EVOLUTION OF CONVENTIONAL GATE ENTRY DESIGN FOR LONGWALL BUMP CONTROL: TWO SOUTHERN APPALACHIAN CASE STUDIES

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ABSTRACT

This paper focuses on the conventional design of gate roads for minimizing bump hazards in longwall mining. The paper describes bump occurrences and the evolution of gate road designs to combat bumps at two southern Appalachian longwall mines. An analysis of gate road system stability at these mines is presented, along with a discussion of the apparent effect of the strength-load ratio on the occurrence of coal bumps. It is suggested that properly sized gate pillars can mitigate tailgate face bumps in many situations by limiting the transfer of abutment stresses to the longwall face.

INTRODUCTION

Coal mine bumps are the sudden, violent expulsion of coal from a rib or active working face into an adjacent entry or entries. (In a coal bump, as opposed to a gas outburst, only a minimal amount of gas is released in conjunction with the ejected coal.) Coal bumps are an extremely debilitating problem, for they can result in personnel injuries and fatalities, damaged equipment, reduced production, and lost reserves. Additionally, the unpredictable nature of bumps has a profoundly negative effect on the morale of the work force. Commensurate with the seriousness of the problem, a significant effort has been expended to better understand the coal bump phenomenon. The U.S. Bureau of Mines (USBM) and several coal companies and universities have been active in this research.

Historically, the coal bump problem has been mitigated through design recommendations that proposed modifying extraction sequences and mine geometry and through various destressing operations. Holland and Thomas (1954) examined 117 bumps that occurred in the United States between 1925 and 1950 and determined that, in many instances, bumps could be alleviated by avoiding unfavorable mining configurations. Iannacchione and DeMarco (1992) presented a review of bump research in the United States that emphasized the success of previous work in (1) identifying the various factors that contribute to bumps and (2) developing mining methods and recommendations to minimize bump hazards. However, an analysis of accident statistics from 1959 to 1984 by Goode and others (1984) confirmed that coal mine bumps constituted a persistent problem and had led to 28 fatalities during that time. These fatalities were equally divided between Eastern and Western U.S. coalfields.

Because the vast majority of the underground coal produced in the United States has been mined by room-and-pillar methods, many of the approaches developed historically to address bump-prone conditions apply only to this method. Room-and-pillar mining provides great flexibility, particularly in terms of cut sequencing, which has been advantageous in several cases (Campoli and others, 1989; Mucho and others, 1993). In contrast, longwall mining follows a fairly rigid extraction sequence and, as a result, innovative design practices are required to address bump problems on longwall faces.

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Challenging bump problems have been encountered with longwall mining as this method has become more prominent in the United States. At least one fatality, several injuries, and one mine closure have been attributed to bumps on longwall sections (Iannacchione and DeMarco, 1992). To date, several different approaches have been undertaken to mitigate bumps in longwall mining operations. In the Eastern United States, a conventional coal pillar design approach appears to have been successful in curtailing bumps at the working face. Alternate approaches adopted in the Western U.S. coalfields include yielding pillar systems in several Utah coal mines (Maleki, 1988; Koehler, 1994) and advancing longwalls in Colorado (Jackson, 1975).

Conventional gate road design is based on the premise that, in some instances, properly sized gate pillars can mitigate tailgate face bumps by limiting the transfer of abutment stresses to the longwall face. Essentially, if tailgate abutment pillar failures and/or bumps are prevented or at least delayed, the abutment pillars may support gob load that would otherwise be transferred to the tailgate corner of the longwall face. However, conventional coal pillar design is not a panacea. Certainly, conditions may be encountered where gate system design will have little influence on bumps. For example, excessive stress conditions could be encountered that would contribute to the occurrence of bumps at midface despite the presence of stable gate pillars. In extreme instances, excessive stress conditions have resulted in bumps during development (Iannacchione and Zelanko, 1995).

This paper focuses on the conventional design of gate roads for minimizing bump hazards in longwall mining. The authors describe bump occurrences and the evolution of gate road design at two southern Appalachian longwall mines.

CASE STUDY MINE 1

The first case study is a longwall mine in Buchanan County in southwestern Virginia. At this mine, eight successive longwall panels have been mined to the north and 10 successive panels have been mined to the south of twin barrier pillars (figure 1). The gate entry system between the sixth and seventh panels to the south contains what is referred to as the 7 development study area. This was the first of three areas studied in detail by the USBM. The other study areas are in 8 development and 10 development, as shown in figure 1.

The mine extracts the Pocahontas No. 3 Coalbed, which is located in the Pocahontas Formation and averages 1.7 m (5.5 ft) thick. Overburden in the three study areas ranges from 400 to 700 m (1,300 to 2,200 ft) thick, and the coalbed dips 1° from east to west (Campoli and others, 1990). The immediate roof in the south end of the mine consists of a widely jointed siltstone overlain by a massive quartzarenite sandstone. In the study areas, the siltstone ranges from 9 to 18 m (30 to 60 ft) thick, and the sandstone ranges from 60 to 75 m (200 to 250 ft) thick. The mine floor consists of a combination of very competent siltstones and sandstones. Underground observations by Iannacchione (1990) indicate a persistent absence of prominent fractures or joints in the immediate roof and floor, and the main roof, dominated by the thick sandstone, is exceedingly difficult to break. In situ stress measurements in the 8 development study area also indicate that the maximum horizontal stress is 23 MPa (3,400 psi) at N. 76° E., and the minimum horizontal stress is 11 Mpa (1,600 psi) (Campoli and others, 1990).

The original gate pillar configuration employed at case study mine 1 consisted of a yield-yield-abutment design in which the yield pillars were 9 m (30 ft) wide, the abutment pillar was 24 m (80 ft) wide, and the crosscuts were spaced on 30-m (100-ft) centers. Throughout the mine, the longwall panels were 183 m (600 ft) wide and roughly 1,800 m (6,000 ft) long. In the original design, the larger abutment pillars were located directly adjacent to the tailgate. During the tailgate phase of the gate road, these 24-m (80-ft) square pillars frequently experienced heavy bumps directly adjacent to the tail drive, causing coal to be thrown into the face area where miners were working.

The second gate pillar design, evaluated in the 7 development study area, was a yield-abutment-yield design with the same size abutment pillar [24 m (80 ft) square] flanked on either side by 9-m (30-ft) wide yield pillars. The crosscuts were again on 30-m (100-ft) centers (figure 2). In this design, the 9- by 24-m (30- by 80-ft) yield pillars apparently yielded during the headgate pass of the longwall (Campoli and others, 1990), thereby eliminating their potential to bump. Then, on the tailgate pass of the longwall, the yielded pillars effectively shielded face workers from thrown coal if the 24-m (80-ft) square abutment pillar bumped in the tailgate.

