

CMRR Aids in Longwall Gate Entries Design

A database analysis may help longwall designers

By Christopher Mark, Frank Chase and Greg Molinda

Successful longwall mining requires a stable tailgate entry. Gate entry performance is influenced by a number of geotechnical and design factors including: pillar size and pillar loading; roof quality; floor quality; entry width; and primary and secondary support. This article describes a comprehensive, practical design methodology, based on statistical analysis of a nationwide database of longwall ground control experience.

Fifteen years ago, no reliable design guidelines for either gate entries or chain pillars existed. Tailgate failures occurred frequently. Regulations introduced by the Mine Safety and Health Administration in 1988 required that roof control plans address the issue of maintaining safe travel-ways on the tailgate side.

Responding to the need for better conditions, ground control researchers focused initially on the design of longwall chain pillars. Many mines had found by trial-and-error that tailgate conditions could improve significantly when pillar sizes were increased.

While pillar design formulations proposed during the 1980s built upon this correlation, it also was evident that pillar design is not the only element affecting tailgate stability. Indeed, experience and common sense strongly suggested that roof quality and entry support play a significant role.

Geotechnical surveys were conducted at 44 U.S. longwall mines, where

underground observations of site geology, entry conditions and support design were recorded. The observations were combined with discussions with mine personnel to identify 69 longwall gate entry designs as satisfactory, unsatisfactory or borderline. Only conventional longwall designs, where the pillars are expected to carry full abutment loads, were included.

The case histories were characterized using five descriptive parameters. Pillar design was described by the Analysis of Longwall Pillar Stability Factor (ALPS-SF). A new contribution to the database was the Coal Mine Roof Rating (CMRR) system, a rock mass classification that quantifies the structural competence of bolted mine roof. Other quantitative measures were developed for primary and secondary support and entry width.

An analysis indicated that in 84% of the cases, tailgate performance could be correctly predicted using just ALPS-SF and CMRR. Most of the misclassified cases fell within a narrow borderline region. The analysis also confirmed that primary support and gate entry width are essential in successful gate entry design, but the importance of the floor and secondary support could not be determined.

Building the database

Data for the study were collected during a series of mine visits conducted between October 1988 and June 1992. The mines were selected to represent a geographic and geologic cross-section of U.S. longwalls.

Standardized data sheets were used to record rock mass properties observed in underground exposures—usually roof falls and/or overcasts.

The discussions with mine personnel focused on past experience with gate entry ground control. Panels in which conditions had been satisfactory were identified, as were locations where conditions were unsatisfactory. Where conditions were considered unsatisfactory, the steps taken by man-

agement to prevent reoccurrence were documented.

Each case history was defined by approximately 50 individual data fields, which were, in turn, used to define seven summary variables. The first is design performance, which is the outcome or dependent variable in the analysis. The other six are explanatory or dependent variables.

Design performance—The case histories each were classified either as satisfactory (30), unsatisfactory (32), or borderline (7). (See Fig. 1) Unsatisfactory conditions almost always included roof deterioration and falls, although excessive floor heave and pillar sloughage were cited as well. To be classified as unsatisfactory, a case had to meet one of four criteria:

- management changed the pillar design or the supports in response to poor tailgate conditions (25);
- the panel was abandoned due to poor conditions (2);
- unacceptable conditions developed in the areas of deepest cover (2); or
- several falls above the bolt anchorage horizon occurred in the tailgate, resulting in tailgate blockages and significant longwall delays (3).

Satisfactory cases, in contrast, were those in which:

- the design was used for at least three successive panels;
- tailgate blockages were very rare or nonexistent; and
- good conditions, with minimal delays attributable to ground control, were reported.

In some instances, a single satisfactory case represented as many as 50 extracted panels. Where the depth of cover varied, the deepest cover was used for the satisfactory case.

Borderline cases were defined as those in which conditions were less than satisfactory, but which did not meet any of the four criteria for unsatisfactory designs.

