ANALYSIS OF PRACTICAL GROUND CONTROL ISSUES IN HIGHWALL MINING

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ABSTRACT

Highwall mining is an important coal mining method. It appears that upwards of 60 highwall miners are presently in operation, and they may account for approximately 4% of total U.S. coal production. A review of the Mines Safety and Health Administration (MSHA) data over the 20 year period from 1983 to 2002 identified 9 fatalities attributable to auger and highwall mining of which inadequate ground control accounted for 1/3. In the past 5 years, 1 fatality occurred in highwall mining. Estimates of the manpower requirements in highwall mining suggest that its fatality rate is essentially the same as for surface coal mining, thus highwall mining appears to be a very safe modern mining method.

Highwall stability is the major ground control related safety concern, and operators are required to develop and follow an appropriate highwall mining ground control plan. The plans usually specify the following geotechnical parameters: hole width, maximum hole depth, maximum overburden depth, seam thickness, web pillar width, barrier pillar width and number of holes between barriers. Calculated web pillar stability factor exceeded 1.3 for most designs evaluated.

This study examined records from 5,289 highwall miner holes with a total completed footage of about 2,560,000 feet to understand the reasons for early pull out. Average lost footage is typically about 20% of planned footage. Only 35% of the holes reached planned depth, and 20% were short due to rockfalls. Water and adverse geology accounted for 15% of the losses. Mechanical/electrical problems, guidance, and slope stability problems accounted for the remaining 30%. Web pillar stability factor for these holes also exceeded 1.3 in 95% of cases.

Best practices to avoid trapped miners include: avoid mining in stream valleys, avoid mining near outside corners, careful alignment of each hole and the use of an onboard guidance system. Several issues in highwall mining ground control require further investigation including highwall mining through old auger workings, highwall mining near old underground mines, multiple-seam and multiple lift highwall mining and finally the size and frequency of barrier pillars.

INTRODUCTION

Auger and highwall mining continues to grow in importance as a coal production method from surface mines in the U.S. Numerous recent articles in World Coal and Coal Age magazines (1-9) discuss recent developments in the technique. According to Walker (1), at least 150 auger units are still at work throughout the eastern U.S. coal fields.

Figure 1. Superior Highwall Miner under construction. Note thin seam cutter-head, control cab and cable reel.

The Superior Highwall Miner Company (5, 6, 10) manufactures the SHM[1] shown in figure 1. In its present design, the miner head is a modified Joy Mining Machinery miner that feeds a series of 20-foot-long pushbeams containing counter-rotating augers for coal transport. Maximum penetration depth is approximately 1,000 feet.

Mining Technologies Inc. (1, 2, 5, 8, 9, 11) builds the Addcar highwall miner system shown in figure 2. MTI developed its own highwall miner heads that are similar to conventional continuous miners. The miner head discharges onto a series of 40-foot-long cascading conveyor sections known as the Addcars. Penetrations up to 1,600 feet have been achieved. Addcar systems are equipped with cameras that allow the operator to view face conditions, and the latest models feature a gyroscopic guidance system (HORTA) for improved navigational control.

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[1] Mention of company name or product does not constitute endorsement by the National Institute of Occupational Safety and Health.

Figure 2. Addcar Highwall Miner in operation. Note: Addcar in launch vehicle, control cab and discharge conveyor.

Table 1 provides an estimate of the number of mining machines, productivity and estimated total production for 2003. Total auger and highwall mining production is estimated at 65,000,000 raw tons. Estimates are that 80% of the highwall miners are operating in the central Appalachian coal fields, mainly in southern and central West Virginia (MSHA District 4) and eastern Kentucky (MSHA Districts 6 and 7). This raw tonnage may reduce to about 45,000,000 clean tons, which is about 4% of total U.S. coal production.

Table 1 - Estimated Auger and Highwall Mining Production for 2003

Machine	Approximate number in operation	Productivity (raw tons per year)	Production (raw tons)
Superior Highwall Miners	30	650,000	20,000,000
Addcar Highwall Miners	30	1,000,000	30,000,000
Augers	150	100,000	15,000,000
TOTAL (raw tons)			65,000,000
TOTAL (clean tons)			45,000,000

MSHA INCIDENT STATISTICS FOR AUGER AND HIGHWALL MINING

Researchers at the National Institute for Occupational Safety and Health (NIOSH) Pittsburgh Research Laboratory (PRL) polled the MSHA accident/injury/illness (AII) file for all incidents under the Subunit number 04 which identifies auger/highwall mining operations within surface coal mines. In the 20 year period from 1983 to 2002 the search identified 605 incidents reportable to MSHA at auger and highwall mining operations distributed as follows:

- 9 fatalities
- 460 non-fatal days lost injuries (NFDL)
- 136 no days lost injuries (NDL)

Figure 3 shows that groundfalls accounted for 70 (12%) of the 605 MSHA-reportable incidents. As shown in figure 4, groundfalls accounted for 1/3 of the 9 fatalities. Close examination of the 70 groundfall related incidents shows that approximately 3/4 of the incidents resulted in serious days-lost injuries (figure 5). In fact, more than 2/3 of these incidents resulted in at least a week off work to recover, and more than half the victims required one month for recovery from their injuries.

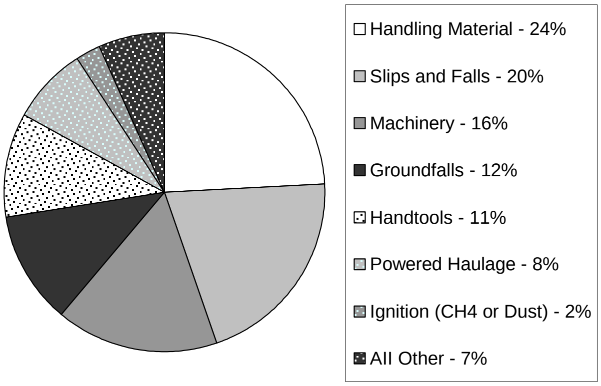

Figure 3. Distribution of 605 incidents in auger and highwall mining.

