PILLAR DESIGN IN BUMP-PRONE
DEEP WESTERN U.S. COAL MINES

by

N.P. Kripakov and R.O. Knisley

ABSTRACT

This paper presents a brief overview of current bump mechanism theories and pillar design methodologies, and relates these concepts to experiences at two mines located in a north-central Utah coalfield where different pillar designs were used to control mountain bumps. Experience gained at the first mine demonstrated the successful implementation of a two-entry, 9.8 m (32 ft)-wide, yield-pillar design. A U.S. Bureau of Mines field study quantified the lining of chain pillar yielding and resulting load transfer from the gateroad. In-mine pillar response, although apparently sensitive to site-specific conditions, compared favorably to estimates derived using two yield-pillar design methods. A second study conducted at another mine located in the same district, but subjected to different geologic conditions, documents the unsuccessful attempts to employ progressively narrower three-entry pillar designs based on successes achieved at the first mine site. This second mine never achieved a true yield-pillar design. Use of pillar widths ranging between 9.1 m (30 ft) and 27.4 m (90 ft) always resulted in violent bumps in the tailgate pillars. The pillars were either too large to yield, or too small to support peak operational loads. Hypothetical gateroad systems were evaluated using both analytical and empirical approaches for configurations comprised of two rows of conventional pillars, and systems incorporating both yield and abutment pillars. Analysis concluded that yield pillars less than 6.1 m (20 ft) wide and abutment pillars ranging between 30.5 m (100 ft) and 30.6 m (100 ft) square would be required to achieve a stable gateroad design. However, results of a field study conducted on a two-entry, 30.6 m (120 ft)-wide abutment pillar concluded that abutment pressures from the first panel overrode the pillar, and that a still larger pillar may be required to preclude bumps in the tailgate during second panel mining. Without the benefit of a demonstrated in-mine success, it is not clear which design would ensure elimination of gateroad bumps.

INTRODUCTION

During the past two decades, much progress has been achieved in controlling mountain bumps in the coal mines of the Western United States. In spite of recent advancements, the potential for future bump problems remains high. As operators exploit deeper, higher-quality reserves, it is anticipated that the bump problem will resurface. During the 1920's and 1930's, when mine mechanization was first initiated, there was an increase in bump activity. With today's high production longwall mining in the longwall faces, several injuries occur in the longwall faces, and at least one mine closure have been attributed to bumps (Linaschone, 1957).

In a longwall operation, bumps generally occur in the tailgate pillars, or on the longwall face. Even with the progress achieved to date, bumps still potentially pose both physical and economic hardship on a mining operation. Safety and health hazards include roof falls, flying coal and rock generated from the force of shock of the sudden release of stored energy, suffocation due to a lack of oxygen, methane gas releases, and under certain conditions, the explosion of gas and/or dust when near an ignition source. Productivity is affected by the time and manpower necessary to clean up and rework the roof. One operator estimated that downtime on a longwall costs $200 per minute (Mark, 1960; Jackson, 1987). Adding to the importance of this issue are the recent findings of a West Virginia Supreme Court decision (Mine Regulation Reporter, 1951) that ruled that a coal company must pay damages for ignoring safety problems that led to injuries resulting from a bump.

The Bureau of Mines, since the mid-1920's, has conducted field studies (Linaschone, 1957; Heasley, 1966; Dempsey, 1988) in deep room-and-pillar and longwall mines of the southern Appalachian basin to quantify the behavior of pillars prone to bumping. These studies concluded that applying the load-bearing
capacity of longwall pillar systems can reduce the incidence of bumps. Implementation of conventional, wide pillar designs used in the east have not always been successful when subjected to western mining conditions. Bureau field studies conducted in the western United States (Haramy, 1988, 1989; DeMarco, 1988; Katesley, 1989; Barron, 1990) have attempted to quantify the behavior of narrower width, or yielding-pillar systems, situated under deep cover in geologic conditions somewhat different than those found in the east. The results of these investigations indicate that a properly designed chain pillar can perform as intended and provide gateroad stability.

This paper presents a brief overview of bump mechanic theories and current pillar design methodologies and relates these concepts to the experiences of two mines located in a north-central Utah coalfield where different pillar designs were used in attempts to control mountain bumps. The results of analytical and empirical analysis complemented the results of field studies used to support the mines experiences.