Pillar design—Pillar design was characterized using the ALPS-SF—the load-bearing capacity of a pillar sys-

Author information

Christopher Mark, Frank Chase and Greg Molinda specialize in ground control with the U.S. Bureau of Mines, Pittsburgh Research Center located in Pittsburgh, Pa.

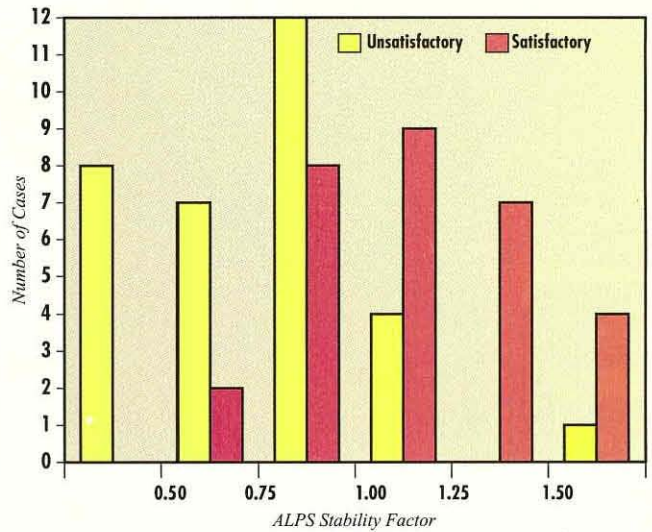
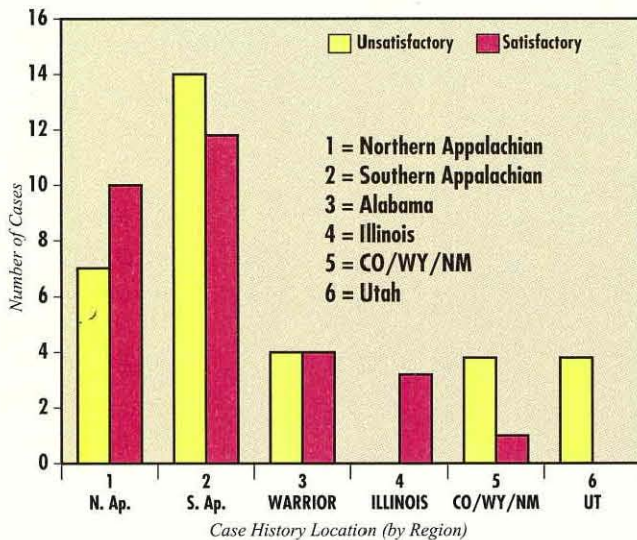


Fig. 1—Regional distribution of the satisfactory and unsatisfactory cases.

Fig. 2—Distribution of ALPS-SF results within the database.

tem divided by the load applied to pillars at the tailgate corner.

The estimated load-bearing capacity is determined by the width-to-height ratios and the total load-bearing area of the pillars. The estimated load is determined by the depth of cover, the panel width and the extraction ratio within the gate entry system (See Fig. 2). Because previous studies had indicated that failures were very rare when the ALPS-SF exceeded 1.3, no cases were included where the ALPS-SF exceeded 2.0.

Roof quality—One of the keys to the success of this research was the CMRR which weighs the importance of geotechnical factors that determine roof competence, and combines these values into a single rating on a scale from 0 to 100.

The rating system focuses on the discontinuities that determine the structural competence of a coal mine's roof sequence. It allows a meaningful comparison of structural competence, even where lithologies are quite different. The bolted interval is treated as a single structure, while considering the contributions of the different rock layers present.

The field data necessary for calculation of the CMRR typically are obtained from underground exposures of the roof strata in roof falls or overcasts. The following features of the roof rock are observed:

- Shear strength of discontinuities (roughness and cohesion);
- intensity of discontinuities (spacing and persistence);
- strength and moisture sensitivity of the rock;

- presence of a strong bed within the bolted interval;
- number of beds within the bolted interval;
- the quality of the rock overlying the bolted interval; and
- the quantity of water inflow.

The CMRR of the roofs observed at the longwalls varied from 30 to 85. Within this range, three broad classes of roof emerged as follows:

Weak Roof (CMRR < 45)—Roof typically consisting entirely of low-strength (less 8,000 psi), closely bedded, jointed, and/or slickensided rocks, (usually shales and coals).

