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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

With Factors for Conversion to Units of the International System of Units (SI)

Abbreviation	Unit of measure	To convert to--	Multiply by--
ft	foot	meters	0.30
in	inch	centimeters	2.54
lbf	pound (force)	newtons	4.45
psi	pound (force) per square inch	kilopascals	6.89

THE EFFECTS OF A RETREATING LONGWALL ON A THREE-ENTRY GATE ROAD SYSTEM

By Richard A. Allwes,[1] Jeffrey M. Listak,[1] Gregory J. Chekan,[1] and Daniel R. Babich[2]

ABSTRACT

The Bureau of Mines conducted an in-mine case study on two consecutive three-entry gate road systems designed in accordance with the stiff-yield pillar design concept. This Bureau study was conducted in order to further develop technology that will improve the health and safety aspects of longwall mining. Support loading and strata activity were monitored to determine the effects of retreat longwall mining on the gate road ground control system. Analyses of pillar stress and roof bolt loading histories revealed that headgate roof support elements experienced cumulative loading throughout the life of the longwall panel. Tailgate pillar loadings had significantly different histories from the loading histories of the headgate pillars. Stress relief occurred in the tailgate pillars following the passage of the longwall face. Moreover, the stiff-yield pillar design, with the abutment pillar placed adjacent to the working panel when part of the headgate system, provided effective ground control in that no major roof falls or roof problems were experienced in the headgate or tailgate systems during longwall mining.

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INTRODUCTION

The design of a longwall ground control system requires knowledge of the local geology, the in situ stress field, and the mechanical properties of the coal and strata overlying and underlying the coal seam. An understanding of how longwall mining affects the stability of gate road entries and the loading of roof support elements is as important to gate road design as are the structural characteristics of the future longwall site. An effective ground control system will control the redistribution of stress in the surrounding rock mass of the gate road during panel extraction to a tolerable level so that the stresses and strata deformations are not beyond the capacity of the roof support elements. Once the capacity of one of the roof support elements is exceeded, strata failure is imminent.

The design of a gate road ground control system is often based upon previous experience with pillar recovery or longwall mining at the mine or at another mine with similar geologic conditions. An operator's dependency on past experience is usually due to a lack of understanding of, and information on the effects of longwall mining on support loading and strata activity. Common problems associated with gate road design include selecting a gate road configuration, sizing the pillars, and determining the amount and type of artificial supports required to maintain entry stability. In addition to the coal pillars, the roof support elements of a gate road ground control system include artificial supports such as roof bolts, trusses, crossbars, posts, cribs, and props.

Significant stress increases, called abutment pressures, are experienced by the gate road pillars and surrounding rock mass as a result of roof strata cantilevering over the mined-out longwall panel. Researchers and operators, also, have reported a buildup of abutment pressures in the tailgate system of the second or third consecutive longwall panel (1-3).[3] The deterioration of tailgate entry stability is attributed to an increase in abutment pressures as each successive longwall panel is mined.

Only two solutions to the problem of abutment pressures are currently known. One solution is to leave a barrier pillar between adjacent longwall panels in order to isolate the effects of one longwall panel from another. This solution is impractical because two distinct sets of gate roads have to be developed for each longwall panel, which results in a loss of coal reserves, higher support system costs, and an increase in development time. The second solution is to properly design the gate roads in order to control the abutment pressures to a tolerable level.

Two basic gate road pillar design concepts exist. One is the stiff pillar design concept, and the other is the yield pillar design concept (2). In the stiff pillar design concept, large pillars, called abutment pillars, are used to maintain entry stability in the gate roads. The abutment pillars adjacent to the working panel will provide enough resistance against the roof to create a shear of the roof strata at the rib line. Extensive shearing will reduce the amount of strata cantilevering over the mined-out panel. This will allow the gob to consolidate and accept load, thus decreasing the amount of abutment pressures occurring in the gate roads. In the yield pillar design concept, small pillars, called yield pillars, are used to maintain gate road entry stability. The yield pillars are designed for limited support capacity, and any excessive loading due to longwall mining is transferred to the adjacent unmined panel and to the gob area of the previously mined-out panel.

The stiff-yield pillar design is a combination of the two basic design concepts and utilizes both yield and abutment pillars. In a headgate system in which the abutment pillars are placed adjacent to

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

the working panel, the yield pillars maintain entry stability while the abutment pillars cause the roof strata to shear. When the yield pillar is part of the tailgate system and adjacent to the working panel, the yield pillars transfer all excessive loading to their companion abutment pillars and the consolidating gob. Conflicting results over the use of these design concepts for maintaining entry stability in both headgate and tailgate systems have been reported by various researchers and operators (1, 3-5).

An investigation was conducted using field interview methods to determine the data and information requirements of the underground coal mining industry for improving coal mine ground control technology and procedures (6). Mine operators expressed major interest in gate road entry design and ground control systems. As part of a program to develop technology that will improve the health and safety aspects of longwall mining, the Bureau of Mines conducted an in-mine case study at a cooperating mine. An instrumentation plan was developed to monitor the changes in pillar stress, roof bolt loading, and strata movement at selected areas along two consecutive longwall gate roads (7). The resulting data provide insight into the effects of longwall mining on gate road entry stability and roof support elements that are essential in the design of a ground control system. This Bureau report presents the final results of that study.

CASE STUDY

DESCRIPTION OF PANEL AND GATE ROADS

Figure 1 shows the general layout of the longwall panels under investigation. Panel 2 is approximately 470 ft wide and 4,800 ft long. The amount of overburden varies continuously along the longwall panel from a minimum of 330 ft to a

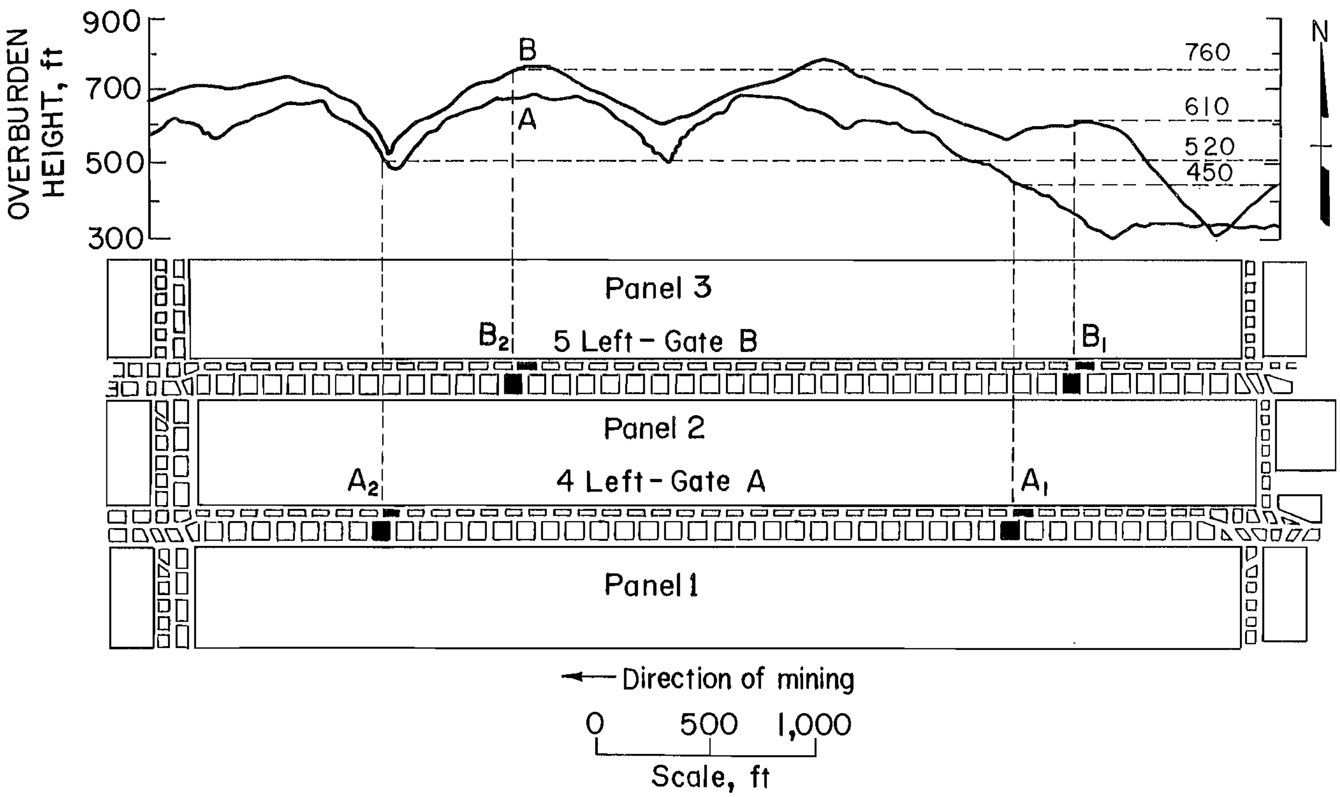

FIGURE 1. - Gate road geometry showing array locations and corresponding overburden heights.

maximum of 800 ft. The gate road systems (4 Left--Gate A and 5 Left--Gate B) are geometrically identical three-entry systems utilizing a stiff-yield pillar gate road design, with the abutment pillar placed adjacent to the working panel as part of the headgate system. The planned dimensions for the pillars are 95 ft by 95 ft for the abutment (stiff) pillars, and 95 ft by 36 ft for the yield pillars. The entries and crosscuts are approximately 15 ft wide. The extraction height in the gate roads is approximately 6-1/2 ft. It should be noted that, in practice, pillar dimensions varied from the stated design values; individual pillar dimensions are shown in the text where appropriate.

