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REDUCING THE RISK OF GROUND FALLS DURING PILLAR RECOVERY

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ABSTRACT

Pillar recovery has been associated with nearly onethird of roof fall fatalities in underground coal mines during the past decade. Safe pillar recovery requires **global stability** and **local stability**. Global stability is addressed primarily through pillar design. The local stability risk factors include cut sequence, the final pillar stump, supplemental supports (timbers vs. Mobile Roof Supports (MRS)), roof bolting, and many others. The National Institute for Occupational Safety and Health (NIOSH) has evaluated each of these factors through field research and analysis of accident statistics. The paper discusses design methods and technologies that have been transferred to the mining community and implemented.

ACKNOWLEDGMENTS

The authors would like to thank all the Roof Control Specialists and Supervisors from every Mine Safety and Health Administration (MSHA) District for providing information on the current status of pillar recovery in the U.S., and George Karabin and Joe Zelanko of MSHA Technical Support for the BESOL modeling and assistance with fatality report analysis.

INTRODUCTION

During the year 2001, nine roof fall fatalities occurred in the U.S. Of the nine, three occurred during pillar recovery operations.

Unfortunately, 2001 was not an unusual year. A NIOSH report (Mark et al., 1997) found that in 1993 pillar recovery accounted for about 10% of all U.S. underground coal production, but was associated with about 25% of the roof and rib fatalities between 1989-96. During the decade 1992-2001, there were a total of 100 groundfall fatalities (roof and rib) in U.S. coal mines. Of these, 27 occurred during pillar recovery operations.[1] Six of the incidents resulted in double fatalities.

Pillar recovery creates an inherently unstable situation. Man-made supports cannot carry the full weight of the overburden. The roof at the pillar line is subjected to severe stresses and deformations. The ground will cave in, the only question is when. Safety requires that the roof be kept up until the miners have completed their work and left the area.

A wide variety of mining techniques are used to accomplish pillar recovery. It seems evident that certain pillar recovery techniques, or certain aspects of the pillar recovery process, may be riskier than others. The goal of this paper is to isolate the most significant hazards, or "risk factors," associated with pillar recovery, so that the overall level of risk can be minimized. Risk factors are divided in two main groups:

1. Global Stability: Prevention of section-wide pillar failure.
2. Local Stability: Prevention of roof falls in the working area.

During the past several years, the regulatory agencies and many mine operators have been very pro-active in implementing new safety technologies to reduce the groundfall risk during pillar recovery. For example, the use of Mobile Roof Supports in the U.S. has increased substantially. However, the purpose of this paper is not to highlight any specific innovation or regulatory action, or to make comparisons between mining regions. Rather, it focuses on the technical ground control aspects of pillar recovery.

PILLAR RECOVERY DEMOGRAPHICS AND ACCIDENT RATES

As part of this study, MSHA Roof Control Specialists and Supervisors from every MSHA District were asked to provide information on pillar recovery practices in each of the mines they inspected. The data included whether the mine extracted pillars, what pillar recovery method they most commonly employed, whether the pushout was recovered, and whether the mine used Mobile Roof Supports.

The information was then linked with the MSHA accident and employment database (MSHA, 2002) for the year 2001 (table 1). In all, retreat information was available on mines that produced 380 million tons underground in the U.S. during 2001. There were 674 room-and-pillar mines (both retreat and non-retreat) in the data base, and they produced 49.6% of the underground tonnage. The Roof

[1] These statistics actually underestimate the number of deaths associated with pillar recovery. In two instances, one in Utah and one in West Virginia, miners were killed by shuttle cars as they attempted to flee premature roof collapses. Both fatalities were classified as "machinery" accidents.

Table 1. Demographics of pillar recovery in the US in 2001

Mine Grouping	Summed hours (millions)	Summed tons (millions)	Tons/hr	Ground fall injuries/200 Khrs
Longwall Mines	30.33	191.2	6.31	0.81
Room-and-Pillar, Non-Retreat	12.42	56.1	4.52	1.79
Room-and-Pillar, Retreat	25.99	108.0	4.16	1.60
ALL MINES	74.36[1]	379.6[1]	5.10	1.35
Type of Retreat Mining				
Full Pillar Recovery	15.14	68.39	4.52	1.85
Partial Pillar Recovery	6.35	22.15	3.49	1.29
Both Full and Partial	4.49	17.47	3.89	1.20
Cut Sequence				
Left-Right	8.77	41.18	4.70	2.14
Outside Lift	4.90	20.65	4.21	1.10
Other Known	0.84	3.24	3.85	2.61
Pushout Recovery				
Recover Pushout	7.25	33.97	4.69	2.07
Do Not Recover Pushout	14.66	56.14	3.83	1.35
Mobile Roof Supports				
R&P Retreat, With MRS	8.96	42.16	4.71	1.67
R&P Retreat, Without MRS	12.28	46.07	3.75	1.53

[1]Totals include contributions from room-and-pillar mines whose retreat status is unknown.