Moderate Roof (45 < CMRR < 65)—Bolted interval usually contains at least one competent unit, typically siltstone or strong shale, that is at least 2-ft thick and contains few bedding planes or other discontinuities.

Strong Roof (65 < CMRR)—Bolted interval typically contains at least one very competent, massive bed, at least 3-ft thick that exceeds 8,000 psi in strength, a sandstone or limestone.

A geographic distribution of the CMRR shows that mines in northern Appalachia were characterized primarily by weak roof. Mines in Illinois and Alabama mainly had moderate roof, and in Utah the roof was usually in the strong category. In the other two regions—the southern Appalachians and in Wyoming, Colorado and New Mexico—the roofs were distributed among all three classes.

Entry Width—(See Fig. 3).

Primary support—Data collected underground included the type of bolt, bolt length and diameter, bolting pattern, plate type and dimensions, and

additional support (mats, headers, mesh, etc.). The Primary Support Rating (PSUP) used in the analysis was developed as a rough measure of roof bolt density:

$$PSUP = (Lb \times Nb \times Db) / (Sb \times We)$$

Lb = Length of the bolt (ft)
 Nb = Number of bolts per row
 Db = Diameter of the bolts (inches)
 Sb = Spacing between rows
 We = Entry width (ft).

Secondary support—By far, the most common type of secondary support used in the tailgates was wood cribbing. Concrete fibercrete cribs were used in just one case, and in three cases no secondary supports were installed. The secondary support rating (SSUP) is a rough measure of the volume of wood installed per unit length of the tailgate:

$$SSUP = (Nc \times Lc \times Wc) / Wc$$

Nc = Number of rows of cribs installed
 Lc = Length of the crib blocks (ft)
 Wc = Width of the crib block (as installed, ft)
 Sc = Center-to-center, cribs in each row (ft).

Characterizing the floor presented special difficulties. While attempts were made to collect data on the lithology and structure of the mine floors, good underground exposures often were unavailable. The floor has received relatively little research attention, so not all of the important information may have been collected. In the end, it was not possible to construct a meaningful floor rating system from the data available, and the floor could not be included in the analyses.

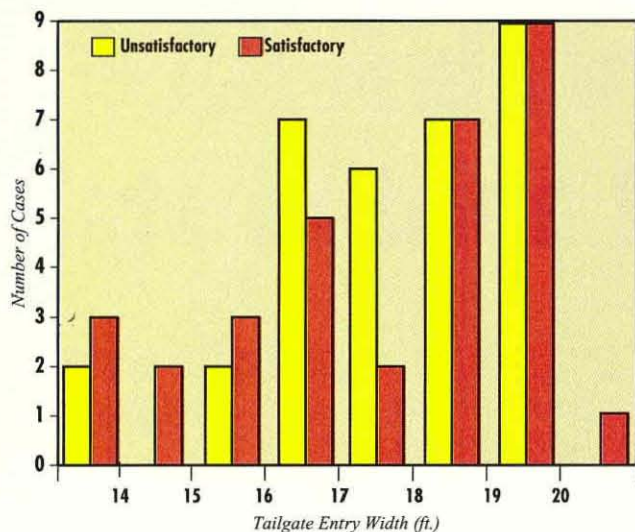


Fig. 3—The range of entry widths within the database.

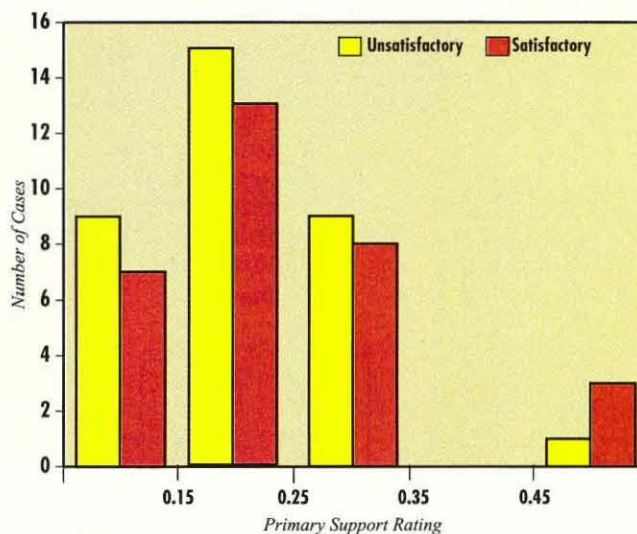


Fig. 4—Primary support rating and its distribution within the database.

