RI 9444

REPORT OF INVESTIGATIONS/1993

Longwall Retreat of Gate Road Pillars

By J. M. Listak and E. R. Bauer

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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Library of Congress Cataloging in Publication Data:

Listak, Jeffrey M.
Longwall retreat of gate road pillars / by J.M. Listak and E.R. Bauer.

p. cm. -- (Report of investigations; 9444)

Includes bibliographical references (p. 11).

1. Ground control (Mining)--Pennsylvania. 2. Pillaring (Mining). 3. Longwall mining--Pennsylvania. I. Bauer, Eric R. II. Title. III. Series: Report of investigations (United States. Bureau of Mines); 9444.

TN23.U43 [TN288] 622 s--dc20 [622'.334] 92-23498 CIP

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	lb	pound
in	inch	pct	percent
kip	1,000 pounds	psi	pound per square inch

LONGWALL RETREAT OF GATE ROAD PILLARS

By J. M. Listak[1] and E. R. Bauer[1]

ABSTRACT

This report describes a U.S. Bureau of Mines investigation into the removal of gate road chain pillars in conjunction with longwall retreat mining. The research objective was to determine, through evaluations of the loads imposed on the gate road pillars and supplemental support elements in the entries, how the pillars, supplemental support, and entries were affected by the longwall abutment pressure. To achieve this goal, vibrating wire stressmeters and hydraulic flatjack pressure cells were installed in the support elements to monitor stress change caused by abutment pressure as a function of longwall face advance. The findings documented in this report are the result of information collected from instrumentation and observation at the mine.

Pillar and support loading measurements and stability observations revealed that the roof and the support elements remained stable during panel retreat, while the face progressed at a normal rate of advance. The ability to safely and efficiently mine chain pillars during panel retreat increases resource recovery and can provide several other benefits described in this report.

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INTRODUCTION

The future of underground coal mining is dependent upon highly productive longwall systems. Innovative methods of increasing longwall productivity are continually being sought by industry and research organizations. An obvious trend that has transpired over the last several years to improve productivity is the increase of panel dimensions. Larger panels have become increasingly popular because they provide increased resource recovery, less gate road development, fewer face equipment moves, increased productivity, and mitigation of long-term surface damage due to differential subsidence. In the last 10 years, panel width has increased more than 43 pct from an average of 495 ft to more than 707 ft (*1*).[2] Although ground control considerations and electrical and hydraulic limitations of longwall equipment continue to dictate longwall face width, technical advances in these areas are allowing for wider faces. Similarly, panel lengths are also increasing but are usually governed by the extent of coal reserves and/or the mine layout relative to surface features (i.e., buildings, highways, topography, etc.).

A longwall panel's boundary is formed by its headgate and tailgate entries, which in turn define the panel's dimensions. Since a new panel must be completely developed before longwall face equipment can begin panel retreat, development of gate road entries often requires utilizing several production units (continuous miners) in order to maintain uninterrupted production from the longwall. Still, continuous miner development is slow compared with retreat of the panel and proves to be a hindrance to an otherwise efficient system, thus making longwall mining dependent upon the efficiency of continuous miner sections. Furthermore, the advance rate of continuous miners is a function of the number of gate road entries employed. Accordingly, advance rates of continuous miners suffer when more gate road entries are developed. The majority of longwall mine layouts in the U.S. employ three- or four-entry gate roads because of ventilation and escapeway requirements. Of the 96 active longwall faces surveyed in 1990 (*2*), 40 pct used 3 entries, 34 pct used 4 entries, 23 pct are unknown, and 3 pct used other configurations for their gate road systems.

Although productivity advances have been introduced to continuous mining by means of satellite miners and extended cut operations, technological advances in longwalling are outpacing these improvements and continue to be developed and readily adopted by operators. This technology has enabled longwall panel extraction rates to more than double over the past 5 years, putting additional pressure on gate road development sections.

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

Since it is likely that continuous mining practices will remain relatively unchanged for many years, other methods of increasing longwall production must be pursued. One such method, which would increase resource recovery, provide additional time for continuous miners to develop gate road entries, and lessen the long-term damaging effects of surface subsidence, would be to extend the longwall face equipment into the headgate in order to mine one or more rows of the gate road chain pillars during retreat of the panel. This would require some additional face equipment; however, the benefits could be significant. For example, coal recovery on a 600- by 5,000-ft face that has a mining height of 6 ft and has a three-gate road entry system using square pillars on 100-ft centers (assume 20-ft-wide entries) can be increased about 10 pct by recovering one row of gate road pillars along with the panel. Furthermore, recovering one row of chain pillars effectively increases the panel's dimensions and, subsequently, the panel's life, thus providing additional time for the development of the next panel by continuous miners. An added benefit to mining a row of gate road pillars is that, for some mines, belt removal and relocation would not be necessary. During continuous miner development in a three-entry system, it is desirable to locate the belt in the center entry for improved ventilation and shorter shuttle car haulage distances. For these reasons, the belt is often located on the center entry but later moved so that the longwall belt can be situated adjacent to the panel. However, in a three-entry system, if the pillar nearest the panel is mined out with the panel, the belt would already be located in the proper entry.

Recovery of gate road chain pillars is not a new idea. In 1976, Simpson applied for and received a patent for headgate chain pillar recovery (*3*). Simpson describes the technique of "pump packing" for control of abutment pressure. Pump packing involves mixing broken coal with a binder such as bentonite and water to form a thixotropic material. Used by the British to construct packwalls, this material flows under pressure and solidifies rapidly when the pressure is relieved. The pumped material provides homogeneous roof support ahead of the longwall face yet is low enough in strength to be easily mined by the shearing machine. Hearnshaw and Gallaher (*4*) discuss a similar approach using pneumatic stowing of gob material for ground control.