GEOLOGY

The coalbed extracted at the study mine is the Pittsburgh No. 8 coal. Normally, the shale parting and rider coal are also extracted, resulting in an average extraction height of 6-1/2 ft (fig. 2). This practice usually results in an immediate roof rock of thinly bedded gray shale (≈3 ft thick), which grades vertically into a thickly bedded calcareous shale (≈4 ft thick). The calcareous shale, in turn, grades vertically into the massive Redstone Limestone member (≈12 ft thick). The next coalbed above the Pittsburgh No. 8 is the Redstone Coalbed; these coalbeds are separated by approximately 21 ft of interburden. The Redstone Coalbed is only 1 ft thick in the study area.

The immediate floor rock of the Pittsburgh No. 8 Coalbed is a competent gray shale 2-1/2 ft thick throughout the study area. The gray shale is underlain by approximately 3 ft of claystone.

INSTRUMENTATION PLAN

Figure 1 shows the positions of the four instrumented areas, called arrays, and their corresponding overburden heights. There is a vertical exaggeration because the scale for the mine layout is much smaller than the scale for the height of overburden. The 4 Left gate road, Gate A, contains arrays A_1 and A_2 located under 450 ft and 520 ft of overburden, respectively. The arrays were positioned at least 800 ft away from the barrier pillars located at the beginning and end of the longwall panels. This was done to avoid any effect which the barrier pillars could have on the loading conditions occurring in the arrays.

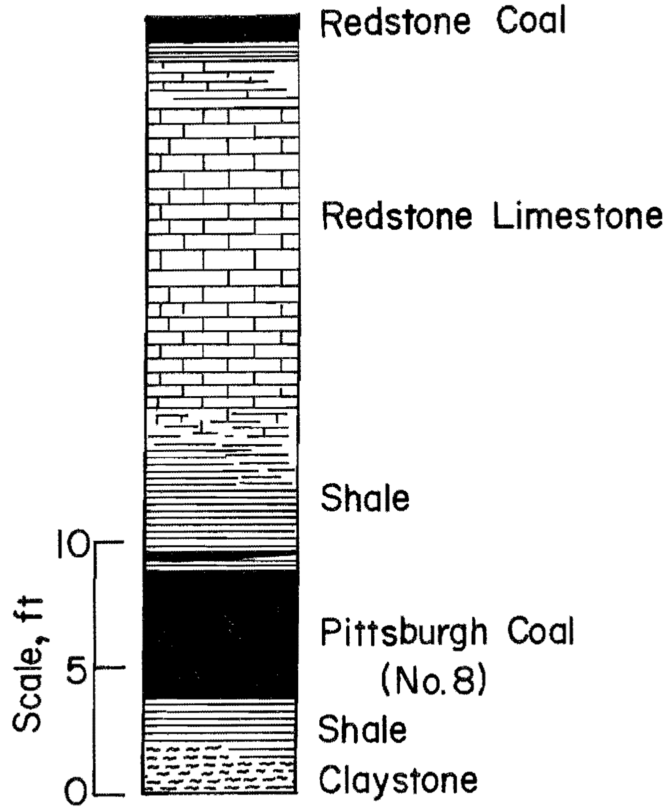

FIGURE 2. - Generalized stratigraphic column of panel 2 area.

Figure 3 (a representative array) shows the relative locations of the vibrating wire stressmeters, convergence stations, multipoint extensometer stations, and flatjack U-cell groups. Owing to the problems experienced during development, the actual location or numbering of the instrumentation in each array varies slightly from the representation shown in figure 3. In order to measure the changes in vertical uniaxial stress, the stressmeters were installed in the abutment and yield pillars. The stressmeters were positioned to determine the general stress distributions in the abutment and yield pillars by monitoring the stress changes lengthwise and widthwise across

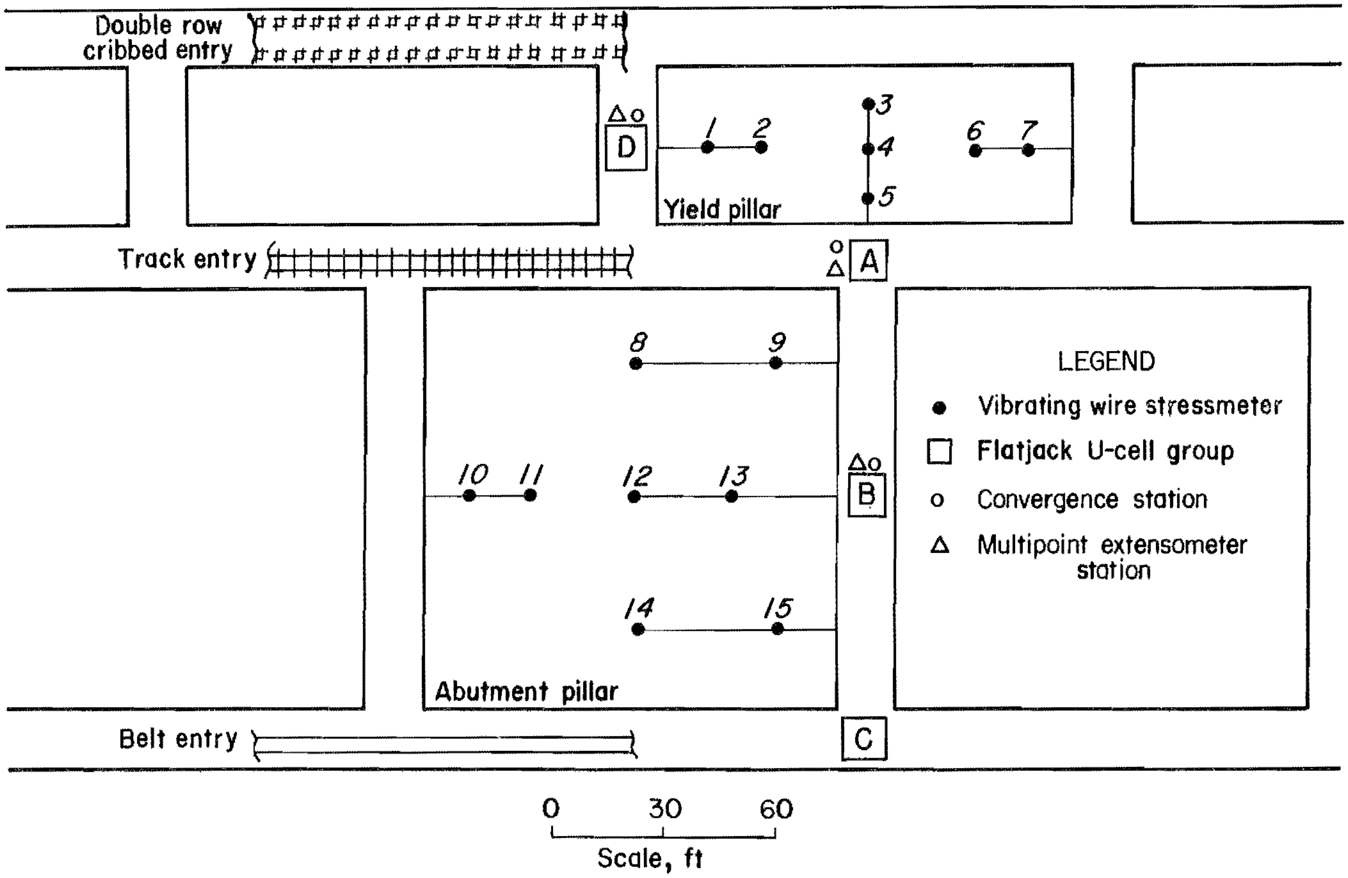

FIGURE 3. - Typical instrumentation plan for an array.

the pillars. Their positions also allowed the difference between the vertical stress change in the core of the pillar and in its outer layer or "skin" to be measured. Additionally, the stressmeters served to determine the stress changes in the pillars as a function of longwall face position and overburden height, and to compare the stress changes in the abutment pillars to those in the yield pillars.

Flatjack U-cells were used to measure the load changes on the 8-ft mechanical roof bolts in the crosscuts and entries. These U-cells are composed of two thin-walled, oil-filled, copper bladders; they measure bolt loads up to 20,000 lbf with an accuracy of ±500 lbf. The U-cells were installed in four groups of 12. Figure 3 shows the location of each U-cell group in the array; figure 4 shows an enlarged view of the flatjack U-cell arrangements.

Convergence and multipoint extensometer stations were installed near the flatjack U-cell groups (fig. 3). A combination convergence and multipoint extensometer station is shown in figure 5. The multipoint extensometer station measures differential strata movement within the mine roof relative to the uppermost roof anchor point. The convergence station measures overall roof to floor convergence. The purpose of the combined stations was to differentiate between roof sag and floor heave. However, the multipoint extensometers did not function properly, and only roof to floor convergence could be determined.

DATA COLLECTION AND ANALYSIS

The vibrating wire stressmeters, flatjack U-cells, and convergence stations were monitored together when they were part of the headgate system. [The 4 Left

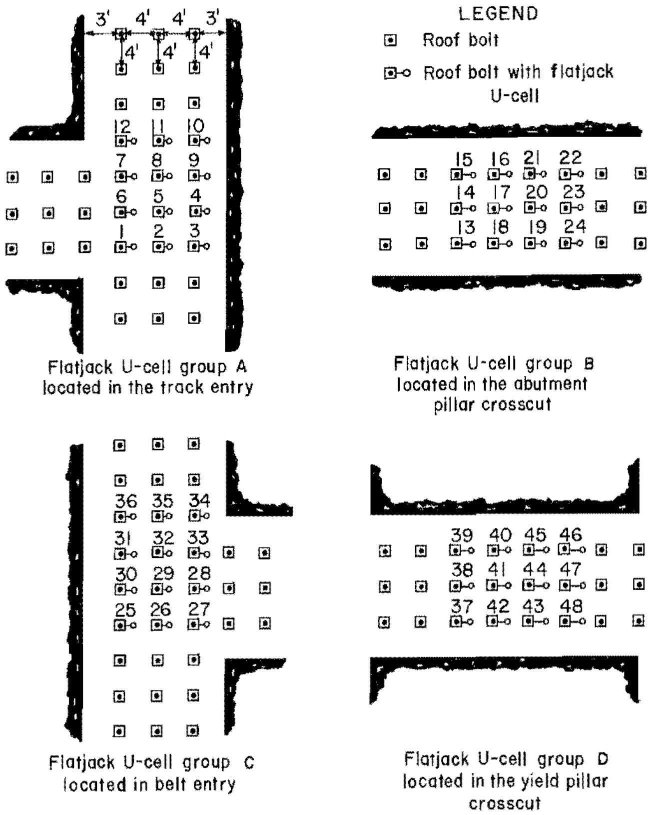

FIGURE 4. - Enlarged view of flatjack U-cell arrangement.