Statistical analysis

The statistical technique of discriminant analysis was employed to interpret the data. Discriminant analysis is a regression method which classifies observations into populations. The discriminant equation relating ALPS-SF to CMRR was found to be:

$$ALPS-SF = 1.67 - 0.014 (CMRR).$$

The model equation successfully identified all but 10 cases, for an overall success rate of 84%. The misclassifications were evenly split between satisfactory and unsatisfactory designs.

While this equation could be used directly in design, a more conservative equation that reduced the misclassification rate for unsatisfactory designs might be more appropriate:

$$ALPS-SF = 1.76 - 0.014 (CMRR).$$

The most significant, and initially surprising, result was that including additional variables in the model did not improve the predictive capacity. The explanation is that primary support and entry width are correlated with the CMRR and the ALPS-SF at a statistically significant level. Of the 15 mines with weak roof, all but one employed entries no more than 18-ft wide. Conversely, of 21 mines with CMRR greater than 50, 20 used entry widths that were 18 ft or wider. It seems that mine operators have "naturally" adapted to weaker roof by using narrow entries.

None of the predictive models included supplemental support. The reason is that the unsatisfactory case

histories in the database tended to use more supplemental support than did the satisfactory cases. The positive correlation between unsatisfactory conditions and heavy supplemental support arises because the installation of more cribbing is often the only available means of trying to save a troubled tailgate.

In other words, the level of SSUP was often a consequence, not a cause, of the outcome. As a result, when SSUP was forced into a predictive model, the implication was that tailgate conditions would improve as tailgate support was decreased. Such a conclusion is incorrect. The data does suggest, however, that installing more supplemental support is not usually a satisfactory substitute for an adequate pillar design.

The gate entry design methodology that resulted from the study should be a valuable aid to longwall mine planners. It is the first design methodology to focus on the tailgate entry itself, rather than on the chain pillars. More importantly, it is based on the scientific interpretation of the ground control experience obtained at more than half of all U.S. longwall operations. The method thus makes the wealth of U.S. longwall experience available in a practical form.

Gate entry design methodology

For practical design, the most significant conclusions from the study are:

- the three elements determining performance are pillar size, entry width and primary support, and
- gate entry design must be based on roof quality.

The first step is to evaluate roof conditions. If underground exposures are available, the CMRR may be determined directly. In most instances, it is probably sufficient to place the mine roof into one of the three categories described earlier—strong roof (CMRR > 65), moderate roof (45 < CMRR < 65) or weak roof (CMRR < 45).

The next step is to use ALPS-SF to determine the pillar size. With the CMRR, the proper ALPS-SF can be obtained using the design equation given above. For weak roof, an ALPS-SF of 1.3 seems appropriate, while in strong roof an ALPS-SF of 0.7 should perform adequately. Pillar widths are then selected so that the design achieves the proper ALPS-SF.

Single copies of the ALPS computer program may be obtained by sending one double-sided, double-density diskette to: Christopher Mark, U.S. Bureau of Mines, Pittsburgh Research Center, Cochran Mill Rd., P.O. Box 18070, Pittsburgh, PA 15236-0070

Finally, the entry width and the primary support may be estimated from what has been successful in the past. In weak roof, it appears that the entry width should be less than 18 ft. Longer bolts, typically at least 6 ft, also seem appropriate in weak roof to achieve a Primary Support Rating of 0.25. In strong roof, entries of 20 ft and a Primary Support Rating of 0.15 appear to be adequate.

