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INTERPANEL BARRIERS FOR DEEP WESTERN U.S. LONGWALL MINING

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ABSTRACT

Western U.S. longwall operators face increasing challenges with optimizing ground control and productivity as mines reach greater depths and coal bursting hazards increase. Some western U.S. mines, many known to be bump-prone, achieved a successful balance between ground control and productivity by transitioning to side-by-side longwall panel mining combined with a yield pillar gateroad system. With this design, development footages could be minimized and pillar bumping averted by controlled yielding at moderate depths, generally in the range of 450 to 600 m. Over the past four decades, the yield pillar system has won wide acceptance among western mines facing pillar bursting hazards, particularly those in the Wasatch Plateau and Book Cliff coal fields of central Utah. However, recent attempts among the deepest Utah operators to mine side-by-side panels with yield pillars at depths in excess of 600 m have been met with mixed success and, in some circumstances, with serious difficulty. Challenges include violent face bursting and excessive tailgate convergence outby the face, which can be crippling to ventilation. The use of interpanel barriers, i.e., barriers left between longwall panels, offers one possible solution to mining under deep cover with bump-prone geology. Interpanel barriers have already been adopted by Utah's deepest longwall mine, and others are considering their use. The geomechanical implications of mining with and without interpanel barriers, and the competing tradeoffs between ground control and ventilation are discussed.

INTRODUCTION

Since longwall mining was introduced to the western U.S. at the Sunnyside Mine in 1961, gateroad design has evolved in accordance with increasingly worsening ground and ventilation conditions. The economic success of most longwall mines operating in today's highly competitive western U.S. coal market is critically dependent upon robust gateroad systems able to perform predictably and safely under deep and severely *bump*-prone (or *burst*-prone) mining conditions.

The transition from early room-and-pillar methods to today's highly optimized fully-yielding longwall gateroad systems has been an intelligent process marked with proven successes and failures [1, 2, 3, and 4]. This 40+ year history is responsible for shaping modern thought about mine design and solidifying convictions held by leading companies about the future of deep longwall mining in the west. Perhaps chief among these convictions is the principle that safe and economic longwall mining requires the use of fully-yielding gateroads to control the ground in bump-prone geology.

The two-entry yield pillar gateroad (Figure 1) has become the *de facto* standard in Utah where bump-prone conditions are recognized to be the most severe in the U.S. However, recent misfortunes, including the loss of production, loss of panels, injuries, and one fatality, have brought this historically successful standard into question for deep mining, which generally surpasses 700 m and is now reaching 900 m of depth.

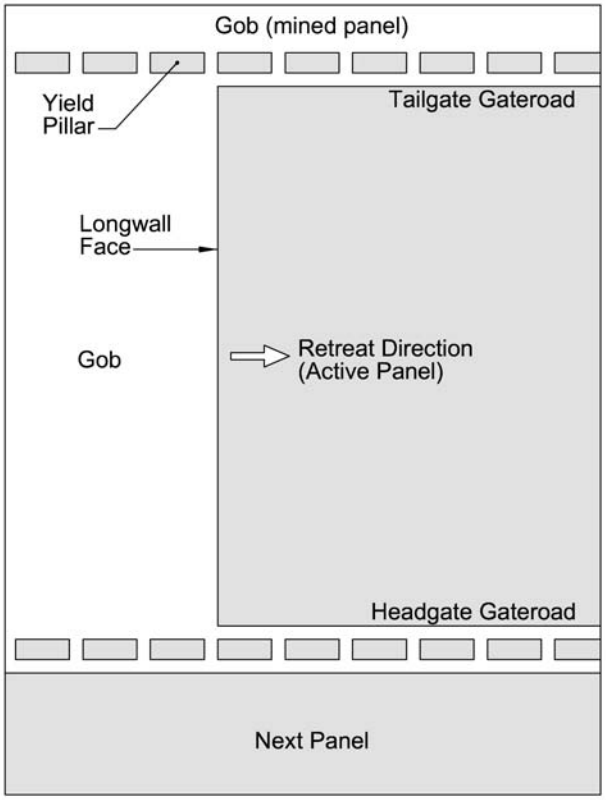

Figure 1. Plan of Two-entry Yield Pillar Gateroad System with Side-by-side Longwall Panels