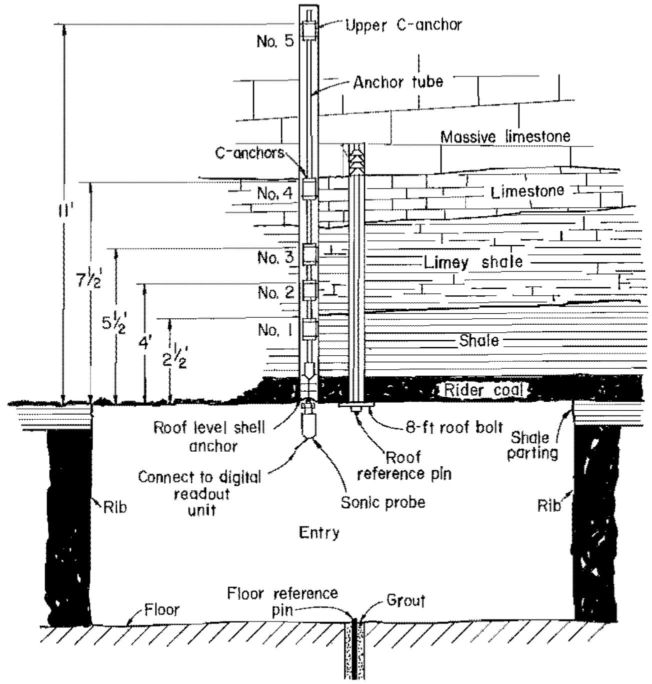

FIGURE 5. - Combination convergence and multipoint extensometer station.

gate road, Gate A, which contains arrays A_1 and A_2, was a headgate during the extraction of panel 1; the 5 Left gate road, Gate B, which contains arrays B_1 and B_2, was a headgate during the extraction of panel 2 (fig. 1).] However, only the vibrating wire stressmeters were monitored when they were part of the tailgate system. (The 4 Left gate road, Gate A, was a tailgate during the extraction of panel 2; the 5 Left gate road, Gate B, was a tailgate during the extraction of panel 3.) Accordingly, only convergence and roof bolt load changes occurring in a headgate system, and stress changes occurring in both headgate and tailgate systems, are discussed here.

VIBRATING WIRE STRESSMETER-- DATA COLLECTION

As the longwall face progressed along the length of the panels, readings were recorded for all of the stressmeters; these readings continued with greater frequency as the face was in the vicinity (±100 ft) of the arrays. The initial readings, taken when the stressmeters were originally installed, together with the additional readings recorded during the advance of the longwall face, were used to determine the change in the vertical uniaxial stress occurring in the chain pillars (yield and abutment pillars). The change in stress was calculated by the equation (8):

$$\Delta\sigma_r = \frac{\left[\frac{422,400}{T_o}\right]^2 \left[1 - \left(\frac{T_o}{T}\right)^2\right]}{11.4 - 0.66 \times 10^{-6} E_r}$$

where $\Delta\sigma_r$ = change in stress (psi),

T_o = initial stressmeter reading (period of vibration),

T = current stressmeter reading (period of vibration),

and E_r = modulus of elasticity, assumed to be 1.0×10^6 psi.

VIBRATING WIRE STRESSMETER-- DATA ANALYSIS

The vibrating wire stressmeter data were analyzed in a variety of ways to better understand the mechanics of vertical stress redistribution in the gate road pillars of a retreating longwall panel. Figure 6, the general form in which the data were first prepared for evaluation, shows a plot of stress change versus face position for each stressmeter in abutment pillar A_2 (fig. 7) when it was part of the headgate system.[4] Figure 8 shows the stress changes occurring in the abutment pillar A_1 (see figure 3 for stressmeter locations) when it was part of the tailgate system.

General considerations of the stress change data when the abutment pillars are part of the headgate system, as shown in figure 6, indicate that (1) all stressmeters in the abutment pillars tended to experience a stress increase throughout the life of the panel, with the zone of maximum stress increase occurring after the passage of the face; and (2) no noticeable stress relief occurred during the extraction of the remaining panel. In the majority of cases (13 out of 21), the general shapes of the stress curves for the other abutment pillars resemble those shown in figure 6.

The stress change data shown in figure 8 for abutment pillar A_1 when it was part of the tailgate system indicate that (1) all of the stressmeters (only those in which the data were complete) tended to experience a stress increase until the face was approximately 140 ft past the array; (2) a noticeable stress relief occurred once the face moved beyond the distance of 140 ft past the array; (3) all of the stress curves had the same general shape as those shown in figure 6; and (4) the stressmeters for which the data were complete showed that slightly more than half of the maximum stress

[4] Some of the stressmeters failed after their installation and are not shown in the figures that depict stress change versus distance to the longwall face.

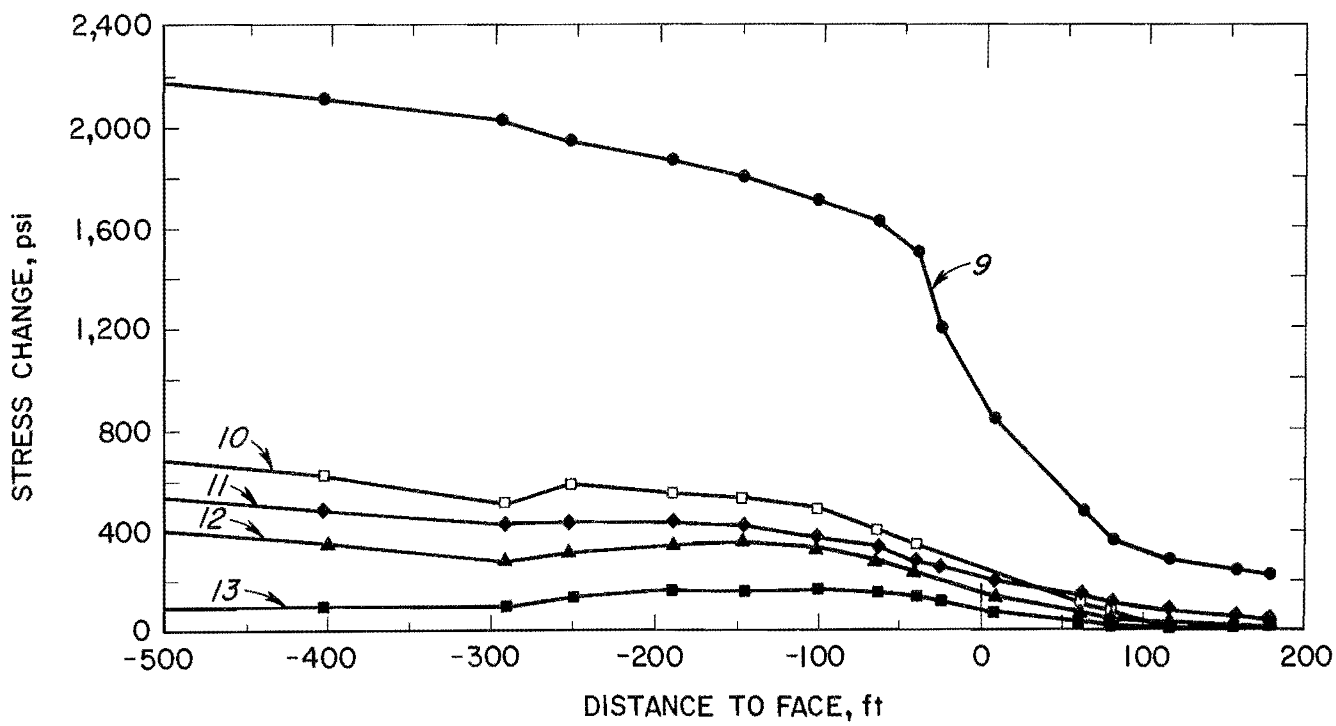

FIGURE 6. - Stress change versus distance to longwall face—array A_2, abutment pillar, headgate system.