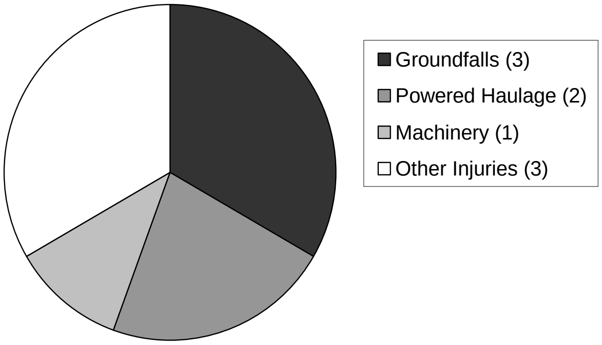

Figure 4. Distribution of fatality causes in auger and highwall mining.

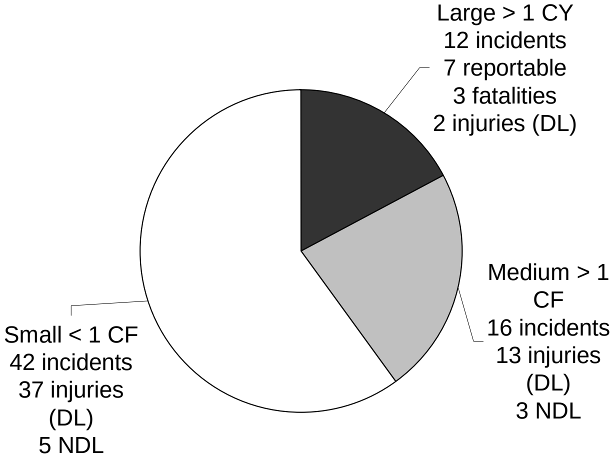

Figure 5 – Size distribution of groundfalls.

Based on the brief descriptions of the groundfall incidents in the MSHA database, the rock fall sizes were classified as large (more than 1 yd^3), medium (between 1 yd^3 and 1 ft^3) or small (less than 1 ft^3). Figure 5 shows that 12 of the incidents (less than 20%) were large rock falls and that all the fatalities were associated with the large falls. Another 16 incidents were from medium-sized rock falls, and the rest, 42 incidents, were from small rock falls, although most of the incidents reported resulted in days lost injuries. About 2/3 of the injury-producing rock falls were classified as small (less than 1 ft^3), which is a key piece of information that requires consideration in any proposed scheme to detect or eliminate rock fall hazards from highwalls.

From 1998 to 2002, one fatality occurred during highwall mining. Based on estimates of the number of operating highwall miners and the approximate crew sizes, it appears that average highwall mining employment during this period is about 1000 persons. With one fatality over a 5 year period among 1000 workers, the fatality rate for highwall mining appears to be 0.02 fatalities per 200,000 employee-hours worked. This rate is comparable to the average fatality rate of 0.02 for surface coal mining in the U.S. and similar to the average fatality rate of 0.024 for surface coal mines in Kentucky and West Virginia during this same time period.

This analysis suggests that as a whole, highwall mining harbors the same fatality risk as ordinary surface coal mining, which agrees with expectations. Based on the distribution of fatal accident classifications shown in figure 4, ground control and in particular highwall stability, along with powered haulage and machinery accidents posed the major risks in this very safe modern mining method.

GROUND CONTROL SAFETY CONCERNS IN HIGHWALL MINING

By far, the overriding ground control related safety concern in highwall mining is highwall stability (4, 13, 14). As discussed in the prior section, 3 of the 9 fatalities connected with auger and highwall mining in the last 20 years were caused by highwall collapse, and the only fatality that occurred in the last five years at highwall mining operations was again due to highwall collapse. Thus insuring highwall stability through proper ground control engineering is of paramount importance to safe highwall mining operations.

In the central Appalachians, where the majority of highwall mining occurs in the U.S., hillseams are the most prominent geologic structures that affect highwall stability. Hillseams (or mountain cracks) are near vertical fractures in the rock that are formed in response to natural weathering and erosion of hillsides (19). They extend from the surface down to several hundred feet. Their orientation is roughly parallel to the hillside, but they can also run across narrow points or ridge lines. They are often accompanied by a secondary set of fractures at right angles to the dominant fracture. Hillseams may cause vertical wedges or long rectangular slabs to separate from the highwall. Figure 6 shows a highwall containing hillseams. A highwall stability safety hazard arises when rock slabs that form along the hillseams detach and fall away from the highwall face. The resulting rock falls can range in size from blocks less than 1 yd^3 to large slabs of more 1,000 $yd.^3$ Many highwall mining operations will skip a hole where a hillseam enters the highwall. Where a hillseam is known to run parallel to the highwall face, the entire area between the entry and exit points may be skipped.

The second concern related to highwall ground control is the stability of web and barrier pillars (4, 13, 14, 16, 17). Figure 7 shows a typical set of highwall mining holes, the web pillar in between holes and a barrier pillar (skip block or skip hole) left between panels. Proper ground control engineering is required for sizing the web and barrier pillars for stability. Layout of these pillars has a profound effect on coal recovery and the project economics; however, equally important is its effect on highwall stability from a safety standpoint. Adequate stability of the web and barrier pillars, especially at shallow depth near the surface, is essential for highwall stability. Web pillar failure and the subsequent subsidence of the overlying rock can destabilize the highwall face. Figure 8 shows an area where web pillar failure led to large rock falls from the highwall. Figure 9 shows an even more spectacular failure (16). In this case, 30 to 50 web pillars failed suddenly, which caused substantial rock fall from the highwall. The rock fall was sufficient to completely bury a 110 ton coal haulage truck. Fortunately no one was in the pit when this failure occurred.

An additional ground control related safety concern with highwall mining is a “stuck” or trapped miner and the ensuing retrieval or recovery operation. Anecdotal evidence suggests that many trapped miners result from a ground control problem such as:

- roof fall
- web pillar failure (ride, squeeze)
- floor failure in multiple lift mining
- excessive span due to cross holes

Roof rock quality is frequently the cause of a roof fall that results in a trapped miner, and it also influences the success in retrieving them. The operator is more likely to pull out a trapped miner under shale roof than under a strong sandstone roof. Weak shale breaks up more easily than strong sandstone during the pull out.