There have also been a few operators that have tried this method. In Illinois, Old Ben Coal Co. developed a three-entry system with the belt located in the middle entry and extracted the 60-ft chain pillar between the belt and intake entries as the panel was retreated. Cavinder

(*5*) reported that several panels were extracted by this method and at times, serious headgate problems developed. The 60-ft pillar size was increased to 100 ft in a few panels, but in 1980 the practice was stopped. The company decided that the overall benefits realized were not worth the ground control risks involved with the method, and the belt was moved adjacent to the longwall panel.

Another failed attempt at chain pillar recovery took place at a mine in West Virginia in August 1989. The pillars that were to be mined were located in a four-entry tailgate system. Conventional rectangular chain pillars were used for gate road support. After mining several of the pillars the procedure was abandoned because of poor ground conditions that developed as the face neared the crosscuts. Front abutment loads coupled with the residual gob loads from the previously mined-out panel created uncontrollable conditions, causing pillar deterioration and roof failure in the crosscuts, even with the use of supplemental support.

To cite another example, Mid-Continent Resources' Dutch Creek No. 2 mine in Colorado successfully mined through previously driven entries (*6*). The success was attributed to steel-fiber-reinforced concrete cribbing in the entries and crosscuts and their alignment. The No. 2 mine was 500 ft above the Dutch Creek No. 1 mine, and the need to realign a panel in the upper mine with a panel in the lower mine made it necessary to mine through previously driven entries. The entries and crosscuts mined through were aligned at 30° and 60° angles to the longwall face. Although there is no evidence to prove that this was a major factor that contributed to the success of the experiment, mine management believed that, in addition to the concrete cribbing, the angled crosscuts provided a favorable condition for roof control.

Two primary goals of the U.S. Bureau of Mines in researching underground coal mining are to reduce the cost of mining coal and to ensure the health and safety of miners. This study seeks to help achieve these goals by evaluating entry stability and the response of support elements while mining a row of chain pillars in a longwall headgate.

CHAIN PILLAR RECOVERY CONCEPT

Figure 1*A* shows a typical longwall panel layout utilizing a three-entry gate road system. The longwall equipment is assembled in the setup entry and only the panel is extracted during retreat. Figure 1*B* illustrates an extended panel with the shearer removing one row of headgate chain pillars during panel retreat. The only additional requirement for mining the pillars is the extension of the face conveyor and roof supports into the headgate. Ideally, recovery of both headgate chain pillars would offer complete resource recovery and eliminate the long-term surface subsidence effects. However, the nature of gob development in mined-out areas requires that at least one row of pillars remain as the tailgate for the next panel. If both pillars are extracted, no tailgate would exist for the next panel. Figure 2 shows that one row of pillars is required to act as the succeeding panel's tailgate.

After the next panel is extracted, the gob flushing around the remaining pillar would close the remaining tailgate entry and, depending upon the amount of supplemental support, could offer lateral confinement that would provide strength to the pillar. The subsidence trough would still remain over the longwall panel, but pillar degradation and the subsequent threat of subsidence would be reduced.

Redistribution of stress as the panel is mined may jeopardize the success of extracting chain pillars. The potential exists for ground control problems to arise when the chain pillar is nearly mined out and the face nears the crosscut between it and the succeeding pillar. As the pillar decreases in size, it loses its capacity to carry load. As a result, abutment loads, advancing parallel to and ahead of the longwall face, will create instability around the pillar, particularly in the four-way intersections between the two rows of gate road pillars. Since the headgate area provides access to the longwall panel and the location of the stage loader and face monitoring equipment, removing the headgate chain pillars could be a risky endeavor. To alleviate problems due to abutment loading, some form of supplemental support is required to maintain entry stability. Consequently, additional support is an added expense, and dealing with supplemental support when each crosscut is mined into could be problematic.

Gate road pillar layout can play an important role in lessening the effects of abutment loads and subsequently the amount of supplemental support required. Since the front abutment travels ahead of and parallel to the face, conventionally developed crosscuts, also parallel to the face, will experience the full effect of the abutment load. In addition, abutment loads around the large exposed roof areas in the four-way intersections could also prove to be a problem. However, by using an angled crosscut, the pillar offset will reduce the area of exposed roof relative to the parallel advance of the front abutment and offer support to front abutment loads as the face approaches and passes through the crosscuts. In addition, the four-way intersections would be eliminated, and the remaining three-way intersections would require less supplemental support. Figure 3 shows how the use of angled crosscuts could help control the front abutment loads.