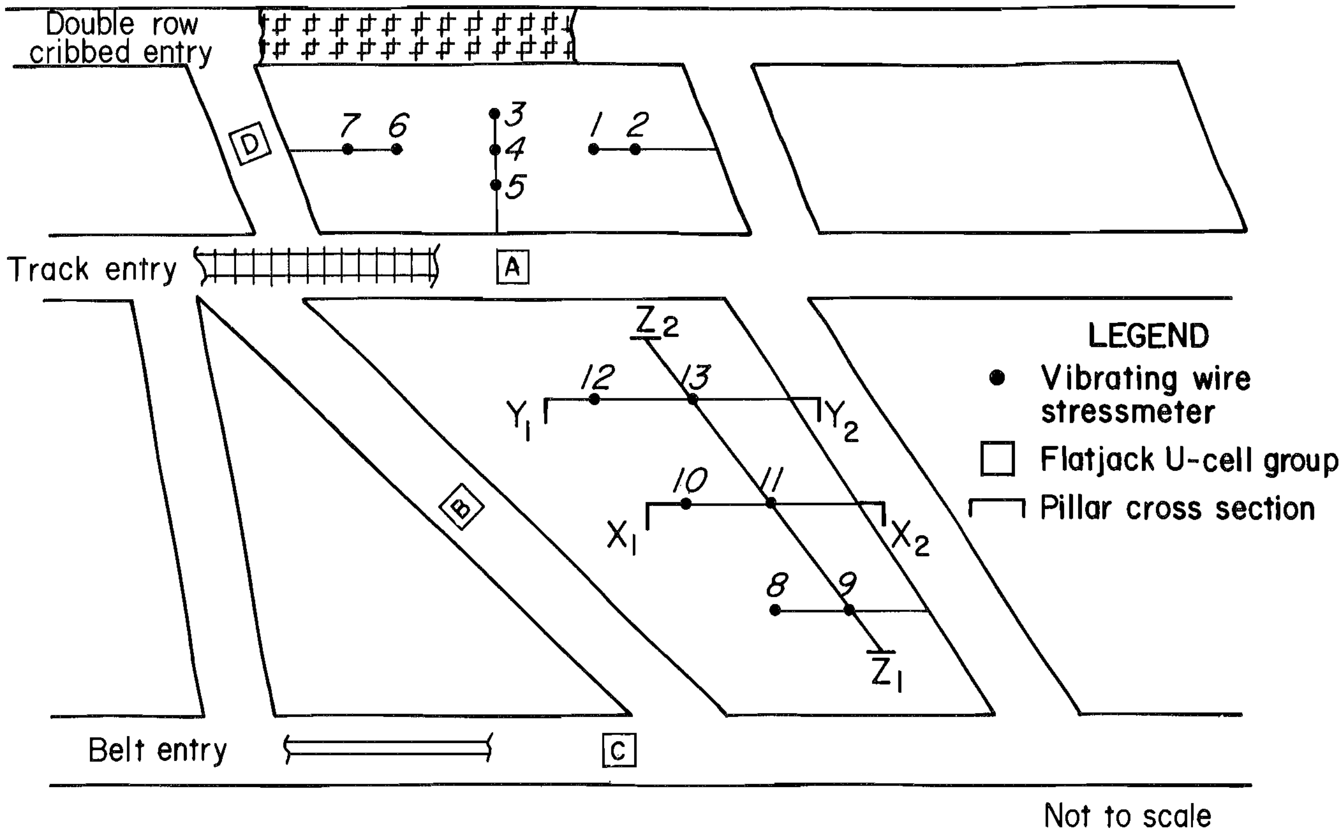

FIGURE 7. - Stressmeter, U-cell group, and cross sectional locations—array A_2, abutment and yield pillars.

increase was experienced when the face was adjacent to array A_1. The stress curves in figure 8 include the stresses caused by the extraction of panel 1.

PILLAR STRESS HISTORY OF PANEL PASSES

The first question addressed in terms of data analysis is when, relative to the moving longwall face, do the chain pillars of a headgate system experience a majority of their vertical stress increase? Figure 9 is a plot of the percent of maximum stress increase versus face position. The magnitudes of the percent of maximum stress increase are determined by the following method. The stress change for each stressmeter at a given face position is divided by the maximum stress change occurring in that stressmeter and expressed as a percentage. The percentages are then averaged to obtain one percentage value for the yield pillar and one percentage value for the abutment pillar.

An analysis of the headgate data in figure 9 indicates that (note—the following statements pertain to the average stress increase within a pillar) (1) at the time when the face passed the pillar location, the abutment pillar experienced only 35 pct of its total stress increase and the yield pillar experienced only 25 pct of its total stress increase; (2) the abutment pillar did not experience 75 pct of its total stress increase until the face was approximately 100 ft past the pillar location; (3) the yield pillar did not experience 75 pct of its total stress increase until the face was approximately 130 ft past the pillar location; (4) both the yield and abutment pillars demonstrated similar characteristics in terms of the assumption of percent of stress

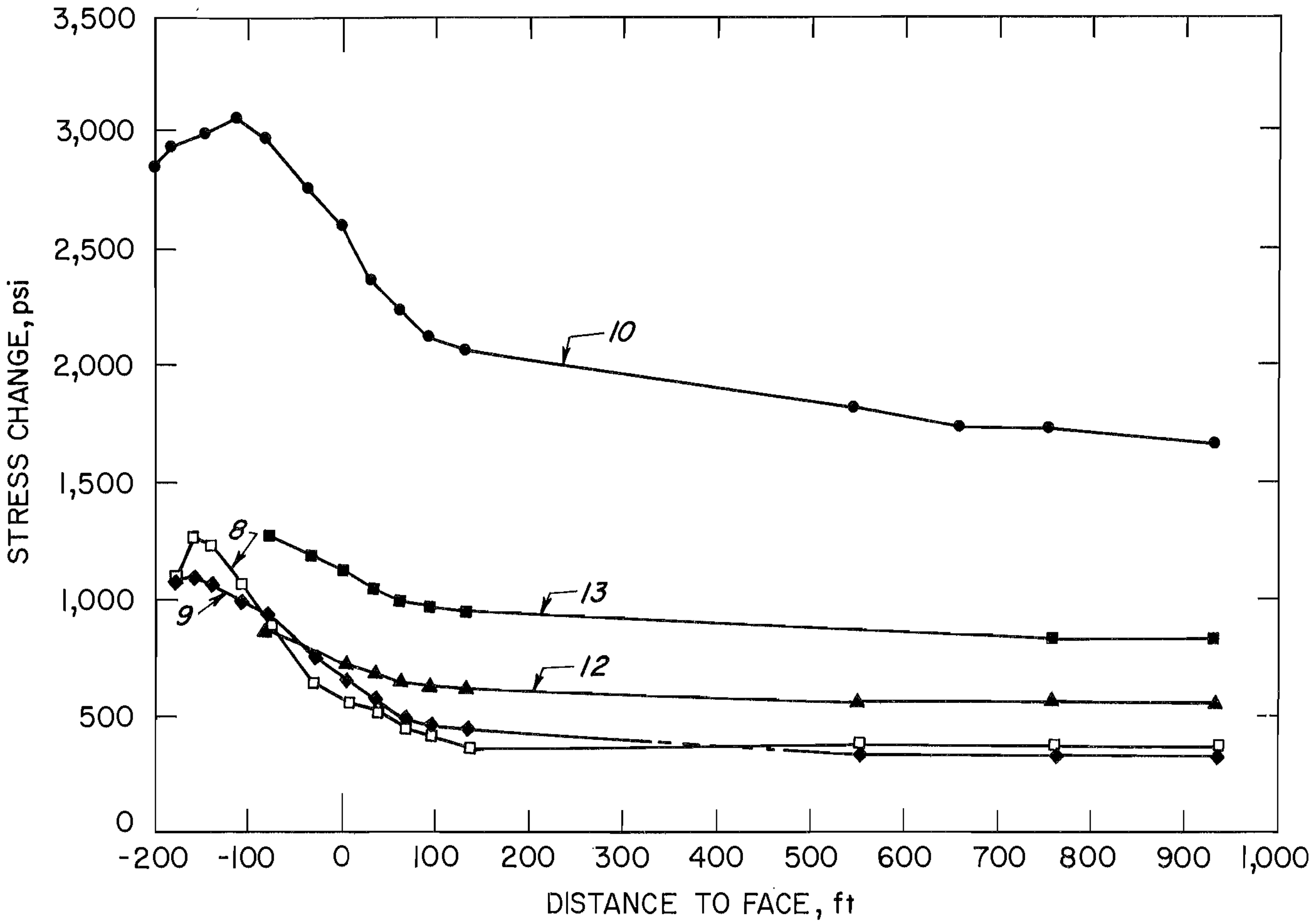

FIGURE 8. - Stress change versus distance to longwall face—array A_1, abutment pillar, tailgate system.

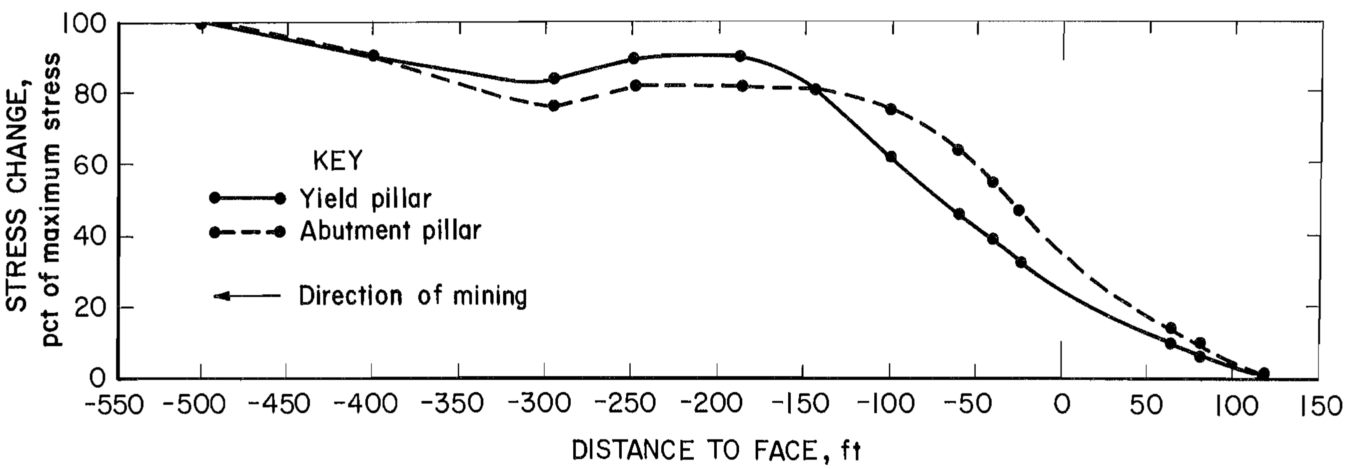

FIGURE 9. - Percentage of maximum stress increase versus distance to longwall face—array A_2, abutment and yield pillars, headgate system.

increase relative to face position; and (5) the abutment pillar tended to assume higher percentages of its full stress slightly before the yield pillar did.