Control Specialists provided data on 524 mines that produced 87% of the room-and-pillar tonnage. Mines that were known to practice pillar recovery accounted for about 108 million tons, or 58% of the total non-longwall production.[2] Assuming that pillar recovery typically accounts for about one-third of the production at these oom-and-pillar mines, then about 10% of all underground production, or about 20% of all non-longwall production, comes from pillar recovery.It seems that the proportion of pillar recovery production has remained essentially constant over the past decade.

The data also confirm that pillar recovery is most prevalent in the central Appalachian coalfields of southern West Virginia, Virginia, and eastern Kentucky. More than 90% of the coal produced by pillar recovery mines was from this area, with 8% coming from the northern Appalachian coalfields (Pennsylvania, northern West Virginia, and Ohio) and 1% from western mines. Currently, there is essentially no pillar recovery taking place in Indiana, Illinois, western Kentucky, or Alabama.

Between 1992 and 2001, 27% of all groundfall fatalities were associated with about 10% of the underground production. Mathematically, a coal miner on a pillar recovery section was more than 3 times as likely to be fatally injured in a groundfall than a miner on an advancing section.

The 1997 NIOSH report found that the roof/rib nonfatal injury rate was generally lower in pillar recovery mines than in other room-and-pillar mines. In 2001, the retreat mine roof/rib injury rate was 1.60 per 200,000 hours, slightly less than at other room-and-pillar mines where rate was 1.79.

FATALITY REPORTS

Whenever a fatality occurs in a US coal mine, MSHA prepares a detailed report. These reports are an invaluable resource in evaluating the importance of the factors associated with pillar recovery fatalities. This study began with 21 groundfall fatality reports (20 roof falls and one coal bump) for the 1992-2001 period. Two roof falls were eliminated, both double fatalities, because they involved drill-and-blast mining with an open-ended cut sequence, a technique that is now apparently extinct. The final group therefore included 19 incidents with 23 fatalities.

Figure 1 shows the location and the year each fatality occurred.All but one incident (a double fatality) were in the central Appalachian coalfields, where most retreat mining takes place.

One significant finding was that in nearly half of the pillar recovery incidents, no citations were issued. In another 5 cases, the mine was apparently following the minimum standards set forth in its approved Roof Control Plan, but was cited under 30 CFR 75.202(a) for failing to recognize and control hazardous conditions. Multiple violations, including not following the approved Roof Control Plan, were given in just 5 of the incidents. It seems, therefore, that the large majority of pillar recovery fatalities cannot simply be attributed to egregious violations of the law.

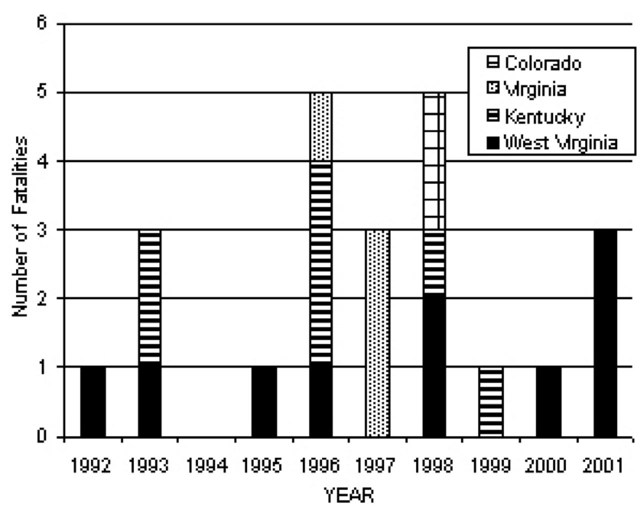

Figure 1. Pillar recovery fatalities, 1992-2001.

[2]Three longwall mines, all located in Southern West Virginia, also engage in pillar recovery using Mobile Roof Supports. Because retreat mining constitutes a relatively small percentage of their total production, they were not included in the analysis.

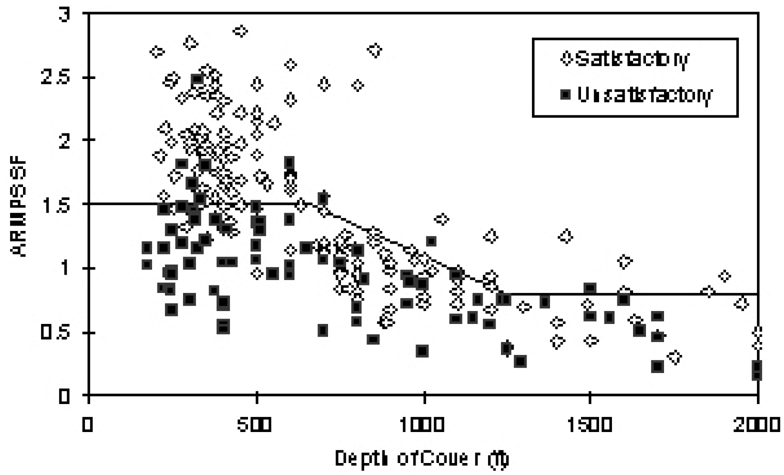

Figure 2. Suggested ARMPS Stability Factors, based on an expanded case history data base.

