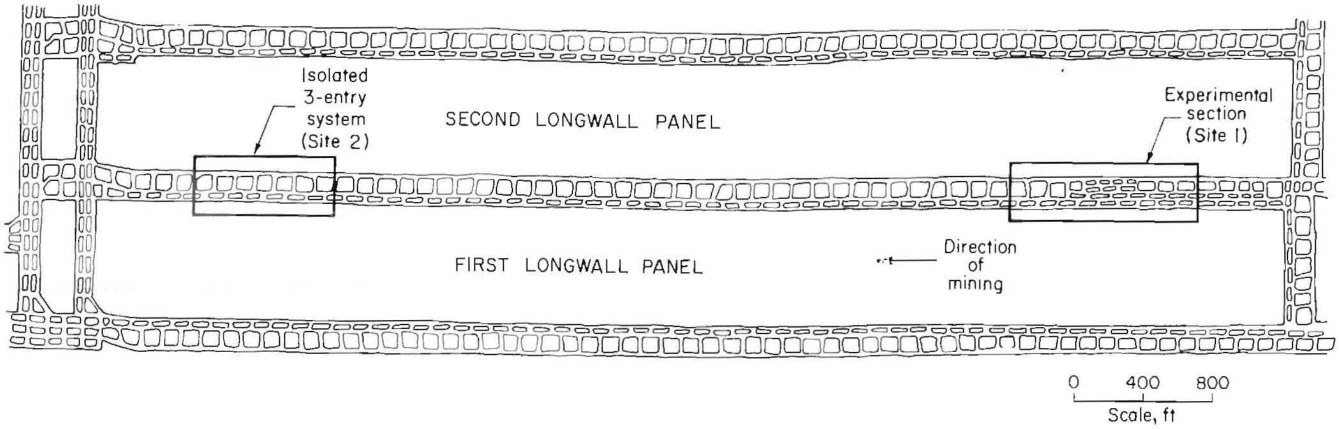

Figure 3.-Location of site 1 and 2 in gate road of first panel in deep-cover reserve area.

DESCRIPTION OF STUDY

To quantify the damage sustained by the gate entries during longwall mining, an array of convergence and roof sag measuring stations were installed at sites 1 and 2. Observations of changes in roof rock quality were also recorded as the longwall mined by each study area. The criteria for judging the performance of the three pillar designs were as follows:

1. Ground control during the mining of the first panel (headgate phase),

2. effectiveness in limiting damage to the No. 1 entry (future tailgate entry), and

3. ground control during mining of the second panel (tailgate phase).

At site 1, the measurement stations were installed shortly before the startup of the longwall face. Convergence stations were installed in the belt, track, and scoop entries at approximately 60-ft intervals (fig. 4). Two rows of convergence stations were installed in the future tailgate entry of the second longwall panel. A total of 18 roof sag stations were distributed between the three pillar designs in the experimental section, though none could be installed in the belt entry. The anchors in the differential roof sag stations were installed at depths of approximately 5, 9, 14, and 18 ft above the roofline. The anchors were installed at specific depths so that the 18-ft-high anchor was located above the zone of significant movement, and the other anchors were placed to measure movement in the immediate roof.

At site 2, the measurement stations were arranged in a pattern similar to site 1 (fig. 5). A total of seven differential roof sag stations and 54 convergence stations were installed. Figure 6 shows Bureau engineers measuring roof sag at the study area (*9*).

Roof quality in both study areas was mapped using a simple rating system based on the number, spacing, and degree of openness (separation) of cracks. The system had five grades:

Very good–cracks very rare, no separation;

Good–crack spacing >5 ft, none to small separation;

Fair–crack spacing >2 ft, separations <0.25 in.;

Poor–many open cracks and large loose pieces of rock; and

Very poor–roof apparently held up only by cribs.

Figure 7 shows the initial distribution of roof quality over site 1. The fair and poor quality roof (these grades are combined in figure 7) was found primarily in the future tailgate entry in the three-entry section and across the central portion of all five entries in the yield pillar section of the experimental section. In general, the fair to poor roof quality in site 1 was most often associated with the presence of thick-shale drawrock or sandstone containing unusual amounts of shale and coal spars. The immediate roof at site 2 was almost entirely sandstone with only small amounts of thin drawrock, and roof quality was good or very good over much of the site (fig. 8). As the study progressed through each site, roof quality was recorded systematically for each instrument station, so that the location, extent, and timing of degradation could be determined with some degree of objectivity.

Core drilling was conducted at two locations in site 1 as shown in figure 4. Figure 9 shows the geologic logs and the results of laboratory strength tests obtained from the core. The classification of Ferm and Weisenfluh (*10*) was used in characterizing the lithology of the roof and floor. Several facies of sandstone were found in the roof, with compressive strengths ranging from 14,000 to 25,000 psi and elastic moduli averaging 5,000,000 psi. The roof shale obtained at site 2 in the experimental section was found to have an average strength of 15,000 psi and an average