The second question addressed is when, relative to the longwall face, do the chain pillars of a tailgate system experience a majority of their vertical stress increase? Figure 10 is a plot of the percent of maximum stress increase versus face position for array A_1. All of the stressmeters active in the yield and abutment pillars are used. The magnitudes of the percent of stress increase are generated in the following manner. The last recorded stressmeter readings for both the yield and abutment pillar of array A_1 (when array A_1 was part of the headgate system) are subtracted from all of the corresponding stressmeter readings of array A_1 (when array A_1 was part of the tailgate system). This allows an analysis of the data to be conducted of stresses in chain pillars caused by the extraction of panel 2 (tailgate stresses), independent of stresses caused by the extraction of panel 1 (headgate stresses). The stress change for each stressmeter at a given face position is divided by the maximum stress change occurring in that pillar, and the result is expressed as a percentage. The percentages are then averaged to obtain one percentage value for the yield pillar and one percentage value for the abutment pillar.

An analysis of the tailgate data (independent of the headgate data) contained in figure 10 indicates that (1) both the abutment and yield pillar experienced approximately 55 pct of their maximum stress increase when the longwall face was adjacent to the instrumented pillars; (2) the abutment pillar experienced maximum stress increase when the face was approximately 140 ft past the pillar location; (3) stress relief began in the abutment pillar once the face moved beyond 140 ft past the pillar location; (4) the yield pillar was never stressed to more than 63 pct of maximum stress increase, due to the fact that the maximum stress change experienced by individual stressmeters occurred at various longwall

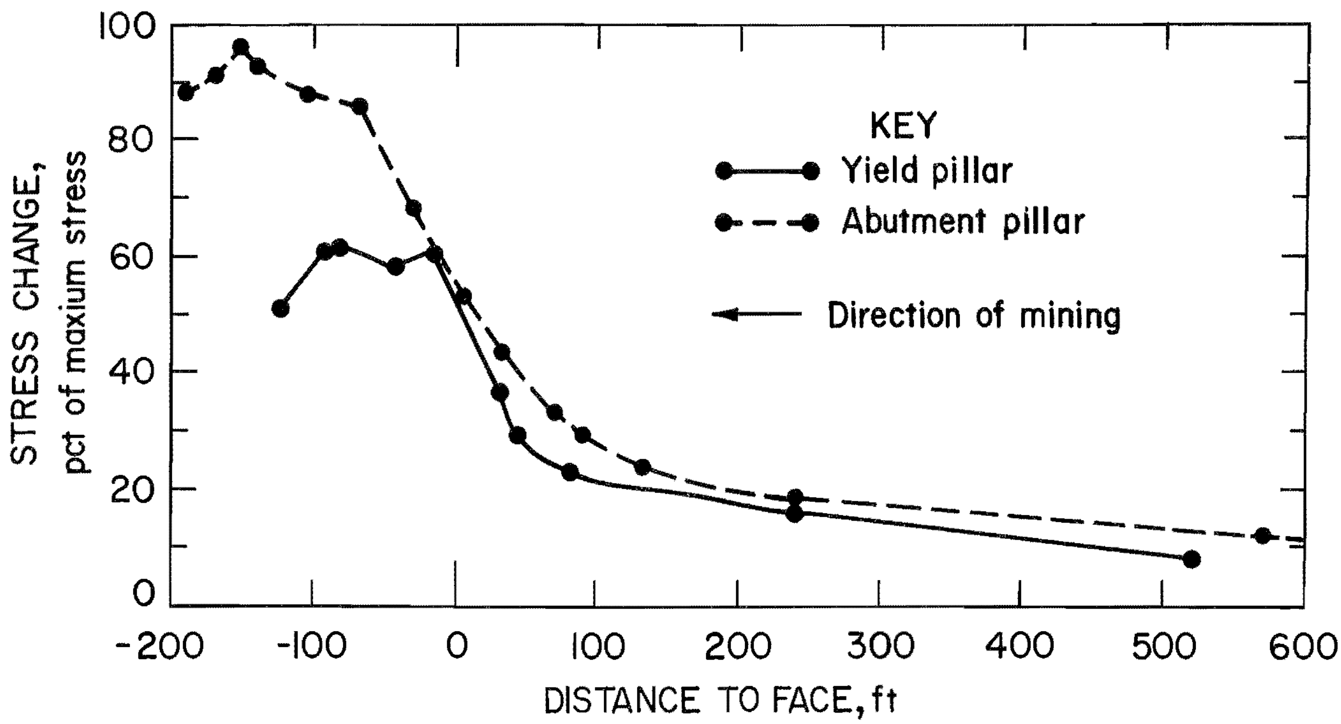

FIGURE 10. - Percentage of maximum stress increase versus distance to longwall face—array A_1, abutment and yield pillars, tailgate system.

face positions; (5) stress relief began in the yield pillar when the face moved beyond 80 ft past the pillar location; and (6) the abutment pillar assumed a higher percentage of maximum stress change slightly before the yield pillar did.

STRESS EXPERIENCE

In discussing the initial and final loading in the headgate chain pillars due to longwall mining, "significant stress increase" (initial loading) is defined as 5 pct of the maximum stress change occurring within a chain pillar, and "final loading" is defined as 95 pct of the maximum stress change experienced by a chain pillar.

Using abutment pillar A_2 as being representative of initial loading experience of headgate chain pillars, it was found that (1) there was significant stress increase within the skin of the abutment pillar (stressmeter location 9) when the face was approximately 150 ft in advance of the pillar; and (2) significant stress increase occurred within the core of the abutment pillar (stressmeter location 10) when the face was approximately 110 ft in advance of the pillar.

Selecting yield pillars A_1, A_2, and B_1 as representatives of the final loading experience of headgate chain pillars, these following statements can be made (1) final loading within the core of the yield pillars was experienced when the longwall face was approximately 280 ft past the pillar locations; and (2) final loading occurred within the skin of the pillars when the face was approximately 600 ft past the pillar locations.

Using the yield and abutment pillar of array A_1 as representative of initial and final loading experience of tailgate chain pillars, it was found that (1) significant stress increase was experienced by the chain pillars when the longwall face was more than 700 ft in advance of the pillar locations; (2) final loading occurred in the abutment pillar when the face was approximately 150 ft past the pillar location; and (3) the yield pillar never achieved the final loading status, owing to the random occurrence of maximum stress increase experienced by individual stressmeters with respect to longwall face position.

STRESS DISTRIBUTION WITHIN CHAIN PILLARS

To address the question of stress distribution within the headgate chain pillars, the data have been treated in two different ways. The stress distributions are shown as stress profiles along specific cross sections for abutment pillar A_2 and as isopachs for abutment pillars B_1 and B_2. Using figures 1 and 7 as references, figure 11 shows stress profiles through the abutment pillar A_2 for both the maximum values of stress increase and the stress increases at the time the face passed the center line of array A_2. Figures 12 and 13 show stress isopachs for the maximum vertical stress increase in the abutment pillars B_1 and B_2, respectively.

An evaluation of the data contained in figures 11, 12, and 13, indicates that

1. The stress distribution in abutment pillar A_2 appears to be highly influenced by the direction of the approaching longwall face, which does not appear to be the case for abutment pillars B_1 and B_2. The skin of the abutment pillar A_2, adjacent to the longwall panel (stressmeter location 9 in figures 7 and 11*A*), contains the peak abutment stress (maximum stress increase experienced by a pillar). However, figures 12 and 13 reveal that the peak abutment pressures occur in the core or central portion of the abutment pillars B_1 and B_2 and not in the skin, as is the case for abutment pillar A_2.

2. The data rarely indicate high skin loadings in the B_1 and B_2 abutment pillars. Maximum stress changes generally tend towards the core of these two abutment pillars.

No statements can be made concerning the sress distributions within tailgate pillars, because the data are insufficient for creating contours of maximum stress increases. Many of the stressmeters and/or their lead wires were destroyed as a result of the mining process,

Stress profile	Distance to face, ft
1	0
2	>-500

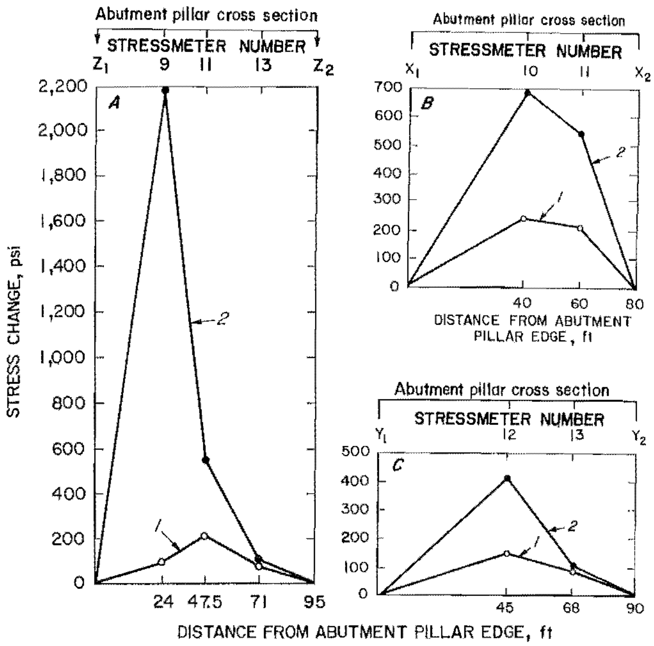

FIGURE 11. - Cross sectional stress increase profiles—array A_2, abutment pillar, headgate system. *A*, Cross section Z_1Z_2; *B*, cross section X_1X_2; *C*, cross section Y_1Y_2.

gate road deterioration, and/or inaccessibility when the longwall face was near the arrays.