The 7 development study area (figure 1) was centered approximately 1,430 m (4,700 ft) from the startup entry of panel 6 under approximately 595 m (1,950 ft) of overburden. The 24-m (80-ft) square tailgate abutment pillars in this gate entry system were observed to bump as the abutment load from the panel 7 gob was superimposed

Figure 1
Map of Mine 1.

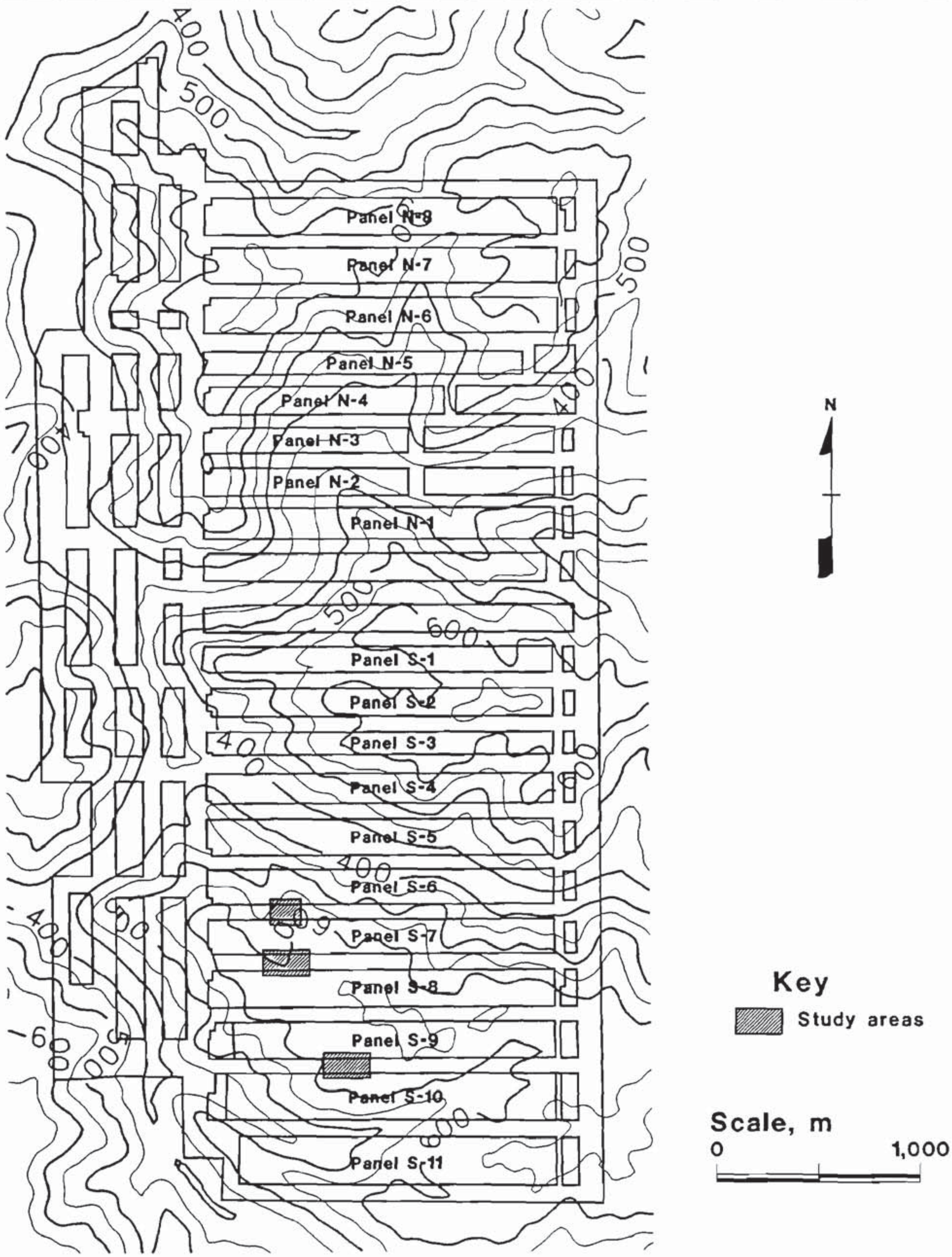
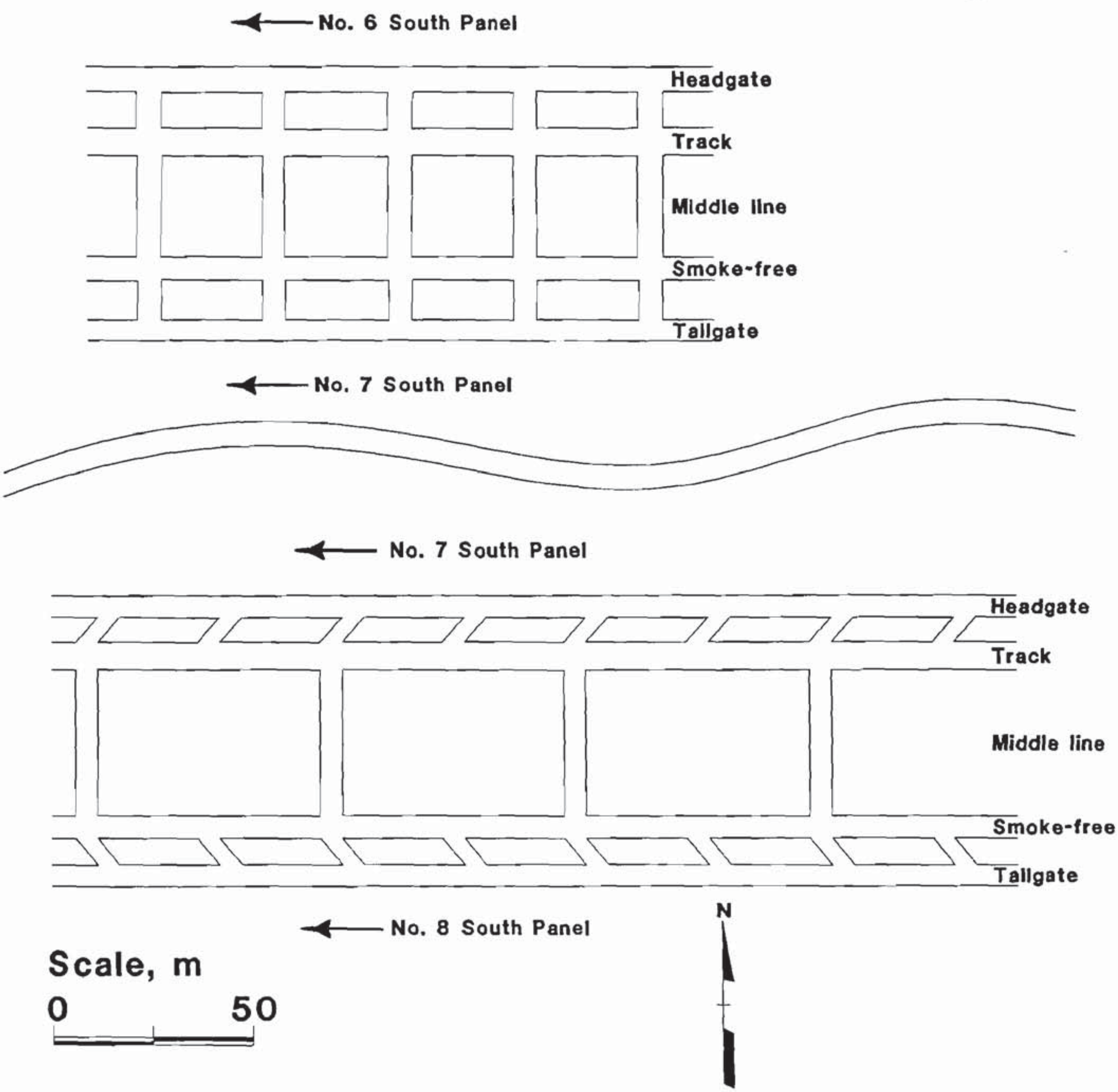