OVERVIEW OF BUMP MECHANICS

A bump is fundamentally the failure of overstressed material. High stresses can be due to any number of factors that include depth of cover, geologic structures, mining-induced pressures, multispan interaction, hanging roof behind the longwall shield, and improperly sized pillars, i.e., pillars too small to carry full operational loads or pillars too large to yield.

Salamon, 1976, and Dobbs, 1986, characterized bumps as dynamic releases of energy that occur when coal and rock strata are unable to absorb the excess energy released by the surrounding rock mass during the failure process. Salamon recognized how the interaction between the surrounding strata and the pillars influenced whether a pillar would fail in a controlled, stable manner, i.e., progressively yield, or fail in an uncontrolled, unstable mode, i.e., bump. Laboratory investigations demonstrated that any given coal could be made to fail both nonviolently, by crushing out, as well as burst violently. The mode of failure was controlled by varying the stiffness of the loading apparatus. The insights gained from these laboratory experiments could be related to actual mining applications. In a mine setting, the stiffness of the test frame is analogous to the term "local mine stiffness," defined as an equivalent stiffness of the roof, seam, and floor strata in different areas of the mine at any stage of mining (Salamon, 1973). This equivalent stiffness of the surrounding strata is represented by a set of parallel lines that Salamon refers to as loading lines. These sets of parallel lines are shown on Figure 1 for different mining stages. The slope of these parallel lines does not remain static, but continually changes. The more mining that occurs, the flatter the slope of the lines, reflecting a lower mine stiffness. The state of stress in the coal seam, the location along the complete stress-strain curve, and its interaction with the local mine stiffness, determines whether any further failure is stable or unstable. As mining advances and more load is imposed on a pillar through the surrounding strata, the point of intersection moves up the stress-strain curve. As this point of intersection moves over the top of the curve, failure begins to occur. As long as the slope of the loading line at the point of intersection exceeds the slope of the tangent of the load-deformation curve, failure occurs in a controlled, stable manner. At the point where the slope of the load-deformation curve falls below the slope of the loading lines, instability occurs, and excess energy is released. This uncontrolled energy release is represented in Figure 1 by the shaded area during the later stages of mining.

Figure 2 further illustrates and explains the concept of why bumps occur. The shaded area under the loading line represents the total strain energy, or work performed by the surrounding strata on a coal pillar for some incremental load increase. The area under the load-deformation curve represents the energy stored or work absorbed by the coal pillar for the same incremental load increase. The energy the coal can store is less than the total energy imposed on the coal. Assuming that no energy is absorbed or dissipated in the roof or floor structure, the excess energy is released as kinetic energy into the entry in the form of a bump.

The exact mechanism(s) actually triggering bumps have been debated for years. Rice, 1935, and Holland, 1984, observed and documented the causes of bumps in many eastern U.S. underground coal mines and summarized guidelines on how to minimize their occurrence. A common thread for all recommendations included reducing, eliminating, or controlling high-stress areas during active mining. Rice, 1935, coined the terms "pressure bump" and "shock bump." Pressure bumps are often thought to be due to the unit loading on some portion of an underground structure exceeding its respective bearing capacity. Shock bumps are believed to be caused by either the sudden failure of a thick, massive, right strata at some distance above or below the coalbed, or a sudden slip occurring along a major bedding plane somewhere in the main roof. In fact, both mechanisms probably contribute to shock bumps, regardless of which one actually triggers the bump, both can be explained with the model described above. Should a particular portion of a mine structure be right on the verge of becoming unstable, any sudden downward movement of the main roof can introduce an incremental load increase onto that structure, creating a bump condition.
FIGURE 1. Relationship between local mine stiffness, coal characteristics, and the propensity of a mine to bumping.

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PILLAR DESIGN METHODOLOGIES TO CONTROL BUMPS

Two schools of thought exist relative to controlling gatered bumps through pillar design: use of conventional abutment pillars versus yield pillars. In some isolated cases, a combination of both types of pillars have been successfully implemented (Hasley, 1988; Carr, 1986; Campoli, 1990). Conventional pillars are designed to support both the overburden weight and the mining-induced loads imposed during extraction of both adjacent longwall panels. The idea is to increase the load-bearing capacity of the longwall pillar system to a point where the average pillar stress is below the failure stress. Although conventional pillars are successfully employed in the eastern United States, their implementation under western conditions has not always been successful, particularly when mining under deep cover. Vary often, large, stiff, abutment pillars are prone to bumping. The problem is magnified when mining in a multiseam setting.