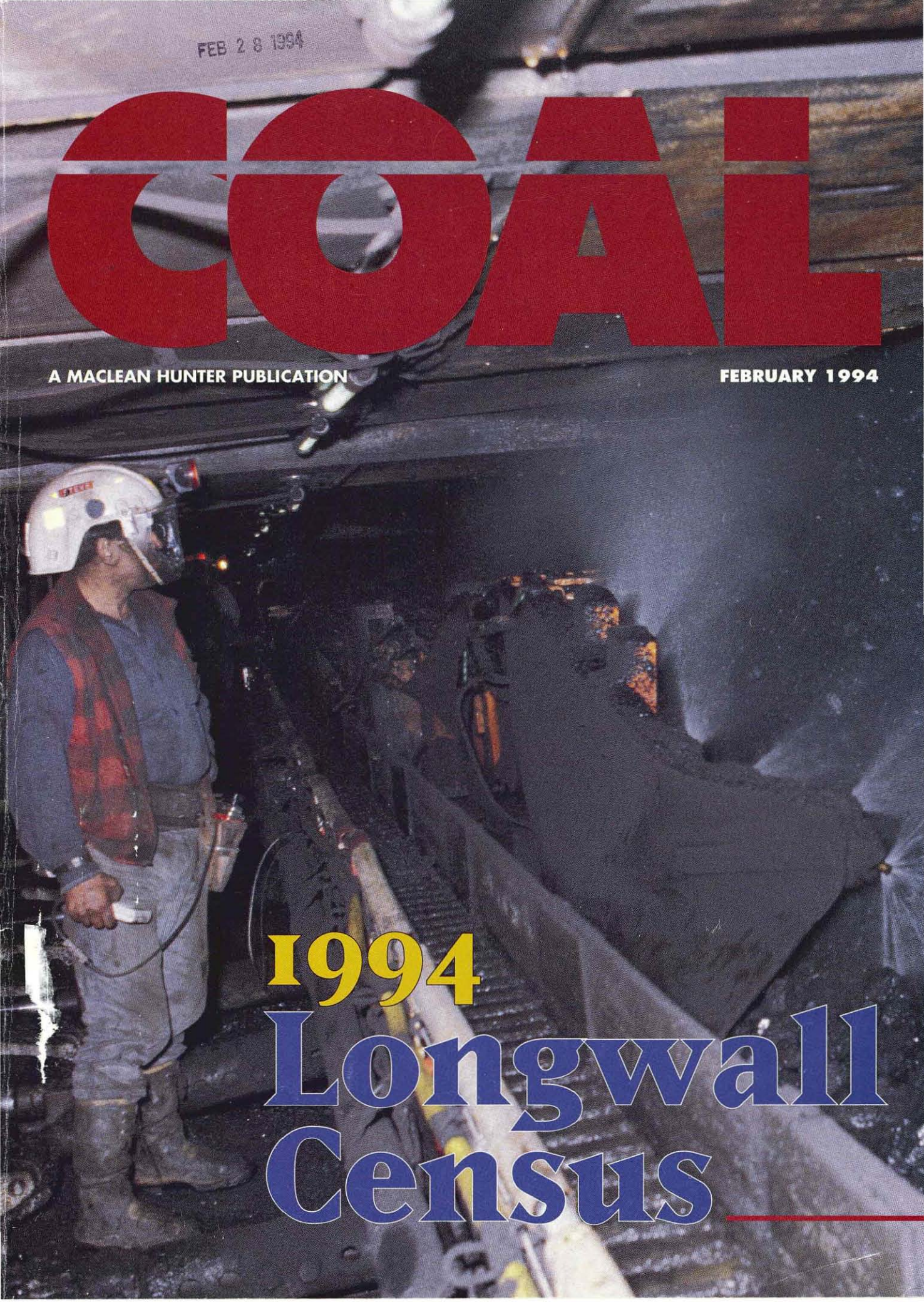
While the study was not successful in defining the necessary secondary support, the indications are that if the other criteria are met, no more than a moderate level of cribbing should be necessary. ■

FEB 28 1994

COAL

A MACLEAN HUNTER PUBLICATION

FEBRUARY 1994



1994
Longwall
Census

Features

1994 Longwall Census26
 Following the same trend over the last few years, the U.S. longwall population decreased, but many are bigger and better

The 1992 Longwall Productivity Survey36
 Longwall productivity and panel size continue to increase

CMRR Aids in Longwall Gate Entry Design40
 A database analysis may help longwall designers

Innovative Conveyor Systems Haul More Coal44
 Booster drives could be the answer for the demands of increased panel length

With this issue of *COAL*, all subscribers receive a copy of *The World Class Performers Showcase*.