Figure 2
Pillar Designs in 7 and 8 Development.

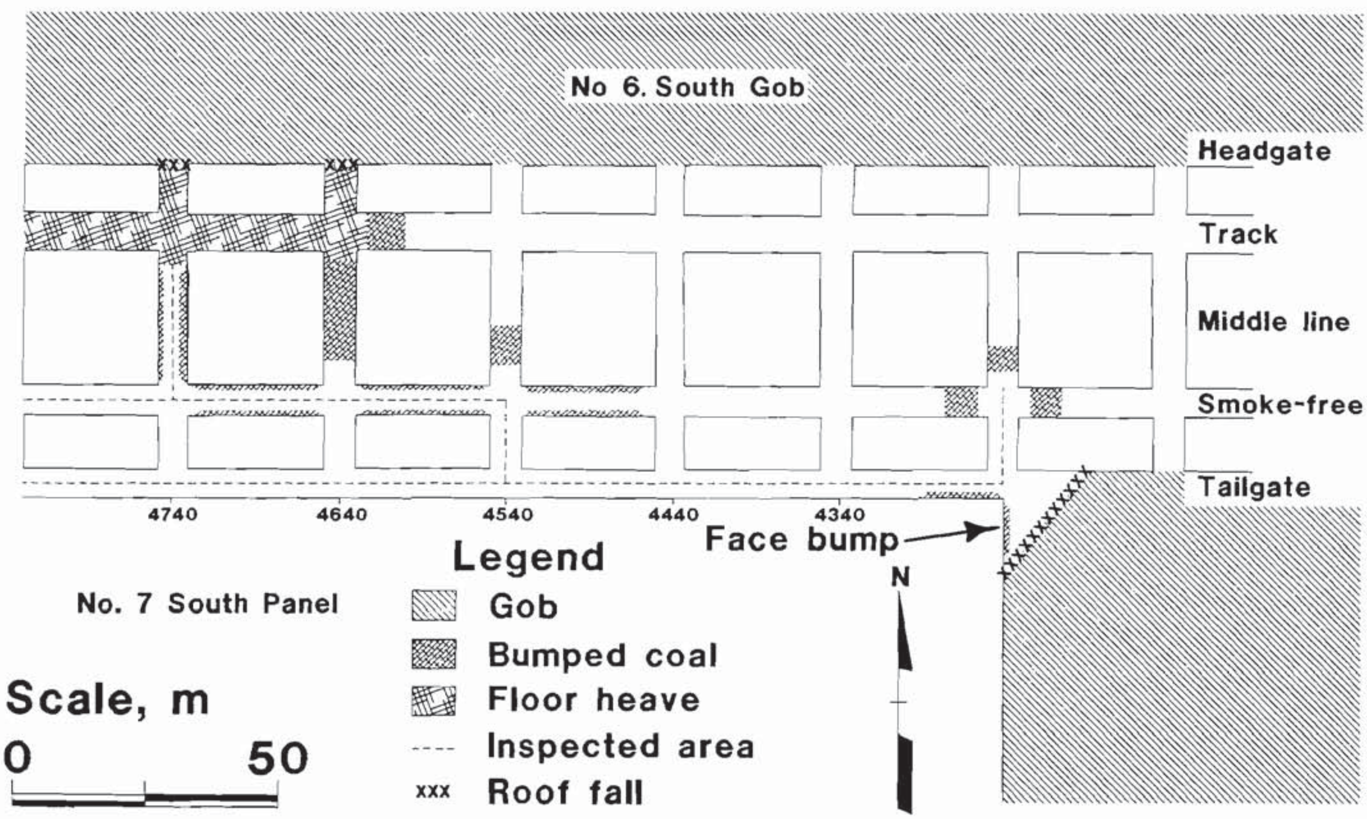


on the pillars. Initially, the abutment pillars bumped inby the longwall face. However, at mid-panel, the abutment pillars were bumping adjacent to the longwall face. After about 1,200 m (4,000 ft) of the panel had been mined, the 24-m (80-ft) square tailgate abutment pillars within this gate entry system were observed to bump up to five pillar rows [150 m (500 ft)] in front of panel 7 (figure 3). Apparently, the failure of the abutment pillars in advance of mining resulted in load transfer to the tailgate corner of panel 7 and subsequent face bumps (Campoli and others, 1990).

To better control ventilation between previous and active gobs, improve tailgate entry stability, control tailgate face bumps, and standardize gate entry system design, mine 1 modified the yield-abutment-yield configuration for 8 development and subsequent gate roads. This new design consisted of 6- by 24-m (20- by 80-ft) yield pillars on each side of a 37- by 55-m (120- by 180-ft) abutment pillar (figure 2). Between the yield pillars, the crosscuts were driven at 60° angles on 30-m (100-ft) centers, whereas between the abutment pillars, the crosscuts were driven at 90° angles on 60-m (200-ft) centers.