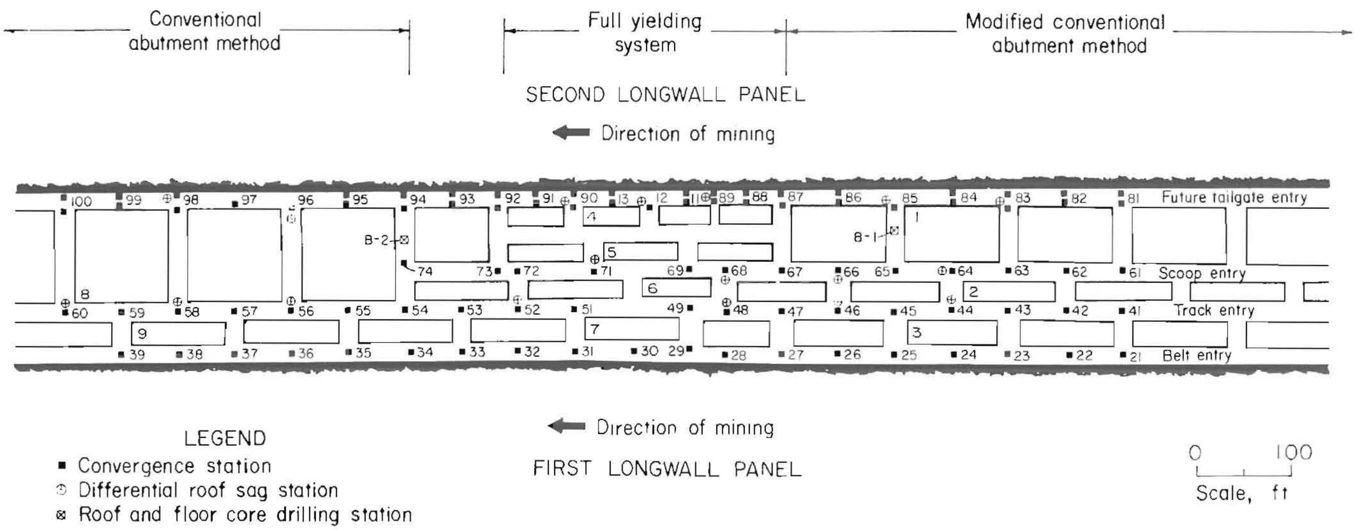

Figure 4.-Map of site 1, showing convergence stations, roof sag stations, and core drilling locations.

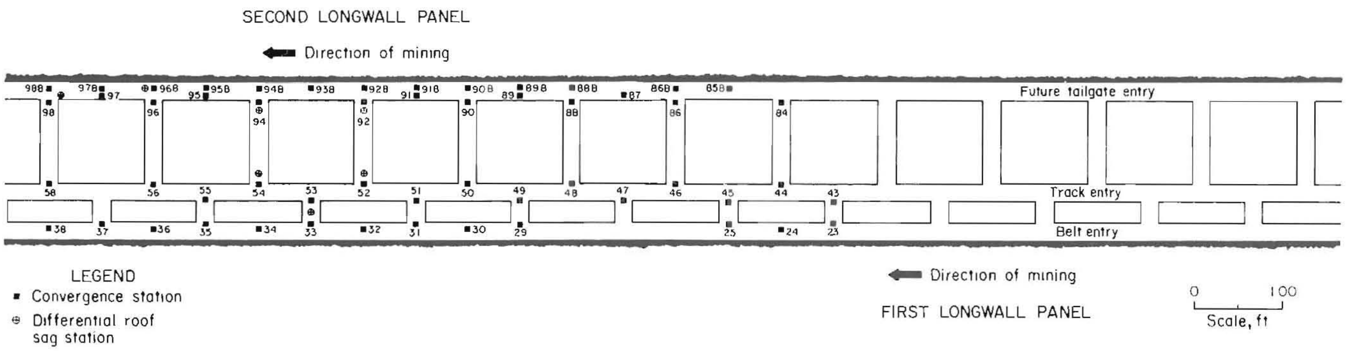

Figure 5.-Map of site 2, showing convergence stations and roof sag stations.

was a uniform shale, with a measured compressive strength in excess of 11,000 psi. No coal samples could be obtained for testing, because all of the ribs of all the pillars in the deep cover area were highly deformed and fractured. No core drilling was performed at site 2.

The severe deformation of the pillar ribs, particularly in the yield pillar area of the experimental section, indicated that the pillars might have shortened significantly as they were developed. To estimate the amount of pillar shortening that might have taken place, some convergence measurements were made next to a yield pillar at a freshly exposed face in the setup rooms. These measurements indicated that 2.5 in of entry convergence occurred between the time measurements began and the start of longwalling. By extrapolating the measured data, an additional 2.5 in of closure was estimated to have occurred within the first 24 h after mining. Pillar shortening of this magnitude could be expected to largely stress-relieve the yield pillars in the experimental section, throwing the bulk of the development load onto the nearby abutment pillars or unmined panels. Near the yield pillar area at site 1, load transfer was evidenced at several locations by floor heave near the solid rib in the future tailgate heading.

Figure 6.-Bureau engineers measuring roof sag.

All of the entries that were monitored were 20 ft wide. Primary support consisted of 5-ft long, 5/8-in grade 40 fully grouted resin bolts, installed on 4-ft centers. Wooden cribs or posts were installed in unstable areas in the track entry when the longwall face was near the unstable areas.

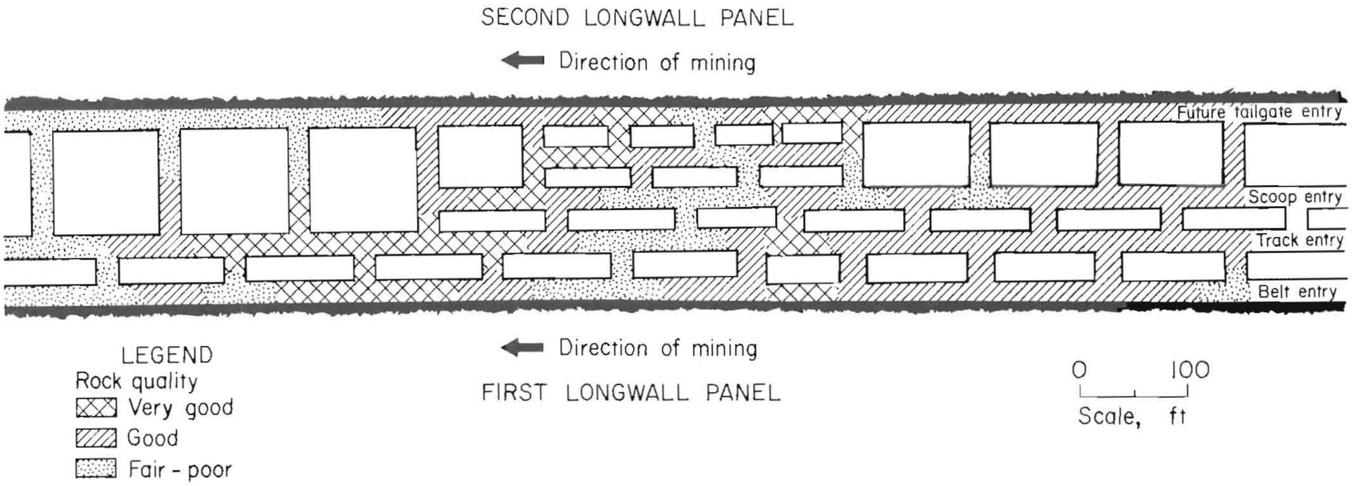

Figure 7.-Map of initial roof quality in site 1.