Yield pillars are designed to gradually fail in a controlled manner and to transfer the roof weight from the pillars onto more competent support structures. However, not everyone agrees on what actually constitutes a true yield pillar and on exactly when the pillar should yield. Some believe that complete yielding should occur during entry development. Others maintain that, as long as total pillar yielding occurs sometime during first panel mining, the gatered will provide a stable, travelable tailgate during second panel mining. From a practical perspective, probably the most critical factor necessary to maintain a stable tailgate requires that the degree of movement in the immediate roof structure, up through second panel mining, is minimized.

The following sections describe the experiences of two mines located in the same mining district where different pillar designs were used to control mountain bumps.

STUDY SITES

The two sites described in this paper are located at the Sunnyside mines, Sunnyside, UT, and the Castlegate mines near Helper, UT. These sites are situated in the upper Cretaceous Book Cliffs coalfield of northcentral Utah. The Book Cliffs form the boundary of the Uinta Basin and extend from westcentral Colorado to northcentral Utah, with minable coal seams along the entire length.

Site 1 (Sunnyside Mine)

The Sunnyside mines, among the oldest and most extensively worked in the Utah coalfields, have a history of coal bumps (Lindsay, 1983). The mines are located at the base of the western Book Cliffs, which range from 904.8 m (3,000 ft) to 457.2 m (1,500 ft) and are cut by numerous steep canyons. Natural conditions conducive to bumps at the mine include depth of cover, primarily up to 100 m (328 ft), rapid variations in relief, and the existence of thick, sandstone strata above and below the coalbed. One 81 m (266 ft)-thick bed, approximately 45.7 m (150 ft) above the seam, created widespread disturbances on active sections upon failure (Jackson, 1971). Although the roof consists primarily of sandstone, bumps...
are often accompanied by falls of the very poor, immediate roof shale and by methane inflows. The floor consists of thin coal, shale, siltstone, and carbonaceous shale resting on a massive sandstone beginning at approximately 4 m (13 ft) below the coalbed (Haramy, 1990). The coalbed dips gently east and northeast at 5 degrees to 15 degrees.

Prior to the introduction of longwall mining in the early 1960's, room-and-pillar mining was practiced in both the upper and lower beds. Violent coal bumps occurred when the pillar line retreated under upper bed pillar remnants. Sudden failure of the upper bed pillars resulted in lower bed bumps, erratic roof action, and punching through of pillar stumps (Coal Age Magazine, 1962). Switching to longwall, the initial panel, 61.6 m (200 ft) wide by 304.8 m (1000 ft) long, was set up using previously driven entries only 6.1 m (20 ft) below the upper bed pillars. The first three panels experienced pillar and face bumps using three-entry systems and conventional pillars. Very often, in order to ensure entry stability, supplemental roof support was required, especially when mining under the upper bed pillars (Peppeaikis, 1968). This supplemental support included rebolting the roof and installing posts, crib, and/or steel arches. After many trials using conventional pillar designs, a two-entry, yield-pillar system eventually evolved. These two-entry, yield-pillar systems have, over many years of extracting numerous longwall panels, consistently experienced less bumping, with the narrower pillars gradually crushing out in a controlled manner during longwall retreat and transferring the weight over onto the adjacent unmined panels (Jackson, 1971; Peppeaikis, 1968).

Site 1 Field Study

As a part of the Bureau of Mines ground control research program to gain information on the structural behavior of different gateroad systems, a field investigation was conducted at the Sunnyside No. 1 Mine. This study site was selected because of its history of bump occurrences and apparent success in controlling bumps using a two-entry, yield-pillar design. Instrumentation was installed in two test areas of the 20th Left longwall panel headgate entries, Figure 3. The first site, designated Section 1, was situated under approximately 533 m (1,750 ft) of cover. The second site, designated Section 2, was situated under approximately 610 m (2,000 ft) of cover. The pillar and entry widths at both sites were 10 m (32 ft) and 6.1 m (20 ft), respectively. These sites were selected to compare gateroad performance between different depths of cover. Relative pressure changes were measured across both Sections 1 and 2 using the Bureau's borehole pressure cells (BPC's) installed at the entry pressures equivalent to the assumed overburden pressures at the sites. Results are presented in Figure 4 and Figure 5. For purposes of orientation, a negative (-) face distance value indicates the distance to the face from a particular instrumentation site, and a positive (+) value indicates the distance that the face has progressed out by the instrumentation location.