The 8 development study area (figure 1) was centered approximately 1,400 m (4,600 ft) from the startup entry of panel 7 under approximately 625 m (2,050 ft) of overburden. Under worst-case conditions, after approximately 1,400 m (4,600 ft) of panel 8 had been extracted (near the center of the 8 development study area), the abutment pillars did not begin to bump until they were approximately 30 m (100 ft) inby the longwall face. Furthermore, the intensity of tailgate abutment pillar bumps was greatly reduced by the new design (Campoli and others, 1990); in fact, many of the observed bump areas may have only been the edge of the abutment pillar. Thus, the 37- by 55-m (120- by 180-ft) abutment pillars supported the applied abutment loads and prevented ground stresses from overriding to the longwall face during panel 8 mining (Heasley and Barron, 1988).

Figure 3
Schematic of Face Bump in 7 Development.



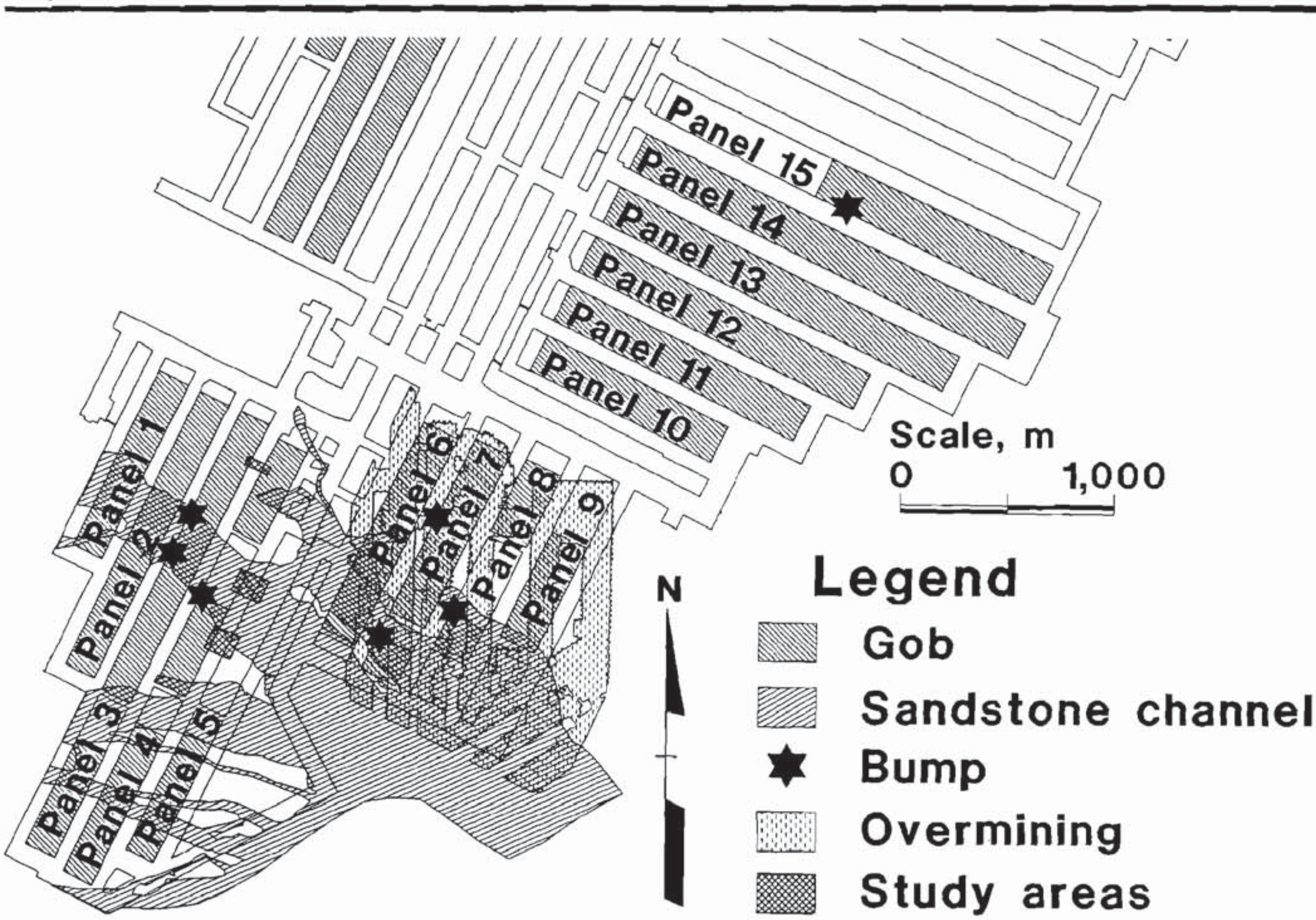
CASE STUDY MINE 2

The second case study is a longwall mine in the Upper Cumberland coal district of the southern Appalachian Coalfield in Harlan County in southeastern Kentucky. This coal district covers an area approximately 160 km (100 mi) long and 13 km (8 mi) wide between Pine Mountain on the northwest and Cumberland Mountain on the southeast (Brant and others, 1983). The mine operates in the Harlan Coalbed. Within the extent of the property, the mined height of the coalbed varies from 2.5 to 3.7 m (8.0 to 12.0 ft). Two other coalbeds, the Kellioka and the High Splint, have been mined on the property. They are located approximately 45 m (150 ft) and 450 m (1,500 ft), respectively, above the Harlan Coalbed.

The Harlan Coalbed is underlain by the subHarlan Sandstone over the entire mine property. However, in many areas an intermediate shale member ranging up to approximately 4.6 m (15 ft) thick also appears between the coal and the underlying sandstone. The immediate roof varies considerably across mine 2. Generally, the roof consists of a laminated gray shale; however, in places, the roof varies from a weak, highly fossilized and slickensided black shale to a strong siltstone. In addition, a sandstone channel system was encountered on the south side of the mine property (figure 4). This channel has been characterized as a deltaic formation with fingerlike projections extending radially outward from a central main channel.

Whereas conditions at mine 1 were relatively consistent across much of the mine property, a number of conditions, which correlate with bumps, varied considerably across mine 2. For example, the sandstone channel system

Figure 4
Map of Mine 2.



caused sudden changes in the geologic and mechanical composition of the immediate roof. Also, topographic relief varied dramatically across the property, and multiple-seam interactions were evident in some areas of the mine. The following is a description of the history of coal bumps at mine 2 and some of the conditions believed to have contributed to these events.