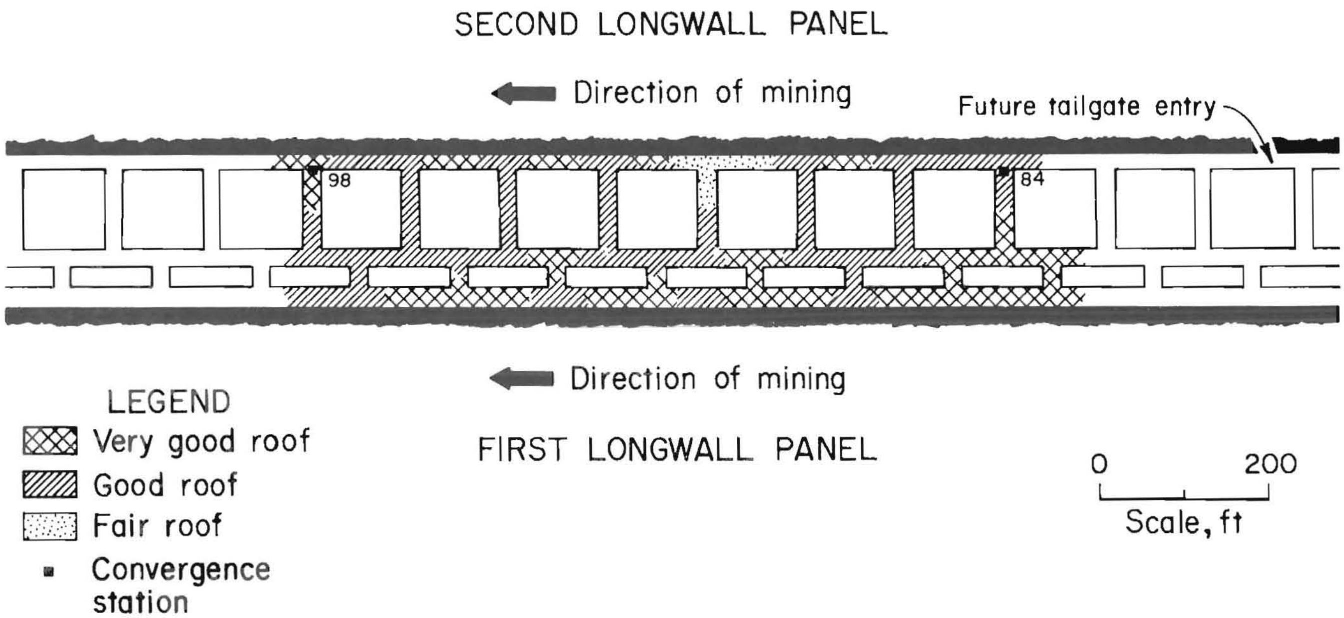

Figure 8.-Map of initial roof quality in site 2.

Concrete donut cribs were installed where necessary in the belt entry because they would not interfere with the shearer as wood might. The 50 ft of the belt entry nearest the face was also supported by 33-ton[3] hydraulic jacks.

[3]In this report, "ton" indicates 2,000 lbf.

Wooden cribs were also installed in the future tailgate entry before the arrival of the face. In the first three, moderate-cover panels, a single row of 3-ft-wood cribs was sufficient to provide trouble-free tailgate conditions. The amount of cribbing in the future tailgate of the study panel varied, and it will be described in detail later on in this report.

