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Effects of Various Longwall Chain Pillar Configurations on Gate Road Stability

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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	psi	pound per square inch
pct	percent		

EFFECTS OF VARIOUS LONGWALL CHAIN PILLAR CONFIGURATIONS ON GATE ROAD STABILITY

By J. M. Listak,[1] J. C. Zelanko,[1] and T. M. Barton[1]

ABSTRACT

The Bureau of Mines conducted a field study to assess the performance of various chain pillar configurations in terms of gate road entry stability. Vibrating wire stressmeters (VWS's) were installed in four consecutive gate road chain pillars. Field data collected during panel retreat were analyzed to gain a better understanding of the mechanics of vertical load redistribution in gate road chain pillars as it relates to ground control problems.

Several different pillar configurations were investigated including abutment-yield and yield-abutment-yield designs. VWS data indicate that average pillar loads were lower and appeared to stabilize when an abutment-yield pillar arrangement was utilized. Data analyses also support the occurrence of severe roof and pillar deterioration that was visually observed in the tailgate entries during panel extraction.

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INTRODUCTION

A major constraint to successful longwall design is the lack of understanding of the induced stresses about the longwall panel and its boundaries. High stress concentrations on any part of the longwall system may lead to severe ground control problems resulting in hazardous conditions, lost production, decreased productivity, and higher mining costs. The inability to control stress redistribution associated with panel extraction affects all areas of the longwall system including the accessibility and stability of gate roads, the stability of the face, the selection of longwall powered face supports, and the maintenance of tailgate entries for ventilation.

The most severe longwall ground control problems are manisfested in the tailgate entries. The inability of pillars to control the roof in the tailgate seriously impedes production by curtailing air courses required for face ventilation. To combat this problem, supplemental support is installed in the tailgate entry adjacent to the longwall panel to maintain entry stability. However, when pillars and artificial roof supports fail to maintain the entry, enormous costs in lost longwall production are incurred while rehabilitation and restoration of the tailgate takes place.

Historically, the sizing and arrangement of pillars in gate roads are based on either trial-and-error practices in the mine or designs that were borrowed from successful operations. However, the performance of these traditionally sized square or rectangular pillars during longwall retreat has been poor, particularly in the tailgate entries. Consequently, the use of alternative pillar arrangements in the gate road entries is being adopted by many operators.

One such arrangement is the abutment-yield pillar configuration, which consists of an abutment pillar and one or more companion yield pillars. The abutment pillar is a support pillar designed to maintain entry stability and is often sized by empirical pillar design equations. The yield pillar is designed to provide a sufficient amount of axial deformation or yielding to allow for redistribution of overburden or abutment loads to accompanying abutment pillars providing a destressed area in the roof, therefore, offering protection to adjacent entries.

In this Bureau of Mines report, the term yield pillar is used to describe pillars that are undersized or smaller than pillars that have been designed according to the commonly used empirical pillar design equations. Except for one instance, which will be described later in this report, it was not possible to determine quantitatively whether the smaller pillars truly behaved as yield pillars.

A Bureau study (1),[2] as well as others (3-7, 12, 14), indicated the abutment-yield pillar method of gate road development was an effective means of ground control for retreating longwall systems. Mark (11) took steps toward the development of systematic guidelines for longwall abutment pillar design. Besides these guidelines, however, very few methods for longwall gate road pillar design are available. Researchers, such as Wilson (16) and Whittaker (15), have studied the effects of stress redistribution around longwall boundaries. However, because many of these investigations were conducted in European coal mines, their overall applicability and usefulness in the United States are limited. Therefore, the Bureau has developed a structured research program that will provide the necessary results to establish guidelines for improved gate road pillar design.

One aspect of the Bureau program was to conduct studies in order to monitor gate road pillar loading during the extraction of adjacent longwall panels. The present report describes a study conducted at a mine in southwestern Pennsylvania, which was experiencing severe ground control

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

problems ahead of the face in the longwall tailgate entries. These problems had drastically cut production and blocked air courses for ventilation. Extensive maintenance was required to reestablish and maintain airflow for face ventilation. Similar, but less extensive problems were experienced in the headgate.

The research was initiated on a set of three projected longwall panels. The Bureau developed an instrumentation plan that involved the three longwall panels and the four corresponding gate roads. Instruments were installed in each of the gate roads during development and monitored throughout the extraction of each panel. The study site was unique because pillar designs varied in each of the gate roads. The different pillar designs utilized in the gate roads enabled the assessment of these configurations under the same general geologic and loading conditions during panel retreat.

The instruments, VWS's, were installed in adjacent pillars in each gate road. Using instrument readings taken prior to mining and subsequent readings taken with respect to longwall face advance, the stressmeters were used to determine the change in vertical stress. This data were then analyzed to gain a better understanding of the mechanics of vertical load redistribution in the gate road pillars. Stress profiles across the pillars show the stress changes as they occur in the center and outer edges of the pillar with respect to face advance.

To assess the various pillar designs employed at the site, pillar stress and strength were compared to VWS data collected during panel retreat.

GEOLOGIC AND MINE SETTING

The longwall gate roads under investigation are located within the Appalachian Plateau's province of southwestern Pennsylvania. Structural 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 is composed of approximately 4 ft of gray shale, overlain by thin members of coal and carbonaceous shale (fig. 1). Upper stratigraphic members are composed primarily of gray sandy shales.

The floor rock varied throughout the four gate roads. Weak gray fire clay was predominant in the first three gate roads. The floor of the fourth gate road was composed of a slightly more competent gray sandy shale. Floor heave was not a problem in the study area, nor were other geologic features (e.g. clastic dikes, kettlebottoms, jointing, etc.).

The study area consisted of a series of three adjacent longwall panels and four corresponding gate road systems (referred to as 1, 2, 3, and 4 left) (fig. 2) the gate road entries and longwall panels are mined to a height of 6.5 ft. The overburden depth over the study area ranged from 455 to 645 ft. The panel dimensions are 600 by 3,850 ft. The average rate of advance for the longwall face was approximately 35 ft per three-production-shift day.

The pillar configuration utilized in the 1 and 2 left gate roads was the same design that had been used, with varying degrees of success, on previous panels. That is, during panel retreat, this design provided adequate support in the headgate entries, but failed to maintain stability in the tailgate entries. For this reason, mine personnel implemented different pillar configurations in 3 and 4 left to alleviate ground control problems, which had been encountered during the extraction of the previous panels. An additional alternative design was used in isolated areas of 3 and 4 left where poor roof conditions were encountered on development of these entries. The performance of these various pillar configurations in maintaining entry stability will be discussed later in this report.

Since stress changes occurring in the gate road pillars were monitored as a function of face advance, the following descriptions will be used to avoid confusion when relating the position of the longwall face to the instrumented pillars. 'On approach' will be used to describe the face advance as the face is approaching the instrumented pillars and a negative sign will be used for face position. 'Adjacent' will be used when the face is next to the instrumented pillars, and 'on retreat' will be used after the face has passed the instrumented pillars and a positive sign will denote face position.

INSTRUMENTATION PLAN

To characterize the stress changes occurring in the gate road pillars, VWS's were installed across the width of selected pillars in each of the gate roads. Stressmeter readings taken prior to mining, and subsequent readings taken with respect to longwall face advance provided data corresponding to changes in vertical stress. The stressmeters were installed in each pillar so that the load redistribution across the width of the pillars could be depicted as stress profiles, showing stress changes as they occur in the center and outer edges of the pillar. Using the pillar stress profiles, pillar stress averages were calculated by integrating across the width.