Figure 4 shows the pressure distribution across Section 1 for three stages of mining: before, during, and after the face passed the instrumentation site. Because the cells were installed after the entries were developed, initial pressure changes near the pillar ribs

![Diagram](image-url)
could not be measured. However, it is still interesting to note that chain pillar rib yielding occurred long before approach of the first longwall face, as evidenced by the stressed central core of the chain pillar and destressed pillar ribs. Note that when the face was mined right up to the instrumentation site, the chain pillar was further destressed, and that load had transferred onto the 21 L panel. The stress distribution in the 21 L panel exhibited an elastic response at the tailgate rib with a gradual decrease of stress into the panel.

Figure 8 shows the pressure distributions across Section 2 for the same mining stages as in Figure 4. Note that, unlike the behavior observed at Section 1 prior to the approach of the first longwall face, the stress distribution in the chain pillar indicates an elastic response, with a higher peak stress value occurring on the rib closest to the 20 L panel. Total pillar yielding apparently did occur as the face approached the instrumented site, as evidenced by the total loss of pillar core pressure. As the pillar yielded, the load transferred laterally onto the 21 L panel. Note that, again, unlike the behavior observed at Section 1, the tailgate panel rib yielded, and the peak abutment pressure not only increased, but transferred deeper into the 21 L panel. As the face continued to advance to a distance of 7 m (200 ft) from the instrumentation site, additional yielding continued in the 21 L panel tailgate rib.

Calculations of yield-pillar widths assuming a nominal 2.4 m (8 ft) seam thickness using methods proposed by Wilson, 1972, and by Kamis, 1989, indicate that the 9.8 m (32 ft)-wide pillar should yield at the 810 m (2,600 ft) depth, but that a slightly narrower, 8.5 m (28 ft) to 9.1 m (30 ft)-wide pillar would be required at a 533 m (1,750 ft) depth. This is somewhat consistent with the results of the field data presented in Figures 4 and 6, as the pillar at Section 1 is situated under less cover than the pillar at Section 2. The pillar at Section 2 tended to initially behave more elastically than the pillar at Section 1, at a face distance of 106.7 m (-350 ft). But, as the face approached both Section 1 and Section 2, respectively, the pillar at Section 1 still maintained some evidence of a small core, whereas the pillar at Section 2 showed no sign of load-carrying capability and had completely failed. It may be that under certain conditions, greater depth could promote earlier yielding of a pillar and cause a greater degree of stress transfer onto an adjacent unmined panel, as illustrated in Figure 8. In any event, both instrumented pillars, situated under different depths of cover, yielded with the approach of the first longwall face, and showed evidence of transferring weight onto the adjacent unmined longwall panel.

Although the Bureau did not monitor pressure cell readings during mining of the 21 L longwall panel, Koehler, 1981, reported that, during extraction of the first half of 21 L panel, mining of the 21st Loop panel proceeded relatively smoothly in regard to bump activity...bumps were limited to the longwall face area within approximately 30.5 m (100 ft) of the tailgate corner, which is typical of most quiet panels at Sunnyvale... and there are no noticeable differences in performance of a 12.2 m (40 ft) design and a 9.1 m (30 ft) design.
during first panel loading...however, the difference in performance becomes quite clear when these two designs are subjected to full tailgate loading...the 1.2 m (40 ft)-wide pillars bump more frequently and with more force, while the 0.9 m (30 ft)-wide pillars rarely bump at all...in addition, tailgate roof stability throughout the mining cycle seems to improve when the 0.9 m (30 ft)-wide design is used.