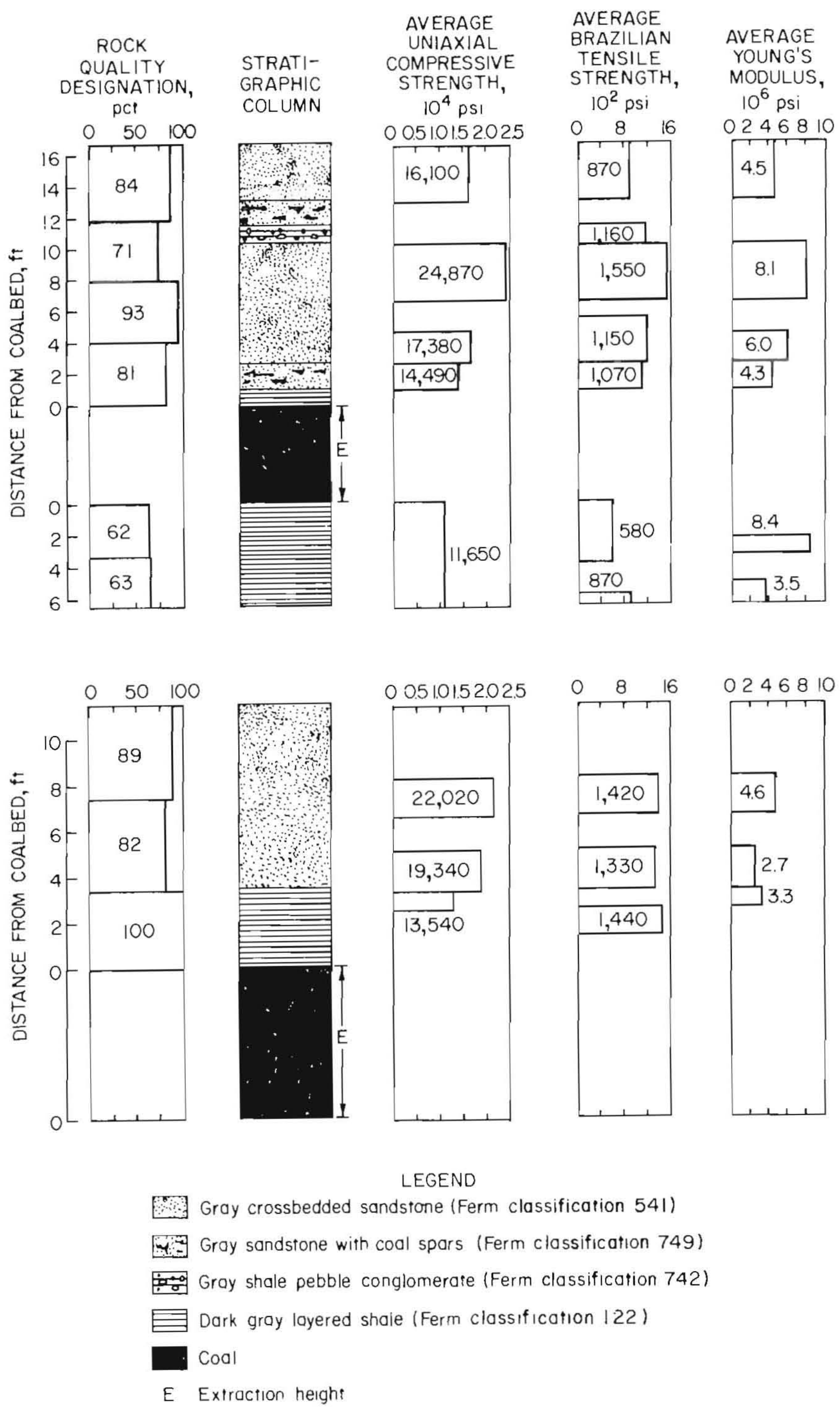

Figure 9.–Geological logs and results of laboratory strength testing obtained from core drilling in site 1. Top, diamond core site B-1; bottom, diamond core site B-2.

RESULTS I–PASSAGE OF FIRST FACE

About 7 weeks were required for the longwall to mine by the three pillar designs in site 1. The face reached the second site 4 months later; 4 weeks were required to mine by it. While the face was adjacent to the sites, measurements were recorded approximately every other day. Later, all of the data were normalized with regards to face position.

The first criterion by which the success of the pillar designs was to be judged was protection of the belt (headgate) entry. Therefore of particular interest are the changes that occurred at face distance (FD) = 0, meaning when the face had progressed to a point adjacent to a row of measuring locations.

Figure 10 shows, except for one localized instance of floor heave in the experimental section (site 1), that convergence in the belt entry at both sites was a consistent 1.5 to 4 in regardless of pillar design. Observations also indicated that the decline in roof quality in the belt entry, which was typically about two grades for site 1, was not affected by pillar design. The minor ground control problems that did develop in the belt entry were attributable to preexisting roof conditions. For site 2, the initial roof conditions were good and did not deteriorate as the face mined by. These observations indicated that not one of the three pillar designs performed noticeably better or worse than the others in providing ground control during the headgate phase.

Figures 11 and 12 summarize the results from all the convergence measurements at FD = 0 for both study areas. Here some differences between the pillar designs do

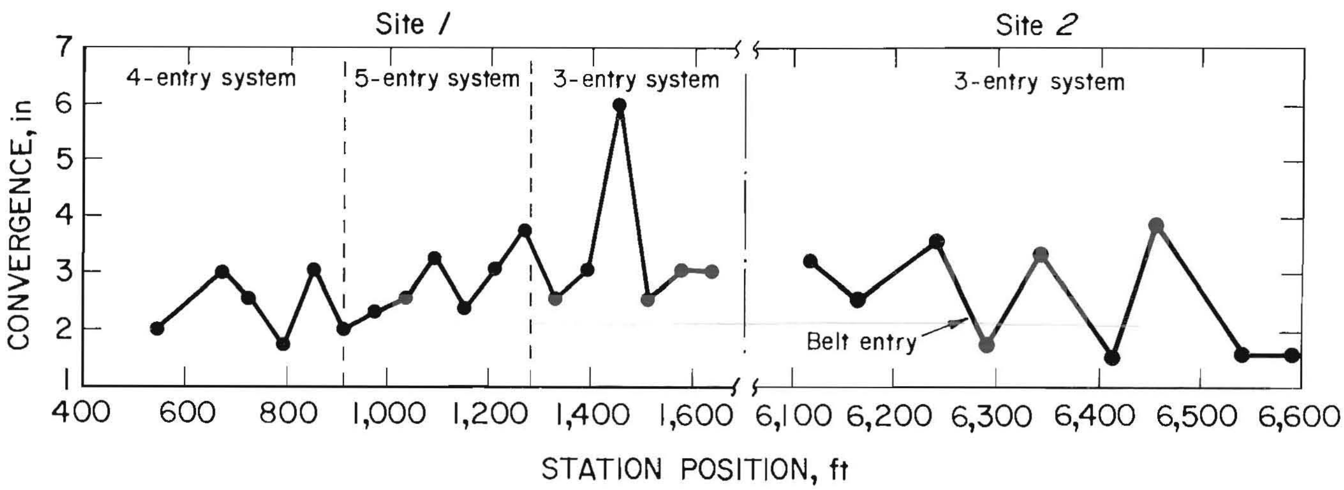

Figure 10.–Convergence measured as the face passed each convergence station in the belt entry (face distance = 0).