Many trapped miners also result from rolls. Undulations of the coal seam or a change in seam pitch may cause tight spots that can trap the highwall miner during withdrawal.

When a highwall miner gets trapped, several options exist as listed below in order of increasing difficulty and frequency used. There are safety hazards to be aware of with each.

- surface retrieval (pull it out)
- surface excavation
- underground recovery

Surface retrieval is by far the least complicated option. Many operators have built special devices to hook onto separated equipment in the hole. The operator pulls on the trapped highwall mining equipment with anything available such as the launch vehicle, dozers, loaders or haul trucks. The major hazards associated with surface retrieval are the tight cables and connectors used during the pull.

Excavating from the surface may be the safest option since the major hazard is again highwall stability. However, removing at least 100,000 cubic yards of rock is not uncommon. Furthermore, during excavation, the trapped equipment is likely to become damaged due to nearby blasting.

Underground recovery is arguably the most hazardous and essentially requires the set up of a small underground coal mining operation. MSHA requires the operator to submit a recovery plan to the District Manager that must be reviewed and approved prior to beginning the underground recovery.

Interviews with numerous MSHA roof control specialists suggest that about 10 to 15 highwall mining systems became seriously trapped during 2003 and required a substantial retrieval effort such as underground recovery, surface excavation or a major surface retrieval. If there were about 60 highwall miners operating in 2003 then the odds are that about 1 in 4 will become trapped during any given year and require a major recovery/retrieval effort.

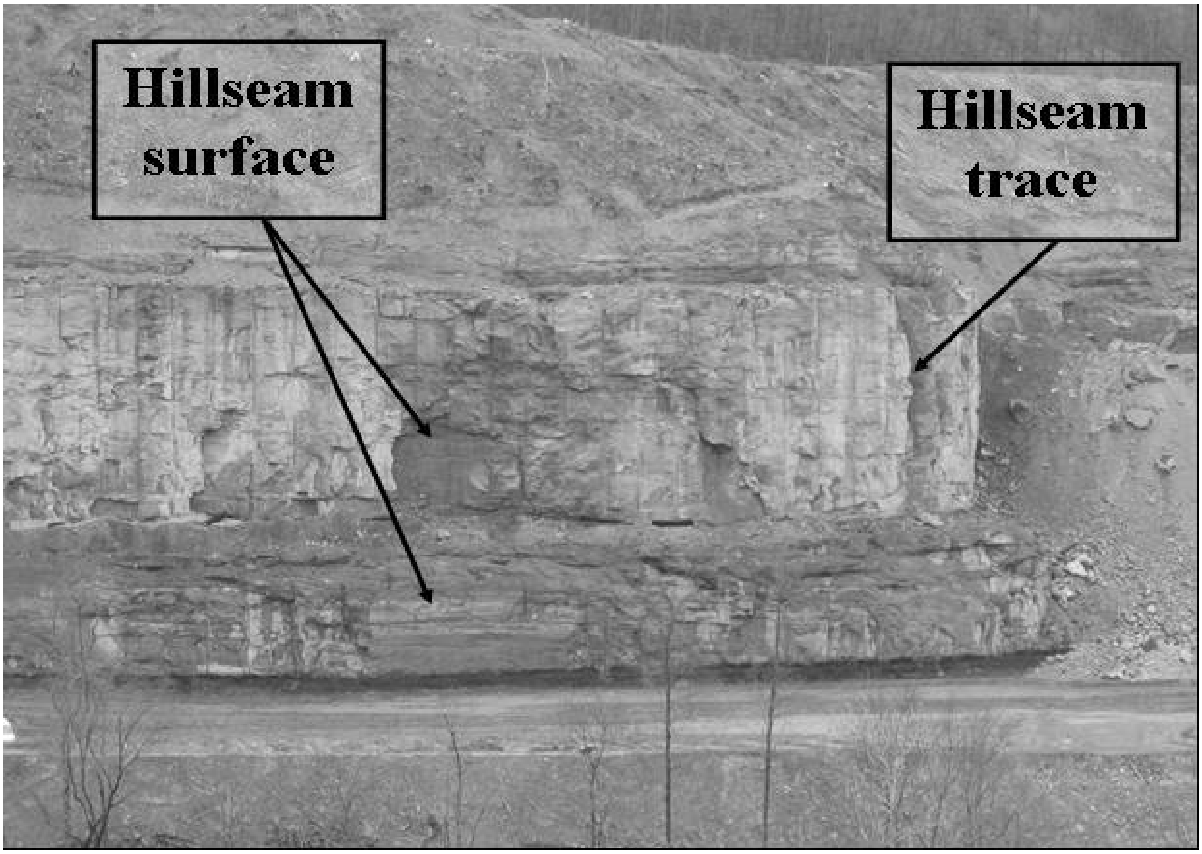

Figure 6 – Hillseams indicated by arrows in contour mine highwall. Note that weathering along hillseams can extend several hundred feet or more below the surface.