Within the last 5 years, at least six different gate road designs were utilized at case study mine 2 (figure 5). Although the current design is a four-entry, yield-abutment-yield layout, the coal pillar configuration historically had been a three-entry yield-abutment design. Pillar dimensions frequently varied from one gate road to the next. However, all of the three-entry systems were configured similarly, with the abutment pillar placed adjacent to the longwall panel in the headgate. In the earlier three-entry designs (figure *5A* through *5C*), the dimensions of both pillars were increased in successive designs, ostensibly to account for increasing overburden. The smaller pillar's least dimension was increased from 15 to 21 m (50 to 70 ft) and the larger pillar's least dimension was increased from 27 to 37 m (90 to 120 ft). The smaller pillar in these gates did not perform necessarily as a true yield pillar. However, in later designs (figure *5D* and *5E*), the dimensions of the smaller pillar were reduced and the dimensions of the abutment pillar were increased. Mine management has come to believe through visual observation that the 12-m (40-ft) wide pillar (figure *5F*) currently acts as a true yield pillar and has improved roof control.

Longwall mining began at mine 2 in 1982 (Schuerger, 1985) and progressed through 10 panels, or portions of these panels, without a coal bump. However, in mid-April 1989, a large bump occurred on the longwall face (panel 3, as shown in figure 4). Investigations following the face bump revealed that the tailgate abutment pillars adjacent to the face and immediately outby had bumped as well. At the time of the bump, the longwall face had begun to advance under a sandstone channel that crossed the panel. The longwall panel was approximately 152 m (500 ft) wide, and the tailgate was a three-entry arrangement with coal pillars 15 and 27 m (50 and 90 ft) wide by 30 m (100 ft) long (figure *5A*).

Production was resumed from the site of the first bump in late April 1989. In early May 1989, after an additional advance of about 180 m (600 ft), a second large face bump occurred as the face was nearing the outby margin of the sandstone channel. The height of the overburden at this second bump site was approximately 380 m (1,250 ft). Reports indicated that the tailgate abutment pillars were completely crushed and the floor was broken and heaved adjacent to the face and at least two pillar rows outby.

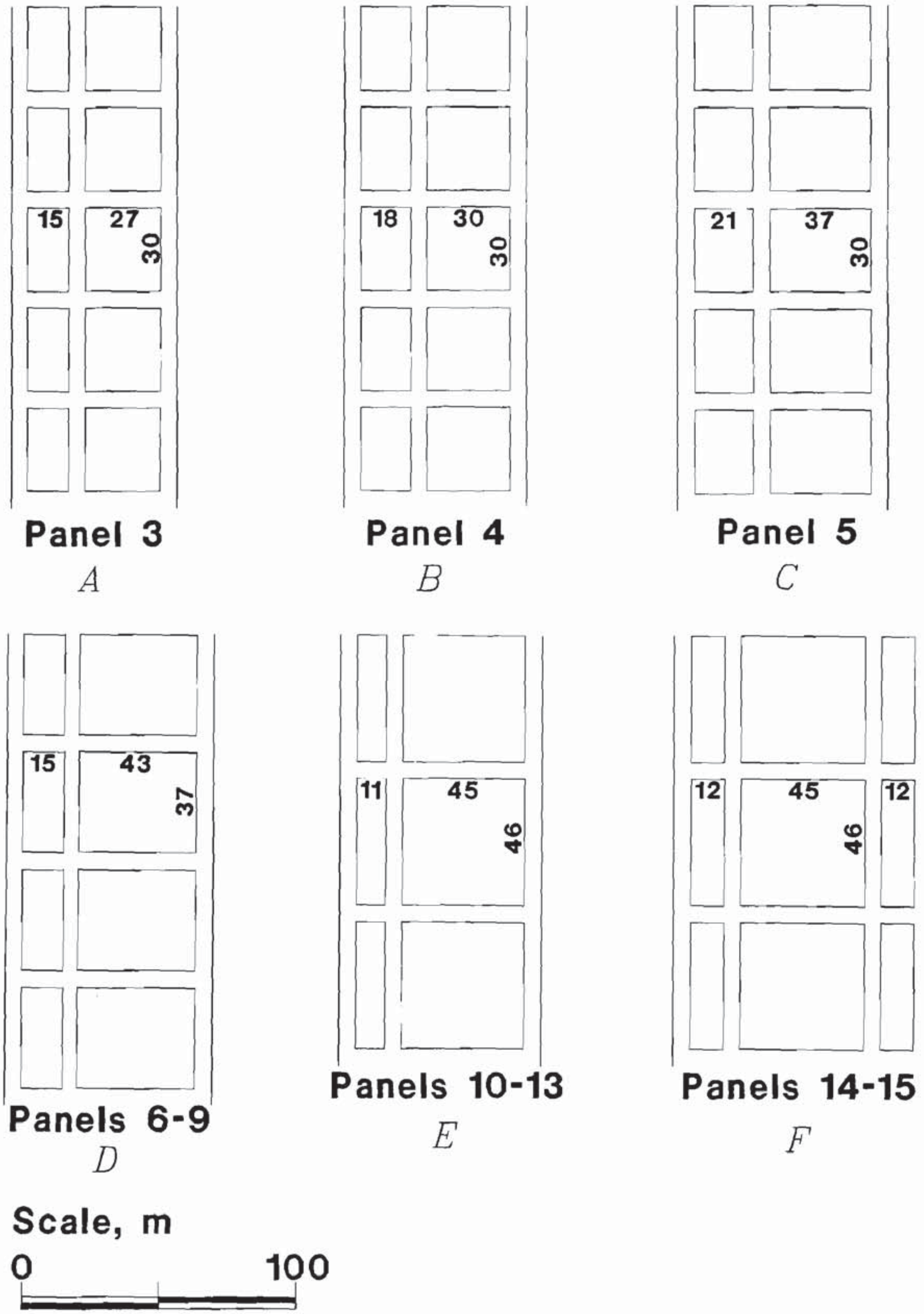
The longwall was advanced from the second bump site to the end of panel 3 without further incident. However, in anticipation of similar bump-prone conditions in panel 4, mine management implemented a stress detection and destressing program. A hand-held pneumatic auger drill was used to detect zones of high stress in the longwall face. Drilling yield (cuttings volume) was monitored, and drilling resistance was observed to determine whether shot firing should be used for destressing. When zones of high stress were encountered, 5-cm (2-in) diam holes were drilled 3 to 6 m (10 to 20 ft) deep within the suspect zone and shot with permissible explosives. In addition, Lexan acrylic sheets were suspended on chains from the shield canopies to help isolate the walkway behind the panline from coal thrown from the working face.

Despite these measures, a major coal bump occurred on the panel 4 longwall face and in the adjacent tailgate pillars. As before, the face was advancing under the sandstone channel, with an overburden thickness of 358 m (1,175 ft). Investigations again revealed that the panel 4 tailgate pillars [18 and 30 m (60 and 100 ft) wide by 30 m (100 ft) long] had bumped at least two pillar rows outby the face (Zelanko and others, 1992). After this bump, management opted for an unplanned face move around the remainder of the channel in this panel rather than risking another such event. Setup entries were mined just outby the channel, and mining was resumed from that location, as indicated in figure 4.