Further complicating the use of the two-entry yield pillar gateroad is the demand for increased ventilation to contend with progressively gassier environments at depth. The two-entry system, inherently restrictive to airflow, has provided an acceptable trade-off between ventilation and ground control for many years. However, as longwall airflow requirements rise and frictional resistance to airflow worsens with increased entry convergence at depth, the cost to ventilation is approaching unacceptable levels at the gassiest operations.

The present issue is two-fold for future deep, bump-prone mining in the west. Firstly, there is an inevitable need for departure from the preferred yield pillar design, which undoubtedly entails higher development costs, and secondly, alternative designs are crucial for sustained production. At Utah's deepest mines, alternative designs are being considered or are already in practice. The reality of deeper reserves makes the development of functional, low-cost alternative longwall designs a paramount technical objective for today's western coal mining industry.

NEED FOR THE TWO-ENTRY YIELD PILLAR GATEROAD SYSTEM

The geology of western coal measures is notoriously bump-prone, particularly in the Wasatch Plateau and Book Cliffs coal fields of central Utah (Figure 2). The history of coal bumps pre-dates longwall mining at the Sunnyside Mine. The main geologic factors responsible for bumping are:

- Thick and competent overburden strata that tend to bridge and interlock, creating high abutment stresses.
- Numerous channels that cause high-stress concentrations.
- Very competent and strong immediate roof and floor sandstone and siltstone strata that confine and load the coal and resist breakage.
- Uncleated or poorly cleated, strong coal that can sustain high stresses and tends to fail suddenly [5].

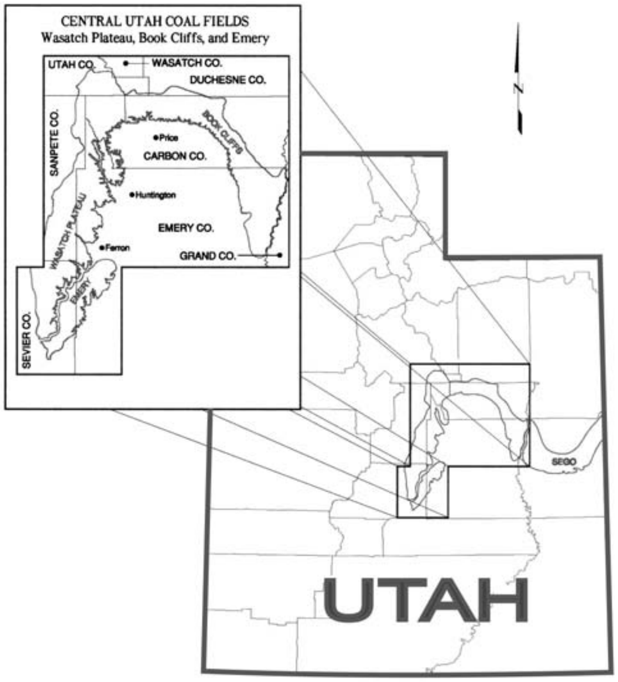

Figure 2. Wasatch Plateau and Book Cliffs Coal Fields Located in Central Utah

Prior to the introduction of longwall mining at the Sunnyside Mine, small, yielding-type pillars were found to alleviate the frequency and magnitude of pillar bumps during retreat room-and-pillar mining. Bumps were essentially eliminated by employing yield pillars in the panels ranging from 7.6 to 10.7 m wide [6 and 7]. However, unstable roof conditions caused by excessive yield pillar convergence forced the transition to longwall mining where the roof and caving could be controlled during retreat mining.

Benefiting from the experience with room-and-pillar mining, yield pillars were quickly adopted for chain pillars in the Sunnyside gateroads. Of the numerous configurations tested in 32 years of longwall mining, two important fundamentals were proved for controlling the risk of pillar bumping: (1) the use of narrow yield pillars, and (2) minimizing the overall width of the gateroad system.