GLOBAL STABILITY RISK FACTORS

Proper pillar design is the key to ensuring global stability. There are three main types of pillar failure, each of which requires its own approach.

Pillar Squeezes

Squeezes occur when the pillars are too small to carry the loads applied to them. As the loads are gradually transferred, the adjacent pillars in turn fail. The results can include closure of the entries, severe rib spalling, floor heave, and roof failure. The process may take hours or days, and can cause an entire panel to be abandoned.

The Analysis of Retreat Mining Pillar Stability (ARMPS) program can be used to help size pillars to carry both development and abutment loads (Mark and Chase, 1997). ARMPS has been calibrated by back-analysis of hundreds of pillar recovery case histories. The database has recently been expanded to include more deep-cover cases, and new design guidelines have been proposed (figure 2 (Chase et al., 2002)).

Massive Collapses

Massive collapses are pillar failures that take place rapidly and involve large areas. One effect can be a powerful, destructive airblast. Of fourteen massive collapses that have been documented since 1980, all but two have occurred in southern West Virginia. They have caused several injuries but, miraculously, no fatalities.

Data collected at the failure sites indicate that all the massive collapses have occurred where the pillar width-to-height (w/h) ratio was 3.0 or less, and the ARMPS SF was less than 1.5. Such conditions occur most often in workedout areas where pillars have been split. Guidelines for preventing or containing massive collapses have been published (Mark et al., 1997). These guidelines have been largely implemented in southern West Virginia since 1998, and no documented massive collapses have occurred since then.

Pillar Bumps

Bumps occur when highly stressed coal pillars suddenly rupture without warning, sending coal and rock flying with explosive force. A total of 172 incidents are included in the NIOSH coal bump database that extends back to 1950. The most recent was a double fatality during pillar recovery operations in an eastern Kentucky mine in 1996. Pillar recovery or barrier mining was associated with 50% of the bumps in the nationwide database. Nearly 95% of the bumps occurred at depths greater than 1,000 ft (Iannacchione and Zelanko, 1995).

Research has shown that bumps are much less likely when barrier pillars isolate each new panel from the abutment loads transferred from nearby gob areas. At depths of greater than 1,000 ft, Chase et al. (2002) suggest that properly designed barriers can enhance pillar line stability. Special extraction techniques, such as the thin pillar method, can also be helpful.

LOCAL STABILITY: PRIMARY RISK FACTORS

Global stability is a necessary, but not sufficient, condition for creating a safe working area. Local stability depends on a number of risk factors, of which the following four are most critical.

Cut Sequence

By far the most popular methods of pillar recovery used today are those that require no additional roof bolting during retreat. There are a wide variety of cut sequences employed, under an even wider variety of names. Most can be classified as either "*left-right*," (also called Christmas tree mining or twinning) in which cuts are taken on both sides of the entry, or "*outside lift*," in which cuts are taken on just one side (see figure 3). Plans that require roof bolting are usually used when the pillars are so large that they must be split before they are fully recovered.

The information provided by the MSHA Roof Control Specialists shown in Table 1 indicates that almost two-thirds of the full pillar recovery tonnage is obtained using some type of left-right sequence. Outside lift plans are used for most of the remaining production. Only handful of mines employ split-and-fender or other plans.

From a rock mechanics standpoint, it makes sense to compare the left-right to the outside lift method. Comparing just these two methods, the left-right plan would be expected to be more risky than outside lifts because:

• Wider unsupported spans are mined;

• More time is spent at the same location (to complete both the left and right lifts), and;

