

# PILLAR DESIGN AND STRATEGIES FOR RETREAT MINING

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## ABSTRACT

One of the keys to miner safety and an efficient recovery of the reserves is to design sufficiently sized production pillars that will prevent pillar squeezes, excessive pillar spalling, severe floor heave, roof falls, and pillar bumps. Currently, few mine operators design sections that will be retreat mined using empirical formulas or numerical models that estimate abutment pressures generated by adjacent mined-out workings. The U.S. Bureau of

Mines is in the process of field testing and refining a "user friendly" computer program called Analysis of Retreat Mining Pillar Stability (ARMPS) to estimate abutment pressures developed during pillaring. Analyses of 68 pillar design case histories using the ARMPS program indicate that it can be successfully employed to predict pillar line stability during retreat mining operations.

## INTRODUCTION

Use of remote-control miners, extended-cut waivers up to 12 m (40 ft), and mobile roof supports have enabled room-and-pillar retreat mining (also referred to as pillaring, robbing, and second mining) to be competitive with longwall mining. While longwall mining can claim an admirable safety record (12),<sup>3</sup> the same cannot be said of retreat mining. During the period between 1989 and 1993, 29% of the roof fall fatalities occurred on retreat mining sections. One of the most hazardous underground operations during retreat or any other type of mining is the removal of the push-out stump. Over a recent 10 year period, 10% of the fatalities resulting from roof or rib falls occurred during the removal of the push-out stump (11).

Roof fall accidents are not the only problem associated with retreat mining. Each year, considerable amounts of coal are lost because of squeezes, heave, pillar line roof falls, and pillar bumps. Yet few empirical formulas or numerical models are available that can estimate abutment pressures that develop when gob areas are created during pillar extraction. As part of its goal to reduce injuries and fatalities, the U.S. Bureau of Mines (USBM) is field testing and refining a method called Analysis of Retreat Mining Pillar Stability (ARMPS) to aid in the design of pillar retreat sections. This paper presents the findings thus far.

## ARMPS METHOD

The ARMPS formula is based on the Analysis of Longwall Pillar Stability (ALPS) method that is widely used for

longwall pillar design (8-9). The ALPS method was originally developed from measurements of abutment loads in five longwalls and later validated by back analysis of more than 100 longwall mining case histories. To be useful for pillar retreat mining, the ALPS method had to be modified for the different extraction geometries that are created during pillar extraction.

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<sup>3</sup>Italic numbers in parentheses refer to items in the list of references at the end of this paper.

The goal of the ARMPS method is to help ensure that the pillars developed for eventual extraction (production pillars) are of adequate size for all anticipated loading conditions. The most severe loadings usually develop on the extraction front (or pillar line), particularly where older gob areas from previously extracted panels are nearby. The ARMPS method determines a stability factor (SF) as—

$$SF = LBC/LT, \quad (1)$$

where LBC = estimated load-bearing capacity of pillars within active mining zone (AMZ)

and LT = estimated load applied to pillars within AMZ.

The AMZ is defined as being the width of the extraction front and three pillars deep (fig. 1).

Studies of longwall gate entries have indicated that three rows of pillars typically behave as a single system and that an SF calculated for the system as a whole is

more representative of conditions than an SF calculated for individual pillars.

The load-bearing capacity of the AMZ is calculated as the sum of the load-bearing capacities of the pillars within it. The strength of an individual pillar (SP) is determined using the Bieniawski formula (3):