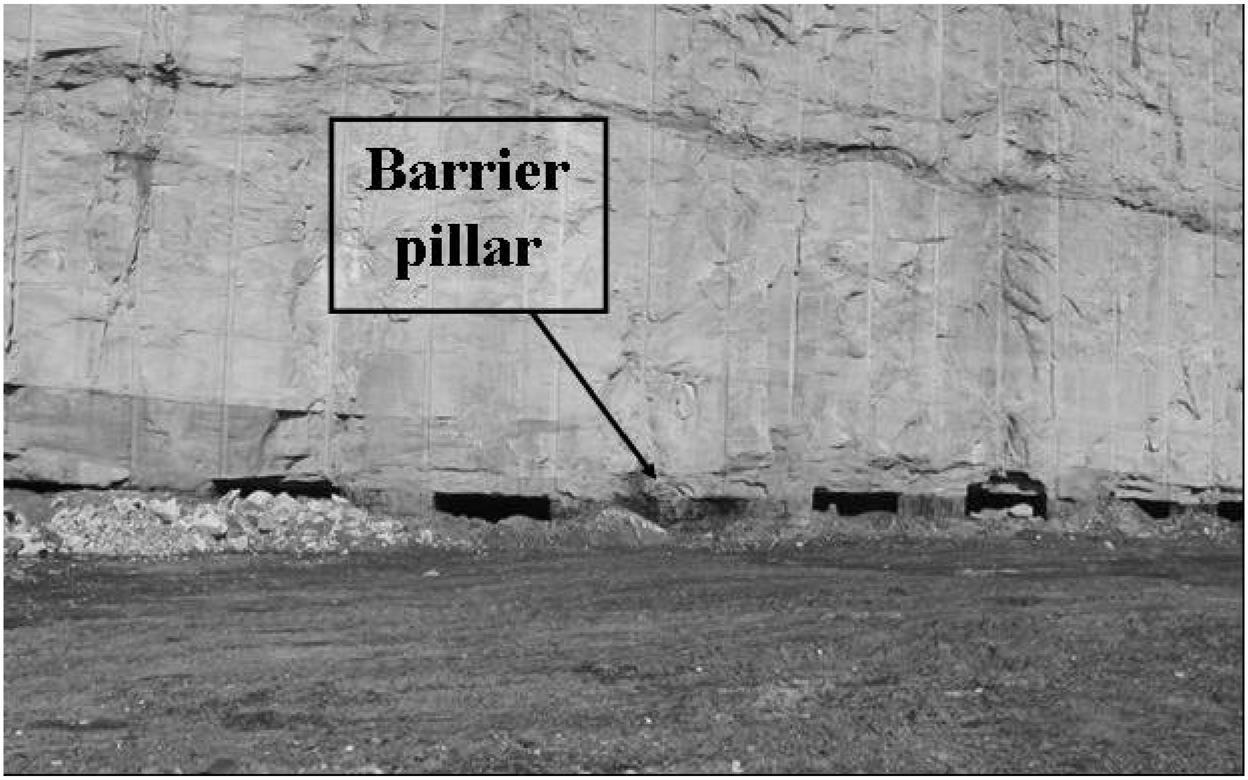

Figure 7 – Typical highwall miner holes and web pillars. Note barrier pillar or “skip hole” indicated by arrow.

Figure 8. Web pillar failure occurred along highwall to the right. Note that several large rock wedges were dislodged as indicated by arrows. Undamaged highwall is to the left.

Figure 9. Site of massive web pillar collapse resulting in highwall slope failure. Photograph is taken from adjacent spoil pile. Highwall is about 150 feet high. A 110 ton coal haulage truck is buried in rockfall debris.

ANALYSIS OF MSHA HIGHWALL MINING GROUND CONTROL PLANS

MSHA recognizes the ground-control-related safety concerns associated with highwall mining and has required each portable auger or highwall mining operation to develop and follow "an appropriate highwall ground control plan, which addresses the web spacing and other measures necessary to safely conduct the high rates of recovery." (12) Various MSHA Coal Mine Safety and Health Districts provided NIOSH-PRL researchers with 40 highwall mining ground control plans. Most of the plans (80%) came from the central Appalachians in Kentucky and West Virginia, and most (again 80%) were dated 2002 through 2004. As expected, about half the plans specified use of a Superior Highwall Miner and the other half planned to use an Addcar system. The number of plans from MSHA is somewhat lower than the number of highwall miners in operation as estimated in table 1; however, this minor shortfall does not detract from our conclusions.

From these 40 plans, 51 distinct cases were compiled from which to evaluate highwall mining designs. Figure 10 shows the distribution of maximum seam thicknesses and maximum cover depths considered in the plans. In three-quarters of the planned highwall mining, maximum seam thickness is between 3 to 6 feet. Relatively few highwall miners (less than 12%) have planned mining heights greater than 7 feet. Most of these thicker seam operations are in the western U.S. in MSHA District 9. In most operations (about 82%), maximum depth of cover is less than 300 feet. The rest have a planned maximum depth of cover in the range 300 to 500 feet. At this time no one appears to be operating under more than 500 feet of cover, although this could change soon.

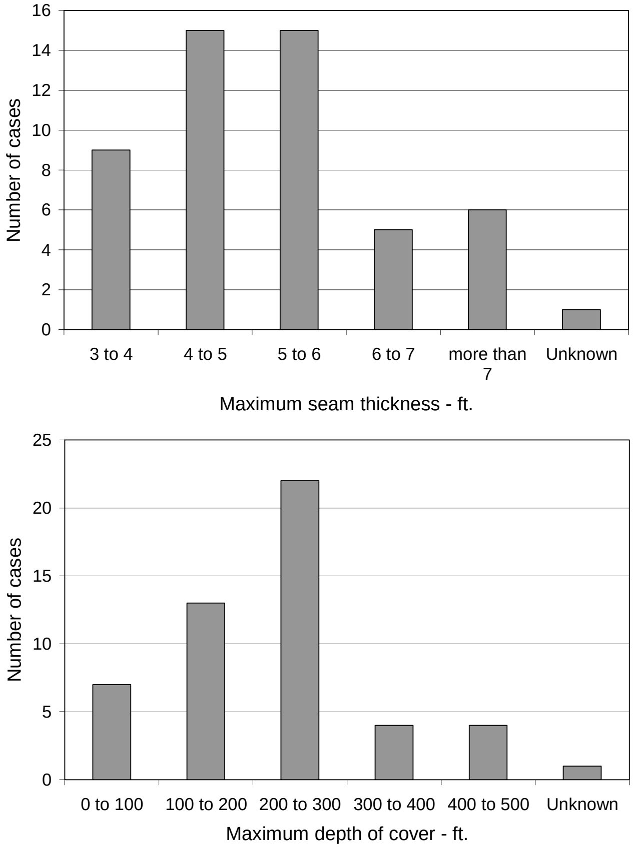

Figure 10. Maximum seam thickness (top) and maximum depth of cover (bottom) distribution from MSHA highwall mining ground control plans.