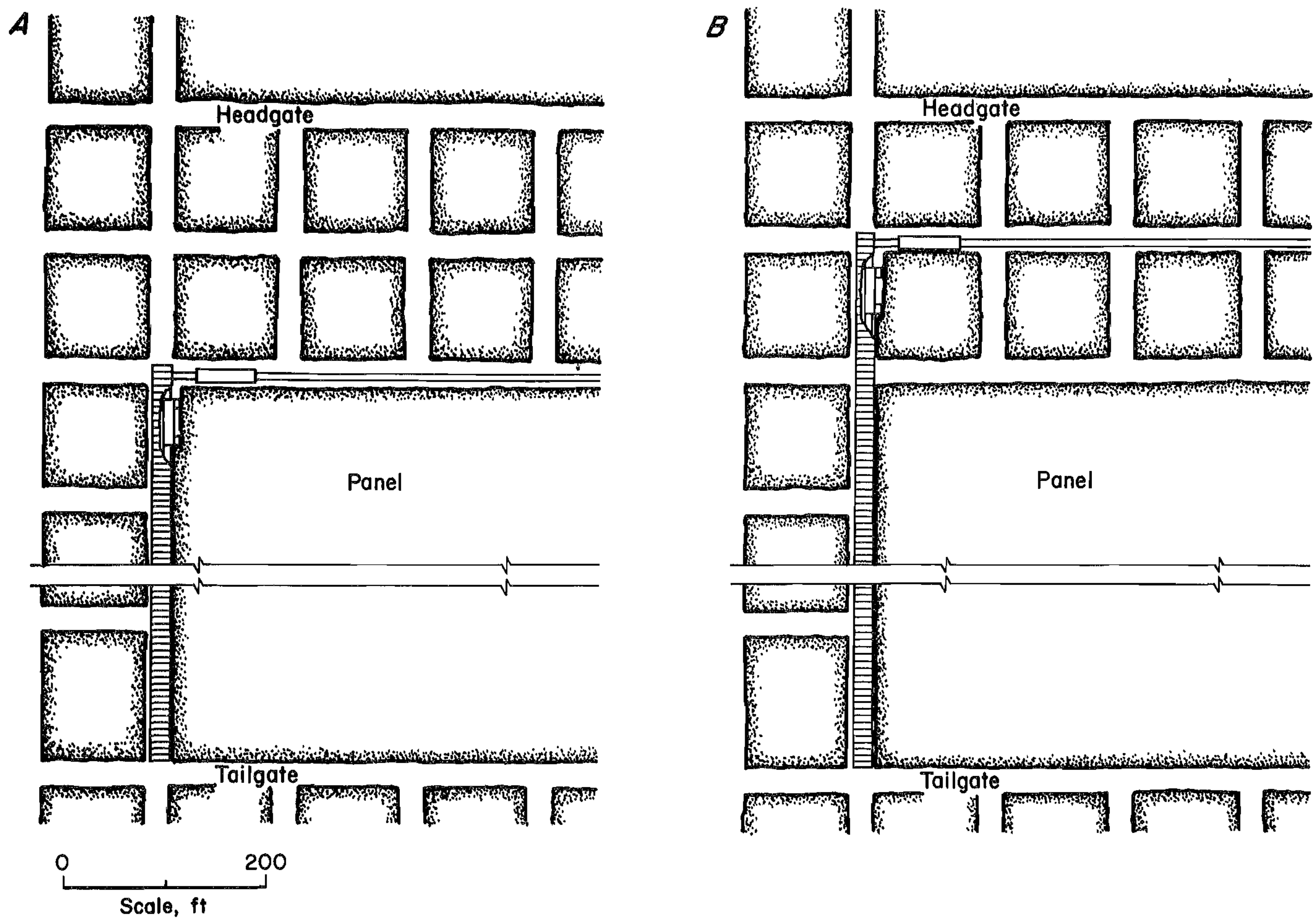

Figure 1.—Conventional and mined headgate-chain pillar panel layouts. *A*, Only panel is mined; *B*, headgate chain pillars are also mined.

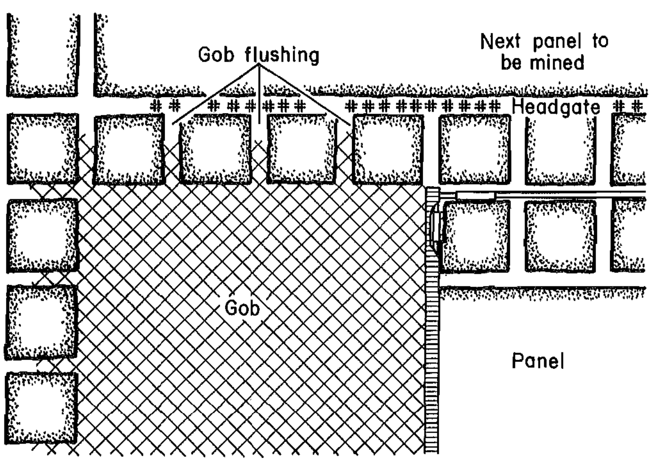

Figure 2.—Gob development behind longwall face.

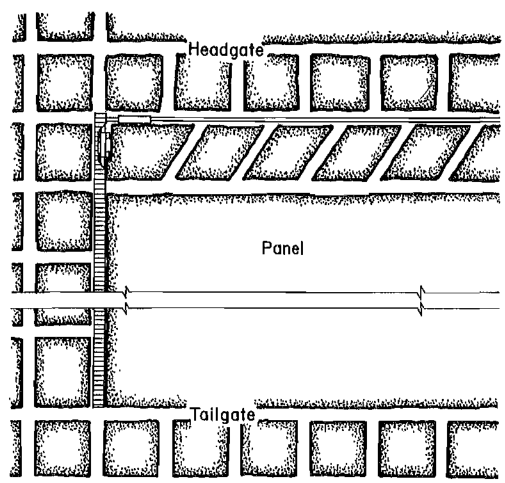

Figure 3.—Chain pillar recovery using angled crosscuts.

FIELD INVESTIGATION

MINE SITE

A study was conducted by BethEnergy Mines Inc. and the Bureau to evaluate entry stability and the response of support elements during the mining of a row of chain pillars in a longwall headgate. The mine is located within the Appalachian Plateau province of southwestern Pennsylvania. Topographic relief in the area does not exceed 350 ft and dips are generally less than 4°. Mining takes place in the Pittsburgh Coalbed, which lies stratigraphically within the Pennsylvania age coal-bearing strata of the Monongahela Group.

The immediate roof was composed of approximately 4 ft of gray shale overlain by thin members of coal and carbonaceous shale. Upper members were composed primarily of gray sandy shales.

The floor rock was composed predominantly of fire clay. Floor heave was not a problem in the study area. Geologic features such as clastic dikes, kettlebottoms, and jointing were managed by the mine's roof control plan.

