Five Stress Factors Conducive to Bumps in Utah, USA, Coal Mines

J.F.T. Agapito, Principal
R.R. Goodrich, Associate
Agapito Associates, Inc.
715 Horizon Drive, Suite 340
Grand Junction, CO 81506

ABSTRACT

High stresses and adverse geology in deep coal mines in the state of Utah, USA, have caused numerous bumps. The larger bumps have been associated with seismic events with Richter magnitudes of 3.6 and greater, and in some cases have filled openings for lengths of 150 m. A better understanding of the mechanisms and stress levels involved in bumping is needed to help develop improved stress control design and bump mitigation methods.

The geology of the area is notoriously bump-prone. The coal has poorly developed cleating and occurs in multiple seams that are often bounded by very strong roof and floor sandstone/siltstone beds. The overburden is formed by thick, competent strata with numerous sandstone channels. This geology and deep cover are the major source of high stresses, causing bumps.

This paper evaluates five common stress factors responsible for bump problems: depth, sandstone channels, arching, faults, and coal thickness. It uses case study data from longwall panels with two-entry/yield pillar systems typical of deeper Utah mines. Results illustrate the importance of analyzing stress factor experience to allow a better understanding of the problem.

INTRODUCTION

Coal bumps in the deep mines of the Wasatch–Book Cliffs region of central Utah (Figure 1) have caused injuries, fatalities, mine closure, and loss of reserves.

The bump problem in Utah coal mines is not new. Some of the earlier published experience is 80-years old (Watts 1918). High stresses and bump-prone geology have been known for many years to be associated with bumps. In addition, some mining practices also have contributed to the problem.

Through the years, many factors conducive to bumping have been recognized, but progress to quantify and predict events has been slow. High stresses are the common ingredient in all the factors, and there is a strong need for better quantification of stress levels to improve prediction of events, mine design, and operations.

This paper presents an evaluation of five common stress factors encountered in central Utah through computer-aided analyses of both generic and specific case studies. The objective is to show that close evaluation of bump factors may lead to a better understanding of the problem and eventually to safer operations.
Most coal mines in the western USA have converted from room-and-pillar to longwall mining for improved safety and productivity at depth. Cover depth in some mines has reached 700 m, and there are plans for mining close to 900 m by the end of the first decade of the 21st Century.

The first longwall operation was introduced in 1961 to the Sunnyside Mine in the Book Cliffs area. However, it was not until the 1970s that this mining method became used in other mines. By 1997, more than 170 longwall panels had been mined (Pollastro[5] 1997). In 1996, 24.5 million tons were produced from Utah coal mines; about 75 percent from longwalls and 25 percent from continuous mining sections. The annual production doubled from 1981 to 1996, while manpower was halved. During this same period, productivity increased from 1.8 to 6.3 tons per man-hour.

Bumps have occurred mostly in tailgates and at the longwall face near the tailgate, and to a lesser extent in the headgate, development entries, and as a result of multiple-seam mining. Some bumps have induced seismic shocks of 3.0 to 3.6 Richter magnitude and have filled openings for lengths of 150 m (Lannocchione and Zelanko[7] 1995, Agapito et al.[8] 1988). The use of two-entry gateroad systems with narrow yield pillars has been a major factor in controlling and minimizing bumps in gateroads. Yield pillars are, for the most part, 9-m wide. Their yielding allows the stresses to be transferred away from pillars and entries onto adjacent abutments that can be large, rigid pillars, solid coal, or gob. Although yield pillars have reduced the number and severity of bumps, they have not eliminated them. Some pillar bumps continue to occur, mostly as depths of 550 m are reached and when the immediate roof and floor are very stiff and strong. Associated with gate bumps, and more difficult to deal with, is bumping at the longwall face.

**BUMP-PRONE GEOLOGY**

The topography of the Wasatch–Book Cliffs region is rugged with large elevation differences between the plateau tops and valley streams. Coal occurs in multiple seams near the base of the Blackhawk Formation in the Cretaceous Mesa Verde Group. Figure 2 is a composite of the lithological section of the region. Except for some differences in Tertiary Period strata, both areas have a similar general lithology, characterized by numerous thick and strong sandstone and siltstone beds. Locally, however, there are marked differences in lithology, not only between mines but within each mine.