A major arm of the sandstone channel system in the vicinity of the three bumps was apparently a deciding factor in the bump occurrence. The cross section of the channel was generally lens shaped, with a maximum thickness of approximately 15 m (50 ft) in the center, thinning to 0 m (0 ft) near the edges. The channel crossed perpendicular to the longwall panels (figure 4) and thus affected a relatively short distance during panel retreat. Scouring or removal of some of the coalbed during deposition of the channel was evident in the gate entries near the channel.

The potential for coal bumps initially appeared to be diminished significantly in the next series of panels scheduled to be mined (panels 6 through 9) (figure 4). The sandstone channel was less apparent in this area; it appeared to be broader and had not scoured the coalbed to the extent observed in the panels mined previously. Although the overburden thickness increased beneath a ridgeline, the abutment pillar dimensions had been increased to 43 by 37 m (140 by 120 ft). In addition, a significant barrier remained between the next series of panels (6 through 9) and the previous gob; the barrier was created by leaving a large portion of panel 5 unmined. Although these attributes reduced the likelihood of bumps, the potential for multiple-seam mining interactions existed in these panels. The Kellioka Coalbed, approximately 45 m (150 ft) above the Harlan Coalbed, had been mined and, in limited areas, partially retreated using room-and-pillar methods (figure 4).

Figure 5
Gate Road Configurations Utilized at Mine 2.



Numbers indicate pillar dimensions in meters.

Although several seismic shocks were reported early in the extraction of panel 6, no evidence of thrown coal was observed on the face or in the gate roads or bleeders, and this panel was extracted without incident. However, a major bump occurred in panel 7 near the tailgate when the face had progressed about 170 m (550 ft) from the startup entry. At the point of this second bump, the face had encountered a zone of heavy scouring. After the bump, coal pillars adjacent to the tailgate and immediately outby one row appeared to be yielding and spalling. Pillars farther inby and outby appeared to be more competent, but as much as 1 m (3 ft) of floor heave was noted. Dimensions of these pillars are shown in figure *5D*.

At the location of the face bumps in panel 7, it was noted that a barrier approximately 75 m (250 ft) wide was left between two room-and-pillar panels in the superjacent Kellioka Coalbed. The upper seam workings were not aligned with the lower seam longwall panels. As mining progressed in panel 7, the potential for zones of stress concentration and relief existed based on the condition of the upper seam and the extent of interaction between seams. After the major face bump in panel 7, the face was moved approximately 110 m (350 ft) outby and restarted. Several subsequent minor events appeared to coincide with the position of abutment zones in the overlying Kellioka Coalbed. In addition, a second serious event, in which the shearer sustained some damage, occurred subjacent to a room-and-pillar development area. Although this second major bump in panel 7 did not occur beneath a barrier, it was noted that the bump occurred near the point of maximum overburden at the juncture of three ridge lines.

Experiences in panel 7 were repeated to some extent in panel 8. Panel 8 was moved ahead 240 m (800 ft) to avoid mining beneath the sandstone channel. A major face bump occurred when the face had advanced about 170 m (550 ft). In the tailgate, yield pillars for six rows outby the face were crushed and yielded; tailgate abutment pillars adjacent to the face showed heavy spalling and displacement into the entries, but no bumping was apparent. At five pillar rows farther outby, portions of several abutment pillars were noted to have bumped. At the time of the bump, the face had advanced so that the tailgate corner was positioned beneath a barrier in the Kellioka workings. The bumped tailgate pillar was similarly positioned beneath an overlying abutment pillar (figure 4).

After the bump, the face was moved outby approximately 430 m (1,400 ft) in panel 8 to avoid superjacent barriers and high cover. No significant bumps were reported as the remainder of this panel and panel 9 were mined. Portions of panel 9 were mined under barriers in high cover; however, the tailgate in most of these areas was adjacent to the unmined length of the previous panel.

Panels 10 through 15 were developed using 45- by 46-m (147- by 152-ft) abutment pillars and either one 11-m (35-ft) wide or two 12-m (40-ft) wide yield pillars. These designs performed well during the extraction of five successive panels; however, a tailgate pillar bump occurred at midlength in panel 15. At the time of the bump, the longwall face had advanced to within 9 m (30 ft) of the outby edge of the adjacent tailgate abutment pillar. Although the face experienced a significant seismic shock, a large volume of material was not involved. Overburden thickness at the bump site was approximately 670 m (2,200 ft). During extraction of the remainder of panel 15, seismic events were reported in the headgate, but no serious events have been encountered to date.

COAL PILLAR DESIGN METHODOLOGY

Traditionally, coal pillar design has been accomplished by determining pillar strength and anticipated loads, then selecting the pillar size with a suitable margin of safety of strength over load. Mark (1987, 1990) developed a method for gate road pillar design called analysis of longwall pillar stability (ALPS), which provides estimates of both pillar strength (load-bearing capacity) and loading associated with longwall extraction. In the basic ALPS approach, pillar strength is determined using the Bieniawski formula, while pillar loading is a combination of tributary area development loading and angle-of-draw abutment loading. Total gate road load-bearing capacity and the total gate road load form a ratio that provides an estimate of the stability of the gate road. Mark analyzed this stability factor using a database of more than 100 case histories of failed and unfailed gate road pillars.

Generally, Mark recommends an ALPS stability factor range between 0.7 and 1.3 for a satisfactory tailgate roof condition, depending on the roof quality. Mark found that mines operating under exceptionally strong roof can utilize lower stability factors, whereas those under weaker, slickensided roof should employ higher stability factors (Mark and others, 1994).

Although ALPS was not developed for design in bump-prone conditions, the ALPS stability factor can provide a simple, quick quantification of the relative stability (or strength-load capacity) of various gate-pillar situations. In the present study, ALPS was used as a method to compare various gate road designs utilizing the same mechanical considerations. Table 1 presents stability factors and pertinent parameters for 10 different gate road situations from the two mines. In all instances, these stability factors represent the strength-load ratio corresponding to a pillar at the tailgate T-junction during second panel mining. Pillar and panel dimensions are given, as well as overburden thickness and coalbed height.