Maximum seam thickness and maximum depth of cover are the main inputs for geotechnical design of web pillar width. In about 15% of the plans examined, the ARMPS program (22) was the analysis method. Over 25% used another form of a tributary area method for analysis. Past experience was the basis for many designs, but unfortunately, the analysis method could not be identified in most of the highwall mining ground control plans examined. As shown in figure 11a, the minimum web width specified in the plans ranges from 3 to 7 feet in over 82% of the cases. More important for stability is the width-to-height (W/H) ratio of these web pillars. Figure 11b shows that W/H is in the 1 to 1.25 range for about 50% of the cases, while it is between 0.5 and 1 in 25% and more than 1.25 in the remaining 25% of cases. In general, keeping the web pillar W/H ratio above 1 is desirable to maintain better web pillar integrity. Designs with W/H ratio less than 0.5 were not encountered.

Finally, figure 11c shows estimates of the web pillar stability factor based on data provided in the ground control plans. The estimates use tributary area method to calculate pillar stress and the Mark-Bieniawski formula (18) to calculate strength of a strip pillar assuming coal strength of 900 psi. In 45 % of the cases, it appears that stability factor exceeds 1.6; while in 31%, the stability factor appeared to range from 1.3 to 1.6. Thus, in over three-quarters of the cases examined, a satisfactory web pillar stability factor most likely exists. However, in a few circumstances (about 8%), stability factor may be in the 1 to 1.3 range, while in another 8% stability factor was apparently slightly less than 1. These stability factor estimates from the ground control plans are estimates only, and judgment of individual plans is not implied.

Figure 12a provides data on minimum barrier pillar width found in the plans. Most barriers appear to range in width from 10 to 25 feet, but in almost half the cases a firm dimension on barrier pillar width was not specified. In most cases, the reasoning behind the barrier pillar width was unknown. Experience-based design rules were employed in some cases. For example, about 15% of the plans sized barrier pillars as 1 web-pillar-width plus 1 hole-width, while another 15% used 2 web-pillar-widths plus 1 hole-width. In about 10% of the cases, barrier pillar widths were designed using tributary area method with a stability factor of one and the assumption that all web pillars in a panel have failed.

Figure 12b shows data on the W/H ratio of highwall mining barrier pillars. Unfortunately there was no information in about one-third of the cases considered. However, when data was available, the W/H ratio was 3 or more in about two-thirds of the cases and less than 3 in the remaining third. For stability reasons, a barrier pillar with a W/H ratio above 3 has sound geomechanics-based advantages (16).

Finally, figure 12c presents data on the number of highwall miner holes between barrier pillars. When information is available, it appears that about 37% of the plans specify no more than 20 holes between barrier pillars; 44% specify 10 holes, and 15% require as few as 5 holes between barrier pillars. Comment on the number of holes between barrier pillars is reserved for later discussion.

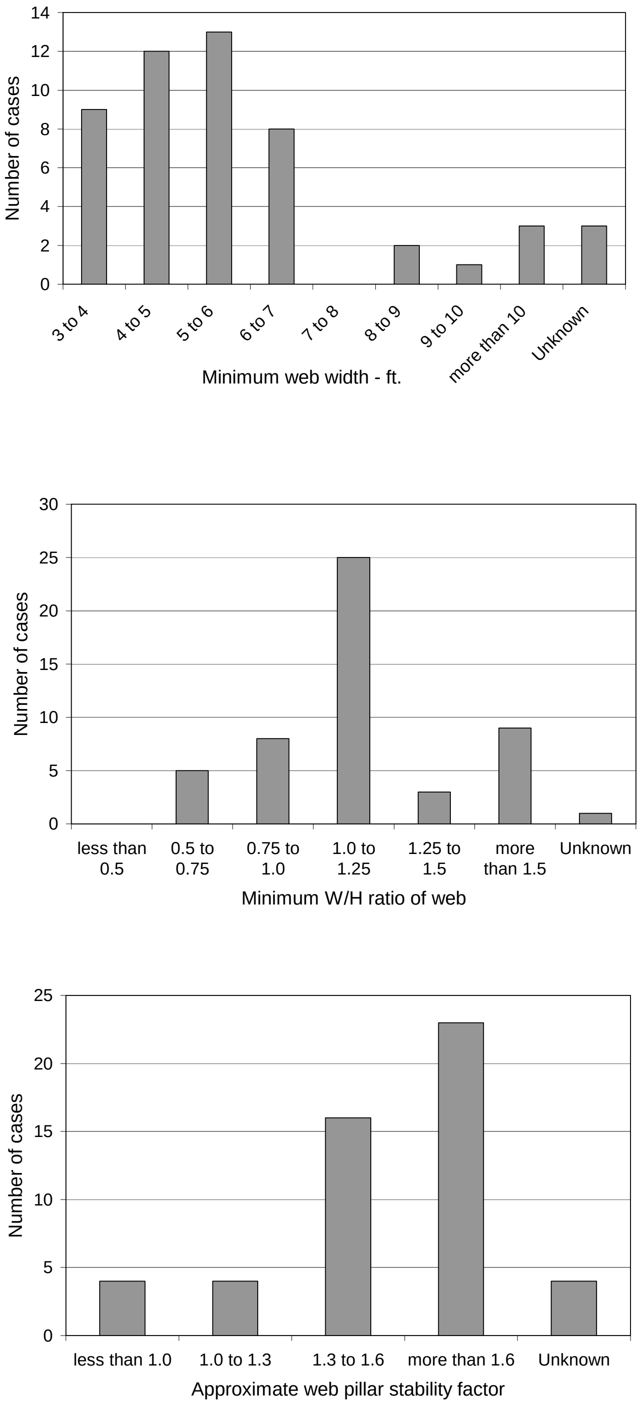

Figure 11. Minimum web pillar width (top), minimum width-to-height (W/H) ratio (middle) and approximate web pillar stability factor (bottom) from MSHA highwall mining ground control plans.