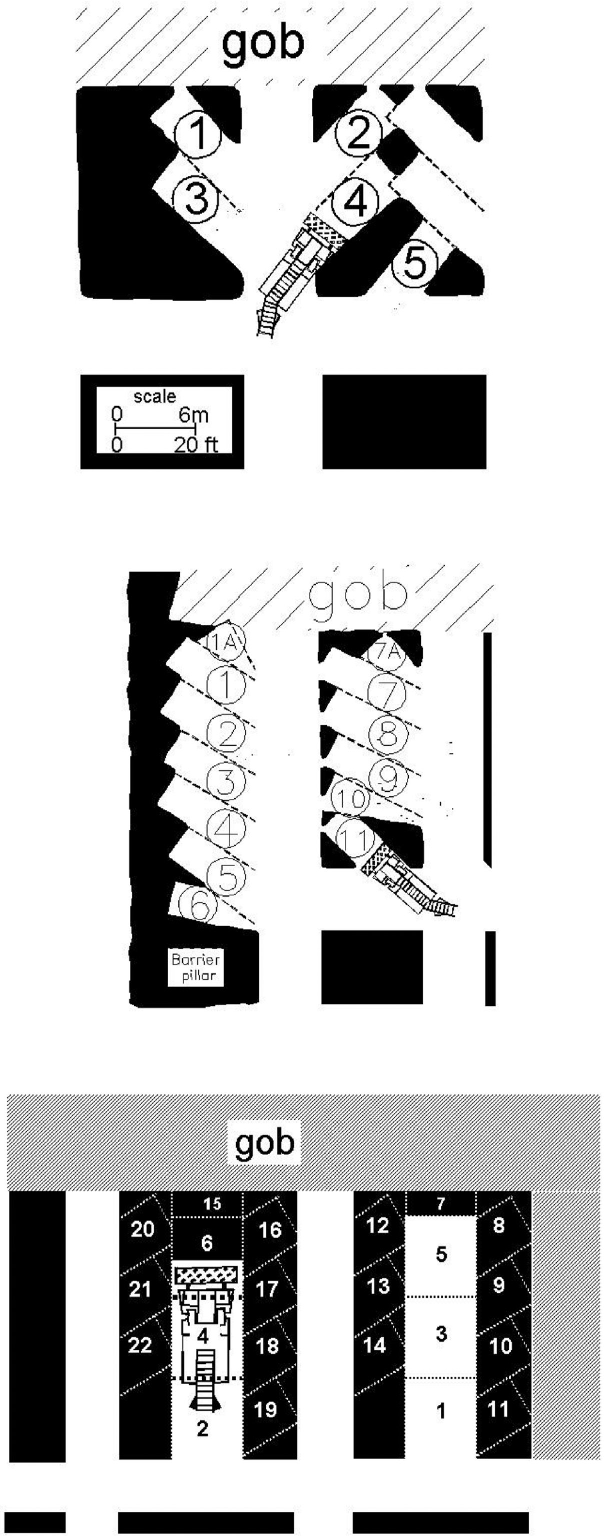

Figure 3. Common cut sequences used in the eastern U.S. Top: Christmas tree. Middle: Outside lift.
Bottom: Split-and-Fender.

• The operator of the remote controlled continuous miner (CM) may stand in a non-optimum location for either the left or the right lifts (see section below on "Operator Positioning").

The basic advantage of the outside lift plan is that the operators always have a solid pillar at their back. It also has some disadvantages, however:

• It can't be used to recover wide pillars without leaving large remnant fenders of coal (and wide pillars may be required to meet global stability requirements in thick seams and/or under deep cover), and;

• It usually employs deeper cuts, making the CM more difficult to extract if it is trapped while extracting a lift by a roof fall or rib roll.

Analysis of the fatality reports seems to indicate that left-right sequences may be slightly more risky than outside lifts. In seven of the fatal incidents, left- and right-hand cuts had been taken. However, in all but two of those incidents, the roof fall occurred during the extraction of the pushout or last lift (see next section).An outside lift sequence was involved in just one incident, also during a last lift.In five other incidents, the fatality occurred during the extraction of the first lift, and might have occurred regardless of the cut sequence. Similarly, two incidents occurred during mining in a barrier pillar, and four involved miners outby the face area.

To provide some further insight into the influence of the cut sequence on ground stability, the boundary element numerical model (BESOL) was used to compare four common pillar recovery plans in an identical mining environment (a 400-ft depth of cover and a 5-ft seam height). The mining methods evaluated were the left-right, split and wing, pocket and fender and outside lift. The particular pillar/opening geometries, cut sequences and timber supports (placed during each cut) used in each model were based on actual plans used by mines in southern West Virginia. More details on the general model geometry and the cut sequences used to simulate each of the pillaring plans can be found in Mark, et al. (2002).

Figure 4 shows convergence contours for each of the four mining methods after roughly one-third of the coal has been extracted. The 0.1-ft convergence level has been highlighted for reference purposes. The convergence data generated represents gross movement of the main roof/floor and higher levels would be indicative of an increased potential for a roof fall.

• *Left-Right (Christmas Tree)* – The 0.1-ft convergence contour extends outby the last cut into the work area of the next cut.

• *Split & Wing* – Because of the substantial yielding of the narrow fenders, the 0.1-ft convergence contour engulfs the entire split and extends well into the intersection outby where the lifts are being taken.

• *Pocket & Fender* – The 0.1-ft contour level engulfs the entire work area and extends down the entry to a point just short of the intersection.

• *Outside Lift* – The 0.1-ft level remains within the last cut taken.

In this particular scenario, the outside lift method appeared most likely to result in stable ground conditions. In general, the models indicate that high stress develops in the fender(s) being mined, that properly sized fenders withstand the stresses developed, and that undersized fenders yield prematurely - allowing gob pressures to override them and cause elevated convergence in the work area.

Final Stump or Pushout

The final pillar stump is a critical element in roof control during pillar recovery. While in place, it helps support the active intersection, which is generally the weakest link because of its wide span. Once the stump is removed, or is made too small to provide support, the