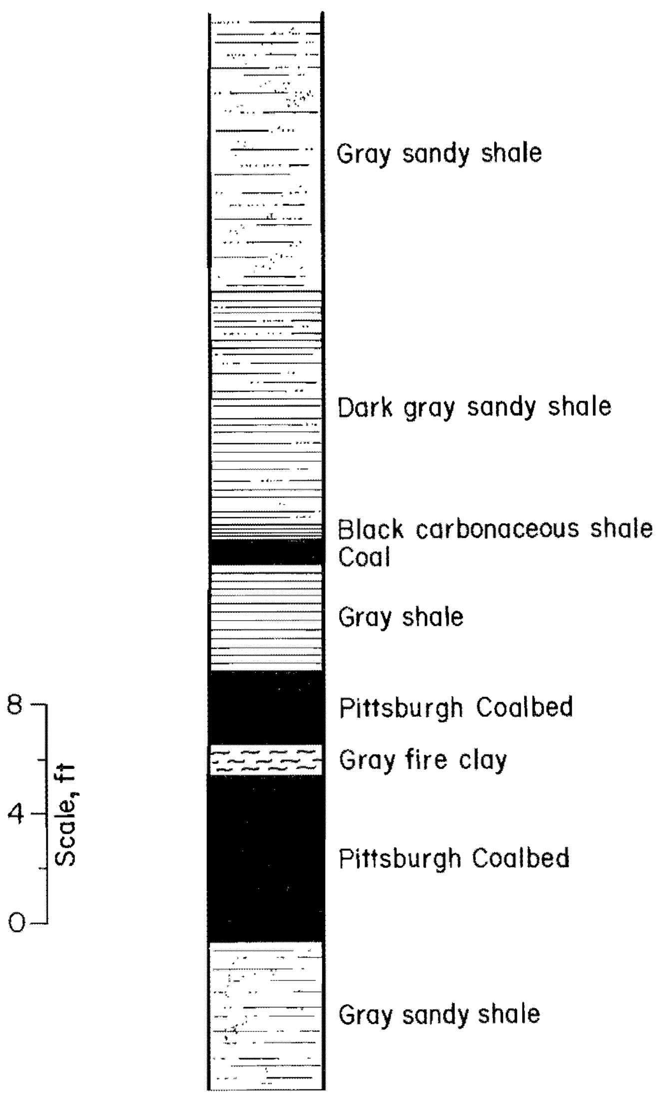

FIGURE 1.–Generalized stratigraphic column of study area.

During the development of 3 left, adverse roof conditions were encountered. These poor conditions were also experienced in other isolated areas around the longwall panels, such as in the 3 left north-east submains and in the 4 left gate road. These ground control problems were attributed to topographical relief created by a stream valley present at the surface, since the poor conditions were encountered when mining beneath this surface feature (fig. 3). The problem areas are significant because a fourth pillar configuration was implemented in several of these areas in an attempt to overcome the adverse roof conditions. In addition, the slow development rate in 4 left, caused by the poor roof conditions, required that panel 3C be shortened.

PANEL 3A

Panel 3A was the first of the three study panels to be mined. This panel utilized 1 left as its tailgate and 2 left as its headgate. The 1 and 2 left gate roads were three-entry systems comprised of two adjacent rectangular chain pillars measuring 45 by 80 ft. Figures 4 and 5 illustrate these pillars and the positions of the stressmeters across the pillar widths. Overburden thickness above the instrument sites in 1 and 2 left were 573 and 643 ft, respectively.

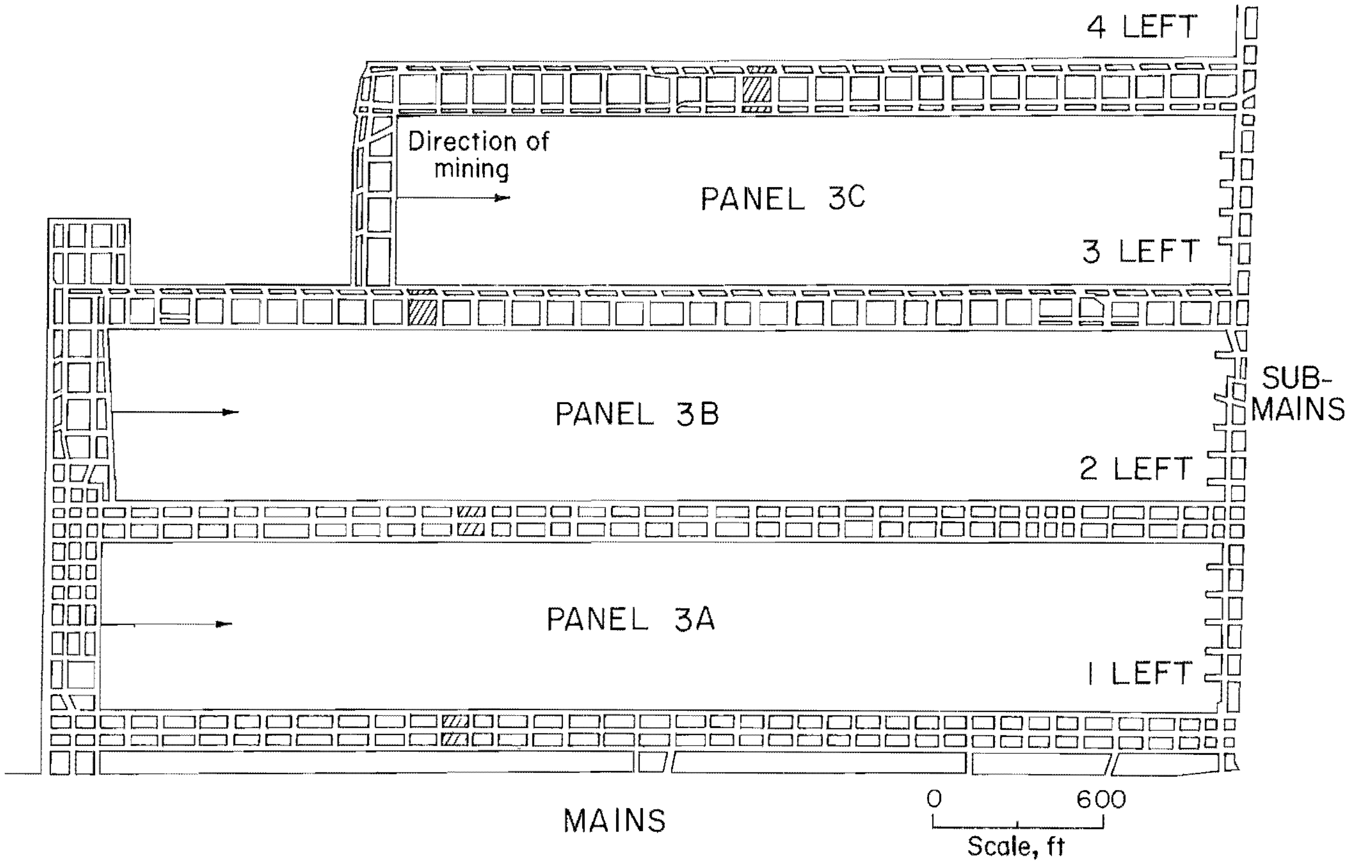

FIGURE 2.--Longwall panel layout and instrumentation sites.

Since panel 3A was the first of the series of three to be mined, pillar loading in 1 and 2 left should have been similar. However, this was not the case. Higher pillar loads were experienced in 1 left as the face approached and passed the instrumented pillars. The higher stresses experienced in 1 left may have been attributed to the influence of the main development entries, which were separated from 1 left by a 70-ft barrier pillar. After the longwall panel had passed the instrument site, difficulties were encountered with several stressmeters. Pillar sloughing damaged the stressmeters' lead wires preventing further data collection. The stress averages at the subsequent face positions were affected by the lack of data and accurate comparisons between 1 and 2 left beyond 100 ft of face retreat could not be made. An example of stress profiles obtained from pillars in 1 and 2 left are illustrated in figures 6 and 7.

