Reducing Roof Fall Accidents on Retreat Mining Sections

Developing and following a mining plan, and using equipment properly could reduce miner exposure to ground falls

BY CHRISTOPHER MARK AND JOSEPH C. ZELANKO

During August, two eastern Kentucky coal miners died in a roof fall during retreat mining operations. They had just finished extracting one pillar block and were moving to the next one when the intersection they were standing in collapsed. Regrettably, this was not an isolated incident. Since the end of 2000, there have been 28 ground fall fatalities in U.S. coal mines. Of these, 10 occurred during pillar recovery operations. Although pillar recovery has been associated with about one third of recent ground fall fatalities, it accounts for only about 10% of U.S. underground coal production. Statistically, a coal miner engaged in pillar recovery is several times more likely to be killed in a ground fall than a miner on an advancing section of a longwall.

Pillar recovery is dangerous because it creates an inherently unstable situation. Once the pillars are extracted, the roof is expected to cave. Safe pillar recovery does not mean preventing roof collapse, it means ensuring that it only occurs after the miners have completed their work and have left the area.

Fortunately, there are a number of proven techniques that can greatly reduce the hazards of pillar recovery. These include better mine planning, improved roof support, and safer work procedures. The goal of this article is to describe the most significant "risk factors" associated with pillar recovery, and prescribe control techniques that, taken together, can reduce the overall risk to miners. The conclusions are based on extensive studies conducted by the National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA) that have included detailed analysis of every fatal retreat mining incident since 1992 (25 incidents resulting in 30 fatalities).

Risk reduction strategies for pillar recovery can be divided into three main groups:

- Global Stability: Prevention of section-wide pillar failure;
- Local Stability: Prevention of roof falls in the working area; and
- Work procedures and worker location: Minimizing exposure to hazardous areas.

GLOBAL STABILITY RISK FACTORS

Proper pillar design is the key to ensuring global stability. There are three main types of pillar failure that can occur during retreat mining—pillar squeezes, massive collapses, and bumps—and each can be mitigated by proper design.

Squeezes occur when the pillars (or the floor beneath them) are unable to carry the loads applied to them. Typically, these failures propagate as individual pillars fail and shed load to adjacent pillars, which in turn fail. The results can include severe rib spalling, floor heave, and roof failure. The process may take hours or days, and can cause an entire panel to be abandoned.

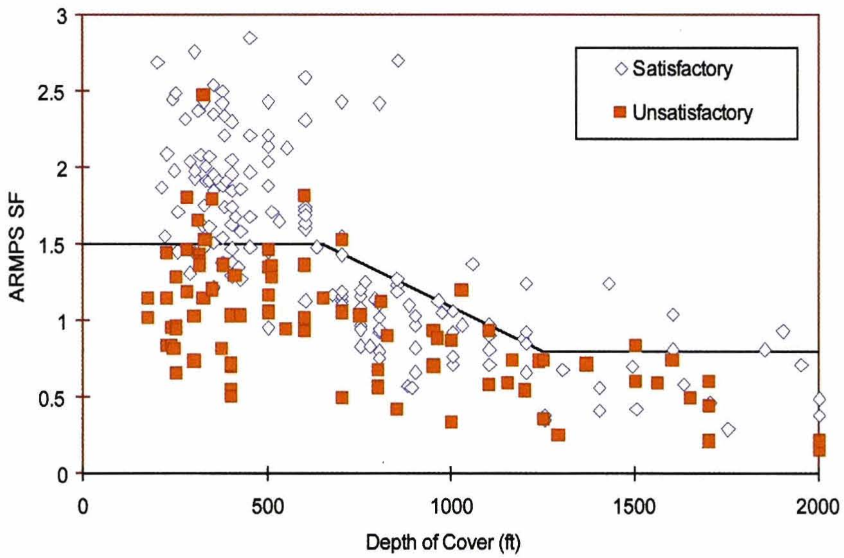


Figure 1. Suggested ARMPS SF based on the case history data base.