Wide yield-type pillars, as large as 13.7 m, were found to respond uncontrollably when subjected to full longwall abutment stresses. Common problems included violent and unpredictable bumping, bump-related roof falls, and floor heave. Figure 3 is a photograph of a rigid pillar after a rib bump at another mine. True pillar yielding was achieved when pillars were narrowed to around 9.1 m or less, a size that has proved reliable almost independent of mining depth [8] and is in use at most Utah mines today. Figure 4 is a photograph of a well yielded, 9.1-m-wide yield pillar.

Figure 3. Aftermath of a 1-m-deep Rib Bump at the Corner of an Abutment Pillar

Figure 4. Full Yielding of a 9.1-m-wide Yield Pillar Under Tailgate Loading Conditions in the Book Cliffs Coal Fields

Limiting the overall width of the gateroad system by employing a two-entry yield pillar configuration proved key to maximizing roof and floor stability. Attempts at using three-entry and wider yield pillar gateroad systems were met with a significant rise in the incidence and severity of floor heave, rib sloughage, and roof falls. Two-entry gateroads also proved superior by requiring significantly less ground support.

So compelling were the early lessons at Sunnyside that the two-entry yield pillar gateroad system has been used almost exclusively to this day at longwall mines deeper than about 600 m in the Wasatch Plateau-Book Cliffs coal fields. In 2002, an estimated 52% of the 17.9 million longwall tonnes in Utah [9] came from panels employing two-entry yield pillar systems.

In addition to ground control, the two-entry yield pillar system realizes distinct operational advantages over other gateroad designs, including the need for shorter crosscut development, improved place-changing efficiency with extended cuts, and less and faster overall development, the latter being critical to keeping ahead of today's ultra-high productivity longwalls.

CHALLENGES AT DEPTH

Ground Control

The yield-pillar gateroad system provides no significant protection to the tailgate corner of the active longwall face from side-abutment stresses. Yield pillar systems succeed when abutment loads are shifted off gateroad pillars, thereby avoiding potentially hazardous stress concentrations, and onto the panel edge where loads can be distributed over a broader area. As a consequence, the risk of pillar bumping is virtually eliminated, but the risk of face bumping is somewhat elevated. In most cases, the net improvement justifies the use of yield pillars.

The risk of bumping at the tailgate corner of the panel is almost always directly related to the severity of abutment loading. Mining depth is the principal factor affecting abutment loads. Cave quality and massive strata in the overburden are also recognized to affect abutment loading. The sequence of numerical models in Figure 5 illustrates the rise in abutment stress acting on a panel as the mining depth increases from 300 to 900 m.

The figure shows a significant rise in stress concentration and bump potential at the tailgate corner of the panel with depth. Experience suggests that abutment stresses reach bump-prone levels at depths on the order of 600 to 750 m with multiple side-by-side panels in the Wasatch Plateau-Book Cliffs coal fields, depending upon the local geologic conditions. Severe longwall bumps have been known to occur as shallow as 365 m in the region.

In the past decade, face bursting has caused three separate mines to prematurely abandon panels during retreat. All three utilized fully-yielding gateroad systems. One of the three operators elected to continue mining in the same seam using a conservative panel-barrier layout, where a complete barrier was left between every panel (Figure 6). At the other mines, operations were terminated after each retreated a final panel adjacent to the abandoned panel. The panel-barrier option and other layouts are being considered for another 800-m-deep mine presently at the planning stage.

Ventilation

Ventilation, in addition to ground control, poses an equally serious constraint to longwall mining at depth with the two-entry yield pillar gateroad system. After first-panel mining, subsequent side-by-side panels are limited to a single ventilation return through the tailgate for air sweeping the longwall face. Usually very little to no flow returns through the gob. The longwall face and tailgate return, without exception, act as the free split in the deeper mines and control overall mine pressure.