The study area consisted of one longwall panel and its associated headgate. The average depth of cover over the panel was 600 ft. The panel under investigation was 2,200 ft long and 900 ft wide (including the recovered pillars). Pillar recovery was planned on this panel because of the panel's unusually short length (2,200 ft). Another reason to recover a pillar from this headgate was the inordinate number of entries that were developed. Because of ventilation and supply considerations, a six-entry, five-pillar headgate system was employed as the headgate. A 100- by 100-ft abutment pillar was flanked on one side by two 20- by 100-ft pillars. Two more pillars were located on the opposite side and adjacent to the panel to be mined: a 20- by 100-ft pillar and a 40- by 100-ft pillar to be retreated with the panel. The crosscuts between the chain pillars to be retreated were mined at 40° angles from the panel's length. Since it was not known how this method of panel retreat would affect the headgate area, the panel was laid out such that the beginning of the panel could be mined conventionally (i.e., not mining the pillars). When the face had advanced approximately 550 ft, the panel's width narrowed to 840 ft, thus allowing the pillars to be extracted with the panel. Figure 4 illustrates the complete longwall panel layout and shows the row of pillars that were mined in conjunction with the retreat of the panel.

To guard against headgate roof falls in the crosscuts and intersections, donut cribs were installed in the angled crosscuts between the pillars that were to be mined. The donut cribs were constructed using 22-in-diam, 3-in-thick reinforced concrete disks that are hollow in the center (donuts). To facilitate load transfer and even distribution of load, 1/8-in-thick plywood disks were inserted between every four courses as the cribs were built. Timber blocking between the last course and the roof, as shown in figure 5, also provided for yielding in the cribs.

No additional supplemental support was used in the entry between the mined chain pillar and the longwall panel (i.e., adjacent to the longwall panel). However, hydraulic supports were used in the headgate area around the stage loader.

INSTRUMENTATION SITE

Roof falls in the headgate area would pose a threat to longwall face personnel and equipment and were therefore the most important aspect of pillar recovery to be addressed. To determine how the removal of these pillars

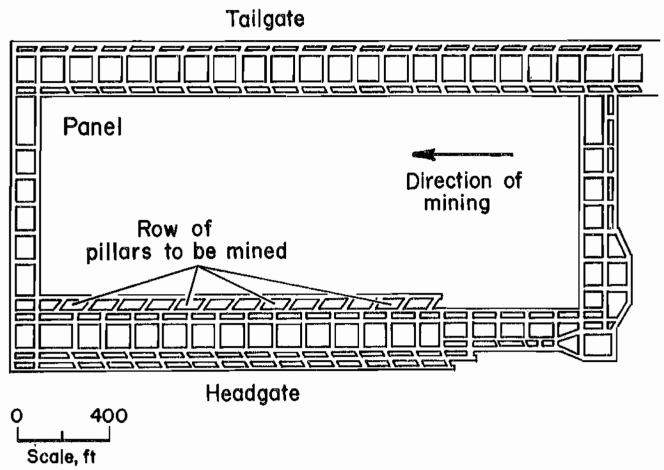

Figure 4.—Layout of study panel.

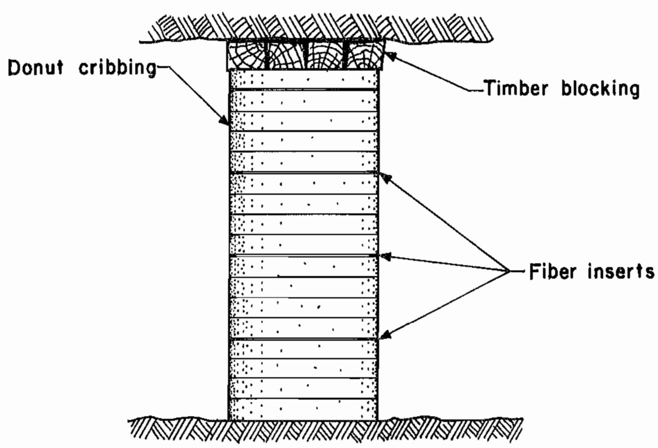

Figure 5.—Typical donut crib construction in angled crosscut.

affected the stability of the area, vibrating wire stressmeters (VWS's) were installed prior to longwall retreat in the pillar to be mined and in the two pillars adjacent to the pillar to be mined. The stressmeters were positioned across the pillars in order to provide a history of pillar loading as a function of longwall face advance. Figure 6 shows an exploded view of the instrumented area relative to the entire longwall panel layout.

The donut cribs were instrumented with hydraulic pressure cells (flatjack cells) to determine the effects of abutment load transfer to the crosscuts and intersections as the longwall face approached. Figures 7 and 8 illustrate the arrangement of pressure cells in the donut cribs. The leads of the VWS's and pressure cells were extended to a central-readout station at a safe location and monitored by mine and Bureau personnel as the longwall face approached the instrumented area, as shown in figure 9. Close visual inspection of the pillars, entries, and entry intersections was also maintained by section supervisors as mining progressed into the pillar removal area.