The Analysis of Retreat Mining Pillar Stability (ARMPS) program can be used to help size pillars to carry both development and abutment loads. ARMPS has been calibrated by back-analysis of hundreds of pillar recovery case histories. For depths of cover less than about 600 ft, Stability Factors (SF) that exceed 1.5 have generally been effective (See Figure 1). Under deeper cover, the SF can be somewhat less, but other precautions such as barrier pillars are suggested. ARMPS can be downloaded from the NIOSH mining Web site (http://www.cdc.gov/niosh/mining/).

Massive collapses are pillar failures that take place rapidly and involve large areas. One effect can be a powerful, destructive air blast. Of 14 massive collapses that have been documented since 1980, all but two have occurred in southern West Virginia. They have caused several injuries but, incredibly, 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 worked-out areas where pillars have been split. Guidelines for preventing or containing massive collapses have been largely implemented in southern West Virginia since 1998, and no documented massive collapses have occurred since then.

Bumps occur when highly stressed coal pillars suddenly rupture without warning, sending coal and rock flying with explosive force. The most recent fatal bump accident claimed two lives in an eastern Kentucky mine in 1996 during pillar recovery operations.

Research has shown that bumps are less likely when barrier pillars isolate each new panel from the abutment loads transferred from nearby gob areas. Special extraction techniques, (i.e. cut sequences) can also be helpful. However, multiple seam interactions (particularly those associated with isolated barriers and gob/solid boundaries) must be considered in order to anticipate anomalously high stress levels that contribute to bumps.

LOCAL STABILITY: PRIMARY RISK FACTORS

Global stability is a necessary, but not sufficient, condition for creating a safe working area. While global stability is largely a mine design issue, local stability depends on providing adequate support to the immediate roof in the working area. The most critical area is the active intersection just outby the pillar being extracted. This intersection is the weakest link because of its wide span and proximity to the gob. Twelve of 25 fatal pillar recovery incidents since 1992 involved falls of the active intersection, and three more took place in outby intersections.

Four important local stability risk factors are: stump (remnant pillar) size, type of standing support, type and density of roof support (bolts), and geologic conditions.

The final pillar stump (sometimes called the "pushout") provides critical roof support during pillar recovery. Once it is removed, or is made too small to provide support, the active intersection may become unstable, similar to a chair with one leg removed. Between 1992 and 2004, nine of the 30 nationwide pillar recovery fatalities, or nearly one-third, occurred during or just after extraction of the final stump or last lift. Since mining the last lift or pushout typically accounts for less than one-third of the pillar recovery process, this accident rate is disproportionately high. Clearly, mining the last lift and push out are high risk activities.

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 were often 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, the optimum pillar extraction plan may be one that purposely leaves a final stump sized to provide roof support without inhibiting caving. Suggested guidelines for sizing the final stump, based on detailed rock mechanics analysis of pillar extraction experience, are summarized in Figure 2.

For a pillar stump to perform its function, it must not be cut any smaller than specified. In addition to the seven fatal incidents that occurred during recovery of the pushout or last lift, in four more cases mining had already come closer to the intersection than recommended. In these instances, lifts were extracted from the bottom ends (crosscuts) too close to the corner, or entry lifts were started very near the outby corner of the pillar.

To ensure that final stumps are properly sized, the cut-to-corner distance (Figure 2) should be specified in the Roof Control Plan. The section foreman or surveyor should use spray paint to mark the stump dimensions on the rib as a guide to the continuous miner (CM) operator.