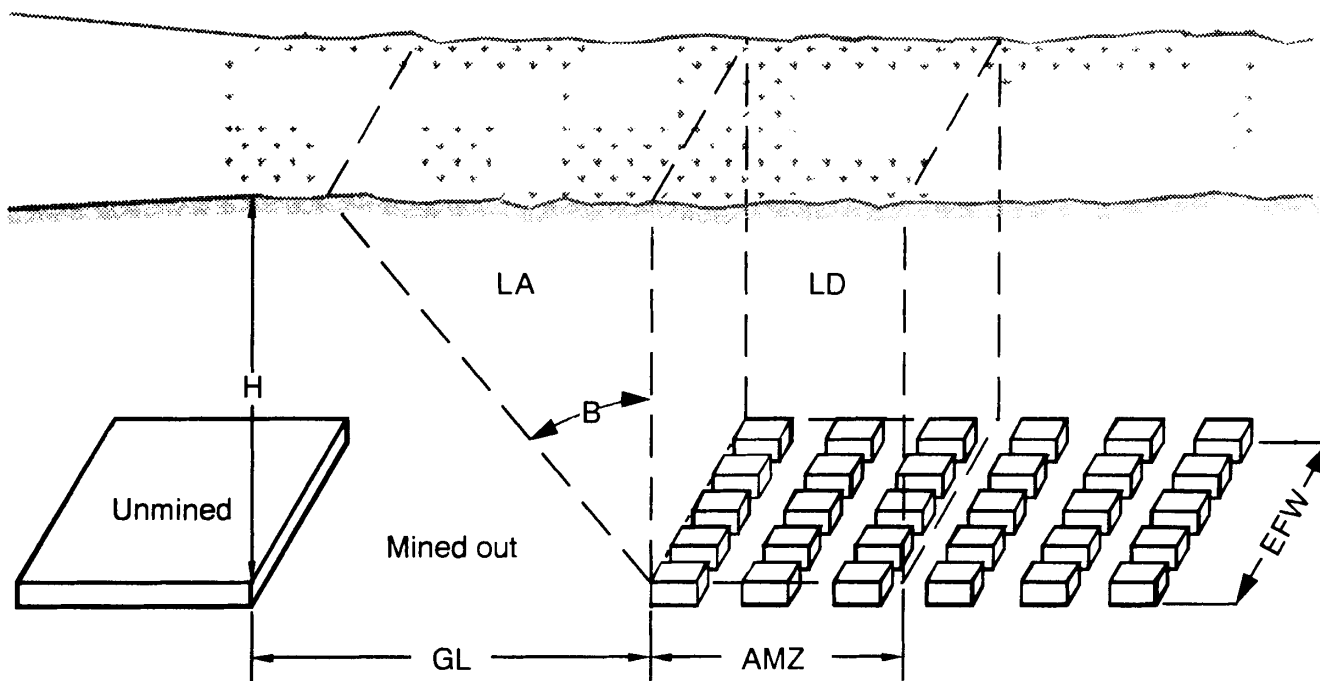
$$SP = S_1 [0.64 + (0.36 w/h)], \quad (2)$$

where  $S_1$  = in situ coal strength [assumed value = 6.2 MPa (900 psi)],

w = pillar width,

and h = pillar height.

Longwall studies have indicated that 6.2 MPa (900 psi) is normally the appropriate value for  $S_1$  for use in this formula (8), and this value was used in all the case history analyses discussed. Current indications are that both coal strength and floor strength may be more important during pillar retreat than they are in longwall operations.



KEY

- |     |                        |    |                  |
|-----|------------------------|----|------------------|
| AMZ | Active mining zone     | H  | Depth of cover   |
| B   | Abutment angle         | LA | Abutment load    |
| EFW | Extraction front width | LD | Development load |
| GL  | Mined-out area         |    |                  |

Figure 1.—Schematic of active mining zone.

The loading applied to the AMZ (fig. 1) is the sum of—

- Development loading present before pillar retreat and
- Abutment loads created by load transfers from adjacent gobbed-out areas.

The development load (LD) is estimated using the tributary area formula—

$$LD = (H) (\gamma) (AT), \quad (3)$$

where  $H$  = depth of cover,

$\gamma$  = unit weight of overburden,

and  $AT$  = total area of AMZ.

Abutment loads (LA's) are determined using either equation 4 or equation 5, depending on the length of the mined-out area (GL):

When  $GL \geq 2 (H \tan B)$ ,

$$LA = H^2 (\tan B) (\gamma/2) (EFW), \quad (4)$$

and when  $GL < 2 (H \tan B)$ ,

$$LA = \left[ \frac{(H)(GL)}{2} - \frac{GL^2}{8 \tan B} \right] (\gamma) (EFW), \quad (5)$$

where  $B$  = abutment angle

and  $EFW$  = extraction front width.

The abutment angle value is dependent upon the caving conditions in the mined-out area. Three possible caving conditions have been found to occur. If good caving has developed in the gob areas and few stumps have been left, then the abutment angle is assumed to be the same as that used for longwall mining, or  $21^\circ$ . At the other extreme, if few stumps have been left, but caving has not occurred in the gob, then  $B = 90^\circ$ . A third case arises when caving has not occurred and significant remnant pillars (fenders or stumps) have been left in the gob. In the later case, it is assumed that the remnant pillars have yielded and their strength is assumed to be 50% of that calculated from equation 2. Then  $B$  is adjusted so that the remnant pillars carry only the load they are capable of and the remainder is transferred.

In its current form, the program can analyze four loading configurations, as illustrated in figure 2. The simplest—loading condition 1—is development loading only. Loading condition 2 occurs where a panel is being fully retreated and no other mined-out areas are nearby. The total applied load is the sum of the development loads and the front abutment load. Loading condition 3 occurs where the AMZ is surrounded on two sides by mined-out areas and the pillars are subjected to development, side abutment, and front abutment loads. When the pillar line is surrounded by gob on three sides (sometimes referred to as bottlenecking), an additional side-abutment load results and loading condition 4 is produced.