PANEL 3B

The second panel extracted, panel 3B, utilized 2 and 3 left gate roads as tailgate and headgate systems, respectively. Gate road 3 left was a three-entry system that utilized an abutment-yield pillar arrangement. Throughout most of the length of 3 left, the abutment pillars were 85 by 95 ft and positioned adjacent to the working panel when that gate road served as the headgate. The yield pillars were 20 by 85 ft and were positioned adjacent to the unmined panel. The instrumentation site was located approximately 2,500 ft from the northeast submains between stoppings 24 and 25. This pillar arrangement was instrumented as shown in figure 8.

Stressmeter readings at this site were initialized when the face was a distance of 500 ft in advance of the pillars. However, at this time, Mine Safety and Health Administration (MSHA)

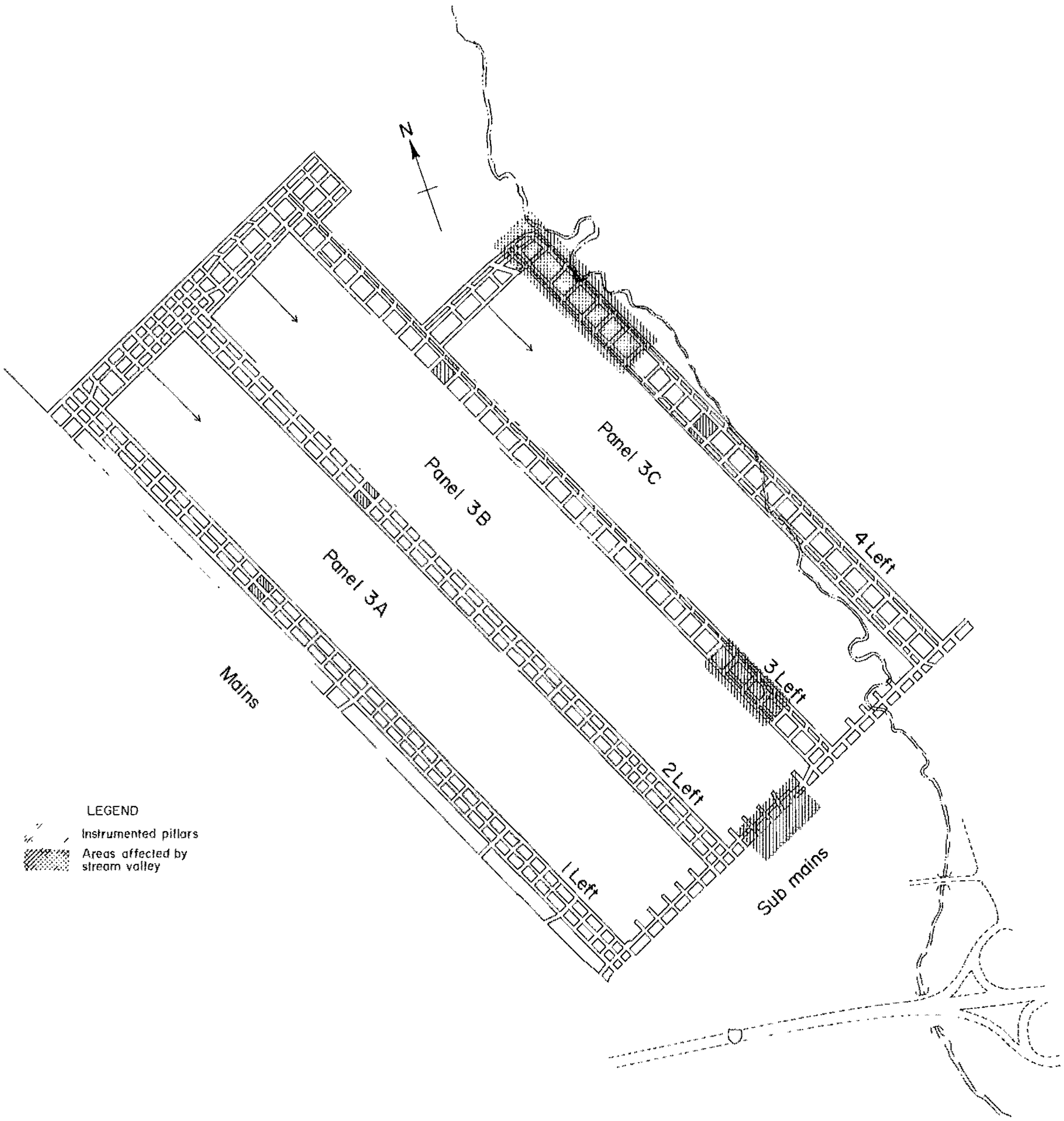

FIGURE 3.—Areas affected by topographical relief associated with stream valley.

permissibility on the stressmeter readout unit was temporarily revoked and monitoring had to be discontinued. Although the small pillar appears to have yielded (as indicated by the lack of pillar edge loading (fig. 9)), the behavior of this pillar, while the face drew near, cannot be determined. Fortunately, the permissibility problem was resolved and data collection resumed when the face was adjacent to the instrumented pillars. With the exception of the pillar edge closest to the working panel, the abutment pillar loading was low and uniformly distributed. Once the face had retreated a distance of 300 ft past the instrumented pillars, the loading appeared to stabilize.

The use of a yield-abutment pillar configuration in the 3 left gate road appeared to result in improved ground control conditions. Whereas, the rectangular pillars in 2 left experienced high core stresses as a headgate, the abutment-yield pillars in 3 left were loaded gradually as the face approached and

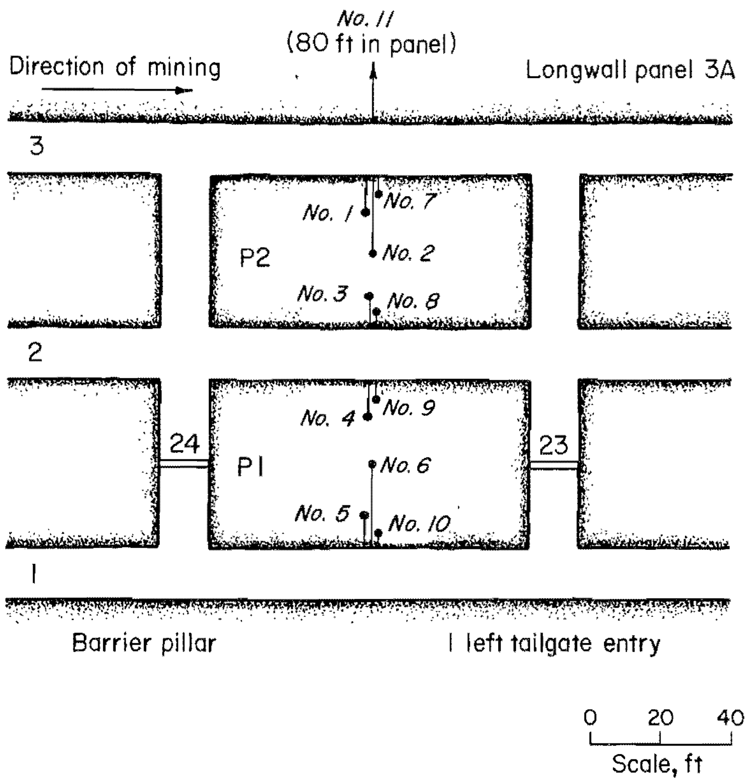

FIGURE 4.–Vibrating wire stressmeter positions (1-11) across width of pillars P1 and P2 in 1 left.