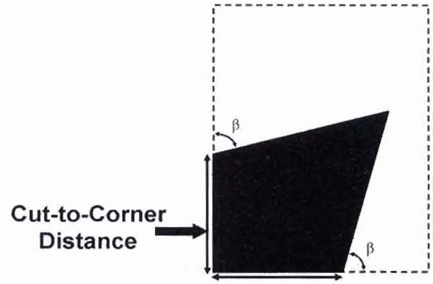
USE MOBILE ROOF SUPPORTS

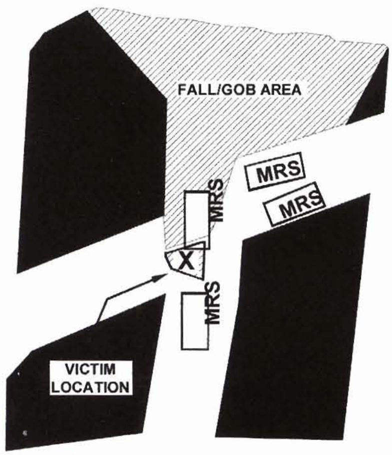
Traditionally, timber posts provided supplemental support for pillar recovery. More

Figure 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





CASE HISTORY NO. 1: WEST VIRGINIA, 2002

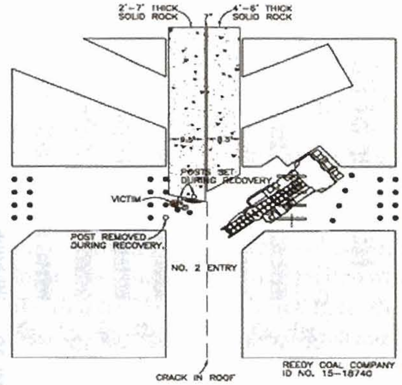
Miners had just completed the extraction of the pushout and were moving the Mobile Roof Supports to the next block. The active intersection collapsed, killing one miner and severely injuring a second. The following risk factors were present:

- The victim was not engaged in moving the equipment, yet was not in a safe, outby location.
- MRS operators, including the injured miner, were also in the intersection.
- The final stump was fully extracted (as allowed by the Roof Control Plan).
- MRS were present, but contrary to the Roof Control Plan, both the No. 1 and No. 3 units were depressurized at the same time.
- Only the 42-inch long, fully grouted pattern roof bolts were in place, but up to 6 ft of roof collapsed.
- Continuous haulage was being used, creating a "pressure point."

CASE HISTORY NO. 2: KENTUCKY, 2004

The crew had just finished setting timbers for retreat mining, and they were observing the roof during the final lift from the No. 2 entry. The roof fall initiated in the entry and extended into the intersection as far as a double-row of breaker posts that had been set there. The following risk factors were present:

- The victim was in an unsafe location, inby the breaker posts and the continuous miner.
- A long roof crack had been observed running down the rib of the No. 2 entry, but it was neither reported nor supported.
- No MRS were used (mining height was less than 48 inches)
- Only the pattern 4-ft long fully-grouted bolts were present, but the fall was up to 5 ft thick.
- The intersection had apparently been widened by a turnout.



than 100 roadway, turn, and breaker posts can be required to extract a single pillar. Unfortunately, setting posts on a pillar line is a very high-risk activity. Since 1992, four miners have been killed while setting posts. Timber posts also have a number of disadvantages as roof supports because they have limited load-bearing capacity and can break after only 1 or 2 inches of roof-to-floor convergence. In addition, the weight and bulk of timber posts can 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. Today there are more than 270 units in use. The advantages of MRS over timber supports are that they reduce miner exposure to roof falls at the pillar line since they can be operated remotely, provide an active support pressure to the roof at the pillar line, provide larger overall capacity (one 600 ton MRS is approximately equivalent to 12 posts), maintain load through a much greater range of displacement, and decrease the potential for material handling injuries.

Two disadvantages of MRS are their initial cost and the resulting necessity to recover them if they are trapped by a rock fall. Site specific recovery plans may be necessary to ensure the safety of personnel. Some mines keep supplemental support beams and/or arch structures readily available for this purpose.