Unfortunately, the irregular mining geometries that sometimes occur in practice can be difficult to categorize into one of these four loading conditions. Efforts are currently underway to expand the number of available loading configurations with numerical modeling.

## VERIFICATION OF ARMPS METHOD

Design criteria have been established for the ARMPS method through back analysis of 68 case histories of pillar design from 10 different States. The case histories were obtained from mine visits and from the literature. Case histories cover an extensive range of geographic locations, roof rock cavability characteristics, extraction methods, and loading conditions. In addition, overburden thicknesses ranged from 53 to 591 m (175 to 1,938 ft), coalbed heights ranged from 0.9 to 3.4 m (2.8 to 11 ft), and pillar width-to-height ratios varied from 1.0 to 11.1.

Each case history was categorized as being either successful or unsuccessful. Unsuccessful cases (table 1) were deemed as being such because one or more of the following unfavorable conditions occurred:

1. Squeezes.
2. Massive pillar failure and resultant airblast.

3. Severe sloughage.
4. Excessive heave.
5. Numerous roof falls.
6. Coal pillar bump.

Case history loading conditions were categorized as being successful abutment loading, unsuccessful abutment loading, and unsuccessful development loading. Figure 3 clearly suggests that many failures, but few successes, have resulted when designs with ARMPS SF's of less than 0.75 were employed. Between SF's of 0.75 and 1.50, there seems to be a "middle ground," where both successful and unsuccessful cases are found. Based on figure 3, failure is unlikely when an ARMPS SF of 1.5 is employed. Bieniawski also recommends an SF of 1.5 for short-term pillars subjected to development loads only (3).