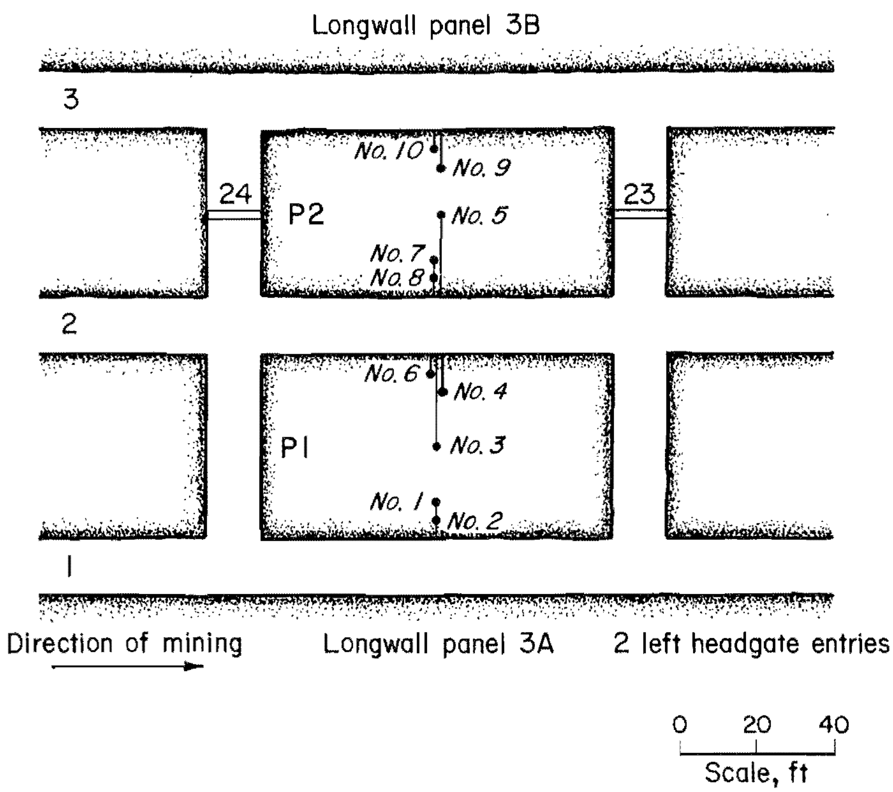

FIGURE 5.–Vibrating wire stressmeter positions (1-10) across width of pillars P1 and P2 in 2 left.

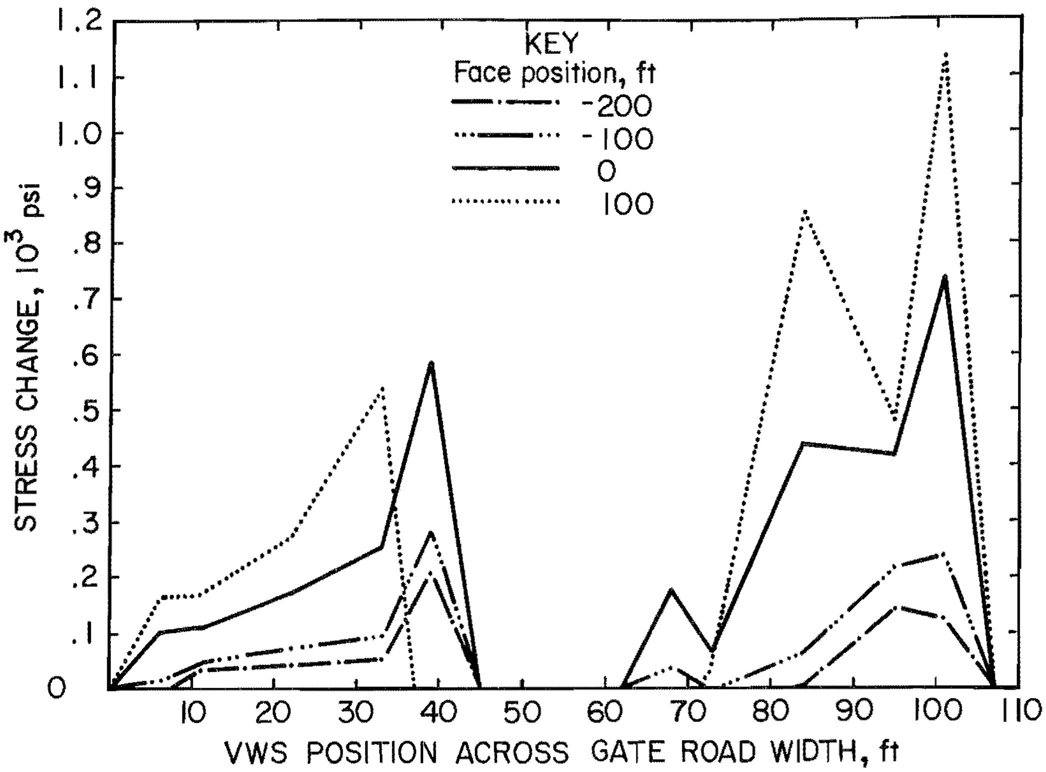

FIGURE 6.–Stress change profiles across width of pillars P1 and P2 relative to longwall face position in 1 left.

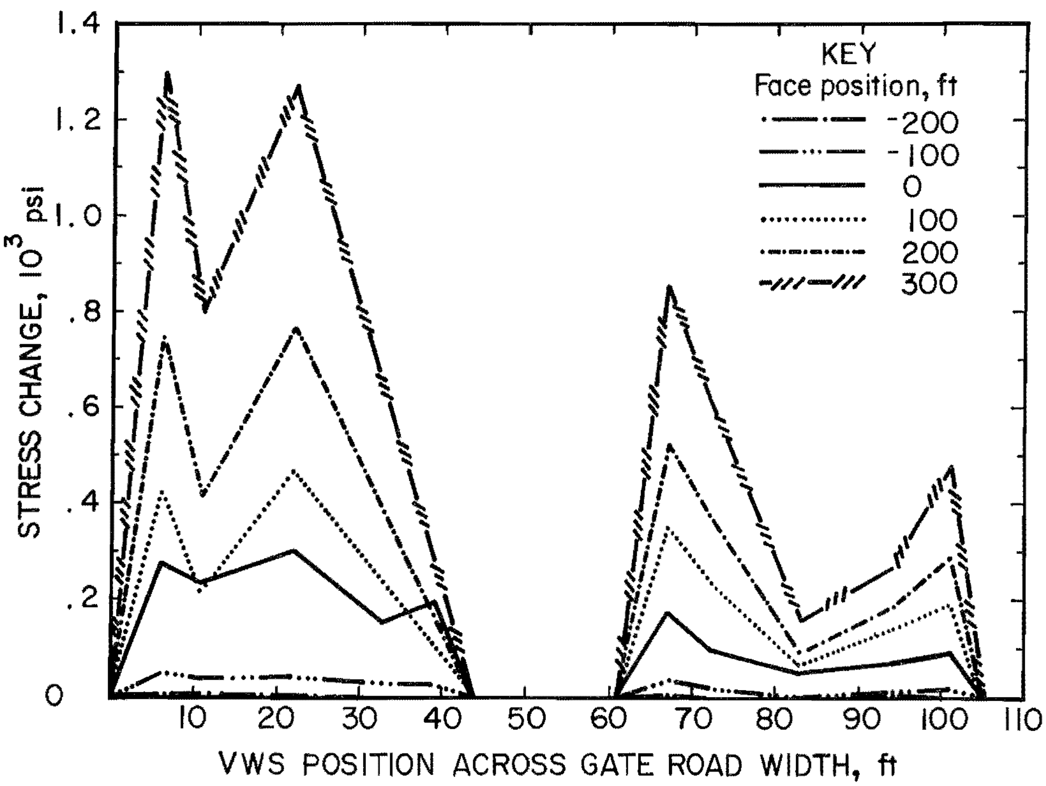

FIGURE 7.–Stress change profiles across width of pillars P1 and P2 relative to longwall face position in 2 left.