The statistics now seem to justify the enthusiasm for MRS. In the past 14 years, six of the 30 pillar recovery fatalities (including this year's double fatality) have occurred where MRS were being used. In 2001, mines that use MRS accounted for about 40% of all the worker hours in full-recovery room-and-pillar mines. Extrapolating backward, a conservative assumption is that perhaps 30% of the pillar recovery worker hours between the years 1992-2005 were on MRS sections. Using these data, it appears that a miner on a timber section has been about 1.7 times as likely to be fatally injured as a miner protected by MRS.

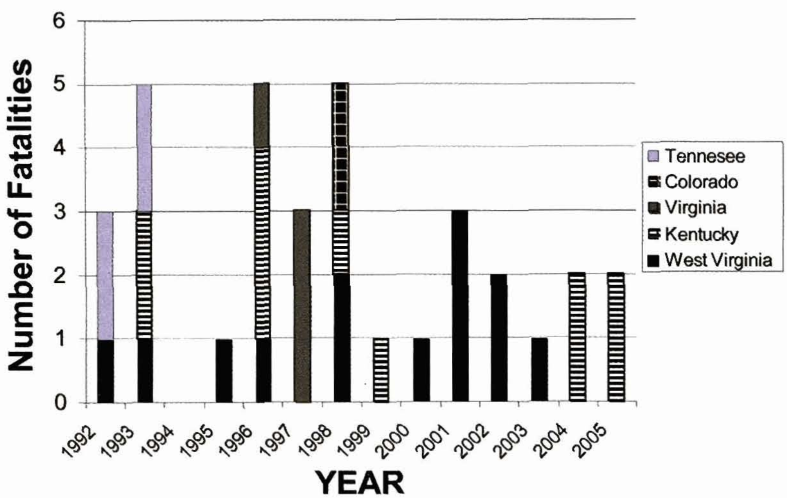
While MRS can be a highly effective means of reducing the risk of pillar recovery, they must be employed properly. One key advantage of MRS is that they can be operated remotely, from safer locations. Yet, in three of the five incidents on MRS sections, miners have been killed standing in the active intersection as the last lift was being mined or after it was completed.

All personnel should be positioned outby the active intersection during the last lift. If the final stump is recovered, four MRS should be used, and two of them should be positioned to narrow the roadway through the intersection as much as possible. During all lifts, the units should be kept as close as practical to the continuous mining machine. Upon completion of mining in a given pillar, the units should be moved sequentially until they are between solid coal. MRS should always be advanced sequentially such that one unit will never be offset more than one half the length of its companion unit. During this process, at least one unit should be pressurized against the roof at all times. Pressure gages or load indicating lights should be visible from a distance, and if the yield pressure is reached, mining should cease in that lift. Personnel should remain at least 20 ft away from MRS when they are being pressurized

PILLAR RECOVERY DEMOGRAPHICS AND FATALITY REPORTS

In our retreat mining study, we reviewed information in the MSHA accident and employment data base and in MSHA fatality reports. The demographic data confirmed that more than 90% of the coal produced by pillar recovery comes from the central Appalachian coalfields of southern West Virginia, Virginia, and eastern Kentucky. About 8% comes from the northern Appalachian coalfields (Pennsylvania, northern West Virginia, and Ohio), and just 1% from western mines. Currently, there is essentially no pillar recovery taking place in Indiana, Illinois, western Kentucky, or Alabama.

Interestingly, our study found that the non-fatal roof/rib injury rate was generally lower in pillar recovery mines than in other room-and-pillar mines. In 2001, for instance, the retreat mine rate was 1.60 per 200,000 hours, slightly less than at other room-and-pillar mines, where the rate was 1.79. This may be attributable to the smaller amount of time spent bolting freshly-exposed roof, which is a major source of injuries on advancing sections.



The fatality reports described 25 incidents involving 30 fatalities that occurred between 1992 and 2005. All of the incidents took place in the central Appalachian coalfields, except for one in northern West Virginia and a double-fatality in Colorado.