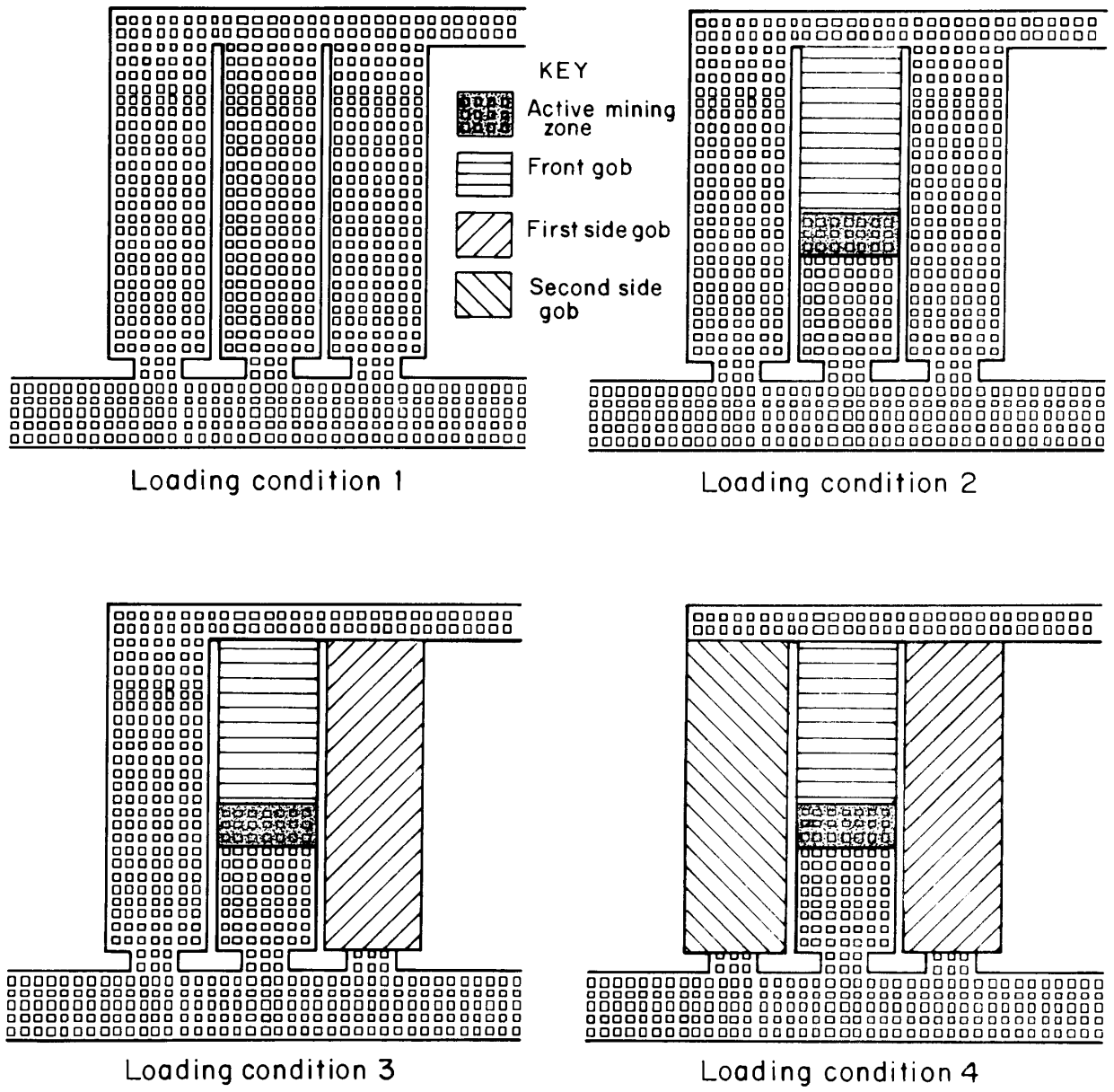


Figure 2.—Retreat mining loading configurations.

Table 1.—ARMPS values for unsuccessful pillar design case histories

Location	Coalbed	Source	Loading condition <sup>1</sup>	ARMPS stability factor	Comments
Alabama . . .	Blue Creek . . . . .	Mine visit . . . . .	2	1.27	Pillar squeeze caused panel to be abandoned.
	.. do. . . . .	.. do. . . . .	2	1.11	Squeeze conditions caused 20 pillars 21 by 21 m (70 by 70 ft) to be lost.
Colorado . . .	Cameo "B" . . . . .	Abel (7) . . . . .	1	0.57	Airblast generated by sudden collapse of 204 by 402 m (670 by 1,320 ft) of 3 by 24 m (10-by 80-ft) fenders.
Illinois . . . . .	Herrin No. 6 . . . . .	Chugh (6) . . . . .	3	.81	Roof falls, 56 cm (22 in) of floor heave, and severe sloughage.
Kentucky . . .	Coalburg . . . . .	Unrug (16) . . . . .	3	<sup>2</sup> .72	Inability to break roof caused excessive pillar spalling and heave.
	Harlan . . . . .	Mine visit . . . . .	1	.96	Coal pillar bump fatally injured roof bolter operator.
	.. do. . . . .	.. do. . . . .	1	1.06	Squeeze conditions caused 14 rows of pillars to be lost. Most of main entries were closed entirely.
	Hazard No. 4 . . . . .	.. do. . . . .	3	.43	Extensive pillar line heave, sloughage, and roof falls caused 9 rows of pillar to be lost.
	.. do. . . . .	.. do. . . . .	3	.46	Squeeze conditions caused 10 rows of pillar to be lost. Numerous roof falls and continuous miner was buried.
	Wallins . . . . .	.. do. . . . .	4	.39	Severe pillar line weighting. Scores of fenders were lost after pillar splits.
Ohio . . . . .	Pittsburgh . . . . .	Artler (2) . . . . .	2	<sup>3</sup> .45	Squeeze conditions caused numerous pillars to be lost.
Pennsylvania	.. do. . . . .	Mishra (10) . . . . .	2	.79	152 m (500 ft) of pillars were lost in 3 days. Large-scale squeeze 1,600 ft outby pillar line.
Tennessee ..	Beech Grove . . . . .	Mine visit . . . . .	1	1.34	Squeeze conditions essentially closed 671 m (2,200 ft) of main entries.
	.. do. . . . .	.. do. . . . .	3	.60	Section and barrier pillar abandoned because of squeeze conditions.
Utah . . . . .	Gilson . . . . .	.. do. . . . .	3	.44	Section abandoned because of violent coal pillar bump.
	.. do. . . . .	.. do. . . . .	2	.40	Excessive roof slaking and subsequent bump due to idle pillar line.
Virginia . . . . .	Pocahontas No. 3 ..	Campoli (4) . . . . .	1	.56	Numerous coal pillar bumps. 274- by 396-m (900- by 1,300-ft) area of pillars was abandoned because of squeeze.
West Virginia	Beckley . . . . .	Mine visit . . . . .	4	.84	Continuous miner was buried for 2 weeks. Crushed out cribs due to 0.9 to 1.2 m (3 to 4 ft) of heave.
	.. do. . . . .	.. do. . . . .	4	.61	Coal pillar bump during pillar split fractured roof bolter operator's leg.
	Coalburg . . . . .	.. do. . . . .	1	.49	Squeeze that occurred in partially pillared workings caused 2 rows of 12- by 15-m (40-by 50-ft) pillars with SF of 1.37 to be lost.
	.. do. . . . .	.. do. . . . .	1	.66	Airblast generated by approximately 100 fenders collapsing blew out 26 cinder-block stoppings and fan-house weak wall. 1 miner was injured.
	.. do. . . . .	.. do. . . . .	1	1.17	10 rows of 12- by 12-m (40- by 40-ft) pillars were lost because of squeeze conditions.
	.. do. . . . .	.. do. . . . .	3	1.31	Dangerous pillar sloughage caused scores of pillar to be lost. Barrier pillar was also lost.
	Dorothy . . . . .	.. do. . . . .	1	1.40	Airblast generated by massive pillar failure blew out 38 stoppings.
	Lewiston . . . . .	Tang (15) . . . . .	1	.63	Massive pillar failure, pillar squeeze, and severe spalling.
	.. do. . . . .	.. do. . . . .	1	1.20	Do.
	No. 2 Gas . . . . .	Mine visit . . . . .	4	.83	After losing several rows of pillars because of squeeze conditions, section was abandoned for fear of losing bleeders.