Measured friction factors in the tailgate return are typically as high as 0.09 kg/m^3 along most of the tailgate and as high as 0.35 kg/m^3 in the front-abutment zone ahead of the face. This compares with friction factors less than 0.01 kg/m^3 in typical mains entries. High resistance is routinely caused by massive convergence, rib sloughage filling the entries, and heavy standing support, typically comprised of a double row of cans or cribs. A typical open tailgate return ahead of the front-abutment zone is shown in Figure 7. A similar tailgate subject to heavy front-abutment loads is shown in Figure 8 after massive convergence.

Where moderate quantities are required at the face, mine pressures generally remain manageable. However, minimum tailgate quantities of 50 m^3/s and higher are being required at some of the gassiest operations to control methane. Fan pressures required to satisfy higher airflows at the face can exceed practical pressure limits for safe and economic ventilation when tailgate resistance is high. At least one Book Cliffs operator is constrained on longwall production because of tailgate resistance. However, the two-entry yield pillar system used at the mine is considered essential for ground control.

ALTERNATIVE DESIGNS

Alternatives to the two-entry yield pillar system require two key components: (1) improved protection from side-abutment stresses, and (2) lower ventilation resistance.

Yield-Abutment Pillar Gateroad Systems

The three-entry, yield-abutment pillar gateroad layout (Figure 9) can provide adequate protection if the abutment (rigid) pillar is properly sized. This system is widely used in other districts, generally under shallower cover and less bump-prone conditions. The yield-abutment-yield system, common to Alabama, represents a four-entry variant.

In Utah, abutment pillars as wide as 120 m or more may be necessary for pillar stability and abutment protection when depths reach 900 m or more. Primary disadvantages are the substantial increase in development footages, requirements for supporting four-way intersections, and some risk of rib bumping with the re-introduction of non-yielding pillars. The row of tailgate yield pillars can serve as a protective "curtain" in the event of abutment pillar bumping.

Panel-Barrier Gateroad Systems

The panel-barrier option becomes an attractive alternative when crosscuts become too long for economic development. Presently, only one operator is regularly using the panel-barrier system in Utah. Good overall performance is reported with 152-m-wide barriers at depths approaching 800 m. Key advantages include the ability (1) to mine safely under extremely bump-prone conditions, (2) the flexibility to seal individual panels after mining, and (3) multiple entries for improved ventilation. Disadvantages include a doubling of gateroad footages, increased mains and bleeder development, and the sterilization of large amounts of longwall reserves.