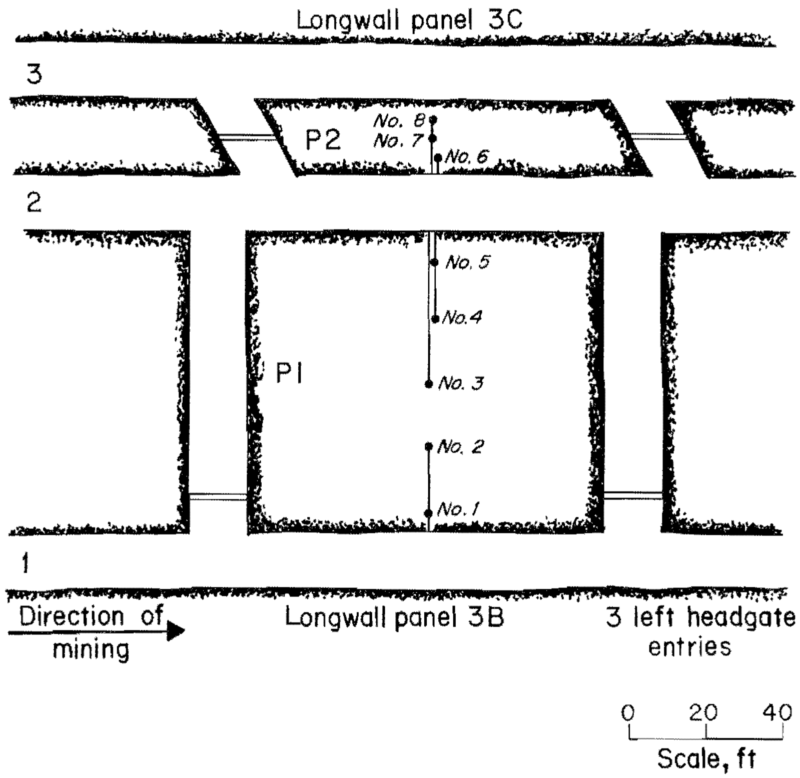

FIGURE 8.–Vibrating wire stressmeter positions (1-8) across width of pillars P1 and P2 in 3 left.

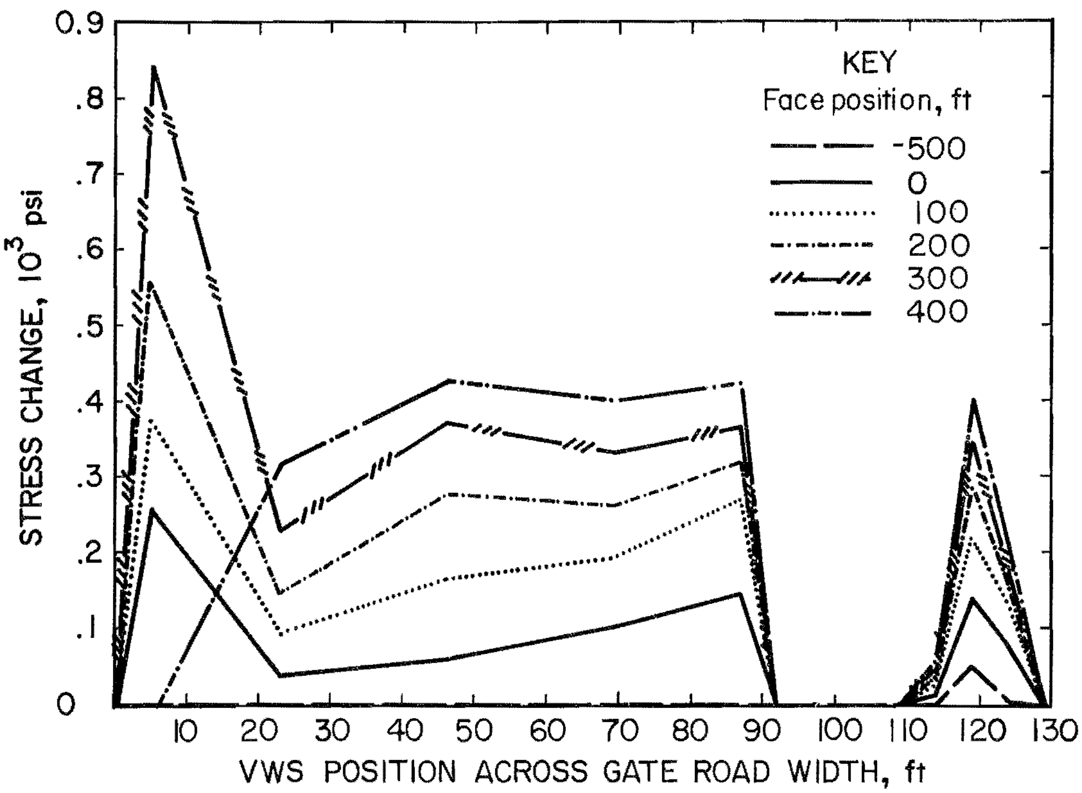

FIGURE 9.–Stress change profiles across width of pillars P1 and P2 relative to longwall face position in 3 left.

passed the instrument site and the pillar stress distribution appeared to stabilize.

An attempt was made to continue to read the stressmeters previously installed in 2 left in order that tailgate data could be analyzed. Unfortunately, a number of these stressmeters were inoperable and the recovered data were inconclusive. However, the detrimental effects of the high pillar stress experienced in 2 left became visually apparent when panel 3B was mined. Tailgate deterioration ahead of the face became so severe that supplemental support was required to enable complete extraction of the panel. The supplemental supports were constructed of concrete, which was poured into premade forms. These concrete pillars measured 4 by 6 ft, and were the height of the extraction. After these pillars were constructed the length of 2 left, the panel was able to be completed.

PANEL 3C

In the final panel that was extracted, panel 3C, 3 left became the tailgate system and 4 left served as the headgate. Four left was a four-entry system that utilized a yield-abutment-yield pillar configuration. The pillar dimensions were the same as 3 left, but an additional 20-ft-wide yield pillar was positioned next to the working panel (fig. 10). Figure 11 illustrates the pillar stress change profiles across 4 left. The small pillar adjacent to the working panel appears to have experienced load transfer, to the abutment pillar, when the face had retreated to a distance of 290 ft beyond the instrumentation site. The small pillar adjacent to the unmined area experienced very little loading, as expected, since it was located 160 ft away from the working panel.

Overburden thickness above the instrumented pillars in 3 and 4 left were 600 and 455 ft, respectively. The variation in overburden thickness was caused by the occurrence of a stream valley on the surface. This surface feature is important because severe roof control problems were associated with it when 4 left was being developed. Because of the slow advance through this area and because no roof improvement was evident, panel 3C was shortened. Consequently, the shortening of the panel prevented meaningful VWS data from being obtained from the 3 left tailgate. However, visual observations in this tailgate revealed that ground control conditions were significantly improved as compared to the 2 left tailgate. Mine personnel described the behavior of the 3 left tailgate as excellent in that excessive pillar sloughing and roof deterioration were not a problem and the panel was extracted without incident.