See footnotes at end of table.

Table 1.—ARMPS values for unsuccessful pillar design case histories—Continued

Location	Coalbed	Source	Loading condition <sup>1</sup>	ARMPS stability factor	Comments
West Virginia (cont.)	Pocahontas No. 4	Campoli (4)	3	0.32	Crushed pillars and floor heave.
	.. do.	Mine visit	1	1.03	Airblast generated by failure of 117 pillars.
	Sewell	Peng (13)	3	1.45	Section abandoned because of concern that floor heave [0.6 to 0.8 m (2 to 2.5 ft)] might prevent equipment retrieval.
	Stockton	Mine visit	1	.74	Airblast generated by 140 fenders collapsing blew out 32 stoppings and fan-house weak wall.
	.. do.	.. do.	1	.72	Airblast generated by 90 fenders collapsing blew out 40 stoppings.
	.. do.	.. do.	1	1.29	Airblast generated by 72 fenders [6 by 12 m (20 by 40 ft)] and 50 pillars [9 by 9 m (30 by 30 ft)] blew out 70 stoppings.
.. do.	.. do.	2	1.17	Squeeze conditions caused 22 pillars [12 by 14 m (40 by 45 ft)] to be lost.	
NI	Lower Kittanning	Tang (14)	1	( <sup>4</sup> )	A massive failure of pillars occurred when pillars to left of chain pillar "A" were split. Severe entry roof falls occurred.
NI	Taggart	.. do.	1	1.14	Massive pillar failure 15 crosscuts outby pillar line.

Do. Same as above.

NI Not indicated.

<sup>1</sup>Loading condition 1 = development loading; 2 = development and front abutment loading; 3 = development, front abutment, and side abutment loading; 4 = development, front abutment, and loading from two side abutments.

<sup>2</sup>Abutment angle = 90°.

<sup>3</sup>Pillars measuring 4.6 by 12 m (15 by 40 ft) had an SF of 0.45.

<sup>4</sup>Pillars measuring 6 by 6 m (20 by 20 ft) had an SF of 1.32; pillars measuring 3.8 by 13.7 m (12.5 by 45 ft) had an SF of 1.08.