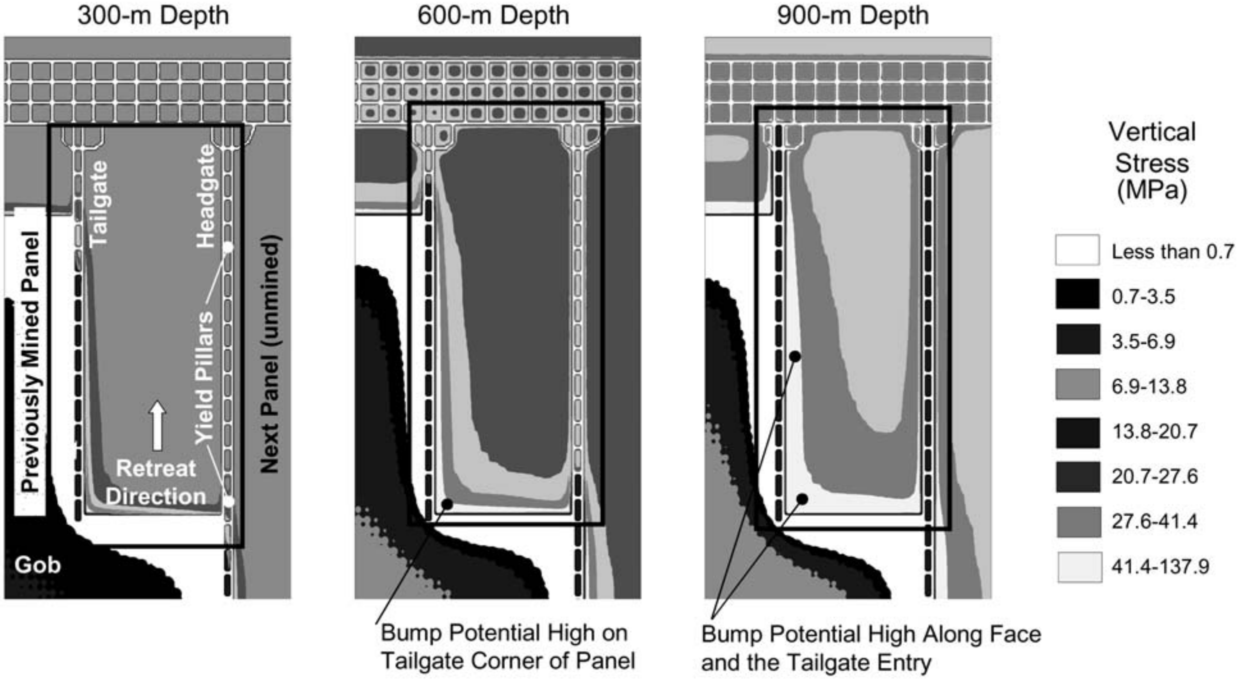

Figure 5. Modeled Vertical Stress Increase with Depth Acting on a Longwall Panel Using a Two-entry Yield Pillar Gateroad System

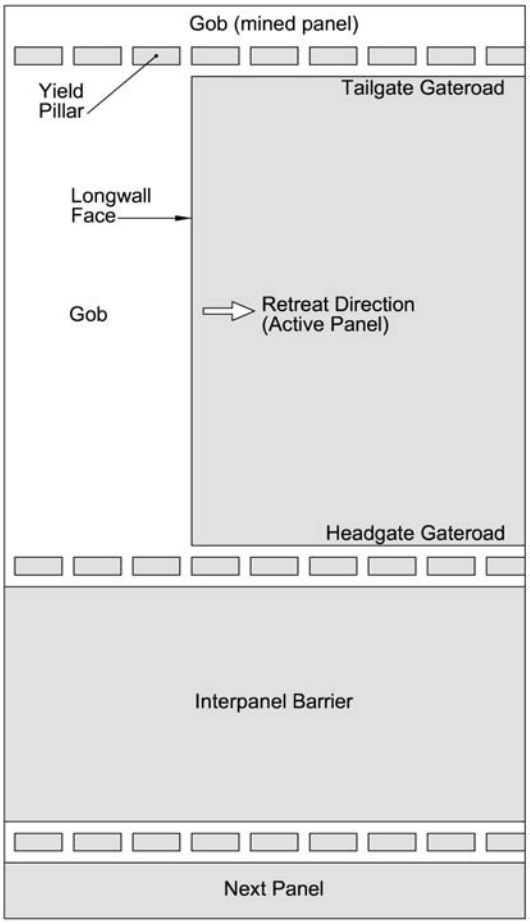

Figure 6. Plan of Panel-barrier Layout Using a Two-entry Yield Pillar Gateroad System

The regular use of interpanel barriers is new to western mining and, consequently, the panel-barrier design warrants refinement. Narrower barriers may be possible depending upon the mine and local geology. Figures 10 and 11 compare the level of abutment stress override across a simulated barrier at a different mine with 180- and 60-m-wide interpanel barriers. Between these limits, tailgate stress levels vary by approximately 6.9 MPa for geologic conditions assumed in the model. Results suggest that an intermediate 120-m-wide barrier is capable of maintaining stresses at historically safe levels when mining at depths of about 800 m.

A variant of the panel-barrier system involves mining only every other panel in high cover regions in an attempt to achieve a panel-barrier effect under the deepest cover. This option has limited applications, mainly to constrained layouts subject to variable cover. Figure 12 illustrates the application of a “checkerboard” layout where the deepest cover occurs toward the center of the panels.