Table 1.–Stability factors and pertinent parameters for different gate road configurations

	Mine 1[1]					Mine 2[2]							
	6 development	7 development		8 development		Panel 3		Panel 4	Panel 5	Panel 7	Panel 8	Panel 13	Panel 15
Pillar width, m:													
1	9	9		6		15		18	21	15	15	11	12
2	24	24			37	27		30	37	43	43	45	45
3	9	9		6		NAp		NAp	NAp	NAp	NAp	NAp	12
Pillar length, m	24	24		24	55	30		30	30	37	37	46	46
Panel width, m	183	183		183		152		152	152	183	183	183	183
Comparative overburden:[3]													
ALPS stability factor	0.46	0.46		0.88		0.44		0.54	0.63	0.67	0.67	0.82	0.81
Maximum overburden:[4]													
Overburden, m . . .	520	600		670		520		550	460	630	630	630	670
ALPS stability factor	0.40	0.33		0.56		0.38		0.44	0.63	0.45	0.45	0.54	0.52
Coal bump:													
Observations	Pillar bumps	Pillar bumps	Face bumps	No bumps		Face bump[5-6]	Face bump[6]	Face bump[6]	No bumps	Face bump[6-7]	Face bump[6-7]	No bumps	Pillar bump
Overburden, m . . .	410	530	600	670		350	440	440	610	640	550	640	670
ALPS stability factor	0.53	0.38	0.33	0.55		0.57	0.48	0.56	0.45	0.45	0.54	0.54	0.52

NAp Not applicable.
[1]Coal seam thickness = 1.7 m.
[2]Coal seam thickness = 2.7 m.
[3]Solely to compare gate road designs, an overburden of 460 m was used.
[4]Maximum overburden experienced by that particular panel.
[5]Under a stream valley.
[6]Under a sandstone stream channel.
[7]Multiple-seam interaction.

COMPARATIVE EVALUATION OF GATE ROAD DESIGNS

Gate road systems at the two mines evolved in response to a variety of issues, one of which was coal bumps. At mine 1, a change from a yield-yield-abutment to a yield-abutment-yield system resulted in improved performance in bump-prone ground. The support capacity of the two gate road systems remained essentially the same, but the yield pillar adjacent to the tail drive effectively shielded workers on the face from coal thrown when the abutment pillars bumped. The next change in the gate road design—from a 24-m (80-ft) square pillar to a larger 37- by 56-m (120- by 180-ft) abutment pillar—involved a significant increase in load-bearing capacity of the system. In fact, the ALPS stability factor [for a uniform overburden of 460 m (1,500 ft)] rose from 0.46 to 0.88 (table 1); this was an increase in calculated load-bearing capacity of more than 90 pct. This increase in strength of the gate pillar system appears to have eliminated face bumps at mine 1.

The calculated load-bearing capacity of the gate road systems at mine 2 also showed a significant increase from the earliest three-entry design to the most recent four-entry system. However, each successive design at mine 2 only resulted in incremental changes in the stability factor (table 1). The incremental design changes from panels 3 to 5 reflected an effort to increase gate road stability as maximum overburden increased over each successive panel in this area. However, the more drastic design changes implemented in panel 7 and again in panel 13 were made specifically in response to coal bumps. Overall, the current four-entry gate road system represents an 84 pct increase in calculated load-bearing capacity over the capacity of the panel 3 tailgate, where the first serious face bump at mine 2 occurred.

Assuming that a stronger gate road system can mitigate tailgate face bumps by limiting the transfer of abutment stresses to the longwall face, one would expect different bump responses based on differing gate pillar strength-load ratios. If the tailgate pillars remain stable as second panel mining proceeds, then both pillar bumps and face bumps should be eliminated. If the pillars are slightly inadequate, pillar bumps may result as the tailgate pillars proceed into the gob. As the strength-load ratio decreases, pillar bumps may occur adjacent to the tail drive or even outby the face. Ultimately, abutment pillar failure outby the face may lead to face bumps. Based on this premise, it follows that the bump hazard should increase from no bumps to pillar bumps to face bumps as the ALPS stability factor decreases.

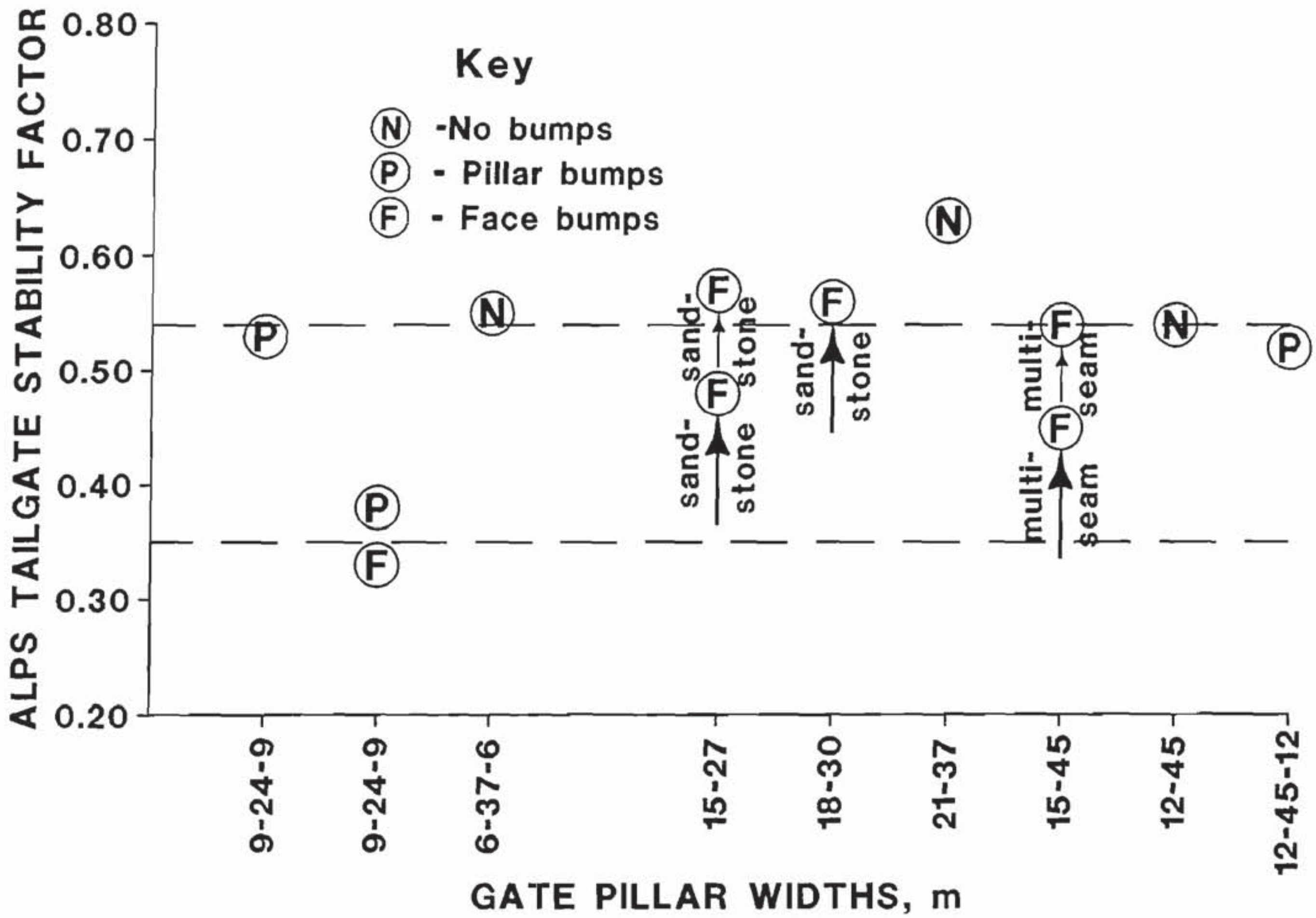
To evaluate the validity of this assumption, coal bumps at the case study mines were examined for decreases in bump activity and severity associated with increases in the ALPS stability factor table 1. The stability factors are also presented in a chart in figure 6. Although this chart represents the experience of only 10 gate road situations, a couple noteworthy observations concerning stability factor and bumps can be made. First, there have been no bumps at either of these mines when the ALPS stability factor for the gate road was greater than 0.6. This supports the premise that a sufficiently strong gate pillar system can help eliminate bumps. Second, both pillar bumps and face bumps occurred in the range of ALPS stability factors from about 0.3 to 0.6; however, as figure 6 shows, the five face bumps associated with stability factors greater than 0.48 were also associated with some geologic, topographic, or geometric anomaly that appeared to be the overriding factor in the bump occurrence. For example, at mine 2 in panels 3 and 4, all of the bumps occurred at the edge of a sandstone channel even though the stability factor of the gate road was lower at some other point. Similarly, at mine 2 in panel 7, the bumps occurred at locations underlying barrier pillars in a superjacent mine (figure 4).