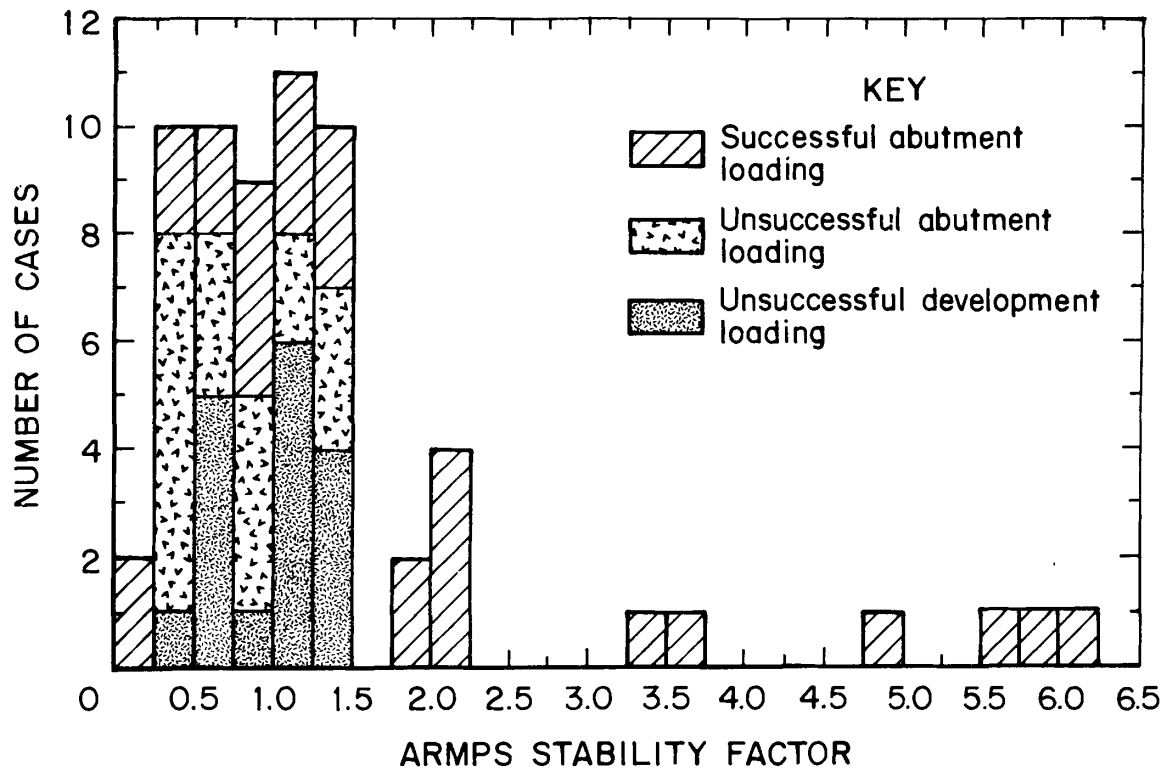


Figure 3.—ARMPS stability factors for case histories.

## ADDITIONAL FACTORS INFLUENCING PILLAR LINE STABILITY

Abutment loads are not the only factor that should be considered in pillar design for retreat mining. Pillar line conditions are also markedly affected by multiple-seam interactions, the rate of pillar line advancement, and roof rock cavability characteristics. In the case of multiple-seam interactions, the best case scenario is to begin with the uppermost seam and to extract it as cleanly as possible. Any barrier, production, or remnants of production pillars (miners refer to these as stumps or sprags) left in the upper seam gob can transfer loads to pillars in the lower seam. However, this is dependent on the thickness and the geology of the interburden and the depth of cover (5, 7). The load transfer is more intense if the pillars and/or stumps left in the upper seam gob are under-designed. In one mine visited in southern West Virginia that had extremely competent roof, the only unintentional fall that ever occurred on the pillar line or in the mine happened directly beneath a barrier pillar. In room-and-pillar retreat mining, the mains, barrier pillars, and panels that are to be retreated should be superimposed for optimum ground conditions.

In virtually every mine visited, operators indicated that the rate of pillar line advancement played a crucial role in overall pillar line conditions. When the pillar line moved slowly or remained idle over the weekend or during a miner's vacation, normally stable pillars began to take weight, as evidenced by sloughage, heave, and even squeeze conditions. Mine operators also remarked that timely pillar line advancement was even more critical when the coalbed thickened because high ribs taking weight caused large rib rolls, which are dangerous to the mine operator and helper.

The caving characteristics of the roof also affect pillar line stability. The Pittsburgh Seam has gained the reputation of having very weak roof where the Pittsburgh Sandstone Member is absent. During pillar retreat, the roof usually breaks directly in by the breaker posts, providing excellent pillar line conditions.

The other extreme roof condition, fairly common in portions of southern West Virginia and areas of eastern Kentucky, occurs where massive sandstones or siltstones [12 m (40 ft) and thicker] are directly above the coalbed. Such roof conditions have been associated with sudden, widespread pillar collapses that, in turn, can cause damaging airblasts (fig. 4). Evidence indicates that massive and competent roof rock units are able to bridge relatively wide spans, particularly when they are aided by the support provided by the regularly spaced remnants of production pillars. When the extraction area is still small, the remnant pillars are not subjected to the full overburden

load because of the stiffness of the roof. A pressure arch is created, with most of the weight being carried by barriers surrounding the extracted area. Eventually, the bridging capability of the main roof can be exceeded, either by overextending the extraction area or by the weakening of the roof and/or remnant pillars over time. Once the pressure arch breaks down, the structural characteristics of the system are such that sudden, massive pillar failures can occur (17). For example, at one of the mines visited during this study, production pillars measuring 12 by 12 m (40 by 40 ft) were split down the middle, leaving 3- by 12-m (10- by 40-ft) fenders in the gob. Shortly after one panel was completed, an area measuring 152 by 152 m (500 by 500 ft) and containing approximately 100 fenders collapsed suddenly. The resulting airblast damaged the fan-house weak wall and 26 stoppings, and closed the mine for days. Fortunately, because of the location of the blast, only one miner was injured.