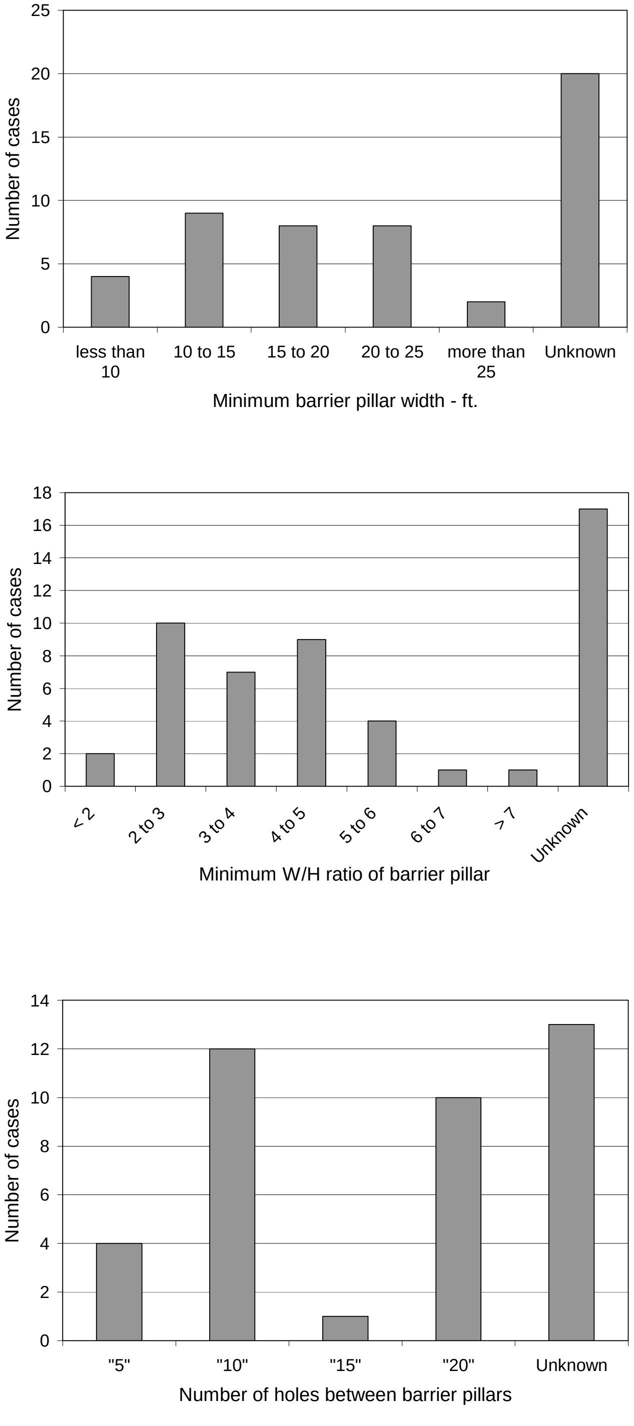

Figure 12. Minimum barrier pillar width (top), minimum width-to-height (W/H) ratio (middle) and number of holes between barrier pillars (bottom) from MSHA highwall mining ground control plans.

PERFORMANCE ANALYSIS OF HIGHWALL MINING

As part of their safety research effort in highwall mining, Pittsburgh Research Laboratory personnel analyzed highwall mining performance data from several highwall mining operations. For planning purposes, most operators develop maps showing the location, orientation and length of their highwall mining holes. Upon completion of mining, the maps are updated to show the actual hole depth mined and the reason for early pull out, if applicable. The analyses conducted herein sought to understand the reasons for early pull out from highwall mining holes in order to avoid trapped miners, improve highwall stability and improve safety.

The company maps covered a three-year period from late 2000 through early 2003 during which time, 5,289 holes were mined for a total completed footage of about 2,560,000 feet of highwall mining hole. Total planned footage was estimated at about 3,192,000 feet; therefore, 632,000 feet or about 20% of planned footage was lost due to early pull out.

Hole Completion Analysis

This analysis examined the various reasons for early pullout from the highwall mining holes. After examining the maps containing the highwall mining performance data, eight "loss" categories were created to summarize the hole completion notes for each hole. The eight categories are:

1. Full depth – No explanation is necessary.
2. Mechanical/electrical – due to broken hydraulic hose, low oil pressure, an overheated motor, tripped breaker and so forth.
3. Guidance – due to crossed holes.
4. Slope stability – due to a bad highwall.
5. Water – due to the hole flooding or severe mud causing the hole to become "gobbed out."
6. Geology – due to a pinching coal seam, a bad roll or hard cutting due to a rock parting.
7. Rock fall – due to bad ground or bad ribs.
8. Barrier/skip hole – No explanation necessary.

Figure 13a shows the number of successfully completed holes (full depth) and the number of holes pulled out of for one of the above reasons. Some findings are:

1. only 35% of holes reached the full depth planned
2. approximately 20% were short due to rock falls
3. approximately 15% were short due to water problems
4. approximately 11% were short because of adverse geology
5. approximately 10% were short due to mechanical/ electrical problems
6. guidance problems and slope stability accounted for the remaining 9% of shortfalls.

Further analyses estimated the coal losses due to early pull out associated with each of the above loss categories. Figure 13b shows that about 31% of the coal losses are due to rock fall, about 20% of the losses were due to water and "gobbed out" and another 19% are due to adverse geology. Slope stability and mechanical/electrical problems with the highwall miner each accounted for about 11% of the losses, and guidance (crossed holes) caused the remaining 8% of the losses. A hole completion analysis was completed for each property and each seam. Different loss categories became more or less important depending on mining property or coal seam, but generally, rock fall and water ("gobbed out") remained the dominant reasons for early pull out.