One significant finding was that in more than a third of the pillar recovery incidents, no contributing violations of the Federal Mine Safety and Health Act of 1977 were cited in the investigations. Multiple high-negligence violations, including not following the approved Roof Control Plan, were cited in just less than one-third of the incidents. It is evident, therefore, that the large majority of pillar recovery fatalities cannot simply be attributed to egregious violations of the law. Rather, it seems that the designs, procedures, and practices that were in place were simply insufficient to prevent tragedy from occurring.

More details on the methodology employed in the retreat mining study can be found in the paper by Mark, Chase and Pappas titled "Reducing the Risk of Ground falls During Pillar Recovery," which can be found at the NIOSH mining Web site http://www.cdc.gov/niosh/mining/pubs/pdfs/rtrog.pdf.

or depressurized. Plans for performing maintenance in safe locations and for retrieving disabled or stuck MRS should be formulated in advance and strictly followed.

MRS are equipped with three means of operation: manual, pendant (umbilical cord) remote control, and radio remote control. It is imperative that these controls be used appropriately. Manual controls are for maintenance use only. They should never be used to tram the units. Pendant controls should only be used to tram the units outby the active pillar line. Radio remote control should always be used to tram, pressurize, and depressurize the units on the active pillar line.

One disadvantage of MRS is that their operating range is usually limited to seams thicker than approximately 42 inches. In southern West Virginia, the vast majority of mines in seams thicker than 52 inches already use MRS (See Figure 3). However, only seven of the 54 mines that reported a seam height of 52 inches or less were using MRS. In these thin seam mines, and other mines that do not employ MRS, a timber plan that requires an adequate number of posts, installed at the proper times and in the proper locations, is essential.

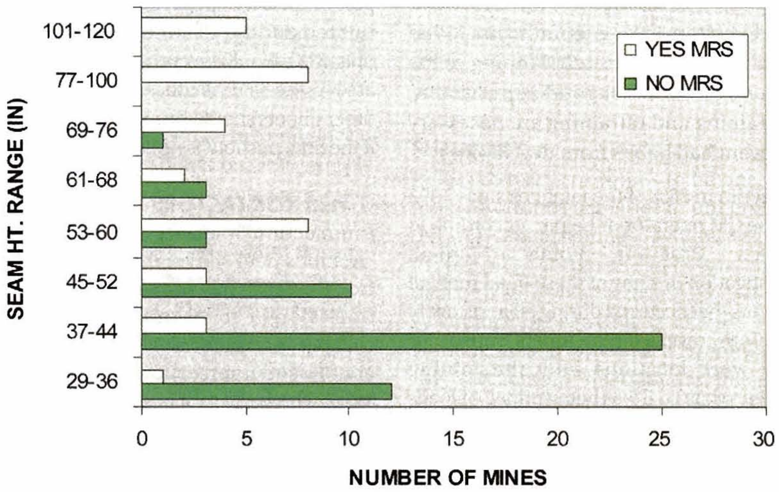


Figure 3. Usage of MRS in mines of varying seam height in West Virginia.

ENHANCE ROOF BOLT SUPPORTS

Even when MRS are employed, they do not provide full roof coverage the way longwall shields do. Roof bolts are usually the only overhead protection miners have during pillar recovery. Yet, in all but one incident during the past 14 years, retreat mining fatalities have occurred when the victims were beneath bolted roof.

Why haven't roof bolts been able to protect miners during pillar recovery? One reason is that many mines use the same roof support in retreat panels that they do elsewhere in the mine. However, retreat sections are subjected to abutment loads just like longwall headgate and tailgate entries.

Accident investigations revealed that roof bolt systems failures have been a major factor in one-quarter of recent pillaring roof fall fatalities, including the following incidents:

- Broken roof bolts, sheared by roof movement, were found in three incidents;
- Missing bolt 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 many cases, it appears that enhancing roof bolt support can be the easiest and most effective way to reduce the risk of roof fall fatalities during pillar recovery.