Site 2 (Castlegate Mine)

The Castlegate mines are also located in the Book Cliffs coalfield of north-central Utah which consists of 13 potentially mineable seams. Overburden depths change drastically as a result of the mesa and canyon topography. Cover depths range between 1 ft at the outcrop portals to nearly 170 m (556 ft) above the most inby workings. Cover depth over the east side of the mine, where the Bureau conducted its investigation, ranges from 74 m (244 ft) to 277 m (911 ft). The overlying strata include two massive sandstone members: a 36 m (118 ft)-thick unit located approximately 16 m (55 ft) above the mined seam, and a 152 m (500 ft)-thick unit located approximately 355 m (1164 ft) above the coal seam. The immediate roof consists of horizontally variable interbedded sandstone, siltstone, shale, limestone, and coal stringers and is transacted by numerous channel sandstones. A 15.2 cm (6 in) layer of hard, brittle carbonaceous siltstone (referred to as snap rock by mine personnel) lies directly above the coal seam throughout most of the mine (except in areas of the mine where channel sandstone contacts the seam). The immediate floor is comprised of a 49 m (160 ft)-thick hard, competent sandstone. The seam consists of a strongly bituminous coal with widely spaced, indistinct cleat. The coal contains large

Figure 6 - Longwall area of Castlegate No.3 Mine, showing location of study sites (Barron, 1990).

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volumes of methane gas, and is transmitted by numerous linear elastic dikes, termed rock spars (Barron, 1990).

Mining has occurred on the Castlegate property by various companies since 1889. Records beginning in 1976 relate a continuing problem with coal bumps. Table 1 summarizes a brief history of longwall mining on the property. Barron, 1990, presents a more in-depth discussion of longwall experiences at the Castlegate No. 3 Mine. Refer to Figure 6 for a layout of the Castlegate No. 3 Mine.

In July 1988, the Bureau performed an analysis to determine what size gateroad pillar(s) would be required to eliminate the occurrence of bumps at the Castlegate No. 3 Mine. Past attempts to employ progressively narrower, three-entry pillar designs, based on the two-entry successes achieved at the Sunnyside Mine, resulted in violent bumping occurring in the tailgate pillars, as documented in Table 1. It would appear that the narrow pillar designs were either too large to yield, or too small to support peak operational loads without bumping. Attempts to implement conventional pillars also resulted in bumps on the tailgate pillars and along the face.

A study was performed using the Bureau's Analysis of Longwall Pillar Stability (ALPS) approach (Mark, 1990) to obtain a qualitative comparison of the stability factor associated with the previous pillar configurations attempted in 2 1/2 East through 9th East; Figure 6, at the Castlegate No. 3 Mine. These analyses were performed to establish a baseline to compare the relative performance of each design.

The results of those analyses are presented in Figure 7. Although Figure 7 wrongly portrays 7th East as a symmetric gateroad system, the varying pillar widths across the gateroad were considered when generating the bar chart. The solid block of coal next to 7th East was not solely considered in Figure 7 since this analysis is comparing relative performance of systems subject to similar loading and coal strength. It must be emphasized that in interpreting the meaning of stability, as presented in Figure 7, a value of 1.0 or greater may or may not represent a stable design. And a value of less than 1.0 does not necessarily mean that the design is unstable.

The data, as presented, simply represent the relative stability of each configuration with respect to each other. Typically, stable pillars provide for stable entries. Figure 7 indicates that an increasing ratio of local pillar width to gateroad width provides for a greater degree of certainty regarding pillar/entry stability. Once a successful gateroad configuration is achieved, this information can be useful in projecting what pillar sizes could provide stable gateroads for future longwall panels. To date, a successful design has never been achieved in the east side of the No. 3 mine.

Previous in-mine experience using three-entry systems with small gateroad pillars was not successful. InB small tailgate pillars were both too large to yield, yet too small to support tailgate loading without failing violently. The ALPS-generated stability factors indicate good qualitative agreement with observed behavior. The generally deteriorating

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![Figure 7 - Stability factors for previous and current gateroad configurations in Castlegate's No. 3 Mine.](image-url)

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Table 1. Longwall mining history at the Castlegate mines.