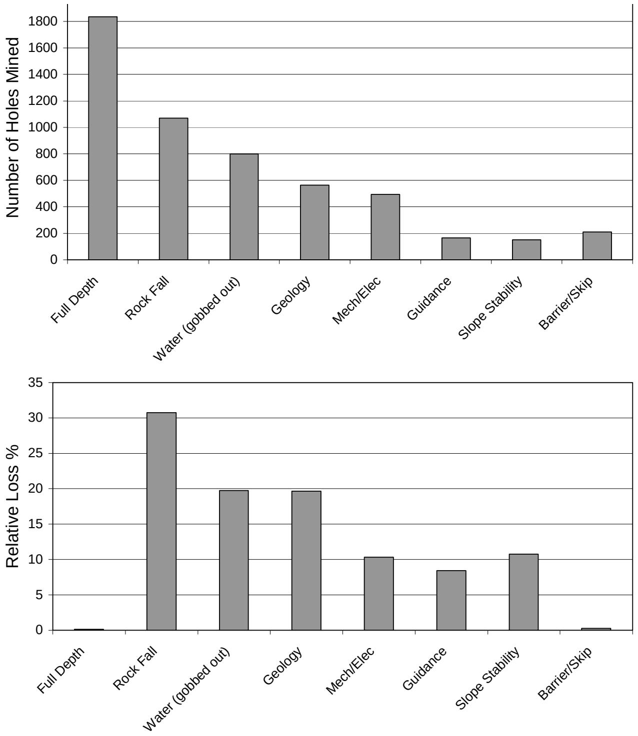

Figure 13. Loss category analysis of 5,289 highwall mining holes (top) and relative losses versus loss categories-3,192,000 planned ft. and 632,000loss ft (bottom).

Stability Factor Analysis

For each panel or logical group of highwall mining holes, web pillar thickness was measured and a maximum depth of cover was estimated. Tributary area theory was used to estimate average pillar stress. These pillar stress estimates did not account for the presence of barrier pillars so the computed stress is likely conservative. Pillar strength was computed using the Mark-Bieniawski strength formula for strip pillars assuming in-situ strength of 900 psi for the coal.

The stability factor for over 3000 individual highwall mining holes was then estimated from the average stability factor for the corresponding panel. About 75% of the stability factors were in the range from 1.3 to 2.2 and averaged about 1.6 as expected. About 5% of the stability factors were in the 1.0 to 1.3 range and the remaining 20% were above 2.2. No stability factors were estimated below 1.0.

Having a stability factor estimate for each highwall mining hole, an attempt was made to correlate this stability factor to the loss category and some performance measure such as depth of hole achieved or coal losses due to early pull out. The working hypothesis was that lower design stability factor should result in more coal losses due to geotechnical problems such as rock falls or possibly slope instability.

Four groups of stability factors were considered, namely 1.00 to 1.30, 1.31 to 1.60, 1.61 to 2.00 and more than 2.01. In each of these stability factor groups, the relative losses were evaluated for each loss category. Figure 14 shows the result. The mechanical/electrical, guidance, slope stability, water (gobbed out) loss categories showed no discernable dependence on stability factor. The rock fall category does show a clear downward trend with higher stability factor; however, it may not be statistically significant. For stability factors in the 1.0 to 1.3 range, rockfalls were the dominant reason for early pullout from the holes. With stability factors above 1.6, reasons other than rockfalls become the main reason for short holes. Planned stability factor for most of the highwall mining holes was about 1.3 and use of this relatively high stability factor minimizes losses due to rock falls and other geotechnical problems. No statistically significant correlation was found between web pillar stability factor and losses due to rock falls. The primary recommendation from the stability factor analysis is to continue designing web pillars with a minimum stability factor of 1.3.

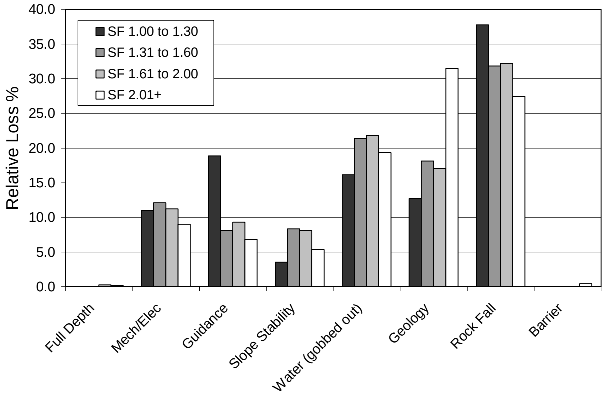

Figure 14. Relative losses as function of loss category and stability factor.

OPERATING PRACTICES TO AVOID TRAPPED MINERS

Up to this point, geotechnical engineering and planning factors have been discussed to improve highwall stability and minimize the risk of a trapped highwall miner. However, certain operating practices can also help decrease this risk. Four practices are summarized that can help highwall mining operators avoid entrapment of valuable mining machinery in the hole as a result of adverse geotechnical conditions.

Avoid Mining Into The "Head Of Hollow"

Stream valleys frequently follow a weakness in the geologic strata. In underground coal mining, it is well know that roof conditions may become very poor under stream valleys or other major surface drainages. The same idea applies to highwall mining. Highly fractured zones under or near the stream may lead to inflow of water and very poor roof conditions for highwall mining and increased risk of a trapped miner. Careful geologic mapping should note the orientation of these weakness zones for future mine planning purposes. Despite the considerable coal reserves that are lost, highwall mining in a head of hollow should be avoided.

Avoid Mining Near Outside Corners

Ridge points, outside corners, cut-throughs or other abrupt changes in direction of a contour mining highwall are areas with increased risk of highwall stability problems. These areas are prone to contain hillseams, that daylight from the highwall. In addition, outside corners may be more highly fractured due to blasting on two sides, especially near cut-throughs. Whenever possible, mining should begin a safe distance from the outside corner and proceed away from the corner. For unknown reasons, pillar stability problems resulting in a trapped highwall miner have occurred when mining towards an outside corner.