Limiting the Number of Side-by-side Panels

The objective of the panel-barrier design is to preserve near first-panel stress conditions in every panel. Mining experience and numerical modeling have demonstrated that abutment stress levels increase significantly once the second panel is mined in a side-by-side sequence. However, increases during the third and later panels are minor compared to the initial increase. Modeling suggests that stress levels acting on the tailgate corner of the panel increase on the order of 50% because of side-abutment loading during second-panel mining, but subsequent panels cause tailgate stress levels to rise less than about 5%. This counters the common notion that side-abutment stresses are largely relieved once the initial overburden arch collapses into the gob, i.e., once a supercritical width is achieved.

Figure 7. Typical Ventilation Return Ahead of the Front-abutment Zone with a Two-entry Yield Pillar Gateroad System

Figure 8. Heavy Convergence in the Tailgate Caused by Front-abutment Loading with a Two-entry Yield Pillar Gateroad System

The lack of relief from side-abutment stresses is likely related to the preservation of overhanging strata above the gob after collapse of the arch. Figure 13 is a model of stress conditions with an intact arch. Figure 14 shows that equivalent abutment stresses at the coal seam are maintained with only a modest overhang after the arch has collapsed. Overhanging is likely in the Wasatch Plateau-Book Cliffs coal fields given the abundance of massive overburden strata, such as the Castlegate Sandstone.

Implications for mine design are that (1) limiting the number of side-by-side panels is not likely to provide effective control of side-abutment stress levels, and (2) stress conditions are unlikely to improve once supercritical widths are achieved.

CONCLUSIONS

The steady increase in mining depths in the Wasatch Plateau-Book Cliffs coal fields has placed heavy demands on the historically successful two-entry yield pillar gateroad system. Alternative, albeit more costly, designs are likely to replace the two-entry system as mining depths reach and move past the 900-m mark, and more mines confront the challenges of ground control and ventilation in what will be an ultra-high stress and exceedingly gassy environment by today's standards. The panel-barrier option is a costly alternative to side-by-side panel mining, but offers the best potential for safe mining at great depth with current technology. The panel-barrier system is a practical solution for a number of the deepest mines already facing the worst conditions in the west.

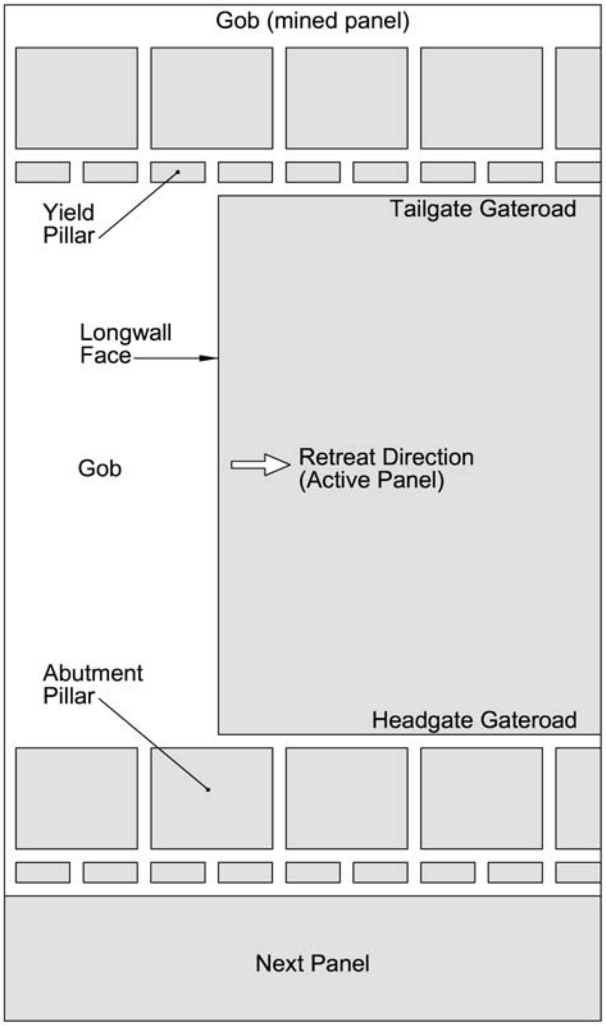

Figure 9. Plan of Three-entry Yield-abutment Pillar Gateroad System with Side-by-side Longwall Panels