Coal in the News

Washington's coal focus to be on rules, not laws10

UMWA could see drop in jobs following strike11

S&P study forecasts drop in western coal demand12

Cyprus Amax agrees to contract with UMWA13

Arco leases Jumbo Mountain federal coal tract in Colorado14

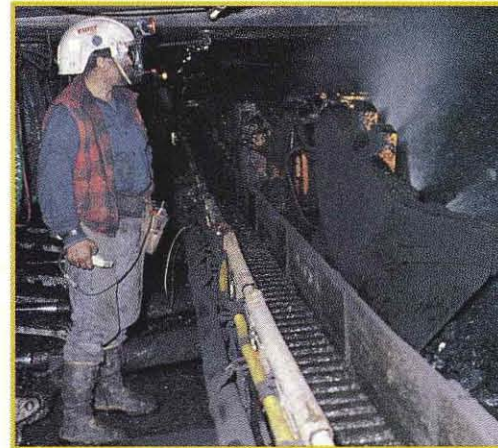
Kentucky workers' comp reform may see action16

Judge rules against Illinois coal protection law17

MSHA assesses stiff penalties for dust fraud20

Company Index

Amax Coal	8, 57	Decker Coal Co.	16	Old Ben Coal Co.	11
Arch Mineral Corp.	11, 57	Eastern Associated Coal	11	Paraki Enterprises Inc.	20
Arch of West Virginia	57	Eastern Coal Co.	20	Pauline Mining Inc.	20
Arco Coal Co.	14, 17	Fording Coal Ltd.	57	Peabody Development Corp.	11
Black Bear Coal Corp.	20	Highlander Coal Corp.	20	Peabody Holding Co.	11
Blankenship & Rife Inc.	20	Hustler Coal Co.	20	Peter Creek Coal Co.	20
Brent Coal Corp.	20	JAL Mining Inc.	11	Pittsburg & Midway Coal	7, 13
British Coal	22	JCB Mining Inc.	11	Rackwood	22
C&S Coal Co.	20	Keystone Coal Mining Corp.	7	Ringold Mining Co. Inc.	11
Carter Mining Co.	8	KYN Coal Co.	20	Southmountain Coal Co.	8
Catenary Coal Co.	11	Marrowbone Development	11	Sphinx Service Corp.	11
Cedar Coal Co.	20	MEPCO Inc.	11	Thunder Basin Coal Co.	8
Consolidation Coal Co.	11	Mibrag	22	Westside River Terminal Inc.	11
Cyprus Amax Coal	57	Mon River Mining Corp.	11	Zeigler Coal Holding Co.	11, 57
Cyprus Amax Minerals	13, 57	Northwestern Resources	18		



The Cumberland mine, in Greene County, Pa., produces about 4 million tons of coal annually. The mine, formerly owned by U.S. Steel Mining Co., was purchased last summer by Cyprus Coal Co., a unit of Cyprus Minerals. This issue of *COAL* focuses on longwall use in the United States, including a new census and productivity survey. (Photo courtesy Bob Lynn, Cyprus Amax Minerals Co., Denver, Colo.)

Departments

Advertising Index48

Blasting Concepts24

Classified Advertising62

Coal in the News10

Coal Worldwide22

Developments to Watch53

Events12

Mining Mart60

New Literature58

New Products59

News Briefs7

Newsmakers57

Operating Ideas56

Reader Service Card49

NEXT MONTH

- New technology survey
- Special report: wheeled haulage
- Equipment guide: continuous haulage