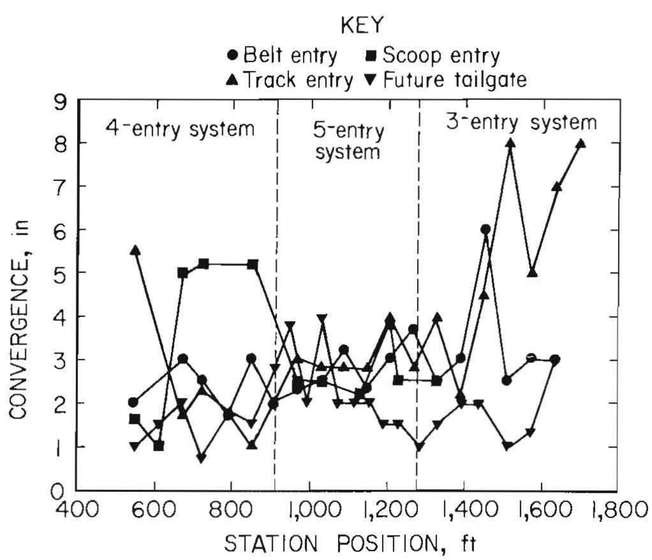

Figure 11.–Convergence measured at all stations in site 1 at face distance = 0.

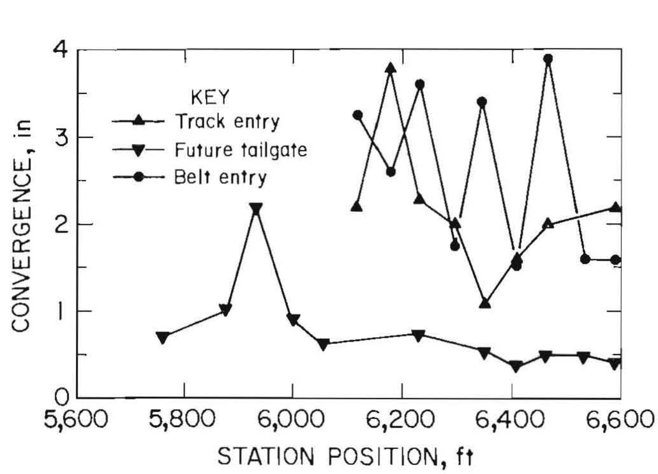

Figure 12.–Convergence measured at all stations in site 2 at face distance = 0.

emerge. In the abutment pillar systems, particularly the three-entry system, convergence in the future tailgate entry was significantly less than it was in the entries nearer the panel. In the yield pillar system (five-entry system), all the instrumented entries closed by about the same amount. In the five-entry yield pillar system, the abutment pressures appear to have been transferred all the way across to the solid coal of the second longwall panel, resulting in uniform entry closure.

Roof sag measurements made during the approach of the face in both sites typically totalled less than 0.25 in, indicating that most of the measured entry closure was due either to pillar shortening or to floor heave. In addition, in 4 of the 18 sag stations in the experimental section rapid roof sag rates were measured that apparently correlated with the onset of roof instability. Figure 13*A* shows the rapid development of sag several days before the roof collapsed at station 44. In contrast, figure 13*B* shows data from station 89 in the future tailgate entry of site 1 that showed no sign of instability, even though nearly 1 in of total sag was measured. The rate of roof sag in site 2 was even lower than the rate shown in figure 13*B* indicating that the conditions in site 2 were better than any of the three pillar design areas studied at site 1; although, this rate could be due to the good initial roof quality. These measurements indicate that the rate of roof sag, rather than the magnitude, could be used to predict the approach of roof instability. Other researchers have also concluded that the rate of roof sag is a reliable means of predicting imminent roof failure (*11*).

RESULTS II–PROTECTION OF FUTURE TAILGATE

The second criterion for evaluating the three pillar designs was protection of the future tailgate. To make the evaluation, measurements and observations were made at the two sites after the face had passed them. Two sets of entry stability measurements were made at site 1, the first when the face was about 1,000 ft past the outby end of the instrumentation, and the second 20 weeks later when the panel was completely mined out. The final measurements in site 2 were also made shortly after the completion of the panel. In addition, conditions were observed along the entire length of the future tailgate entry at the time of this final visit.

SITE 1

Figure 14 summarizes the results of the survey made in site 1 when the face was 1,000 ft outby. Significant differences between the pillar systems were apparent regarding protection of the future tailgate entry. In fact, there appeared to be *five* distinct zones of strata behavior, corresponding to the three pillar designs and two transition zones between designs.

The worst conditions were observed in the two transition zones, near stations 86 and 94. Total convergence near the solid rib at these stations measured in excess of 2 ft (fig. 14*A*), with convergence rates still much higher than in adjacent areas (fig. 14*B*). The roof quality had also deteriorated to the point of collapse. It appeared that the severe differential floor heave at these locations might have caused the roof damage.

There did not appear to be much difference between the performances of the two abutment pillar systems in site 1. Greater total entry closures were measured in the four-entry system, but the three-entry system had been mined by more recently and was still converging at a greater rate. The roof quality in both areas had declined on average by one full grade (fig. 14*C*). The roof in the three-entry system was in particularly poor shape, but that could be attributed to its lower initial quality (refer to figure 7). Roof sag exceeded the 1.5-in range of the instrument at one location in the three-entry system, but was about 1.1 in at the three other stations installed in the abutment pillar systems.

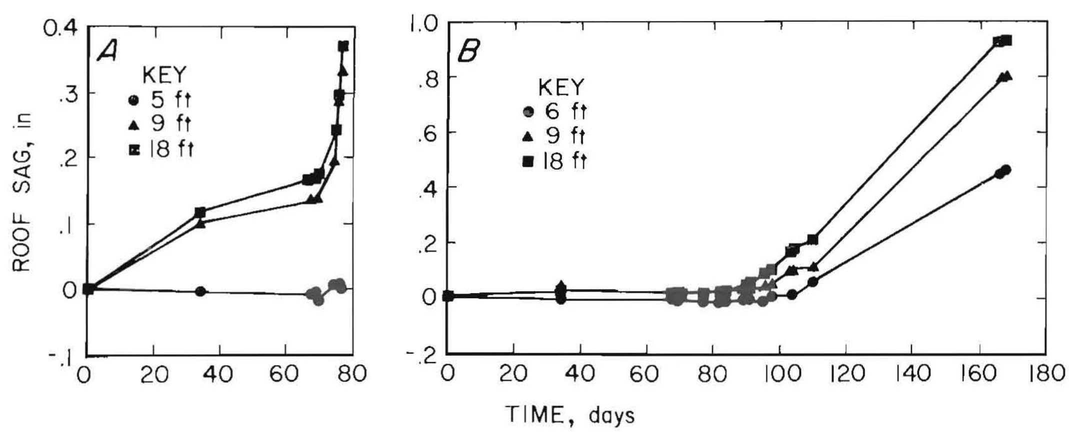

Figure 13.–Results of roof sag measurements in the track entry. *A*, **rapid sag rate several days before failure, station 44;** *B*, **steady sag in stable roof, station 89.**