Carefully Align Each Highwall Miner Hole

Proper hole spacing and alignment at the beginning of each hole is essential to maintain design web width for the entire length of the hole. Maintenance of proper web width is essential for avoiding web failure, crossed-holes and the risk of a trapped highwall miner. Careful alignment is especially important in multiple lift mining where highwall miner holes are stacked, and interburden thickness is less than one hole width. Any misalignment can result in collapse of the septum between layers of holes and a trapped miner.

Consider Using An Onboard Guidance System

Initial alignment of a highwall miner hole is especially critical since it is generally not possible to steer the highwall miner head much with either the Superior or Addcar highwall mining system once it is in the hole. Local geologic anomalies such as rolls can deflect the miner slightly with potentially adverse effects. And as Schafer (7) and Arrowsmith (8) point out, once you are in the hole, the operator has no idea where the miner really is, thus there is little control and verification of actual web width. An onboard guidance system provides location of the current hole, relative to the previously mining holes. Again, although steering the miner head in itself is generally limited, a guidance system is likely to prevent many trapped miners due to crossed holes, web pillars too small and roof falls caused by poor guidance (17).

CONCLUSIONS AND RECOMMENDATIONS

Under most circumstances, design of web and barrier pillars to maintain adequate highwall stability during highwall mining is a straightforward and well-understood endeavor. Tributary area method (16), ARMPS (18) and numerical models (14, 17, 19) are available to estimate pillar stresses. Coal pillar strength is also well understood and can be estimated by various coal pillar strength formulas such as Mark-Bieniawski formula (18) or others (19, 20). In applying these strength formulas, coal strength of 900 psi is normally used, unless well-justified field experience dictates otherwise. Experience has shown that laboratory tests do not necessarily provide a reliable estimate of pillar strength.

Several issues pertaining to highwall mining web pillars have emerged, namely previous auger mining holes in web pillars and the presence of nearby underground mining. Many highwall miners are re-working highwalls that were auger mined. The old auger miners may have penetrated only 100 to 200 feet into the highwall with circular holes anywhere from 12 to 36 inches in diameter; whereas today's highwall miners can penetrate over 1000 feet, if they are able to negotiate past the old auger holes. Examination of MSHA highwall mining ground control plans showed that old auger holes were expected in at least 11 out of 51 cases or about 20%. The ground control unknown is the strength of a highwall mining web pillar that contains several auger holes. The issue is especially critical since this part of the web pillar is right under the highwall where stability is most important. One logical approach to the problem is to decrease the coal strength depending on the size and spacing of the old auger holes, and thus substantially increase the width of the web pillars. NIOSH is currently examining this problem to of provide simple, practical guidelines for the strength of web pillars containing auger holes.

Another related issue is the presence of nearby underground mining, either in the same seam or seams very close above or below. In addition to ground control issues, old workings may present gas and water inundation hazards. Again, examination of

MSHA highwall mining ground control plans showed that nearby mining was expected in at least 20% of the cases. In no cases were the nearby mines active, but their operating status was not always clear. Many operators choose to stay away from old workings by at least 50 feet. Others have attempted to recover pillars in old workings now accessible with highwall mining equipment. Results of such endeavors are unknown. Again, the ground control unknown is the strength and stability of the remaining "pillar" in the old underground mine. Success of such operations will depend on accurate and reliable maps of the old workings coupled with accurate guidance and control of the highwall miner.

When seams split, many operations conduct "multiple-seam" highwall mining. The choice of sequence, top then bottom split or vice versa, depends on operational requirements. Again, accurate guidance and control of the highwall miner is essential to carefully stack web pillars and to assure that the pillars remain stacked deeper in the hole. The multiple-seam issue is really only a consideration if the seams are less than one hole-width apart and the seam thickness is less than the hole width. If the separation distance is sufficient, the highwall mining layers are independent of one another and can be designed separately. However, if the seams are close, the highwall mining layers will interact and the strength of the two-layer system is less than the strength of either layer. The ground control unknown is the strength of this layered system. Simple practical guidelines for this issue are forthcoming.

A related problem to multiple-seam highwall mining is multiple-lift highwall mining as applied to thick seams. First, a top cut is mined followed by a bottom or floor cut. This situation is more common in the western U.S. and also Australia, where thicker seams prevail. The major ground control problem is the strength of the taller web pillar which will usually have a W/H ratio less than one. Web pillars with low W/H ratios are inherently weaker, and it becomes imperative to maintain proper web width through accurate guidance and control of the highwall miner. In thick-seam, multiple-lift highwall mining operations, many operators find it prudent to employ a guidance system such as HORTA for better web pillar width control.

A final ground control issue with highwall mining concerns barrier pillars where the major design question is their width and the number of highwall miner holes between barrier pillars (14, 16, 17). Barrier pillars serve several important safety functions. First, they act to stiffen and stabilize the highwall. Coal removal during highwall mining softens the base of the highwall causing it to move downward. This motion can destabilize the highwall and lead to potential failure. Periodic barrier pillars reinforce the highwall against potential slope failure. Second, barrier pillars will increase the overall stability of the system, preventing a domino-type pillar failure (pillar ride, squeeze or cascading pillar failure). Figure 9 shows the consequences of not having barrier pillars (16). Once a web pillar failure starts; it is difficult to stop, and the web pillar failure can induce a catastrophic highwall slope failure. Barrier pillars behave like bulkheads on a ship by compartmentalizing the mine layout and limiting failure consequences to a smaller area.

In addition to safety, the use of barrier pillars also provides economic benefits. Barrier pillars appear to cost companies money because of the coal resources left in the ground. The only real economic cost of a barrier pillar comes from consuming exposed highwall 5 to 10 % faster depending on whether barrier pillars are left every 10 holes or 20. However, productivity in tons per unit time (day, month or year) remains constant and may actually increase. The presence of a barrier pillar is likely to prevent a ride or a roof fall, thereby promoting better mining conditions and possibly preventing a seriously trapped highwall miner. The use of barrier pillars is thus likely to prevent months of lost production revenues, which are very real economic costs. NIOSH is examining the safety aspects of barrier pillars and potential new highwall mining layouts that may provide greater highwall stability without decreasing coal recovery.

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