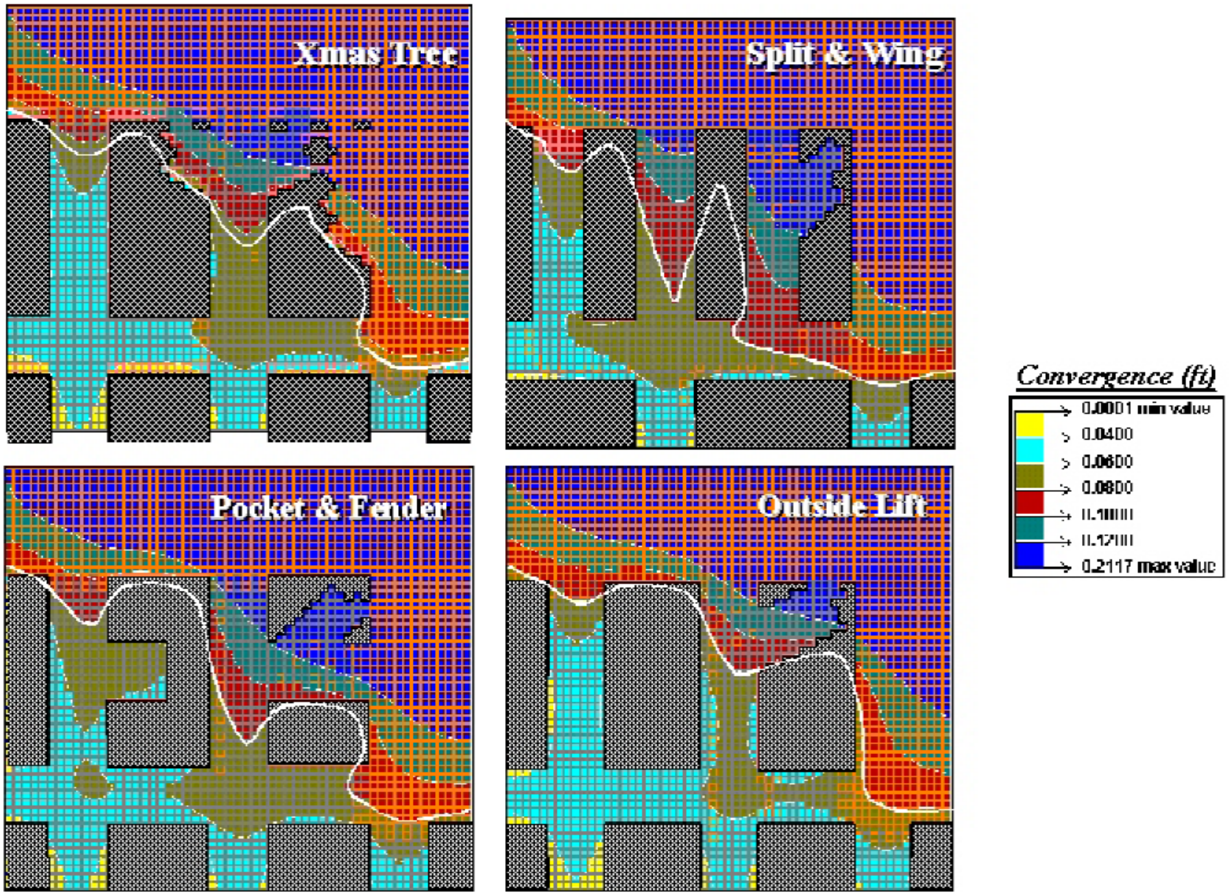

Figure 4. Roof convergence contours after several cuts. The 0.1 ft convergence contour is highlighted in white.

intersection may become unstable, like a chair with one leg removed. The data in Table 1 indicate that today only about one-third of full recovery production comes from mines that attempt to recover the final stump.

Nevertheless, between 1992 and 2001, 6 of the 21 nationwide pillar recovery fatalities, or 28%, occurred during extraction of the final stump or last lift. Since the final lift accounts for less than 28% of the total time required to recover a pillar, even at those operations that mine the pushout, this is clearly a very high-risk activity.

Traditionally, miners have been reluctant to leave the final stump because they were concerned that stumps in the gob would inhibit caving and cause a squeeze. Recent experience seems to indicate that fears about leaving stumps might have been exaggerated. While fewer and fewer mines attempt to recover the pushout, the incidence of squeezes does not seem to have noticeably increased.

In most cases, it appears that the optimum pillar extraction plan may be one that purposely leaves a final stump sized to provide roof support without inhibiting caving. Guidelines for sizing the final stump were recently published (Mark and Zelanko, 2001), and are summarized in table 2.

Table 2. Guidelines for sizing the final stump

Seam Height (ft)	Stump size (ft)*
4	8.5
6	9.5
8	10
12	10.5

*Cut-to-corner distance (see figure 5).

In addition to the six fatal incidents that occurred during recovery of the pushout or last lift, in two more cases mining had already come closer to the intersection than recommended by Table 2. In one, a lift had been extracted from the bottom end near the corner, and in the other, the first lift of a 3-cut plan started very near the outby corner of the pillar.

For a stump to perform its function, it must not be cut any smaller than specified. Plans that indicate a set number of lifts can result in undersized stumps if the lift angles or actual pillar dimensions are different than expected. A better practice is to specify the cut-to-corner distance (figure 5). Foremen can use spray paint to mark the stump dimensions on the rib as a guide to the CM operator.