<table>
<thead>
<tr>
<th>Year</th>
<th>Panel</th>
<th>Pillar size, m (ft)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>3rd East #3 mine</td>
<td>15.2 by 25.9 (50 by 85) tailgate 12.2 by 25.9 (40 by 85) headgate</td>
<td>Tailgate pillars failed. Bumps were commonplace.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 entries</td>
<td></td>
</tr>
<tr>
<td>1977</td>
<td>4th East #3 mine</td>
<td>12.2 by 25.9 (40 by 85) tailgate 9.1 by 25.9 (30 by 85) headgate</td>
<td>Violent bumps in the tailgate and on face.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 entries</td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>5th East #3 mine</td>
<td>9.1 by 25.9 (30 by 85) tailgate 9.1 by 25.9 (30 by 85) headgate</td>
<td>Violent bumps in the tailgate and on face.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 entries</td>
<td>Panel abandoned due to equipment failure.</td>
</tr>
<tr>
<td>1980</td>
<td>6th East #3 mine</td>
<td>9.1 by 25.9 (30 by 85) tailgate 6.1 by 26.9 (30 by 85) headgate</td>
<td>Violent bumps as in 4th and 5th East. The panel was ended prematurely due to a fire.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 entries</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 entries</td>
<td></td>
</tr>
</tbody>
</table>

Longwall production was moved to the #5 Mine.

<table>
<thead>
<tr>
<th>Year</th>
<th>Panel</th>
<th>Pillar size, m (ft)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>6th West #5 mine</td>
<td>9.1 by 30.5 (30 by 100) tailgate 25.9 by 25.9 (85 by 85) headgate</td>
<td>Better conditions, only roof spalling and small headgate bumps 2 entries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 entries</td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td>9th/10th West #5 mine</td>
<td>25.9 by 25.9 (85 by 85) tailgate 25.9 by 36.8 (85 by 120) headgate</td>
<td>Minor ground control problems.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 entries</td>
<td></td>
</tr>
</tbody>
</table>

Mining continued using the 9th West design until December 1984, at which time the mine was idled. The mine was reactivated in May 1986 under new ownership, and the 11th West longwall panel began operation in October of 1986.

<table>
<thead>
<tr>
<th>Year</th>
<th>Panel</th>
<th>Pillar size, m (ft)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>11th West #5 mine</td>
<td>25.9 by 36.8 (85 by 120) tailgate 25.9 by 36.8 (85 by 120) headgate</td>
<td>Minor ground control problems.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 entries</td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>12th West #5 mine</td>
<td>25.9 by 36.8 (85 by 120) tailgate 25.9 by 36.8 (85 by 120) headgate</td>
<td>Minor ground control problems.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 entries</td>
<td></td>
</tr>
</tbody>
</table>

The #6 mine was closed and production switched to the #3 mine.

<table>
<thead>
<tr>
<th>Year</th>
<th>Panel</th>
<th>N/A</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>7th East #3 mine</td>
<td>This panel was not mined and served as a barrier.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>8th East #3 mine</td>
<td>25.9 by 36.8 (85 by 120) tailgate 15.2 by 36.8 (50 by 120) headgate</td>
<td>No ground control problems, although loud &quot;booms&quot; were heard.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>9th East #3 mine</td>
<td>25.9 by 36.8 (85 by 120) tailgate 36.8 by 36.8 (120 by 120) headgate</td>
<td>Extraction of this panel began in June 1988 with severe bumping occurring in the tailgate and along the face.</td>
</tr>
</tbody>
</table>
conditions observed at Castlegate are qualitatively validated by the overall downward trend in stability factors for the 3rd East through 6th East gateroads. The ALPS-generated stability factors for the 6th East and 8th East two-entry, conventional pillar designs were also qualitatively compatible with observed conditions. ALPS analysis indicates that the 25.6 m (85 ft)-wide pillar in 6th East should fail, and reports of tailgate pillars failing violently outby the panel corner seem to corroborate the prediction. ALPS-generated stability factors for the 9th East design, a 26.6 m (120 ft)-wide pillar, are also qualitatively compatible with observed conditions. Computed safety factors (S.F.) for different support conditions are summarized below:

- Headgate Loading, S.F. = 1.29
- Tailgate Loading, S.F. = 0.53
- Isolated Loading, S.F. = 0.46

Headgate loading refers to gate loads generated by the first panel mined up to the pillar in question; tailgate loading assumes one panel removed and the second panel even with the pillar in question; and isolated loading refers to pillar/entry loading with gob on both sides. Predicted stability agrees with reported mine conditions for headgate loading, but without a demonstration of success, it is not known whether the 26.6 m (120 ft)-wide pillar is wide enough to ensure stability during tailgate loading. Minimum conventional pillar width requirements, using ALPS, range between 30.5 m (100 ft) to 36.6 m (120 ft), depending on whether a combination of two wide square pillars are used, or a wide pillar is used in combination with a 9.1 m (30 ft) nonyielding pillar.