As a whole, the geology of the region is notoriously bump-prone as follows:

1. Thick, competent overburden strata that tend to bridge and interlock, creating high abutment stresses.
2. Numerous channels that cause high stress concentrations.
3. Very competent and strong immediate roof and floor sandstone/siltstone strata that confine/load the coal and resist breakage.
4. Uncleated or poorly cleated, strong coal that sustains high stresses and tends to fail suddenly.

As opposed to the above characterization, and creating a different set of ground problems, is the occurrence of very soft shales and mudstones in the immediate roof. Abrupt changes in lithology are difficult to predict. Many roof falls have occurred in these softer rocks, sometimes triggered by bumps. Soft shales are also encountered in the floor, but to a lesser extent. This is beneficial for reducing bump potential by allowing stress/strain relief through floor heave.

The great differences in rock strength are shown by simple uniaxial compressive strength tests. Whereas strengths of shales and mudstones range from 10 to 70 MPa, the fine-grained sandstones and siltstones range from 150 to 220 MPa. Coal strengths usually range from 15 to 25 MPa.

**FIVE STRESS FACTORS CONducive TO BUMPING**

Causes of high stresses present a complex problem since they can be linked to numerous factors. However, the five following stress factors are of major importance because they have played an important role in causing many bumps:

1. Depth of cover
2. Channels
3. Arching of strata
4. Faults
5. Coal seam thickness

Through the years, Agapito Associates, Inc. (AAI), has had the opportunity to evaluate many bump-related problems using a combination of in situ observations and measurements with computer back-analysis. The quasi three-dimensional code EXPAREA was used in the analyses of the above stress factors (St. John[6] 1978). This code uses the displacement-discontinuity technique for modeling excavations of large, tabular, seam-type deposits. It incorporates linear elastic, elastic-plastic, elastic-strain-softening (yield), and bilinear constitutive models for representation of confined coal, pillars, and gob. The capabilities of EXPAREA have been improved during the last 20 years by AAI. The code has been used in many projects as a tool for mine design and to help management make decisions on ground control.

**Depth of Cover**

Mines in the Wasatch–Book Cliffs region are located beneath the flanks of plateaus, with large elevation differences between ridge tops and canyon bottoms over short lateral distances. Single longwall panels can experience cover depths ranging from 300 to 700 m and more. Many of the future mines will be deeper than 600 m.
A rule of thumb used by mines in the region is that bump problems may begin in areas with strong immediate roof and floor when the depth reaches about 450 m. However, exceptions to this guideline occur often depending on geologic and mining conditions. While bumps have occurred at shallower depths than 450 m, mining has been conducted at depths of more than 600 m without bump problems.

Figure 3 shows the large stress differences experienced when a longwall panel is mined at depths of 300, 600, and 900 m. The model uses typical strong material properties for the region and shows a second panel being retreated. A 225-m-wide face and a two-entry layout with 6.0-m-wide by 2.4-m-high openings and 9.0-m-wide by 25.0-m-long yield pillars was used. No major geologic structures, such as channels or faults, were included in the model.

Areas of potential bumping are indicated in Figure 3 at the tailgate corner for 600-m depth. This expands considerably along the gates and face for 900-m depth. It should be noted that these are potential bumping areas for openings with strong immediate roof and floor (sandstones and siltstones). The likelihood of bumping decreases considerably if shales and mudstones bound the opening or if the coal seam is thick and coal is left in the floor. The softer materials provide a beneficial stress relief mechanism for bump control.
Sandstone Channels

These deposits have been associated with many bumps when present in the immediate mine roof. Channels are formed by ancient streams that cut into older sediments such as coal or shale beds. Subsequently, the stream fills the channel with younger sediments, commonly sandstone. The channel size can vary greatly from a half-meter to more than 30 m in thickness, and from a few tenths to more than 100 m in width. They can meander for thousands of meters over an entire mine. Many roof falls have occurred in strata under-neath and at the channel margins due to poor bed consolidation.