FIELD DATA ANALYSIS

Pillar Response

The VWS's were installed in the gate road pillars after development and prior to longwall retreat. Therefore, data in this report represent the stress change from development loading rather than absolute stress. As previously stated, stressmeters were installed across the width of the headgate pillars in order to characterize stress changes due to abutment pressure as a function of longwall face advance. Baseline stressmeter data taken prior to mining,

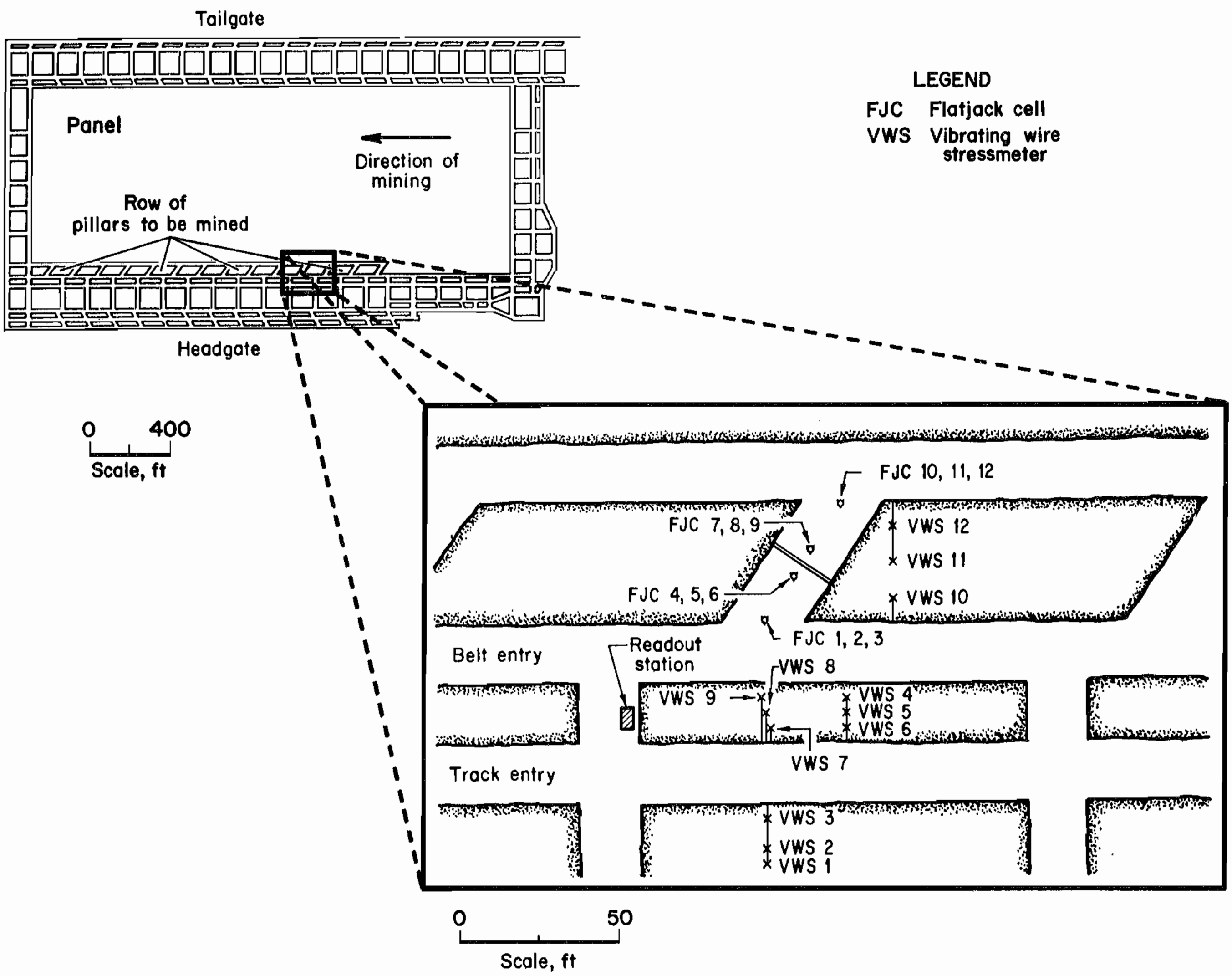

Figure 6.—Detailed area of instrumentation site.

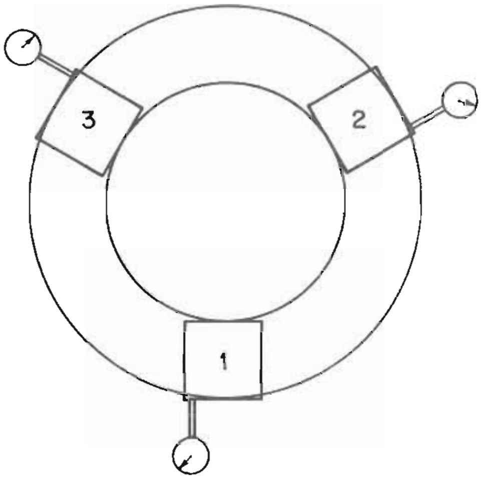

Figure 7.—Donut crib shown with installed hydraulic flatjack.

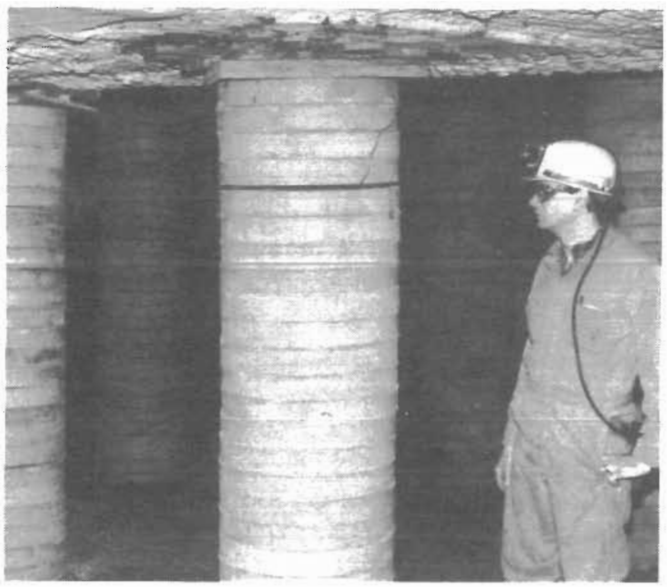

Figure 8.—Hydraulic flatjack arrangement in donut crib.

and subsequent data taken with respect to longwall face advance, provided information corresponding to vertical stress. The three instrumented pillars, designated as P1, P2, and P3, are shown in figure 10. Pillar P1 is the pillar that was mined out with the longwall panel, and it was monitored to determine how the front abutment affects the stability of the pillar and the entries around it. Pillars P2 and P3 were also monitored to determine the effects of stress transfer as pillar P1 was mined. The

Figure 9.—Instrument readout station.

abutment-yield[3] pillar arrangement used in the study area was the same configuration that had been proven to offer good ground conditions on previous panels. An earlier Bureau study concluded that average pillar loads were lower, and they appeared to stabilize when an abutment-yield configuration was utilized (*8*).