Bureau calculations using Wilson’s approach (Wilson, 1972) suggest that, for the conditions at Castlegate, a pillar width between 4 m (13 ft) and 5.8 m (19 ft) would be required to achieve a true yield pillar. In fact, following the abandonment of Third panel mining, Castlegate experimented with 6.1 m (20 ft) pillars, developed off of the 5th East gateroad, and reported that the pillars yielded and the entries remained stable.

**Site 2 Field Study**

A gateroad field study was conducted by the Bureau in July 1986 at Castlegate’s No.3 Mine to (1) quantify the structural performance of the 36.6 m (120 ft)-wide chain pillar separating the Sixth and Seventh longwall panels, Figure 6, and (2) use this information to establish engineering design parameters for mining of future panels. The study site was located in the 6th East headgate shown in Figure 6. The instrumentation consisted of borehole pressure cells (BPC’s) installed and oriented both vertically and horizontally to record pressure changes across a section of the 36.6 m (120 ft)-wide chain pillar.

The overall results of the field study are summarized by Barron, 1990, and will not be repeated here. However, Figure 8 is used to illustrate the override of the headgate pillar by the side abutment load, as demonstrated by the gradual load increases recorded by the two cells positioned at 9.1 m (30 ft) and 12.2 m (40 ft).
ft), respectively, into the tailgate rib of the future Seventh panel. This constitutes an override of close to 61 m (200 ft) from the active Fifth panel.

CONCLUSIONS

Use of wide abutment pillar designs commonly employed in eastern coal mines to control bumps have not always been successful when subjected to western mining conditions. Western conditions often include deep cover, massive and stiff geologic structure hosting the coal seam, and hard, brittle coal prone to bumping. The situation is often complicated by the presence of old workings above or below the seam being mined. A number of western operations have evolved, through painful experience, toward the use of two-phase, yielding systems to minimize the occurrence of these catastrophic ground hazards.

Results from a Bureau of Mines rock mechanics study conducted at the Sunnyside Mine indicated that the 9.8 m (32 ft)-wide chain pillar yielded with approach of the longwall face during first panel mining. Pressure cell measurements suggested the existence of a pressure arch over the longwall panel entries prior to longwall passage. At first panel mining approached and passed the instrumented sites, measurements indicated that pillar yielding contributed to destruction of the longwall gateroad through the transfer of potentially dangerous stress concentrations onto the tailgate rib of the adjacent panel.

In contrast to the Sunnyside experience, use of narrow-width pillars in the gateroads at Castlegate failed miserably. Three-entry systems using 12.2 m (40 ft)-wide pillars, 12.2 m (40 ft)-wide pillars, and 6.1 m (20 ft)-wide pillars all resulted in violent bumps in the tailgate area. Use of 6.1 m (20 ft)-wide pillars in one section of the mine exposed to high abutment loading indicated pillar yielding with stable entry conditions, suggesting that pillar widths less than 6.1 m (20 ft), used in a garedoosed system, may provide a stable entry. However, without the benefit of a demonstrated in-mine success, it is not clear whether a pillar width this narrow will yield before bumping, or simply crush, nonviolently, and cause excessive convergence in the entry.

In lieu of implementing a yield pillar design at Castlegate, because of the extremely difficult mining conditions, it may be prudent to completely isolate the effects of each panel from the other. As reported above, the 26 m (85 ft), 8th East pillars bumped violently during tailgate loading when cover depth exceeded 488 m (1,800 ft). Although the 36.6 m (120 ft), 9th East pillars situated under 488 m (1,600 ft) to 671 m (2,200 ft) of cover remained stable during headgate loading, the high and rapid load responses observed in these pillars indicate that they may bump during extraction of the next panel. Should a Seventh panel be extracted, the combined effect of side abutment loading from the Fifth panel and forward abutment loading from the Sixth panel could lead to pillar and/or face bumps and outbursts near the tailgate.

In summary, it is very difficult to know or predict, beforehand, exactly how a given pillar design will respond in a particular geologic setting. The success of a design is often contingent on the experience and background of the personnel at a particular mine, an understanding of why certain designs worked while others failed, and a willingness to be flexible and experiment in order to truly arrive at an optimum configuration for a given set of conditions.

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