Channels are well known for creating high stress concentrations. Figure 4 shows the results of an analysis conducted to evaluate the stress concentrations caused by a 55-m-wide by 10-m-thick channel running perpendicular to the longwall face near the tailgate. The panel is the third in a coal block at a depth of 600 m. The stresses are presented in plan view and in more detail through a cross-section taken 3 m ahead of the face. Peak stresses are increased by almost 60 percent from 70 MPa (the highest value at the corner of the tailgate) to 110 MPa at the channel. Peak stresses in the range of 4.2 to 5.5 times the pre-mining overburden stresses have been measured at the face near the tailgate corner at approximately the same depth of 600 m (Haramy and Kneisley 1990). These measurements were made by hydraulic pressure cells in longwalls using a two-entry gateroad system at the Sunnyside Mine in the Book Cliffs. The range of these measured peak stresses is equivalent to about 64 to 83 MPa (with no channel effects being reported) as extraction approaches critical width.

Arching of Strata

Experience in many mines of the region has shown that ground conditions tend to worsen as extraction approaches critical width. For face widths of 200 to 250 m and depths of 500 to 700 m, this usually occurs during the extraction of the third adjacent panel. A recent case study at the Deer Creek Mine in the Wasatch Plateau clearly shows a side-abutment effect (Agapito et al. 1997). High stresses are caused by pressure arching formed by the interlocking of large blocks of competent subsiding strata.

Figure 5 shows back-analysis results of the longwall area as a plan view, with the bump locations and cross-sectional stress distributions. Arching of strata over the first two panels causes a marked stress increase at the face near the tailgate of more than 30 MPa, sufficient for triggering the bumps. Stress bumping levels were estimated at about 60 MPa for this specific case.

Bumping occurred in the third, completely recovered, panel of a large coal block when the 225-m-wide longwall had retreated for a length of 460 m at a depth of 600 m. Most of the bumps occurred in a 60-m length near the tailgate. There were no tailgate pillar bumps and pillar yielding proceeded in a controlled manner three to four pillars ahead of the face. Note that no significant bumping occurred in the second longwall at the same depth as the third longwall.
Figure 4. Stresses Caused by Sandstone Channels

Figure 5. Stresses Caused by Arching of Strata
Faults

The occurrence of bumps during development in the vicinity of faults was reported as early as 1918 in the Book Cliffs area (Peperakis, 1958). Numerous other occurrences since then have indicated that high stresses are associated with some faults and intrusive igneous dykes. The mechanisms that lead to high stresses are not fully understood.

In a recent case study at the Deer Creek Mine in the Wasatch Plateau, stress determinations were made by the overcoring technique along development entries through faults of a graben structure at a depth of 580 m (Goodrich et al., 1998). The faults, location of measurements, and vertical stress magnitudes are shown in Figures 6a and 6b. Measurements indicated stresses of nearly twice the magnitude of in situ vertical stresses on the outside flanks of the graben, and stresses of 17 percent less magnitude than the in situ stresses within the graben. The measurements were made before longwall mining as part of an evaluation to determine the feasibility of mining through the graben.

During development, considerable pillar spalling and failure occurred before and after crossing the graben faults, but good ground conditions were found inside the graben. This experience agreed well with the stress determinations. Figure 7 shows typical pillar failure observed just before crossing the graben in the 6th West gateroad (Figure 6a) about a year before the stress measurements in 5th West.

In practice, it is difficult to detect small faults ahead of development and to predict if high stresses are present.

Coal Seam Thickness

The thickness of mineable coal seams presently being worked varies mostly from about 2.5 to 5 m, and the size of most openings range from 2.4- to 2.7-m high by 5.5- to 6.3-m wide. In any of the mines in the Wasatch–Book Cliffs region the roof and, to a lesser extent, the floor lithology can vary significantly over short distances. It is very difficult to foresee these changes ahead of mining. The coal seam thickness varies also, but generally not as abruptly as the roof strata. Thus, forecasts of coal seam thickness changes are often more reliable than roof and floor lithological changes. The roof line is usually kept at the same horizon at or near the top of the seam. It is a well-known fact in all mines of the region that the stresses near the openings are attenuated and the likelihood of bumping decreases when the floor is formed by coal or a soft shale. Small to moderate amounts of floor heave are often welcomed as a sign of stress relief.