STRESS INCREASE MAGNITUDES

The general questions of magnitudes of chain pillar stress increases for both headgate and tailgate systems are addressed in tables 1 and 2. The following explanation of the symbols used in the tables is given. The maximum increase in vertical stress experienced by any active stressmeter within a chain pillar is listed as $\Delta\sigma_{max}$. The maximum increase in vertical stress experienced in the core (central portion) of each chain pillar is listed as $\Delta\sigma_{max\text{-}core}$. The symbol σ_o represents the in situ vertical stress that existed in the coal prior to the start of mining (assumed to be 1 psi/ft of overburden). The final change in headgate stress recorded during the extraction of a longwall panel is listed as $\Delta\sigma_f$. The symbol $\Delta\sigma_r$ is the resultant change in stress and is equal to the maximum tailgate stress change ($\Delta\sigma_{max}$) minus the last recorded headgate stress change ($\Delta\sigma_f$) for a particular stressmeter. Therefore, $\Delta\sigma_r$ is the maximum stress change experienced

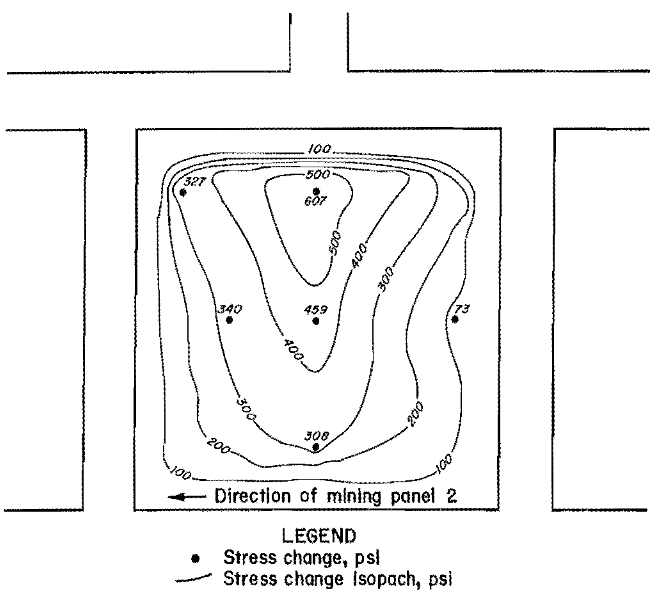

FIGURE 12. - Stress isopachs for maximum vertical stress increase—array B_1, abutment pillar, headgate system.

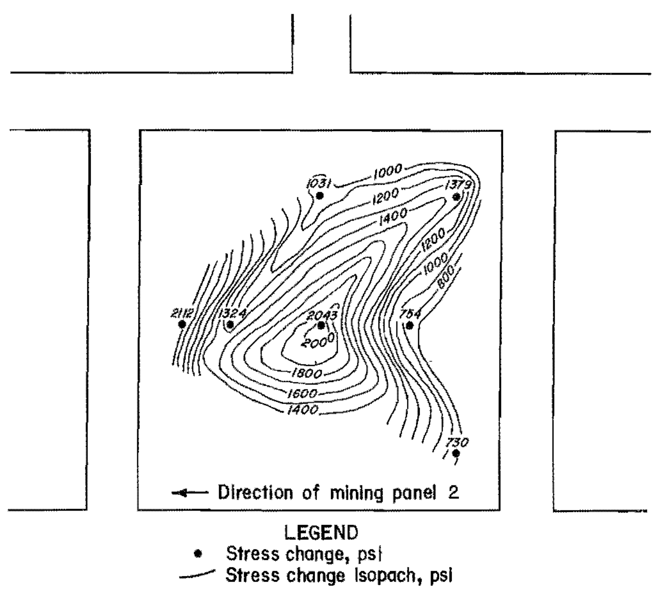

FIGURE 13. - Stress isopachs for maximum vertical stress increase—array B_2, abutment pillar, headgate system.

TABLE 1. - Overburden stress factor--headgate system

Instrumentation site..	Array A_1		Array A_2		Array B_1		Array B_2		Pillar averages	
	Abutment	Yield	Abutment	Yield	Abutment	Yield	Abutment	Yield	Abutment	Yield
Maximum pillar stress:										
$\Delta\sigma_{max}$..........psi..	1,640	580	2,180	460	630	690	2,110	890	1,640	655
Face position...ft..	-2,580	-200	-500	-500	-2,380	-2,045	-135	-415	NAp	NAp
$\Delta\sigma_{max}/\sigma_o$............	3.6	1.3	4.2	0.9	1.0	1.1	2.8	1.2	2.9	1.1
Maximum core pillar stress:										
$\Delta\sigma_{max-core}$.....psi..	520	340	690	460	600	460	2,050	890	965	538
Face position...ft..	-2,580	-200	-500	-500	-2,045	-1,395	-135	-415	NAp	NAp
$\Delta\sigma_{max-core}/\sigma_o$.......	1.2	0.8	1.3	0.9	1.1	0.8	2.7	1.2	1.6	0.9

NAp Not applicable.
$\Delta\sigma_{max}$--The change in maximum stress occurring in the pillar.
σ_o--The virgin stress, assumed to be 1 psi/ft of overburden.
$\Delta\sigma_{max-core}$--The change in maximum stress occurring in the core of the pillar.

TABLE 2. - Overburden stress factor--tailgate system

Maximum stress.................	Pillar		Core of pillar	
	Abutment	Yield	Abutment	Yield
$\Delta\sigma_{max}$.....................psi..	3,070	2,460	NAp	NAp
$\Delta\sigma_{max-core}$................psi..	NAp	NAp	1,580	1,390
Face position..............ft..	-104	-124	-193	-189
$\Delta\sigma_f$.......................psi..	1,640	370	80	130
$\Delta\sigma_r$.......................psi..	1,430	2,090	NAp	NAp
$\Delta\sigma_{r-core}$..................psi..	NAp	NAp	1,500	1,260
$\Delta\sigma_{max}/\sigma_o$......................	6.8	5.5	NAp	NAp
$\Delta\sigma_{max-core}/\sigma_o$..................	NAp	NAp	3.5	3.1
$\Delta\sigma_r/\sigma_o$.........................	3.2	4.7	NAp	NAp
$\Delta\sigma_{r-core}/\sigma_o$..................	NAp	NAp	3.8	2.8

NAp Not applicable.

$\Delta\sigma_{max}$--The change in maximum stress occurring in a pillar during extraction of panel 2.

$\Delta\sigma_{max-core}$--The change in maximum stress occurring in the core of the pillar.

$\Delta\sigma_f$--The final change in stress recorded during extraction of panel 1.

$\Delta\sigma_r$--Resultant change in stress ($\Delta\sigma_{max}$-$\Delta\sigma_f$).

$\Delta\sigma_{r-core}$--The resultant change in stress ($\Delta\sigma_{max-core}$-$\Delta\sigma_f$) occurring in the core of the pillar.

σ_o--The virgin stress, assumed to be 1 psi/ft of overburden.

by a stressmeter during the extraction of a second panel independent of the extraction of the first panel.

The following comments relate to the headgate data contained in table 1.

1. On the average, abutment pillars experienced stress increase of 2.5 times the stress increases experienced by yield pillars ($\Delta\sigma_{max-abutment}/\Delta\sigma_{max-yield}$).

2. On the average, the maximum stress increases within a yield or abutment pillar were 1.4 times the stress increases experienced at the core of the pillar.

3. A reasonable correlation exists for the parameter $\Delta\sigma_{max}/\sigma_o$ for all four yield pillars, with an average value of 1.1; such a correlation does not exist for the abutment pillars.

Only the stressmeter data of array A_1 could be used to make inferences about magnitudes of tailgate chain pillar stress increases. The following comments relate to the tailgate data contained in table 2.

1. The abutment pillar experienced a stress increase of 1.2 times the stress increase experienced by the yield pillar.

2. The maximum stress increase within the yield or abutment pillar was 1.9 times the stress increase experienced at the core of the pillars.

3. On the average, the yield pillar had a higher increase of maximum stress change than the abutment pillar with reference to $\Delta\sigma_r$; overall, however, the abutment pillar was still more highly stressed than the yield pillar with reference to $\Delta\sigma_{max}$.

A comparison of tables 1 and 2 shows that the extraction of panel 2 caused a stress increase in the yield pillar A_1 3.6 times the stress increase in the same pillar when panel 1 was mined. This can be seen by comparing the yield pillar A_1 values $\Delta\sigma_r$ and $\Delta\sigma_{r\text{-}core}$ of table 2 with the yield pillar A_1 values $\Delta\sigma_{max}$ and $\Delta\sigma_{max\text{-}core}$ of table 1. No conclusive statement can be made concerning the stress increase of abutment pillar A_1 during the extractions of panels 1 and 2.

ROOF BOLT LOADING

Changes in loading of the 8-ft mechanical roof bolts were measured with flatjack U-cells. The U-cells were monitored only when they were part of the headgate system. The general form in which the U-cell data were prepared for analysis is shown in figure 14, as a plot of the percent of maximum load change, experienced collectively by U-cell subgroups, versus longwall face position. The relative positions of the U-cells of group B are shown in figure 15. The position of group B in array A_2 is shown in figure 7. The magnitudes of percent load change were determined by the following method. The U-cells of each group were broken down into subgroups according to their position in the entry or crosscut [against the rib (rib-line) or centerline]. The loadings of the U-cells for each subgroup were averaged at specific longwall face positions and then expressed as a percentage of maximum load change experienced by that particular subgroup.

A comparison of the load change graphs of groups A and D with B of array A_2 (figure 14 is used as a representation of bolt loading trends) revealed that all of the subgroups showed similar loading trends. When the longwall face was adjacent to array A_2, the highest percentage of maximum load change experienced by any subgroup was 37 pct. Therefore, the majority of headgate bolt loading occurs after the passage of the face. The zone of maximum bolt loading was experienced when the longwall face was adjacent to and 200 ft past array A_2. All of the centerline subgroups tended to experience a higher percentage of maximum loading than the rib-line subgroups.