Figures 11*A* through 11*D* illustrate the progression of stress increase in the three pillars as the longwall face approached the instrumentation site. Four graphs are shown for the three pillars because stressmeters 4 through 6 and 7 through 9 were located in the same pillar. Figure 11*D* shows the abutment pressure ahead of the face in pillar P1. Initially, three stressmeters were installed in this pillar; however, the lead wire of VWS 10 was cut by rib sloughage and is not presented on the graph. The graph shows the gradual increase of stress, beginning when the face was approximately 200 ft ahead of the instruments. When the face was approximately 25 ft away, a rapid increase in stress change occurred before VWS 11 and 12 were lost (in this case, and others, where data are

[3]The term "abutment-yield" is used for descriptive purposes to designate the existence of two adjacent pillars, one large and one small. The smaller 20-ft pillar is referred to as the yield pillar even though it does not exhibit yield pillar behavior. Theoretically, a true yielding pillar (based on Wilson's (*7*) equations) at this mine has a width of about 10 ft.

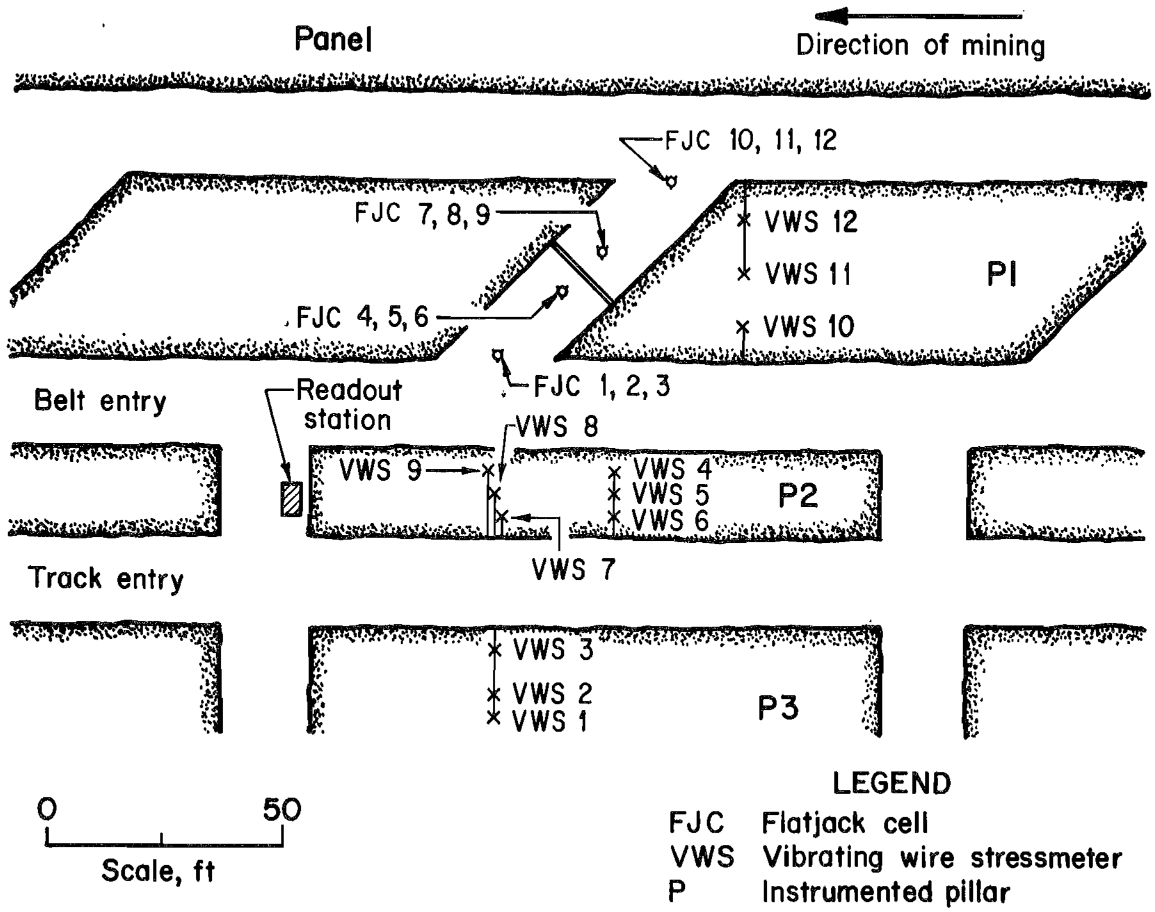

Figure 10.—Stressmeter and flatjack location in pillars and donut cribs.

incomplete, instrument recording was terminated because of wire damage from rib sloughage). The steep rise in stress change in the pillar was not accompanied by any problems on the longwall face or in the gate entries. As shown in figures 11*B* and 11*C*, stress change increases in pillar P2 were gradual with the exception of VWS 4. VWS 4 was located 5 ft from the rib in pillar P2 and was the stressmeter located next to the mined pillar. Peak stress change and subsequent unloading was experienced in VWS 4 when the face was about 30 ft away from this set of stressmeters, indicating that pillar failure occurred in the form of rib sloughage or yielding. However, if rib sloughage occurred, it is likely that the stressmeter's lead wire would have been severed, rendering it unreadable. VWS 9, located 5 ft from the rib in pillar P2 approximately 40 ft outby VWS 4, did not exhibit the same behavior. The increase in stress change continued at a gradual rate until the face had passed the instrument. This may be accounted for by the stressmeter's proximity to the donut cribs. Stressmeters located in pillar P3 (figure 11*A*) showed very little increase in stress change.