When comparing headgate data, pillar stresses experienced in 4 left were small relative to 2 left, but followed similar loading patterns experienced in 3 left, where comparisons could be made. This evidence suggests that the use of both the abutment-yield and yield-abutment-yield pillar configurations were effective in controlling stress in the headgates during panel extraction.

YIELD PILLAR INVESTIGATION

In addition to the pillar arrangements presented above, an alternative pillar design was implemented to combat poor roof conditions encountered early in the development stage of the 3 left gate road (approximately 150 to 350 ft from the 3 northeast submains). Yield pillars, measuring 10 by 60 ft, were driven on both sides of a 60- by 60-ft abutment pillar. This design created a four-entry system for approximately 200 ft of the gate road entries and positioned yield pillars adjacent to both the unmined and working panels. VWS's were installed in two of these pillars between stoppings 4 and 5. In order to better understand how these pillars would behave when subjected to longwall panel retreat loads, mine personnel drove an experimental yield pillar in good roof conditions near the end of 3 left between stoppings 30 and 31 (fig. 12). This pillar arrangement also was instrumented with VWS's and monitored during panel retreat.

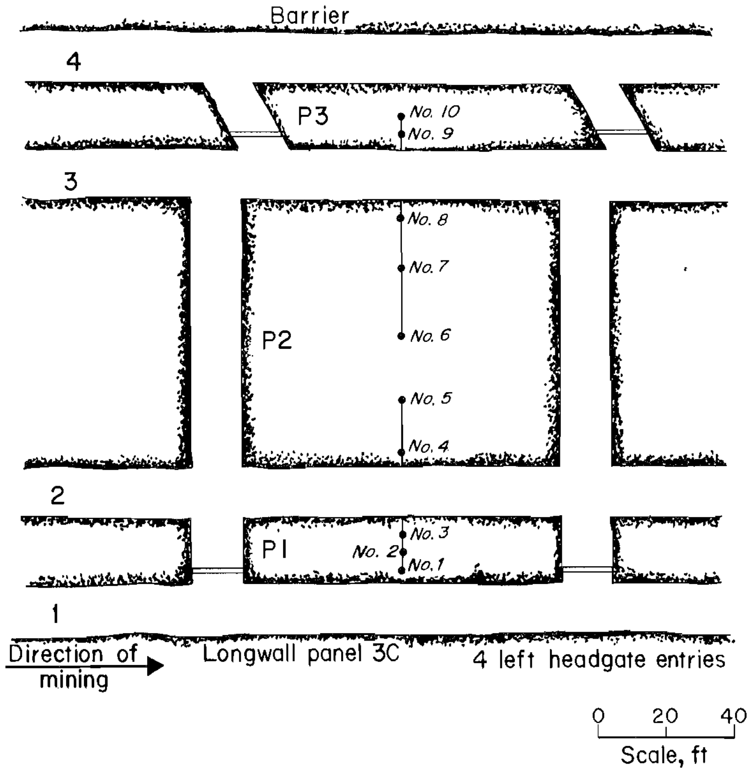

FIGURE 10.—Vibrating wire stressmeter positions (1-10) across width of pillars P1, P2, and P3 in 4 left.

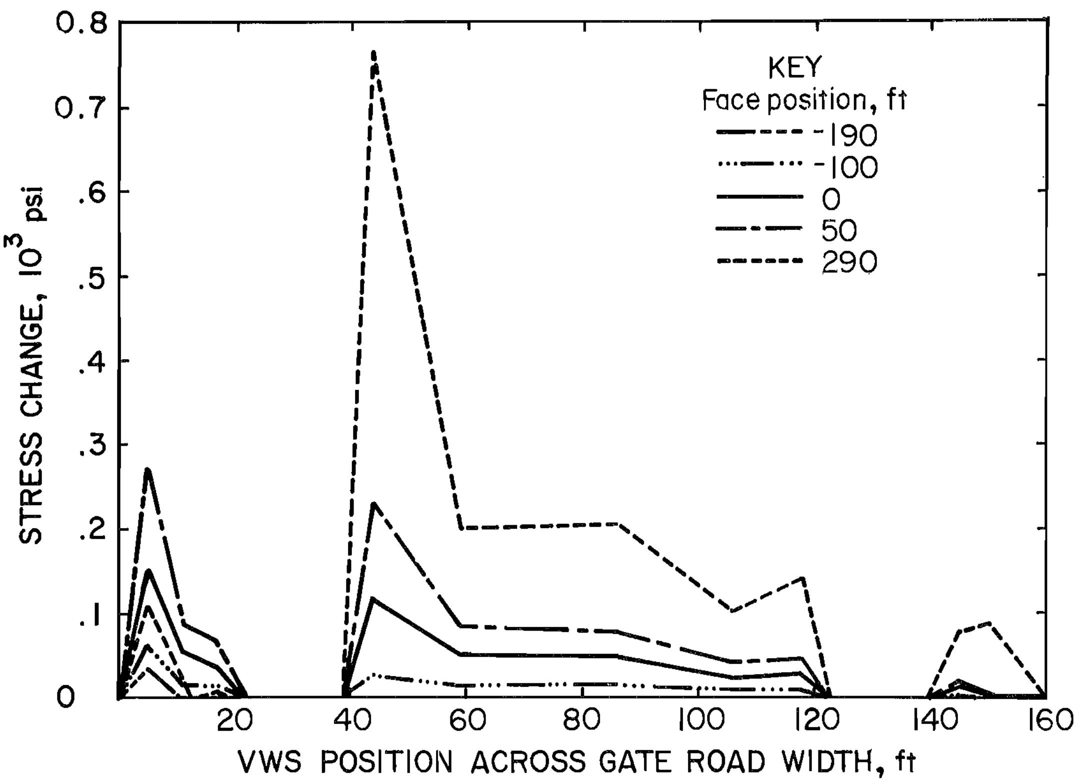

FIGURE 11.—Stress change profiles across width of pillars P1, P2, and P3 relative to longwall face position in 4 left.