Underground observations and analysis suggest that two alternative strategies may be successful in preventing airblasts under competent roof conditions. One approach is to limit the partial pillaring conducted in a panel with the intention of designing for long-term stability. This can be accomplished either by increasing the size of the remnant pillars or by periodically leaving rows of unsplit pillars as barriers between smaller areas of split pillars. The latter was successfully employed in a southern West Virginia mine that experienced two moderate-to-severe blasts. The second strategy is to go to full pillar extraction. By removing the support provided by the fenders, the bridging capacity of the roof should be substantially reduced. If the roof does not break during full pillar extraction, caving can be induced through explosives (16).

In another mine visited, pillar splitting was responsible for three significant airblasts. Wanting to arrest the situation, the "Virginia three-cut method" was employed (fig. 5). The sequence in which the lifts are extracted are numbered as shown in figure 5. In the collapsed areas where 12 × 12 m (40 × 40 ft) pillars were split, the extraction percentage was 78% as opposed to 74% using the 3 cut method. However, the 3 cut method leaves non-uniformly spaced stumps that have an irregular geometry in the gob. According to the mine operator, these stumps routinely yielded and crushed out. Since the 3 cut method has been used in this mine, no airblasts have been recorded.

Finally, it appears that massive pillar collapses may be more likely where the floor and roof are strong. Where the floor is weak, the pillars should be more prone to punch, resulting in a pillar line squeeze.

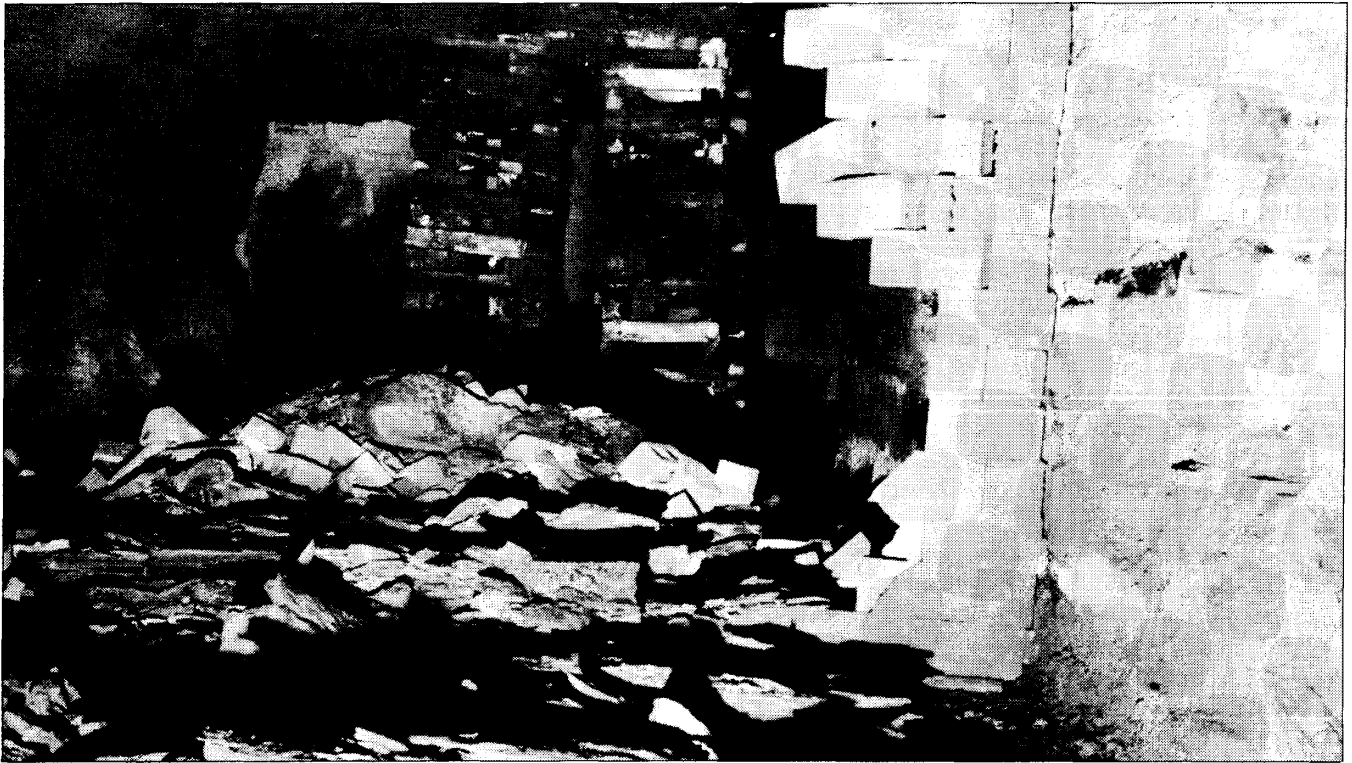


Figure 4.—Concrete stopping damaged by airblast.