Figure 12 illustrates VWS 4 through 6 as stress profiles, at various face positions, of the 20-ft pillar (P2) adjacent to the mined-out pillar. There is a distinct difference in pillar behavior shown during the 30 ft of face advance that is presented in the graph. When the face was 20 ft from the instrument site, loading on the outer edge of the pillar nearest to the panel was more than two times that of the pillar's core and opposite edge. This is the distribution of stress that is normally associated with an abutment pillar. However, as the face drew nearer to the instrumentation site, loading on the outer edge nearest to the panel continually decreased while the pillar's core loading continually increased. When the face had progressed to 10 ft past the instrumentation site, stress redistribution in the pillar has caused the core to be loaded higher than the outer edges, and thus the pillar took on the characteristics of a yield pillar.

To further characterize pillar and entry behavior in response to longwall retreat of the chain pillars, comparisons were made between data collected during this study and pillar and front abutment information from previous studies conducted at this mine (*8-9*). The previous studies show that stress change behavior in the abutment and yield pillar in the study panel was similar to the behavior exhibited by pillars in this study during normal longwall face retreat. When compared with data from previous studies, there was no discernable difference that would suggest abnormal behavior in the pillars.

Analysis of the stressmeter information from this site did not reveal any conditions that could be interpreted as out of the ordinary for this mine. Although visual observation showed that some rib sloughage and pillar degradation occurred, these occurrences were not unlike the usual longwall gate road entry incidents that transpire during longwall retreat.

Donut Crib Response

Hydraulic flatjack cells were located around the perimeter of each of the donut cribs to determine the load experienced by the cribs in the angled crosscut and the headgate intersection. The cribs were designated as C1, C2, C3, and C4 and were located in the angled crosscut from the belt entry to the entry adjacent to the longwall panel as shown in figure 13. The disparity of readings obtained from the three flatjack cells in each crib indicated that the cribs experienced uneven loading. The uneven loading could be attributed to irregular contact area between the roof or floor, nonvertical crib attitude, or the effects of wedging at the roof. Therefore, the readings from the three cells were averaged to obtain one reading for each crib. Figure 14 shows the average stress change in the donut cribs relative to longwall face position. The readings were also converted to pounds to obtain the load on the cribs. The loading on the donut cribs relative to the last 40 ft of face advance before the cribs were mined out is summarized in table 1. The highest loading condition, 68,817 lb or 68.8 kips, occurred in crib C1. This was expected because of its proximity to the intersection of the belt entry and because of its location relative to pillars P1 and P2. Although the highest loading was

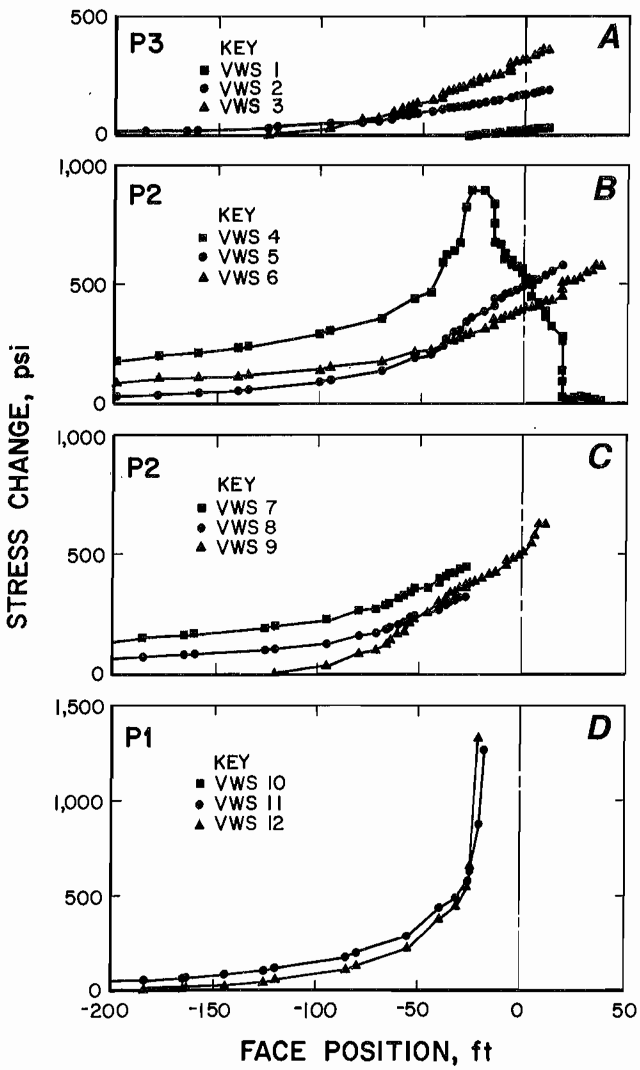

Figure 11.—Progression of stress change increases in pillars P1, P2, and P3.