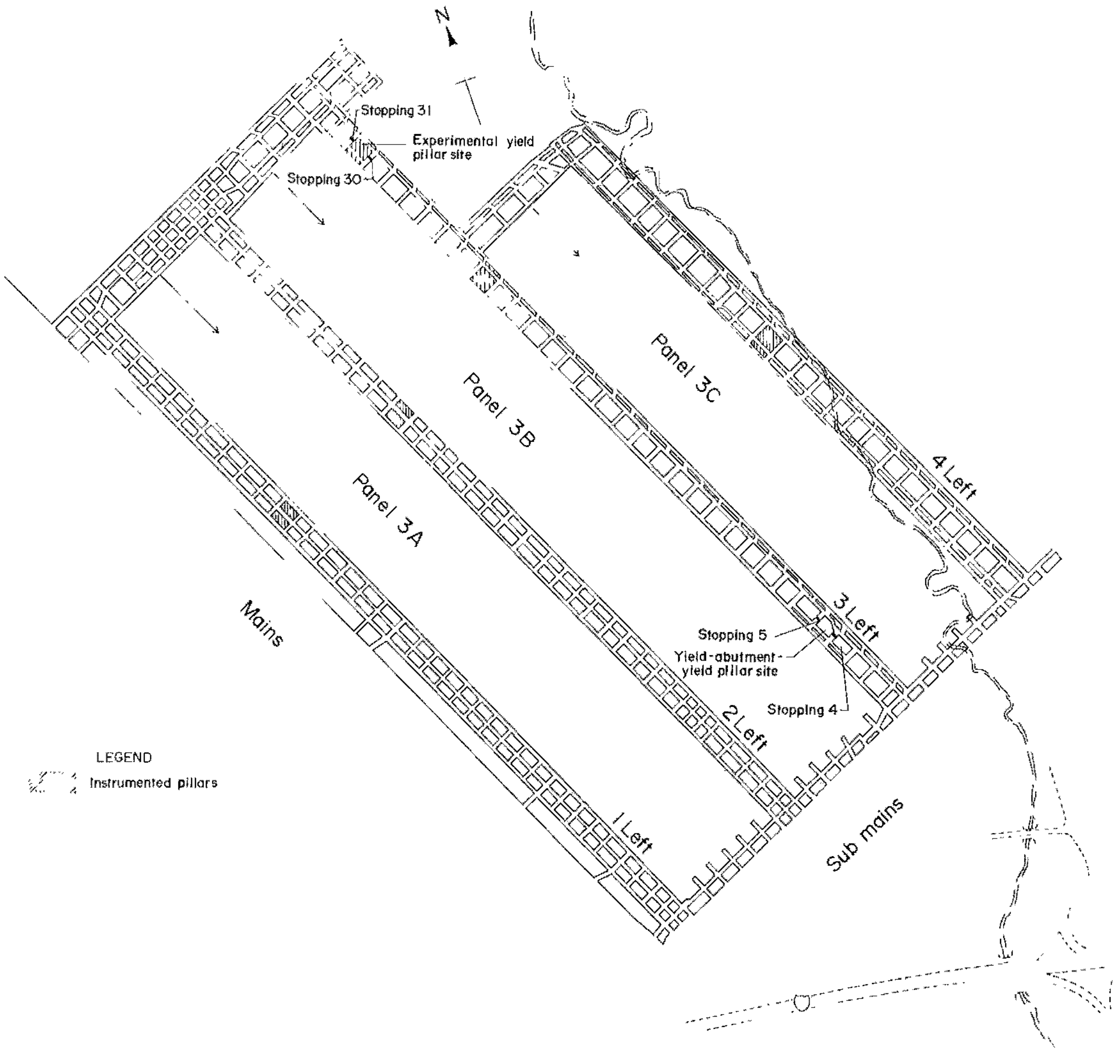

FIGURE 12.—Yield pillar locations in 3 left.

During the driving of the 10-ft-wide pillars, mine personnel continually monitored roof conditions and believed that the small pillars yielded and provided stress relief in the area. Dramatic roof improvement was realized two crosscuts after this pillar design was implemented. However, it was not possible to quantitatively determine whether the mechanism of yielding of the small pillars was responsible for the improved conditions on advance. It is possible that mining had progressed to a point where the effect of the stream valley was less severe or a general improvement in roof conditions was encountered. The following sections describe the behavior of the instrumented pillars at the two sites.

STOPPINGS 30 AND 31

To determine the behavior of this small pillar (7.5 ft wide), three stressmeters were installed at equal intervals across the pillar width, well in advance of panel extraction. In addition, visual observations were made when the face was in the process of mining past this pillar. The site was monitored on two separate occasions while the face was mining past the yield pillar. During the first visit, the face was positioned

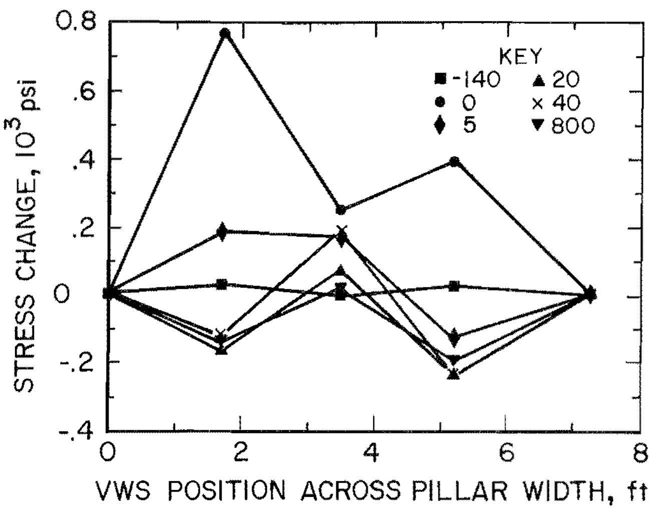

FIGURE 13.–Stress change profiles across width of experimental yield pillar relative to longwall face position in 3 left.

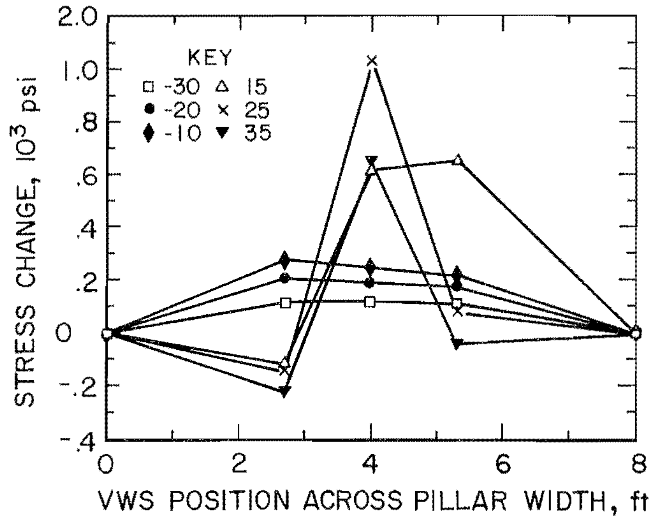

FIGURE 14.–Stress change profiles across width of yield pillar relative to longwall face position in 3 left.

about midway along the length of the panel, the area around the yield pillar was working (i.e., there was strong visual and audible evidence of roof strata and pillar activity). This activity was characterized by cracking and popping in the roof and by pillar sloughage. Stressmeter data collected at this time revealed that the pillar edges were experiencing increased loads. Four hours later, when the face had progressed approximately 5 ft, the same area was quiet and stress change data showed an unloading of the pillar (fig. 13). These visual and audible observations made while the face was progressing past the pillar indicated that the pillar transferred or "shed" its load to surrounding support members. The authors believe that this pillar's behavior was indicative of true pillar yielding.

STOPPINGS 4 AND 5

The small pillar at this site experienced very high loading at its core, and as similar to the experimental yield pillar, appears to have experienced yielding and load transfer (fig. 14). By comparison, the abutment pillar experienced very low, uniformly distributed stress changes. Although extremely poor roof conditions had been encountered during development in this area, only routine problems were prevalent during panel retreat.

ANALYSIS OF VIBRATING WIRE STRESSMETER DATA

The data presented below represent stress change rather than absolute stress values. Prior to gate road development, there exists some in situ vertical stress, which for the purposes of this paper, will be assumed to be equal to 1.1 psi per foot of overburden thickness. Development of the gate roads induces a redistribution of stress about the mined entries creating stress increases within the pillars. Since the stressmeters were installed in the gate road pillars after development, the stress states that existed prior to instrument installation must be assumed.

Table 1 shows the ratio of average pillar stress increases to the estimated average overburden stress for each of the gate roads. For example, a value of 9 represents an increase in average pillar stress of 9 pct of the estimated overburden stress. The original instrumentation plan called for the stressmeters in 2 and 3 left to be monitored when these gate roads served first as headgates and then later as tailgates.