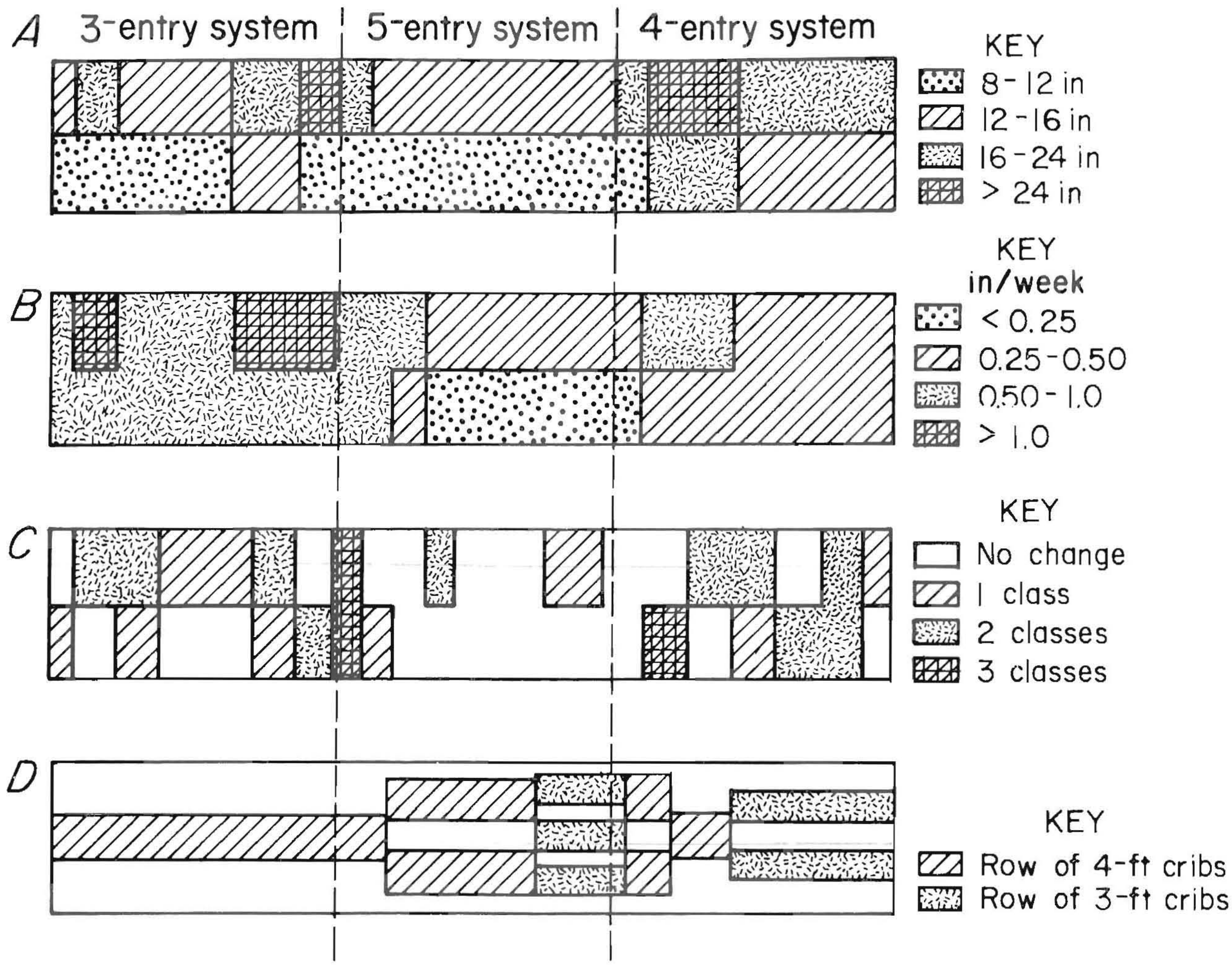

Figure 14.–Analysis of the future tailgate entry when face was 1,000 ft outby site 1. ***A*****, total entry convergence;** ***B*****, entry convergence rate;** ***C*****, change in roof quality;** ***D*****, crib support pattern.**

In the yielding pillar area the future tailgate entry apparently received much less damage. Significant convergence had occurred, particularly near the solid rib, but the convergence rates were lower than anywhere else in the future tailgate entry. More importantly, there was very little degradation in roof quality, even though nearly 1 in of roof sag was measured at all three of the sag stations installed in the five-entry system.

The final visit, made when the panel was completed, confirmed the trends described above. At this time the panel was barely accessible due to very poor ground conditions in the four-entry system inby the experimental section and in the three-entry portion of the site. Final convergence measurements indicated that approximately 2 ft of floor heave occurred near the solid rib in the yield pillar area, but the roof was still largely undisturbed.

The conditions in the future tailgate corresponded closely to the density of the supplemental wood cribbing that was installed (fig. 14*D*). Where the cribs were placed closest together, in the five-entry system, the conditions were best. The worst conditions, outside of the transition zones, were found where only a single row of cribs were installed. The conditions were so poor in these areas that mine management decided to make a double row of 4-ft cribs the standard for the remaining length of the future tailgate.

The timing of the convergence sheds more light on the conditions observed in the future tailgate entry. Figure 15 shows convergence histories from representative stations located in each of the three pillar designs in site 1. In the yield pillar area (station 90), convergence developed more rapidly, but leveled off earlier than in the abutment pillar areas. It is possible that the abutment loads initially caused additional shortening of the yield pillars, again stress-relieving the area and resulting in lower rates of floor heave. The abutment pillars, on the other hand, apparently retained high loads, causing higher long-term rates of floor heave.