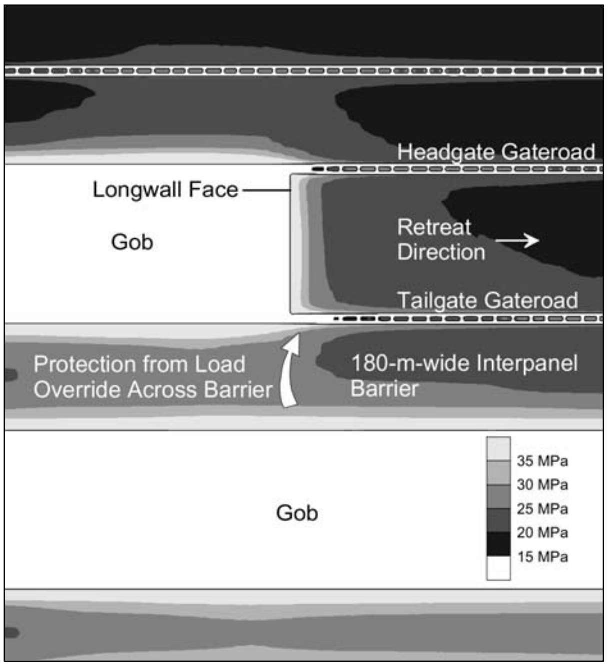

Figure 10. Modeled Vertical Stress Map of a Panel-barrier System Using a 180-m-wide Interpanel Barrier

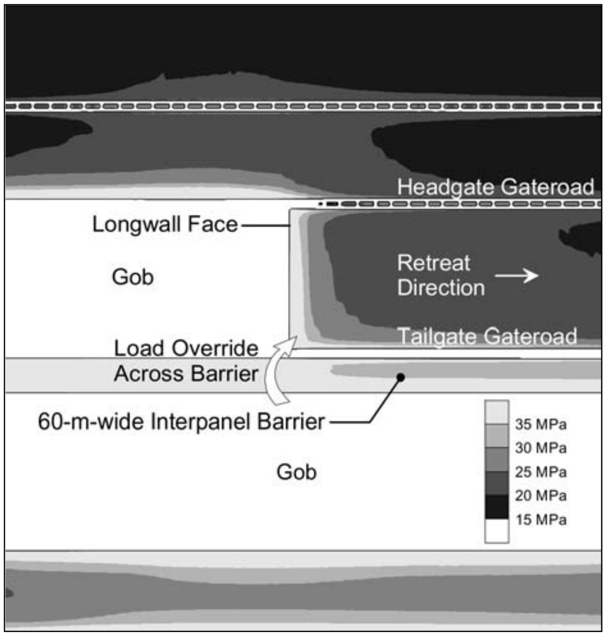

Figure 11. Modeled Vertical Stress Map of a Panel-barrier System Using a 60-m-wide Interpanel Barrier