TABLE 1. - Increase in average pillar stress over estimated average overburden stress, percent

Face position, ft	1 left,[1] 573-ft OB[2]		2 left, 643-ft OB		3 left, 600-ft OB		4 left, 455-ft OB		
	P1[3]	P2	P1	P2	P1	P2	P1	P2	P3
-200.....	9	7	0	0	([4])	([4])	0	0	0
-100.....	15	16	5	2	([4])	([4])	6	0	0
0........	36	57	33	12	17	11	16	7	0
100......	35	81	49	25	31	19	28	14	0
200......	38	109	87	37	44	24	([5])	([5])	([5])
300......	24	75	152	60	60	29	([5])	([5])	([5])
400......	([5])	([5])	182	95	52	34	([5])	([5])	([5])
500......	([5])	([5])	229	113	52	37	([5])	([5])	([5])
600......	([5])	([5])	245	107	53	38	([5])	([5])	([5])
700......	([5])	([5])	([5])	75	53	39	([5])	([5])	([5])
800......	([5])	([5])	118	59	53	41	([5])	([5])	([5])

[1]1 left represents stress change data as a tailgate system.
[2]Overburden. Overburden stress is assumed to be 1.1 psi per foot of overburden thickness.
[3]P1, P2, and P3 represent the pillars in each gate road.
[4]Data not obtained because of temporary suspension of MSHA approval on VWS equipment.
[5]Data obtained were inconclusive owing to limited number of operating stressmeters.

Although an attempt was made to read the gages to obtain pillar stresses in the tailgates, a number of the instruments were inoperable and the data proved to be inconclusive. Thus, with the exception of 1 left, stress change data presented in table 1 represent average pillar stress changes only in headgate systems. The significance of these data are discussed in the following section in reference to the observed behavior of each of the gate roads.

ANALYSIS OF SAFETY FACTORS FOR GATE ROAD PILLARS

To evaluate the performance of the various pillar configurations, several sets of safety factors were calculated. First, one set of values was obtained by relating the overburden stress calculated via the tributary area theory to an estimated pillar strength. Pillar strengths were estimated using three different empirical equations (2, 9, 13). A second set of values was determined by combining average pillar stresses (due to panel retreat), which were obtained from field measurements with the estimated overburden stress and relating these numbers with pillar strength estimates.

Holland's (9) equation was used to estimate pillar strength:

$$\delta_p = \delta_1 (w/h)^{.5},$$

where δ_p = pillar strength, psi,

δ_1 = compressive strength of Pittsburgh coal, psi,

w = pillar width, ft,

and h = pillar height, ft.

These data are given in table 2. The compressive strength of the Pittsburgh Coalbed was assumed to be 930 psi (8, 10). The safety factors given in table 2 indicate that all pillars were adequately designed to support gate road development

TABLE 2. - Factors of safety based on Holland's (9) pillar strength equation[1]

Face position, ft	1 left		2 left		3 left		4 left		
	P1[2]	P2	P1	P2	P1	P2	P1	P2	P3
([3])......	2.28	2.28	2.03	2.03	2.83	1.13	1.49	4.62	1.49
-200.....	2.17	2.19	2.03	2.03	([4])	([4])	1.49	4.62	1.49
0........	2.11	1.74	1.72	1.90	2.81	1.09	1.40	4.35	1.49
200......	1.89	1.44	1.38	1.70	1.96	1.04	1.35	4.20	1.48
300......	([4])	([4])	1.12	1.54	1.77	1.02	([4])	3.59	1.41
500......	([4])	([4])	.91	1.26	1.86	1.00	([4])	([4])	([4])

[1]Holland's method is used to calculate factors of safety because it yields values that fall between the least conservative (Bieniawski (2)) and most conservative (Obert (13)) methods.

[2]P1, P2, and P3 represent the pillars in each gate road.

[3]Safety factors based only on pillar loads estimated from the tributary area theory.

[4]Sufficient data not available for calculation of safety factor.

stress. However, a reduction in safety factors results as stresses associated with panel extraction are imposed on the gate road pillars. In some cases, the safety factors indicate that the pillars should have become unstable (i.e., factors of safety less than 1). One such case is evident in 2 left when the face had progressed to greater than 200 ft past the instrumented pillars. Mine personnel and the authors continually observed the onset of headgate pillar instability 200 to 300 ft behind the face in the forms of rib sloughage, local roof falls, and cutters. These visual observations are substantiated by data that show a clear drop in loading at the pillar edges and a shifting of load to the center of the pillar.

The deterioration of pillar stability was more readily apparent when 2 left acted as a tailgate. As discussed earlier, pillar and roof instabilities became so severe that extreme measures were required to maintain the tailgate for ventilation. In several instances caving occurred ahead of the face and supplemental support in the form of solid concrete cribs (formed and poured in place) were installed as the face was retreated.

In contrast, 3 left conditions were entirely different. Although safety factors for the 20-ft-wide pillar approached levels where instabilities would be expected, no extreme signs of deterioration were apparent. In addition, when 3 left acted as a tailgate no serious problems were encountered. The stress increases in 2 left as compared to 3 left is illustrated in figure 15.

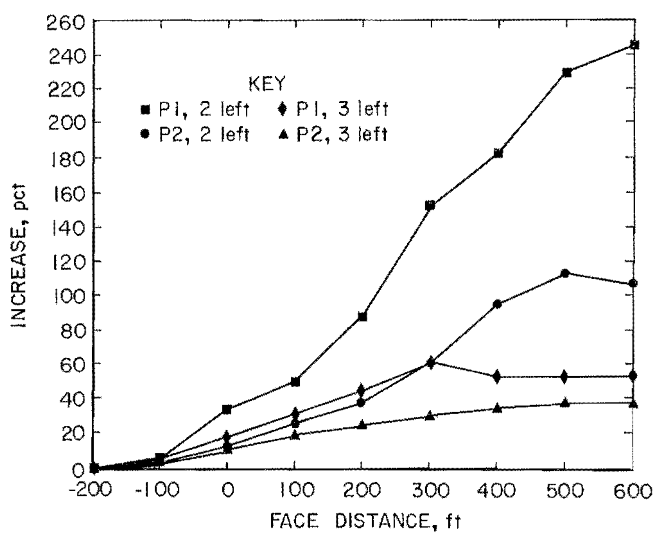

FIGURE 15.–Pillar stress change in 2 and 3 left as percent of average estimated overburden stress.

CONCLUSIONS

Several conclusions may be drawn from the information gained in this study. First, several characteristics of pillar loading became apparent from the collected data. The first noticable increase in pillar stress occurred when the longwall face had approached to within 200 to 300 ft of the instrumented pillars. Maximum pillar loads were not experienced when the face was adjacent to the instrument sites. In all cases pillar load continued to increase until the face had progressed to at least 300 ft past the sites.

Second, the pillar configurations utilized in 3 left (abutment-yield arrangement) and 4 left (yield-abutment-yield arrangement) proved to be more effective in maintaining gate road stability. VWS data indicate that average pillar loads were lower and appeared to stabilize when these configurations were used. The superior behavior of the abutment-yield and the yield-abutment-yield configurations was also evidenced by the fact that gate road stability was maintained throughout the extraction of panel 3C.

Third, data obtained from the yield pillars, as well as visual and audible evidence, suggest stress relief due to load transfer to surrounding support members during panel retreat.

Finally, although safety factors calculated from several commonly used pillar design equations indicated that the yield pillars utilized in 3 and 4 left were undersized, entry stability in these gate roads did not prove to be a problem. This study suggests that the use of one or more yield pillars in conjunction with a larger abutment pillar may result in improved ground control. These results point out the need for a comprehensive yield pillar study to determine the mechanisms associated with the transfer of abutment loads and to establish guidelines for yield pillar design.

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