It appears that a simplistic analysis using only ALPS can provide some insight into the bump potential of a particular gate road design. However, where sandstone channels, multiple seams, and/or multipanel interactions are present, the ALPS stability factor alone (which does not consider these conditions) is not sufficient for generating a practical bump control design. Under these anomalous conditions, a more detailed analysis of bump potential may be needed.

One method that can supplement a stability factor analysis in bump-prone ground is a geologic bump hazard analysis such as described by Sames (1995). This analysis uses a relational database to evaluate geologic information against a given set of criteria. The approach provides a means of quantifying geologic parameters and the interactions among them that can affect bump-proneness.

The assumptions incorporated into ALPS for estimating pillar loads are not appropriate for anomalous situations, such as those encountered in multiple-seam mining. In such a situation, a more detailed mechanistic analysis of the site should be utilized in which the complete elastic response is investigated and the multiple-seam interactions and the overall panel geometry are considered. For example, a boundary-element analysis performed by USBM researchers at mine 1 showed that the calculated elastic strain energy released from the tailgate corner of the longwall face was halved owing to the change in gate road design between 7 development and 8 development. In a similar analysis by Heasley and Zelanko (1992), the energy released from the tailgate corner of a longwall face at mine 2 was 15 pct greater when the face was overlain by a barrier pillar than when the face was overlain by a pillared section (figure 4). Energy release has proved useful as a tool in several other bump investigations (Maleki and others, 1987; Zipf and Heasley, 1990; Heasley, 1991).

Figure 6
Comparison of Coal Mine Bumps Using ALPS Stability Factors.



DISCUSSION AND CONCLUSIONS

Although the specific mechanisms responsible for coal mine bumps are not completely understood, one established factor in their occurrence is the presence of high vertical stress. The case studies of two mines presented in this paper support the premise that, in some instances, properly sized gate pillars can mitigate tailgate face bumps by limiting the transfer of abutment stresses to the longwall face. Both studies demonstrated that an increase in the effective strength-load ratio of the gate road pillars helped eliminate or reduce longwall face bumps.

The case studies of these two mines, particularly that of mine 2, also underscore the fact that coal pillar design has limitations regarding the control of longwall face bumps. In several instances, geologic anomalies and multiple-seam interactions apparently instigated face bumps in specific locations even though the gate road design had been used successfully elsewhere in the mine under similar or deeper cover. There are also certain longwall face bump situations where increasing gate road strength would not apply to bump mitigation. For instance, under extremely deep cover, abutment stresses on the longwall face may be sufficient to facilitate face bumps regardless of the strength of a conventional gate road design. Midface bumps, for example, would probably be affected very little by increases in gate system load-bearing capacity. In these extreme stress conditions, yield-pillar systems (DeMarco and Koehler, 1995) may effectively eliminate gate road pillar bumps, and destressing techniques (Haramy and others, 1995) would be more appropriate for effective bump control at the face. Moreover, operational, economic, and/or legal constraints often determine the maximum abutment pillar size that can be used.

The two case studies demonstrate several additional interesting aspects of longwall design for coal bump control. First, the technique of placing a yield pillar between the abutment pillar and the tailgate to shield the tailgate drive area from an abutment pillar bump has been quite effective. This location for a yield pillar can also help reduce floor heave in the tailgate by physically separating the high-stress abutment pillar from the high-stress tailgate corner of the face. Second, in addition to the geologic, multiple-seam, and overburden factors mentioned above, several geometric factors pertaining to longwalls in the case studies appear to enhance the likelihood of face bumps. For example, on several occasions there appeared to be some correlation between single and/or multipanel gob size and bumps. In two instances at mine 2, the face had advanced approximately 170 m (550 ft) when bumps occurred. This amount of advance made the open gob area just about square. Although the panels had already had a first fall, this geometric configuration would conceivably cause the largest stress concentration on the face because it would create a suspended main roof. Similarly, but on a larger scale, the 6th and 7th panels at mine 1 and the 15th panel at mine 2 experienced bumps after the multipanel gob was approximately square.

An intuitive feeling is that at a deep mine there should be overburden interaction between successive panels and that the magnitude of this interaction should increase until the accumulated width of the panels is essentially equal to their length. Therefore, a given gate road design may not experience a maximum abutment load until both a full panel abutment load and a full multipanel abutment have been achieved. This implies that a gate road design can be successful in supporting the immediate panel's abutment load in the tailgate of the first few panels, but may not be strong enough to support both the immediate panel's abutment load and the cumulative multipanel abutment load as successive panels are mined.

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