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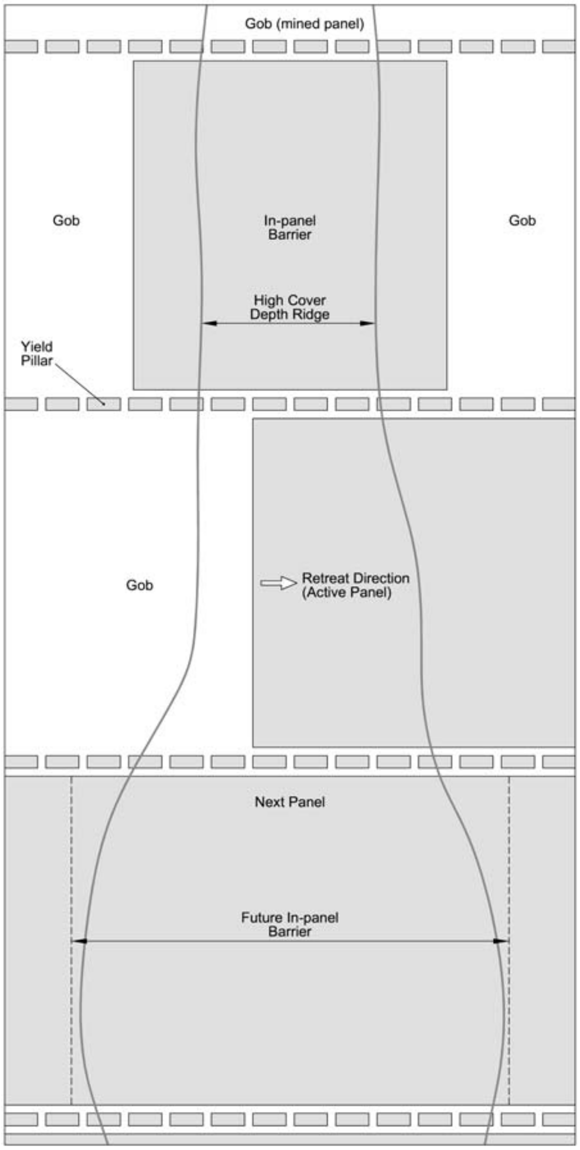

Figure 12. Plan of Modified "Checkerboard" Panel-barrier System under a Deep-cover Ridge

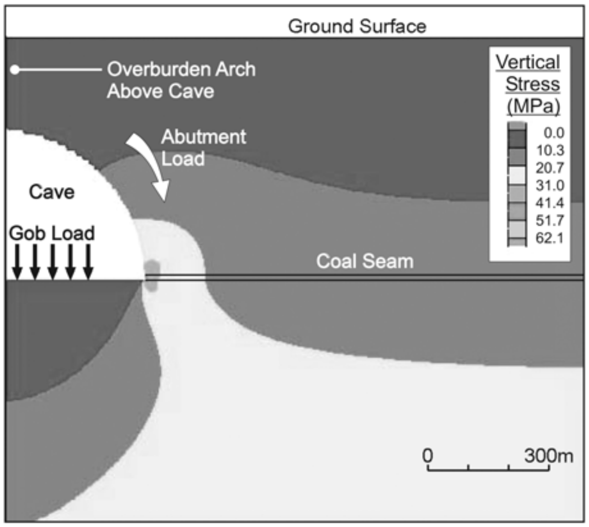

Figure 13. Modeled Vertical Stress Profile of Side-abutment Loading Caused by Overburden Arching

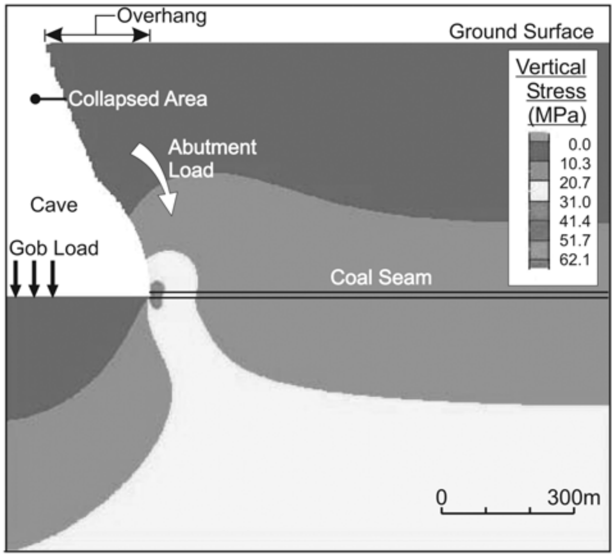

Figure 14. Modeled Vertical Stress Profile of Side-abutment Loading Caused by Cantilevered Strata Overhanging the Gob

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