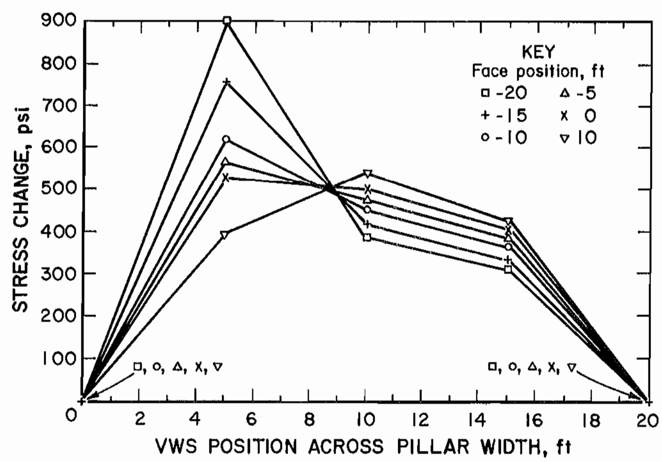

Figure 12.—Stress profile across pillar P2.

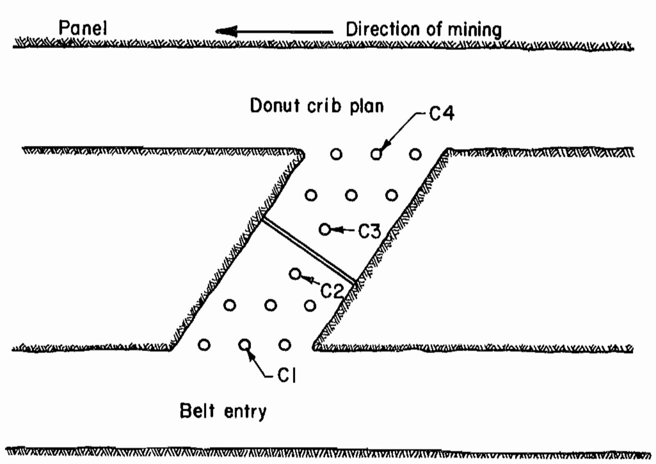

Figure 13.—Location of instrumented donut cribs in angled crosscuts.

experienced by C1, the cribs were never in danger of failure. Since the ultimate strength of steel-fiber-reinforced cribs ranges from 800 to 1,000 kips (*10*), C1 (the crib that experienced the greatest amount of loading) reached less than 8 pct of its ultimate strength. Therefore, the loads experienced in the angled crosscut were probably never a threat to entry stability. Visual observation also revealed that the cribs remained stable until they were mined into. Crushing of wooden header blocks between the roof and cribs was seen to occur, but the cribs showed no sign of weakening. The shearing machine was able to mine into the entry and mine out the cribs with little change to its normal shearing pattern.

Table 1.—Average load on donut cribs in angled crosscut, pounds

Face position, ft	C1	C2	C3	C4
Minus 40	28,203	23,691	13,311	16,923
Minus 35	32,151	24,819	14,100	18,051
Minus 30	36,663	29,331	14,667	20,307
Minus 25	41,742	29,895	14,667	24,255
Minus 20	48,510	34,971	15,231	15,947
Minus 15	51,894	40,614	18,051	32,151
Minus 10	55,842	47,946	19,743	32,715
Minus 5	60,306	43,998	23,127	36,099
Minus 3	68,817	47,382	27,639	43,998
0	0	0	0	0

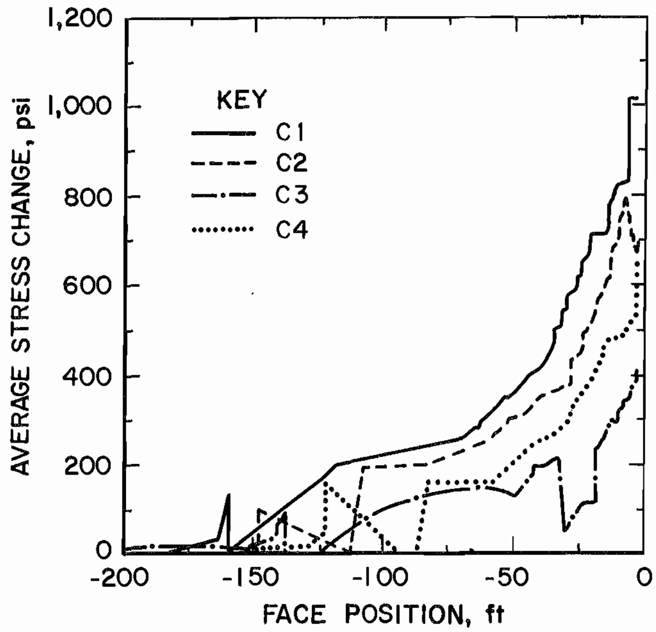

Figure 14.—Average stress change in donut cribs.

CONCLUSIONS

Information obtained from this study indicates that gate road chain pillars can be mined successfully during panel retreat. Recovery of chain pillars can increase resource recovery, increase productivity, and lessen the long-term detrimental effects of surface subsidence. There have been few successful attempts at chain pillar recovery because of the difficulty in controlling the front abutment pressure ahead of the face.

From an operations perspective, this method was considered a success by mine personnel because the roof, pillars, and entries remained stable and face advance progressed at a normal rate as the panel and the chain pillars were mined.

From a research perspective, the Bureau sought to determine if this method of longwall retreat mining created abnormal and/or uncontrollable loading conditions in the headgate that would make pillars and entries unstable, thereby precluding the mining of the chain pillars. Pillar and supplemental support behavior, both recorded and observed, indicates that, for this panel's layout and conditions, roof, entries, pillars, and supplemental support remained stable. The data revealed no unusual loading conditions that would suggest that extracting the chain pillars is detrimental to safety.

This study has shown that, through the use of angled crosscuts between the chain pillars, along with proper support techniques in the entries and crosscuts, safe mining of chain pillars was accomplished under the conditions at this site. However, because of the headgate's importance to the entire longwall operation, extreme caution should be the rule; an unsuccessful attempt to recover chain pillars could prove to be dangerous as well as very costly.

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*USGPO: 1993--709-008/60098