The result of a case study illustrating the above was given by the experience of longwall mining through the graben discussed in the previous section. Two analyses were made for coal seam thicknesses of 2.4 and 4.8 m, respectively, with the material properties and all other geometry being kept equal. Figures 8a and 8b show the stresses for a position when the longwall was intersecting the western fault of the graben at a depth of about 580 m. Stress field input takes into consideration the stress measurement results. The headgate is in the low stress regime inside the graben, and the tailgate is in the highest stress area before the fault. The plan view in Figure 8b pertains to a coal seam height of 4.8 m. The analysis for the 2.4-m height shows similar stress distributions, except for the portion of the face near the...
tailgate. This can be seen in the cross-section taken 3 m into and parallel to the face (Figure 8a). There is significant reduction in stresses from the thicker coal, sufficient to lower the stresses below expected bump levels.

The coal seam was approximately 4.3-m thick when the longwall was mined through the graben. No coal bumps occurred, but the tailgate heaved considerably leaving, in some places, only about half a meter open. It is relevant to contrast this experience with that of Figure 5, where the coal seam thickness was only about 2.4 m and numerous bumps occurred. Longwall dimensions were similar, but pre-mining stresses in the thicker coal area were higher because of the graben. These two longwalls were located in the same seam at a distance of about 4.3 km.

MINIMIZING BUMP HAZARDS IN THE 21ST CENTURY

In the 20th Century, the progress of design and mitigation for minimizing bumps has been slow. Many of the stress factors
conducive to bumping have been recognized for the last 70 or 80 years. Measures for minimizing bump hazards were employed 40 years ago at the Sunnyside Mine in the Book Cliffs area (Peperakis, 1958). These measures consisted in de-stressing with long-hole shooting, avoiding using large extraction pillars, sequencing mining to avoid locating openings into high abutment areas, and use of extensive support including yieldable steel sets, ribs, roof bolts, and hydraulic backfilling of old workings.

The general concepts of de-stressing techniques such as shot firing, auger drilling, and water infusion have been established for many years. However, experience with de-stressing in the Utah mines has been in a small scale and results have been inconclusive. These techniques are unpopular with mines in the region because of the expense and the bump triggering potential when drilling into highly stressed areas, which has caused some injuries in the past.

To minimize and mitigate bump hazards in the 21st Century, wider application of existing technology, as well as development of new methods, is needed in the following five areas:

1. Detection—Use of geologic mapping, geophysical instrumentation, stress determinations, computer modeling, etc., to detect structures associated with bumps, changes in lithology, and high stress areas.
2. Mine Design—Minimize high stresses in working areas (yield pillars, panel orientation, barrier sizing, mining sequence, number of panels per block, multi-seam impacts, ground support, etc.).
3. Longwall Equipment—Protect and minimize miner and equipment exposure (remote control of shields and shearer, shield support density, spalling plates, rock bump valves, etc.).
4. Operational Procedures—Protect and limit miner exposure and predict high stress areas (miner protective gear, training, monitoring of ground conditions, instrumentation, mining rate, etc.).
5. De-stressing—Develop and demonstrate safe methods with large-scale testing (shot firing, auger drilling, liquid infusion, hydraulic fracturing, etc.).

Application and development in the above five areas need to be done in a cooperative manner between the mining industry, equipment manufacturers, and research and regulatory government agencies.

CONCLUSIONS

Safety problems caused by coal bumps in the Wasatch-Book Cliffs region of Utah highlight the need for improvement in avoiding, predicting, and mitigating these events. This is critical as mines become deeper.

Depth of cover and adverse geology are the source of high stresses causing bumps, which occur mostly in tailgates and at the longwall face near the tailgate.

A better understanding of bump stress levels is needed for improved prediction and development of safer mine design and operations. With this objective in view, an evaluation of five common stress factors encountered in Utah mines was made for typical longwall layouts using two-entry gateroads with yield pillars. The evaluations used simple computer modeling based on extensive field experience, geologic mapping, and instrumentation. A seam bounded by strong, stiff strata was assumed in all analyses.

The evaluation of stress factor experience is of primary importance to help mine management develop safer plans and strategies for the future.

Improvement of the bump problem in the 21st Century requires a wider range of existing technology and the development of newer systems. Future work should be concentrated in improving prediction, mine design, equipment, operating procedures, and de-stressing methods.

REFERENCES