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 or cables that build a thicker beam or anchor in better quality strata;
- Stronger bolts, using larger diameter rod or higher grade steel, or cables that are less likely to break from rock movement; and
- Point anchor resin-assisted bolts that can provide warning of high loads (while fully grouted bolts may break along their lengths without warning).

Given their vulnerability, intersections are the most critical candidates for enhanced roof bolting. Secondary roof bolt support can be installed well outby the pillar line, before the ground is affected by the high stress environment. Early installation (e.g., during development) provides an additional advantage since the support functions throughout the mining cycle.

KNOW YOUR ROOF GEOLOGY

Retreat mining imposes severe stresses and strains on a mine roof. Rock that seemed stable after development can suddenly be broken or pulled apart. Weak rock, or rock that contains pre-existing geologic fractures, is particularly susceptible. Ten of the 25 fatal pillar recovery incidents occurred where the roof consisted of weak rocks like shale, mudstone, or drawrock. Geologic discontinuities, such as slips, slickensides, horsebacks, joints, or hillseams, contributed to seven more pillar line fatalities.

Safety during pillar recovery depends upon identifying and controlling hazards prior to mining. In more than one-third of the fatal incidents, reports indicated that the installed support systems failed to control poor conditions that were observed in the area before the fatality occurred. It is essential that preshift and on-shift examinations include a thorough assessment of geologic conditions, and that hazards be reported and dangered off or appropriately supported. Examinations should include areas outby the pillar line since observed trends may be used to anticipate geologic conditions prior to retreat.

Major roof fractures should be marked, mapped, and supported and test holes may be useful to determine if roof separation is occurring. Some mines use paint or flags to note the presence of faults, hillseams, or other hazardous features. It is good practice to plan to skip some lifts in order to leave coal as support for such features. In extreme cases, such as where hillseams run down entries for long distances, it would be prudent to forego pillar recovery operations.

WORK PROCEDURES & MINER POSITIONING

Global and local stability are typically addressed by careful selection of engineering parameters. In contrast, the third risk reduction strategy involves human behavior. For example, the pillar line is a dangerous place, and miners should never congregate there. At least nine of the 30 pillar recovery victims were not performing an essential production function when the roof fell. Moreover, since 1992, there have been five multiple ground fall fatality incidents during pillar recovery, and none during any other activity. The toll could have been much worse. In eight 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 are necessary to prevent bad habits from developing.

The victim in 36% of the fatalities since 1992 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 and the presence of other miners should be minimized, especially if the final pushout is removed.

OTHER RISK FACTORS

Intersection Span—Intersections are the "Achilles heel" of coal mine ground control. Research has shown that an intersection is eight to 10 times more likely to collapse than an equivalent length of entry or crosscut. Intersection hazards are most acute where the roof is weak. The following measures can reduce intersection spans:

- Minimizing the entry width;
- Limiting the number and depth of turnouts during development (ideally, only one turnout should be made for each pillar row); and
- Never turning both directions in the same intersection.

These measures will also help reduce the likelihood of roof fall injuries to continuous miner operators during the development of turnouts.

Depth of Cover—Greater depth means higher stress, both vertically and horizontally. During the past 14 years, more than one-third of the pillar recovery fatalities have occurred in the relatively small number of mines where the depth of cover exceeds 750 ft. Proper pillar design is critical to successful mining at deep cover, but deep cover also magnifies the importance of all the other risk factors. Appropriate cut sequences also will be required to safely recover larger pillars under deep cover.

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

METHODS TO EXTRACT PILLARS

Mines employ a wide variety of cut sequences to remove pillars, under an even wider variety of names. The most popular methods of pillar recovery used today do not require bolts to be installed as pillar recovery lifts are mined. Most of these plans 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 (A), or "outside lift," in which cuts are taken on just one side (B). Plans that require cuts to be bolted are usually used when the pillars are so large that they must be split before they are fully recovered (C).