Group C of array A_2, located in the entry adjacent to the longwall panel, experienced a totally different loading pattern (fig. 16). Subgroup 1C was immediately adjacent to panel 1 (fig. 17) and experienced a higher percentage of maximum loading than rib-line subgroup 2C. The majority of roof bolt loading occurred after the longwall face was within 140 ft of array A_2 (60 pct for subgroup 1C and 75 pct for subgroup 2C).

The load histories of the U-cell subgroups are used to examine the maximum roof bolt loading due to location within a gate road. Figure 7 shows the relative positions of the U-cell groups in array A_2. The magnitude of loading for any group was equated to the maximum loading

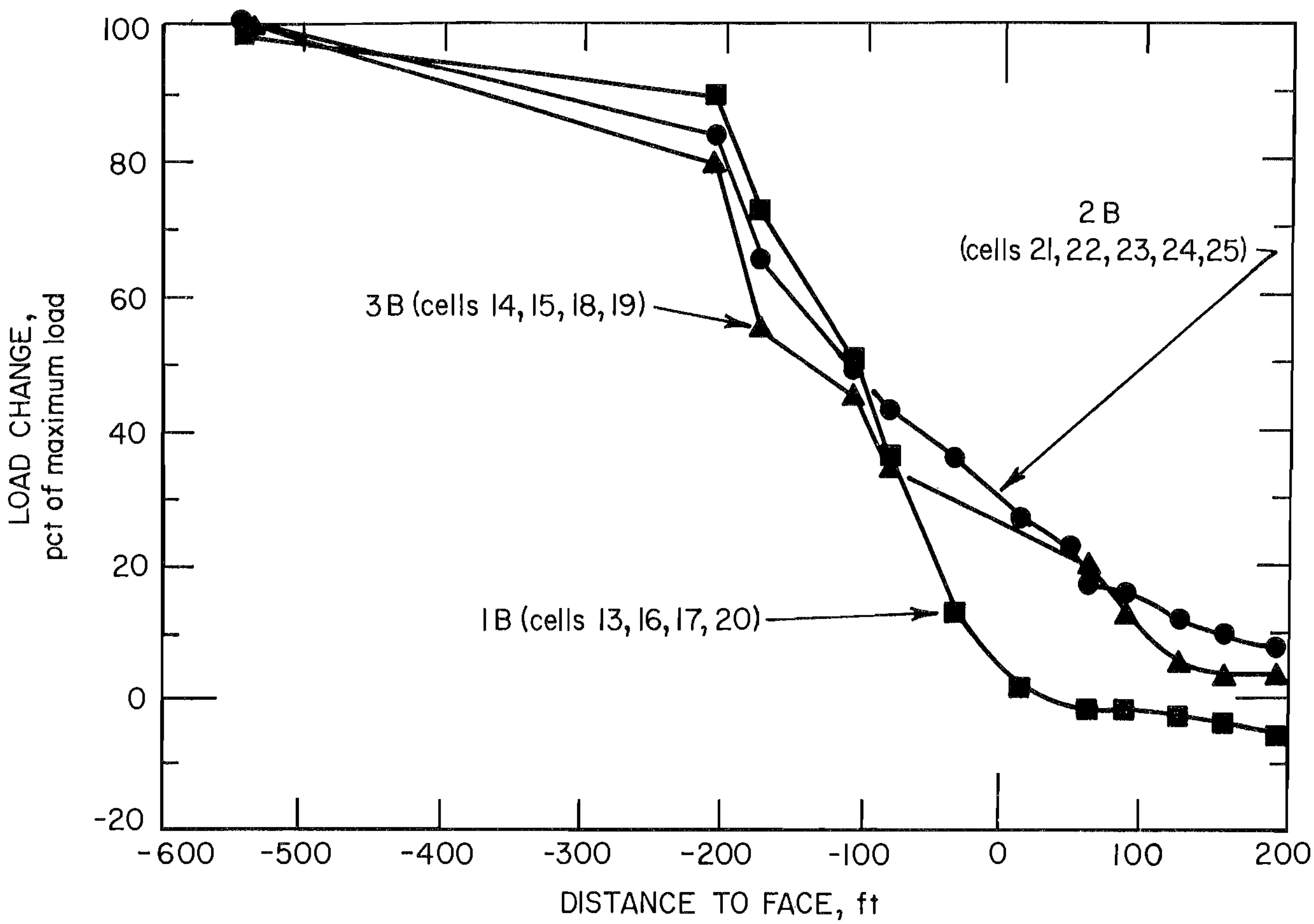

FIGURE 14. - Percentage of maximum load change versus distance to longwall face--array A_2, group B, headgate system.

achieved by any of its subgroups. Groups A and D experienced a maximum loading of approximately 10,800 lbf. Group B experienced a maximum loading of 17,300 lbf. This high bolt loading of group B may be due not only to the extraction of the longwall panel, but also to the irregular shape of the abutment pillar A_2 and to an increase in the crosscut width. The maximum bolt loading of group C was 11,800 lbf, which was 9 pct higher than the maximum bolt loading of groups A and D.

CONVERGENCE AND EXTENSOMETER STATIONS

Convergence and extensometer stations were installed in arrays B_1 and B_2 (fig. 1). Figure 3 shows the location of these stations within the arrays. Three combined convergence and extensometer stations were installed in identical locations in each array: station C_1 in the abutment pillar crosscut, station C_2 in the track entry, and station C_3 in the yield pillar crosscut.

Soon after installation, the convergence pins installed in the floor of array B_2 were destroyed by moving face equipment (fig. 5). In addition, the extensometer data were inaccurate, owing to slippage of the C-anchors. The only reportable data of strata movement were obtained from the convergence stations in array B_1. These stations were monitored over a 125-day period. Soon after the readings were initiated, the longwall face was idled by a miners' contract strike. The longwall panel was idled for 56 days with the face positioned approximately 350 ft from the convergence stations. This data analysis will focus

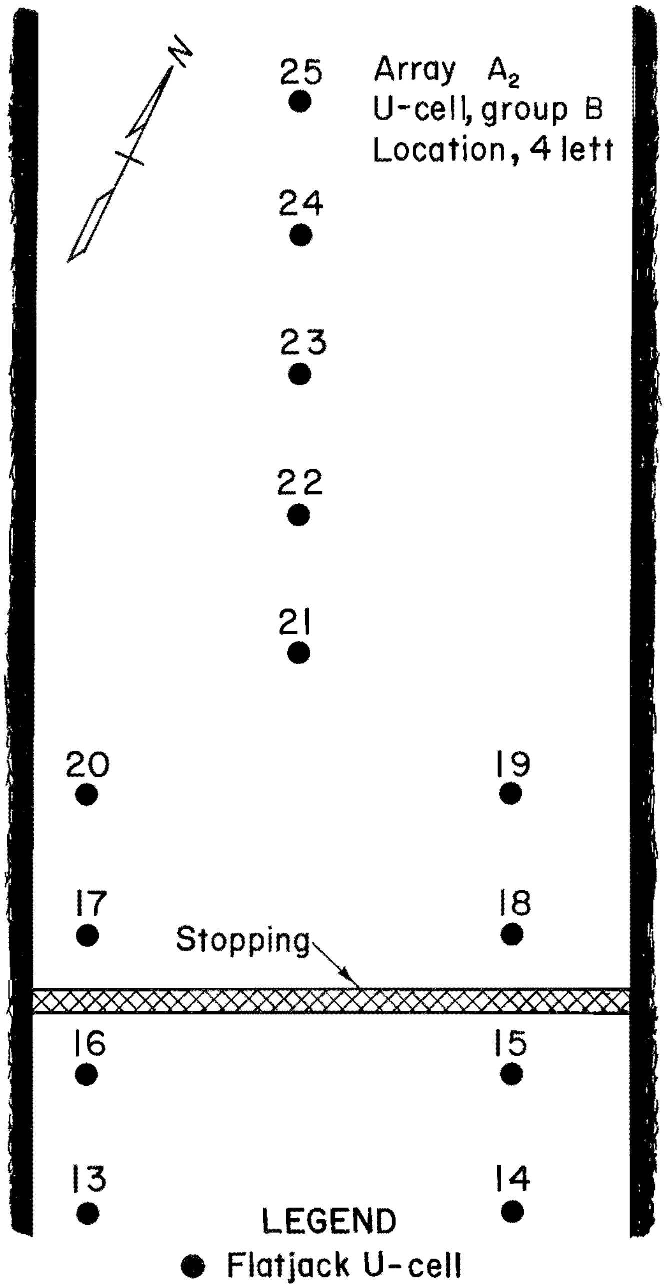

FIGURE 15. - Location of U-cells—array A_2, group B.

on convergence during the idle period as well as the convergence that was recorded when longwall mining activities were resumed.

To better understand strata movement in array B_1, convergence data were graphed as a function of face position (fig. 18). Station C_2, located in the track entry, experienced a total convergence of 1.358 in during the 125-day monitoring period. Station C_1, located in the abutment pillar crosscut, converged 0.871 in during this period. The least movement, 0.240 in, was recorded at station C_3 located in the yield pillar crosscut.

Total convergence for each station was subdivided into three separate situations, as shown in table 3. Situation I shows the amount of convergence each station recorded during the initial 56 days when mining was idled by the strike. Situation II shows the amount of convergence that occurred when mining activities resumed up to the time the longwall face was 200 ft past the stations. Situation III shows convergence from the time the face was from 200 to 700 ft past the stations.

TABLE 3. - Convergence—array B_1, inches

	Station C_1	Station C_2	Station C_3
Situation I...	0.538	0.482	0.067
Situation II..	.256	.493	.112
Situation III.	.077	.383	.061
Total....	.871	1.358	.240

Situation I: Convergence when panel was idle and 350 ft before the convergence stations (56 days).

Situation II: Convergence when mining resumed until longwall face was 200 ft past convergence station (42 days).