Mobile Roof Supports vs. Timbers

Traditionally, timber posts provided supplemental support for pillar recovery. More than 100 roadway, turn, and breaker posts can be required to extract a single pillar. As supports, timber posts have a number of disadvantages:
Setting posts exposes miners to groundfalls. During the past decade, four miners have been killed while setting posts;
• Posts have a limited load-bearing capacity. A typical 6-in diameter hardwood post can carry about 50 tons, but most actual

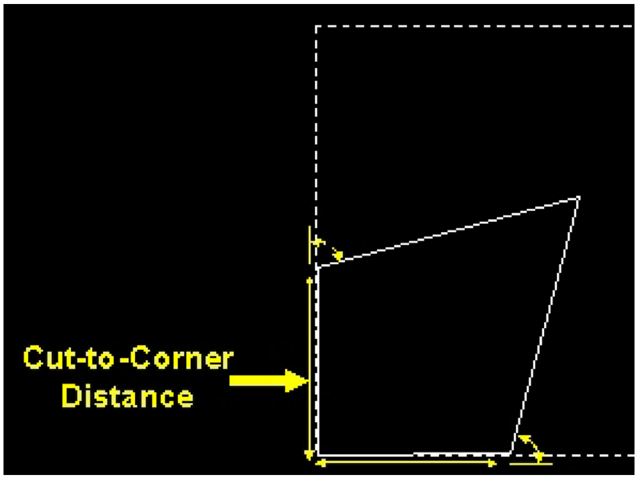

Figure 5. Cut-to-corner distances for the final stump.

posts have flaws and are even weaker;

• They have limited convergence range. Wood posts can break after only 1 or 2 in of roof-to-floor convergence, and their post-failure strength is almost nil, and;

• Their weight and bulk result in material handling injuries, particularly in high coal.

For all of these reasons, both MSHA and NIOSH have advocated the use of Mobile Roof Supports (MRS) for pillar recovery. MRS are shield-type support units mounted on crawler tracks (figure 7). They were first employed in West Virginia in 1988, and more than 100 units were in use in the U.S. by 1997 (Chase et al, 1997). The advantages of MRS are that they:

• Are operated remotely, at some distance from the pillar line;

• Have a support capacity of 600 or 800 tons per unit, and are employed in pairs or sets of four;

• Can maintain their load even if the roof moves downward more than a ft, and;

• Eliminate most material handling.

Two disadvantages are their cost and the resulting necessity to recover them if they are trapped by a rock fall.

The statistics now seem to justify the enthusiasm for MRS. In the past 10 years, only three of the 23 pillar recovery fatalities occurred where MRS were being used[3]. Table 1 indicates that in 2001, MRS mines accounted for about 40% of all the worker hours in full-recovery room-and-pillar mines. Extrapolating backward, a conservative assumption is that perhaps 25% of the pillar recovery worker hours between 1992-2001 were on MRS sections.

Using these data, it appears that a miner on a timber section has been about twice as likely to be fatally injured than a miner protected by MRS. Using MRS can be a highly effective means of reducing the risk of pillar recovery. However, they must be employed properly (Chase et al., 1997). The pillaring plan should show the proper location for every MRS during each lift, and the plan should be

Figure 6. A Mobile Roof Support.

followed carefully. If the pushout is recovered, four MRS should be used, and at least two of them should be located directly in the intersection. MRS should always be moved in pairs, one canopy length at a time, so that they can support each other.

One disadvantage of MRS is that their operating range is usually limited to seams thicker than approximately 42 in. Figure 7 shows that in southern West Virginia, the vast majority of mines in seams thicker than 52 in already use MRS. But of the 54 mines who reported a seam height of 52 in or less, only 7 were using MRS. In these thin seam mines, a timber plan that requires an adequate number of posts installed at the proper times and in the proper locations is essential.

Roof Bolting

The failure of roof bolt systems has been a major factor in nearly a third of recent pillaring roof fall fatalities, including:

• *Broken roof bolts, sheared by roof movement, were found in*

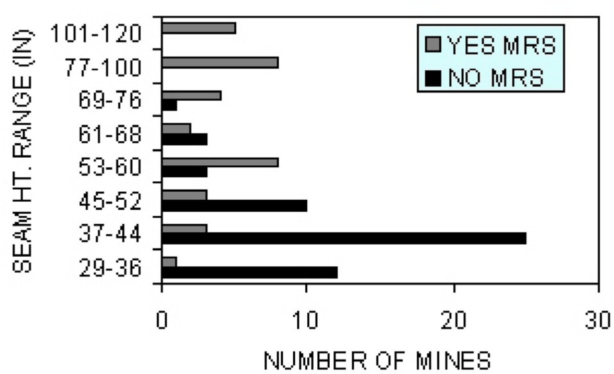

Figure 7. Distribution of MRS by seam height in southern West Virginia.

[3]The MRS were only implicated in the fatality in one of these instances. In the other two cases, broken roof bolts were considered the primary cause.

three incidents;

• Missing heads and plates, cut off by the CM, were found in two incidents, and;

• Bolts were too short and missed their normal anchorage in sandstone when the underlying shale thickened in one incident.

In four other incidents, the bolts were less than 48 in long.

Longwall mine operators recognize that headgate and tailgate entries will be subjected to abutment loads during retreat mining, and will therefore require *extra* roof bolts. Unfortunately, pillar recovery panels have sometimes been considered "short term," and therefore candidates for a lower density of roof support. In fact, increasing the roof bolt support in many cases can be the simplest way to reduce the risk of roof falls during pillar recovery.