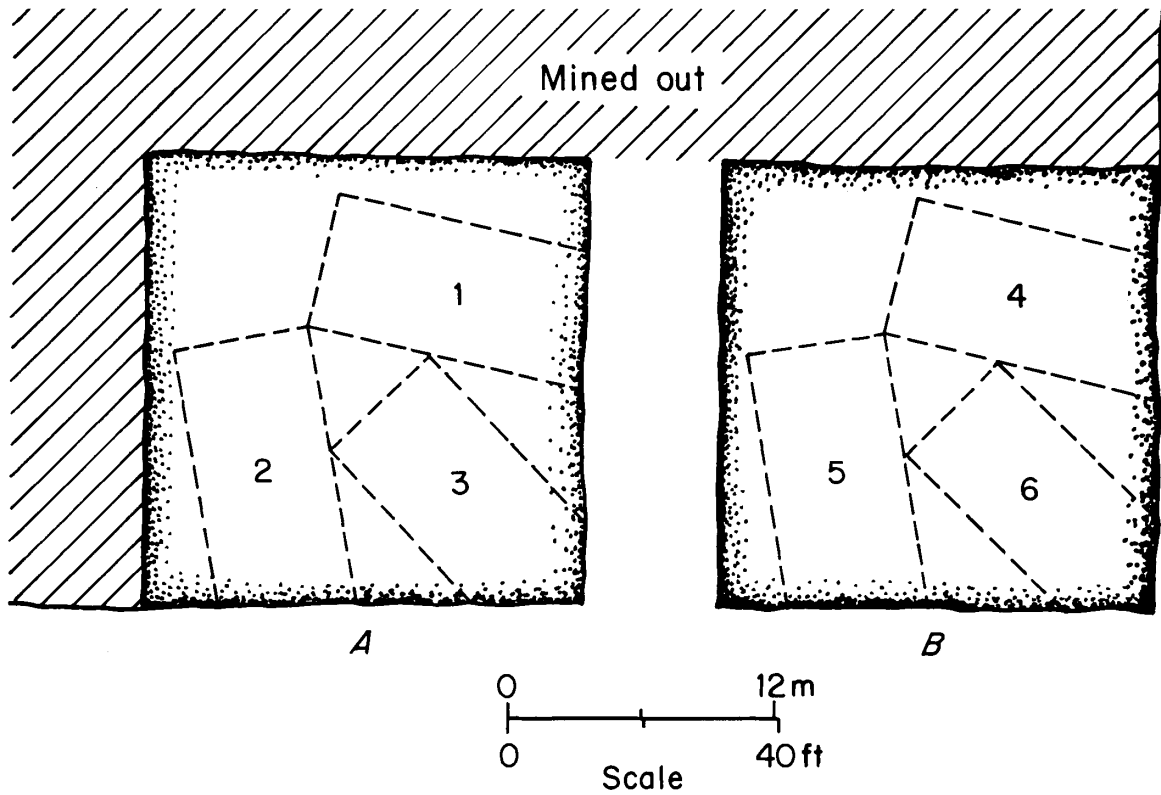


Figure 5.—Virginia three-cut pillar extraction method. A, First pillar mined; B, second pillar mined. (Numbers indicate sequence in which lifts are extracted.)

## CONCLUSIONS

Information gathered during this investigation lends credence to the following conclusions:

1. Properly sized production pillars that are designed considering the front and/or side abutment pressures generated by gob creation can result in better miner safety and more efficient recovery of reserves.
2. Case histories analyzed using the ARMPS method examined an extensive range of geographic locations, depths of cover, width-to-height ratios, roof rock cavability characteristics, floor conditions, and extraction methods that are representative of the population as a whole. It appears that production pillars with an ARMPS SF of 1.50 or greater have a high probability of being extracted without a problem.
3. Multiple-seam interactions can have detrimental effects on pillar line stability. The effect is dependent

upon the sequence in which the seams are mined, the thickness and geology of the interburden, overburden, and the presence of production pillars or stumps left in the gob.

4. Normally stable pillar line conditions often deteriorate if the pillar line moves slowly or remains idle for an extended amount of time. This deterioration can manifest itself in the form of excessive sloughage, heave, and squeezes.

5. Airblasts or squeezes have occurred in mines that have competent and massive roof rock units that will not cave. If partial pillaring is to be conducted under competent roof that will not cave, the long-term stability of the gobbed-out area should be considered. This can be accomplished either by increasing the size of the production pillar remnants or by leaving rows of unsplit pillars as barriers between smaller areas of split pillars.

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Proceedings: Bureau of Mines Technology Transfer Seminar

Compiled by Robert H. Peters



United States Department of the Interior  
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**Special Publication 18-94**

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**Compiled by Robert H. Peters**

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