Further evidence of stress relief in the yield pillar area was provided by the conditions of the adjacent unsupported entries and crosscuts. In the four-entry area, the crosscuts had heaved to within 3 ft of the roof, and several falls had occurred in the old scoop entry. In the three-entry area, all of the crosscuts had collapsed. In contrast, all the crosscuts were open in the yield pillar area, and the scoop entry apparently suffered very little degradation once the face had passed. At the time of these final readings, one monitoring station (No. 71) was still accessible in the scoop entry in the heart of the yield pillar system. Measurements indicated that this location had experienced less total convergence and roof sag than any other point in site 1.

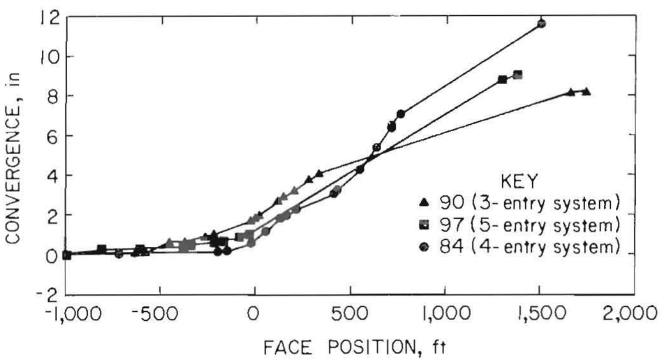

Figure 15.–Typical convergence histories from selected convergence stations from each of three pillar designs in site 1.

SITE 2

Ground conditions in site 2 after the face had passed were far better than had been the case in site 1. Roof quality observations, supported by the roof sag measurements, indicated that relatively little damage to the future tailgate entry had occurred due to the passage of the first face. Total convergence was also lower, and convergence rates were less than 0.25 in/week over much of site 2, considerably less than had been observed in the three-entry system of site 1 (fig. 16).

Based on these observations alone, it might be concluded that the three-entry system performed very well in protecting the tailgate. Unfortunately, the conditions over much of site 2 were apparently not representative of typical ground conditions in the future tailgate. In 4,000 ft of the three-entry system between the two sites significant entry deterioration had occurred. The double row of cribs that was installed outby site 1 provided much more stability than the single row in site 1, but conditions were still poor enough that nearly the entire length of the future tailgate entry inby site 2 was closed to personnel. As figure 16 shows, there was one section of site 2 where convergence and convergence rates were considerably higher than in the rest of the site, and these measurements may have better represented typical three-entry conditions.

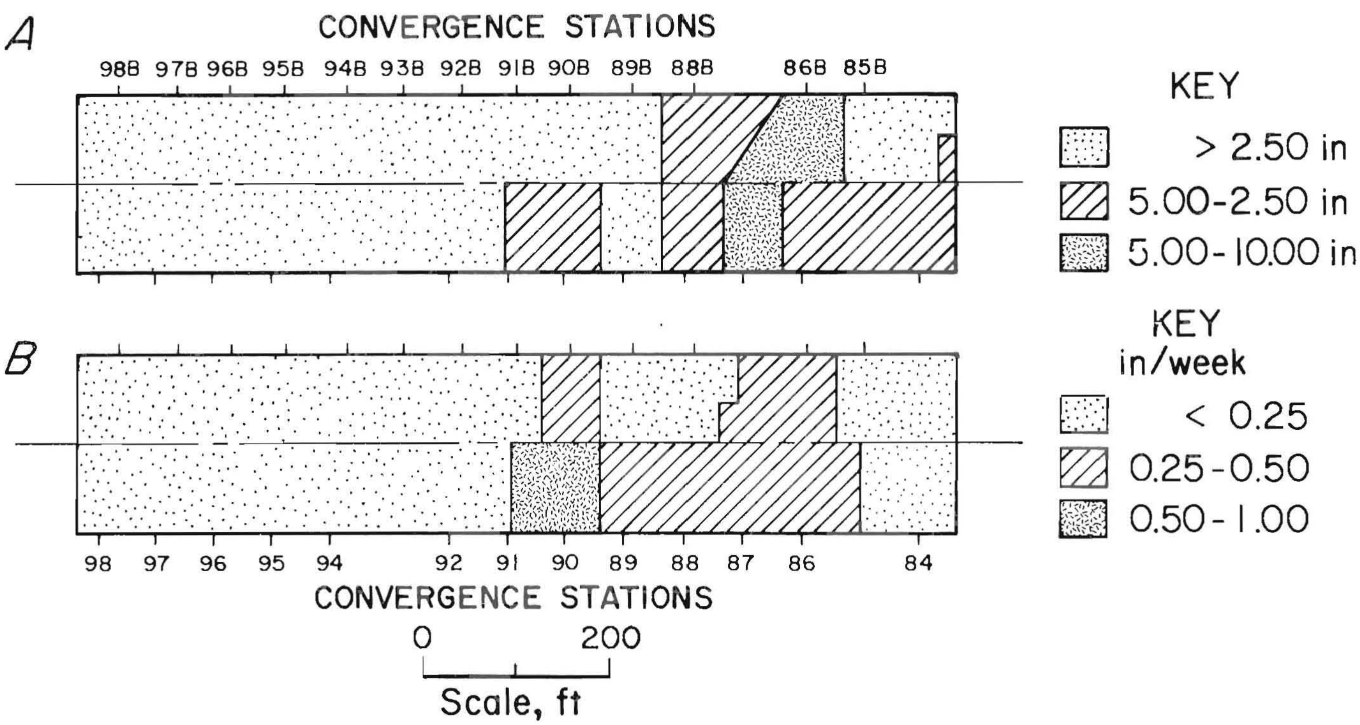

Figure 16.–Analysis of future tailgate entry when face of first panel was at its furthest point outby site 1. ***A*****, total entry convergence;** ***B*****, entry convergence rate.**

RESULTS III–PASSAGE OF SECOND FACE

The third criterion for evaluating the three pillar designs was the ground control in the gate road while it acts as a tailgate. No Bureau personnel were at the mine while the second panel was being mined, but reports were obtained on the stability of the tailgate, the weight distribution across the second face, and the longwall face advance rate.