More fundamentally, roof bolts are usually the only overhead protection miners have during pillar recovery. Mobile Roof Supports do not provide full roof coverage the way longwall shields do. Yet in all but one incident during the past decade, the pillar recovery fatalities have occurred when the victims were beneath bolted roof.

There is no widely accepted method for designing roof bolt patterns for retreat mining, though the Analysis of Roof Bolt Systems (ARBS) method can be a good starting point (Mark, 2002). In general, depending on the roof strata and other factors, the effectiveness of roof bolt systems for pillaring can be improved by using:

• Longer bolts that build a thicker beam or anchor in better quality roof;

• Stronger bolts, using larger diameter rod or higher grade steel, that are less likely to break from rock movement,

• Extra intersection support such as cable bolts, and;

• Point anchor resin-assisted bolts that can provide warning of high loads (while fully grouted bolts may break along their lengths without warning).

Another advantage of supplemental roof bolt support for pillar recovery is that bolts can be installed well outby the pillar line, before the ground is affected by the high stress environment.

OTHER RISK FACTORS

Roof Geology

Weak rocks like shale, mudstone, and coal, are more likely to be fractured and damaged by abutment stresses on the pillar line. Eight of the 19 fatal pillar recovery incidents occurred where the roof was either shale or drawrock beneath sandstone. Geologic discontinuities, such as slips, slickensides, horsebacks, contributed to four more pillar line fatalities.

Weak or fractured roof normally requires a higher level of roof bolting. Leaving a final stump for roof support is also more critical where the roof is weak. Every effort should be made to identify major discontinuities before mining and apply supplemental support. It may be necessary in some cases to avoid pillaring certain areas where hazardous roof features are known or suspected. In more than one-third of the fatal incidents, the reports indicated that poor conditions were observed in the area before the fatality occurred.

Intersection Span

Intersections are the Achilles heel of coal mine ground control. Research has shown that an intersection is 8-10 times more likely to collapse than an equivalent length of entry or crosscut. Even a seemingly small increase in the intersection span can greatly reduce stability, because the rock load is proportional to the *cube* of the span (Molinda et al., 1998). Intersection hazards are most acute where the roof is weak.

Nearly half of the fatal incidents in the data base involved intersection falls. Three more took place in the wide places that are created when lifts are turned.

Maintaining stable intersections is essential to safe pillar recovery. This can be accomplished by:

• Minimizing the entry width;

• Reducing the number and depth of turnouts during development;

• Using longer, stronger bolts in the intersections;

• Leaving an adequate final stump, and;

• Installing extra standing support (MRS or roadway posts) in the intersection if the final stump is extracted.

Depth of Cover

Greater depth means higher stress, both vertical and horizontal. During the past decade, approximately 30% of the pillar recovery fatalities have occurred in the relatively small number of mines where the depth of cover exceeds 750 ft. It seems that because global stability is harder to achieve at depth, the roof is more likely to be unstable. Proper pillar design is critical to successful mining at deep cover, but deep cover also magnifies the importance of all the other risk factors.

Multiple Seam Interactions

Many U.S. coal reserves, particularly in the Central Appalachian coalfields, occur where previous mining has been conducted above or below. Localized high stress zones can occur either above or below old works, and subsidence can damage the roof hundreds of feet above abandoned gob areas. In recent years, at least three pillar line fatalities appear to have been influenced by multiple seam interactions. Zones of potential interactions should be carefully mapped in the planning stage, and pillar recovery should be avoided where severe interactions are anticipated.

Recovery of Older Pillars

In many mines, pillars in old workings constitute substantial coal reserves. Such pillars can present an attractive target for extraction. Unfortunately, in many cases those workings were not designed with pillar recovery in mind. The pillar dimensions may be inappropriate or irregular, and entry and intersection spans may be too wide. Most importantly, the roof bolting may be inadequate, and the roof rock may have degraded over time. The age of the workings may have been a factor in at least three of the last decade's fatalities. Supplemental bolting is often required, particularly in intersections, to prepare old works for pillar recovery.

Non-Uniform Pillar Dimensions

Pillar recovery is safest when a routine can be developed and strictly followed. Developing panels with uniformly sized pillars, which facilitates a controlled and orderly extraction procedure, is strongly recommended. Where pillars are different sizes, whether by design or because of poor mining practice, "improvisation" is often necessary. In such cases, plans that call for a fixed number of lifts can result in a final stump that is too small. Requiring specific minimum cut-to-corner distances can help ensure that a properly sized final stump is left in place.

Odd-sized pillars can also result in oversized intersection spans. Pre-mining surveys should be completed to identify such hazards, and resupport may be necessary.