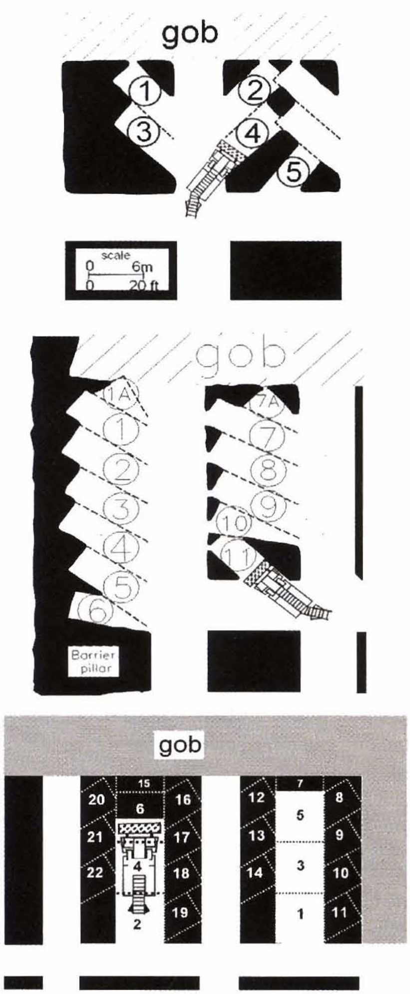
Almost two-thirds of the full pillar recovery tonnage is obtained using some type of left-right sequence. Outside lift plans are used for most of the remaining production. Only a handful of mines employ split-and-fender or other plans that require roof bolting in the cuts.

From a stability 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 for the following reasons:

- Wider unsupported spans are mined;
- More time is spent at the same location (to complete both the left and right lifts), and;
- The operator of the remote controlled continuous miner (CM) may stand in a non-optimum location for either the left or the right lifts.

The basic advantage of the outside lift plan is that the operators always have a solid pillar at their backs. It also has some disadvantages, however it cannot 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). Also it usually employs deeper cuts, making the CM more difficult to extract if it is trapped by a roof fall or rib roll while extracting a lift.

Analysis of the fatality reports seems to indicate that left-right sequences may be slightly more risky than outside lifts. In 11 of the 25 fatal incidents, left- and right-hand cuts had been taken. However, in all but two of those incidents, the roof fall occurred during or just after the extraction of the pushout or last lift. 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 six involved miners outby the face area.



From the top down A, B, and C.

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 fatalities in the past decade. 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 re-support may be necessary.

It is important to recognize the influence of changes in pillaring direction. For example, efforts to recover mains or submains outby previously mined pillar panels should anticipate abutment loading from the adjacent gob(s). Pillar dimensions that were effective in an isolated panel may be unacceptable under combined front and side abutment loads. Pillar recovery should always proceed in an orderly fashion. However, abutment loads imposed by directional changes may necessitate leaving some pillars or portions of pillars intact.

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 continuous haulage operations, the system works out of the center entry intersection. The pillars must be retreated from both sides towards the middle, resulting in a pillar point. 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 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. At this mine site, the system allowed each row of pillars to be completed in one of the outside entries adjacent to the solid coal or barrier, thereby eliminating the pillar point at the center of the section.

SUMMARY

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. Roof Control Plans developed at each underground coal mine often address both engineering parameters and human behavior issues (e.g. worker positioning). These plans are essential to all mining activities, but nowhere are they 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 site-specific conditions, and then carefully implemented and followed. Miners and foremen involved in pillar extraction should be trained to know and understand the plan prior to beginning retreat mining.

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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.

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 worked-out 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?

Local Stability Risk Factors (Primary)

- 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?
- Geology: Are all geologic hazards being identified and addressed?

Work Procedures and Miner Positioning

- Operator locations: Have safe locations for miners been developed and incorporated in the pillar recovery plan?
- Training and supervision: Do all miners know where they should be, and are procedures in place to ensure that the plan is followed?

Other Risk Factors

- Intersection span: Have entry widths and turnouts been minimized?
- Cut sequence: Is an outside lift sequence being used?
- 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?