Situation III: Convergence when panel was from 200 ft to 700 ft past the convergence stations.

From this analysis, several generalizations can be made concerning roof-floor behavior in array B_1 as panel 2 was mined. First, during situation I, there were significant amounts of convergence measured at all stations, although the panel was idled more than 300 ft outby. Station C_1, located closest to the longwall panel, recorded the largest amount of convergence of all three situations. Second, during situation II when mining activities resumed, stations C_2 and C_3 recorded their maximum convergence as expected. The convergence recorded at station C_1, during this period of longwall movement, was considerably less than expected. Finally, all three stations recorded the least movement during situation III.

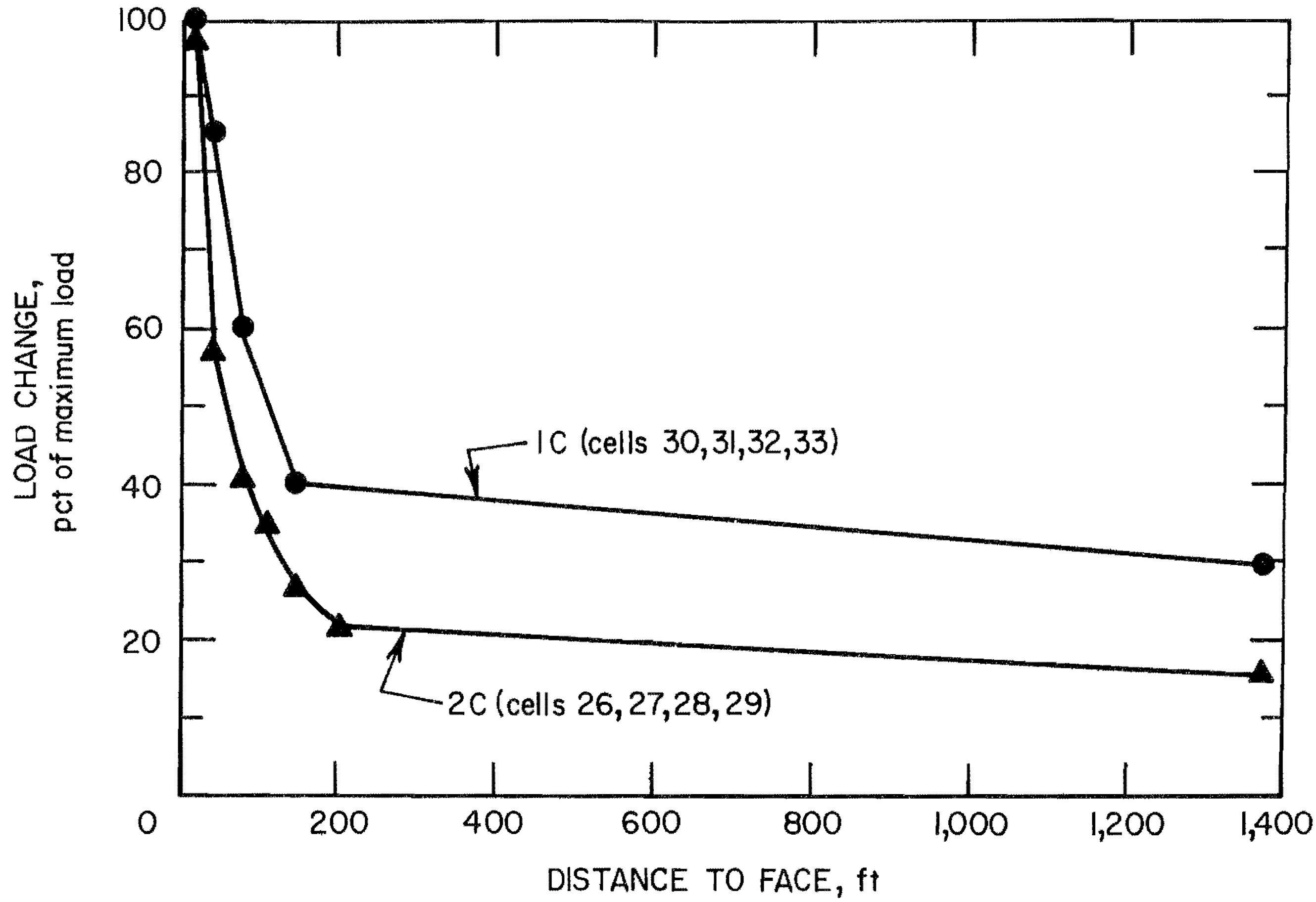

FIGURE 16. - Percentage of maximum load change versus distance to longwall face—array A_2, group C, headgate system.

LOADING TRENDS OF HEADGATE AND TAILGATE SYSTEMS

The loading histories of the instrumented chain pillars can be used to make inferences concerning the loading trends occurring in both headgate and tailgate systems. Although the information available for tailgate stresses is strictly limited to those stresses experienced by the yield and abutment pillars of array A_2, the data are still valuable for comparative purposes and for discussing the effects of longwall mining on headgate and tailgate systems.

In the following discussion of loading trends in the two gate road systems, "headgate stress" is defined as the abutment pressures transferred onto the headgate chain pillars, and "tailgate stress" is defined as the abutment pressures transferred onto the tailgate chain pillars independent of the headgate stresses. Cumulative gate road stress is the summation of the headgate and tailgate stresses.

The headgate stresses were significantly different from the tailgate stresses in terms of loading trend and magnitude. The zone of maximum stress increase occurred in the headgate pillars after the passage of the longwall face and accounted for 65 to 75 pct of maximum stress increase. Conversely, the tailgate pillars experienced approximately 55 pct of maximum stress increase before the passage of the face. Stress relief never occurred in the chain pillars of the headgate, but began in the tailgate when the face was approximately 140 ft past the chain pillar location. Tailgate stresses were approximately 2.6 times the headgate stresses when expressed as

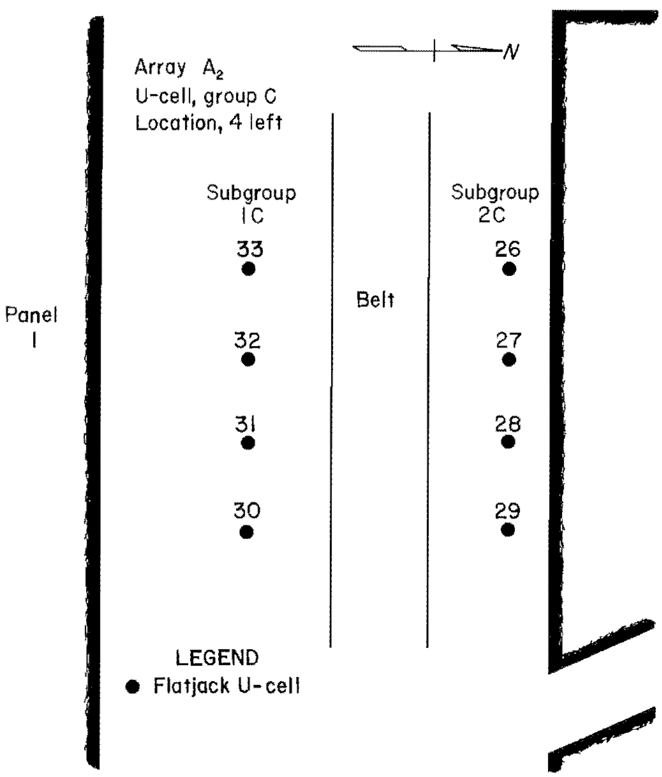

FIGURE 17. - Location of U-cells—array A_2, group C.

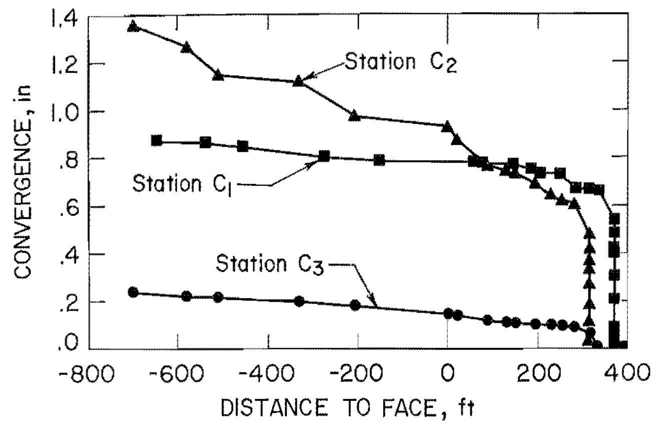

FIGURE 18. - Convergence versus distance to longwall face—array B_1, stations C_1, C_2, and C_3, headgate system.

ratios of overburden stress ($\Delta\sigma_{max}/\sigma_o$). Based upon the headgate stresses and cumulative gate road stresses, the abutment pillars of both gate road systems are considered to have functioned properly since, in all cases, they supported a significantly higher load than the yield pillars.

CONCLUSIONS

Based upon an evaluation of the data collected in this study and observation of the actual mining of the longwall panels involved, the following conclusions were reached:

1. The stiff-yield pillar design, with the abutment pillars placed adjacent to the working panel when they are part of the headgate system, provided adequate support in that no major roof falls or roof problems were experienced in the headgates or tailgates during the mining of panels 1, 2, and 3. Local roof falls occurred in the tailgate, but did not halt production or inhibit ventilation.

2. The abutment pillars functioned properly since, in all cases, they were more highly loaded than the yield pillars for both headgate and tailgate systems. This is the objective of the stiff-yield pillar design, and the loading behavior of the instrumented chain pillars supports the theory behind this particular design concept.

3. Based upon the histories of roof bolt loading and pillar stress increase of headgates, it can be stated that maximum loading of headgate roof support elements occurs after the passage of the face.

4. While no definitive conclusion can be reached as to whether the pillar design was conservative, it can be said that the design was at least adequate for the particular geology involved and panel layout used.

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