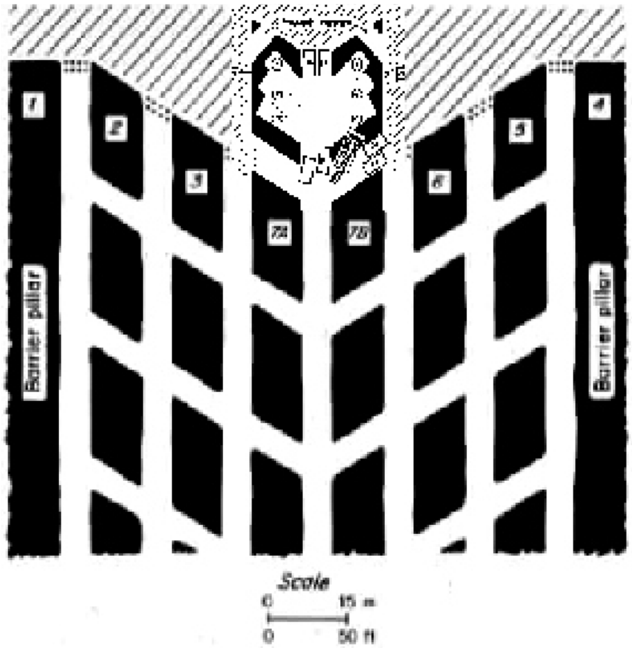

Figure 8. Pillar point created by mining with continuous haulage.

Continuous Haulage

Continuous haulage systems can result in improved productivity, particularly in thin seam operations. Unfortunately, they have several disadvantages for pillar recovery. In normal operations, the haulage system works out of the center entry intersection. The pillars must be retreated from both sides towards the middle, resulting in a pillar point (figure 8). Also, the center entry is often mined wider to accommodate the equipment, and the center entry intersections are particularly vulnerable to roof falls. Finally, the haulage system is more difficult to withdraw quickly if a hazard develops.

One partial solution was developed by a West Virginia mine after a fatality. An extra bridge was added to the haulage system, which then allowed it to be worked from the outby intersection. Then the entire row of pillars could be worked from right to left, eliminating the pillar point. It is also helpful to flatten the croscut angles out as much as possible.

Operator Positioning

The victim in 44% of the past decade's fatalitiies was the CM operator or helper. According to MSHA's Program Policy Manual, "Investigation of a few of these [fatal roof fall accidents that occurred during pillar recovery operations] revealed that miners were occupying work locations inby the mining machine while coal was being mined or loaded. This practice should be discouraged, recognizing that recently mined coal pillars reduce the amount of support in these areas." With regard to 30 CFR 75.221, Roof Control Plan Information, the Policy Manual states that "work procedures and location of miners while coal is being mined or loaded should be incorporated into the roof control plan as part of the description of the mining system utilized during pillar recovery." Ideally, the operators should be outby the wide place created by the lift at all times.

The pillar line is a dangerous place, and miners should never congregate there. At least five of the 23 pillar recovery victims were not performing an essential production function when they were killed. Moreover, during the past decade, there were six multiple ground fall fatality incidents during pillar recovery, and *none* during any other activity. The toll could have been much worse. In six other pillar recovery incidents, miners were injured by the same roof falls that killed their co-workers. Careful planning of the production process, good supervision, and training and retraining may be necessary to prevent bad habits from developing.

PILLAR RECOVERY RISK FACTOR CHECKLIST

The Risk Factor Checklist can be used to identify potential problem issues for specific pillar plans. The more questions on it that can be answered with a "yes," the less risky the plan is likely to be. The checklist does not weight the individual risk factors, nor is it necessarily a comprehensive list. It is simply a tool to help mine planners evaluate the overall level of risk, and possible ways to reduce the risk.

Local Stability Risk Factors (Primary)

- **Cut sequence:** Is an outside lift sequence being used?
- **Final stump:** Is an adequate final stump consistently being left in place?
- **Support:** Are Mobile Roof Supports being used?
- **Roof bolts:** Is extra roof support used in intersections?

Global Stability Risk Factors

- **Pillar Design:** Is the ARMPS SF adequate to prevent a squeeze?
- **Collapse Prevention:** If the ARMPS SF<2.0 and the pillar w/h<4.0, either on advance or in the workedout area, have steps been taken to prevent a massive pillar collapse?
- **Barrier Pillar Design:** If the depth of cover is greater than 1000 ft, are stable barrier pillars (SF>1.5 to 2.5) being used to separate the panels?

Other Risk Factors

- **Roof geology:** Is the roof at least moderate in strength?
- **Intersection span:** Have entry widths and turnouts been minimized?
- **Multiple seam interactions:** None anticipated?
- **Depth of cover:** Less than 650 ft?
- **Block size:** Are the blocks uniform in size?
- **Age of workings:** Is the development less than 1 year old?
- **Continuous haulage:** None?

CONCLUSIONS

Pillar recovery continues to be one of the most hazardous activities in underground mining. Global stability, achieved through proper pillar design, is a necessary prerequisite for safe pillar recovery. Local stability means preventing roof falls in the working area. It is achieved by minimizing the "risk factors" described in this paper.

The Roof Control Plan is essential to every underground coal mine, but nowhere is it more important than in pillar recovery. Pillaring leaves little tolerance for error, and mistakes can be deadly. Roof Control Plans must be carefully drawn up to address the site-specific conditions, and then carefully implemented and followed. Both miners and foreman involved in pillar extraction should be trained to know and understand the plan.

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