Mining of the second panel was accomplished through site 1, but not without difficulty. The most consistent ground control problem was that floor heave in the tailgate entry had to be removed by the shearer so longwall extraction could be conducted. More importantly, rock falls occurred in front of the shields in the three-entry section of site 1, where the most severe roof degradation had occurred. As a result, the advance rate was somewhat slower during second panel mining than first panel mining.

CONCLUSIONS

First, all three pillar designs apparently provided adequate ground control to the belt entry in the headgate phase. The roof problems that developed appeared to be due to local geology, and could be controlled by additional support.

Second, the sections of the future tailgate heading of the experimental section that received the most damage were the transition zones located just adjacent to the all-yield section. It appears that these areas were subjected to a significant portion of the abutment load that was transferred from the yield pillars. To avoid the creation of such highly stressed transition zones, great care should be exercised when a yield pillar system is used near an abutment pillar system.

Neither the three- or four-entry systems performed adequately in protecting the tailgate. The four-entry system in particular suffered severe floor heave and roof instability along its entire length. Typical conditions in the three-entry system were neither as poor as the first site indicated, or as good as the second site implied. The exceptionally poor conditions in the first site may be attributed to the low initial roof rock quality, some stress transfer from the all-yield pillar area, and the lack of adequate supplemental support. The good conditions at the second site may have been due to the shorter time lag between mining and the final set of measurements. More typical were the conditions between the two sites, which were passable, but hazardous in spite of the presence of two rows of cribs.

The total-yield pillar system performed nearly as well as the three-entry abutment pillar system in protecting the tailgate. Although serious floor heave and roof sag were measured in the yield pillar area, very little roof degradation occurred and the second face mined by the area with little difficulty. The key to the success of the yield pillar area may have been the heavy secondary support, which was installed in the tailgate entry.

The study highlighted some of the limitations of the conventional pillar design philosophy for deep-cover longwalls. The ALPS method predicted a stability factor of 0.5 for the three-entry design under 1,800 ft of cover, indicating that poor conditions might have been anticipated. Unfortunately, in order to achieve an ALPS stability factor of 1.0, the mine would have to increase the width of the abutment pillars to more than 150 ft. Such large pillars would be slow to develop and would reduce the overall extraction ratio.

The study indicated that yielding pillar systems, combined with heavy artificial support, may be a viable ground control alternative for deep-cover multientry longwalls. While the ground conditions resulting from a yielding pillar would not be expected to be as favorable as those associated with a conventional pillar design with an adequate stability factor, the yielding pillar design might be cost effective because it would have the following benefits:

- a reduction of the amount of coal left in gate road pillars, thereby conserving coal resources and increasing extraction;
- an increase in the rate of gate road development because the length of the crosscuts is reduced.

Other potential advantages of a yield pillar system may be improved ground control in multiseam situations and improved subsidence control.

However, the development of design guidelines for yielding pillar systems will require much additional research. In this study site five entries were used, but that was necessary to maintain a constant distance between the headgate and future tailgate entries. In general, the number of yield pillar entries should be minimized to aid in the formation of a pressure arch. Also, in this test the yield pillar portion of the future tailgate entry was very heavily cribbed, but typical support requirements for yield pillar systems are not known. The study did not address the proper width of pillars for use in total-yielding pillar systems. Future Bureau research will investigate these issues in greater detail, and will be directed toward developing scientific guidelines for yielding pillar design.

REFERENCES

1. Mark, C. Longwall Pillar Design–Some New Developments. Soc. Min. Eng. AIME preprint 89-103, 1989, 10 pp.
2. Hsuing, S. M., and S. S. Peng. Chain Pillar Design for U.S. Longwall Panels. Min. Sci. Technol., v. 2, 1985, pp. 279-305.
3. Carr, F., and A. H. Wilson. A New Approach to the Design of Multi Entry Developments for Retreat Longwall Mining. Paper in Proceedings Second Conference on Ground Control in Mining. Morgantown, WV, 1982, pp. 1-21.
4. Martin, E., S. Stehney, J. Gambrell, M. Gauna, N. Browne, and R. Southerland. Yield Pillar Applications - Impact on Strata Control and Coal Production (Handout 4th Conf. on Ground Control in Min., Morgantown, WV, July 22-24, 1985, 15 pp.); available upon request from C. Mark, BuMines, Pittsburgh, PA.
5. Maleki, H. N., J. F. T. Agapito, R. G. Lauman, and J. Hatrick. Tailgate Support Evaluation at Plateau Mining Company. Paper in Proceedings Fifth Conference on Ground Control in Mining, ed. by A. Khair and S. S. Peng, Morgantown, WV, 1985, pp. 297-305.
6. Martin, E., and Carr, F. Recent Strata Control Advances at Jim Walter Resources Mining Division–Case Studies. Paper in Proceedings Seventh International Conference on Ground Control in Mining. Morgantown, WV, 1988, pp. 66-75.
7. Lu, P. H. Biaxial-Loading Measurement for Mine-Pillar Stability Evaluation–Case Studies. Paper in Proceedings International Symposium on Application of Rock Characterization Techniques in Mine Design. Soc. Min. Eng. AIME, 1986, pp. 142-151.
8. Bieniawski, Z. T. Rock Mechanics Design in Mining and Tunneling. Wiley, 1987, 212 pp.
9. Bauer, E. R. Ground Control Instrumentation - A Manual for the Mining Industry. BuMines IC 9053, 1985, 68 pp.
10. Ferm, J. C., and G. A. Weisenfluh. Cored Rocks of the Southern Appalachian Coal Fields. Univ. KY, Lexington, KY, 1981, 112 pp.
11. Maleki, H. N., and J. R. McVey. Detection of Roof Instability by Monitoring the Rate of Movement. BuMines RI 9170, 1988, 12 pp.

INT.BU.OF MINES,PGH.,PA 29030