DEVELOPMENTS IN COAL PILLAR DESIGN AT SMOKY RIVER COAL LTD., ALBERTA, CANADA

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ABSTRACT

Smoky River Coal Ltd. mines low-volatile metallurgical coal by surface and underground methods in the foothills of the Rocky Mountains of Alberta, Canada. Current underground operations are confined to the 5B-4 Mine. Development of 5B-4 began in January 1998; production from depillaring sections commenced in July 1998.

This paper describes the history of underground mining on the Smoky River property in terms of extraction methods and pillar design. The development of the present pillar design guidelines is discussed in this context. Recent work to prepare a number of case histories for back-analysis using the Analysis of Retreat Mining Pillar Stability (ARMPS) method is described, along with the modifications developed for calculating the ARMPS stability factor for retreat extraction of thick seams. The design criteria are described, as well as the geotechnical program implemented in order to verify its applicability.

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INTRODUCTION

The Smoky River Coalfield is located in west-central Alberta, Canada, within the inner foothills of the Rocky Mountains. The mine is approximately 20 km north of Grande Cache and 360 km west of Edmonton (figure 1). Most of the property is contained in a block approximately 29 km long by 19 km wide. The coal leases cover about 30,000 ha. The general mine layout is shown in figure 2. Underground mining is currently located in the 5 Mine area.

The coal seams and surrounding strata are within the Gates Formation (of the Lower Cretaceous Luscar Group) and outcrop near the mine. The Gates Formation is divided into three members: Torrens, Grande Cache, and Mountain Park (figure 3). The Torrens is a distinct marine sandstone and siltstone sequence about 30 m thick. It is overlain by the Grande Cache Member, which consists of approximately 158 m of nonmarine siltstones, sandstones, mudstones, and all of the significant coal seams in the area. The Grande Cache Member is overlain by the Mountain Park Member, which consists of 155 to 192 m of nonmarine sandstones, mudstones, siltstones, and minor coal seams.

The predominant structure of the coalfield strikes northwest to southeast and comprises thrust sheets containing folded layers of competent sandstone and siltstone units, incompetent mudstone, and coal. Dips vary considerably, from horizontal to overturned. Underground mining by room-and-pillar methods is restricted to areas where the strata dip less than 16°, which is the practical limit of continuous miner and shuttle car operation. The orientation of the underground mine workings in figure 2 gives a clear indication of the structural environment; the workings are either faulted or steeply folded off on the northeast and southwest limits of mining.

The significant coal seams present are numbered from the lower (older) to the upper (younger) and comprise the 4, 8, 10, and 11 Seams. 4 Seam has been mined extensively (figure 2) using conventional room-and-pillar mining techniques. 8 and 11 Seams are not considered economical to mine because of thickness and low quality. Mining in 10 Seam has been attempted, including two longwall panels above 9G-4 Mine; however, a weak immediate roof comprising two 0.6-m coal seams in the first 2 m of strata has always presented stability problems.

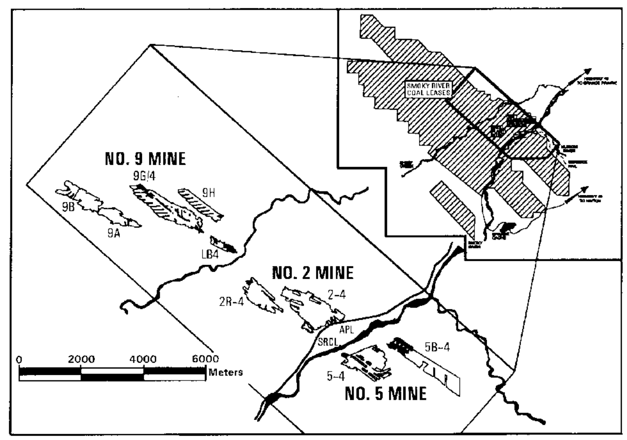

Figure 2.—Site layout.

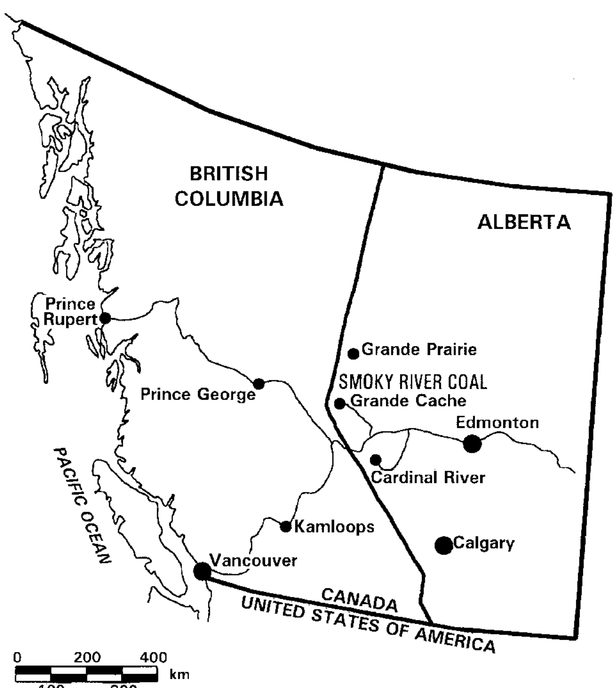

Figure 1.—Location of Smoky River Coal Ltd.

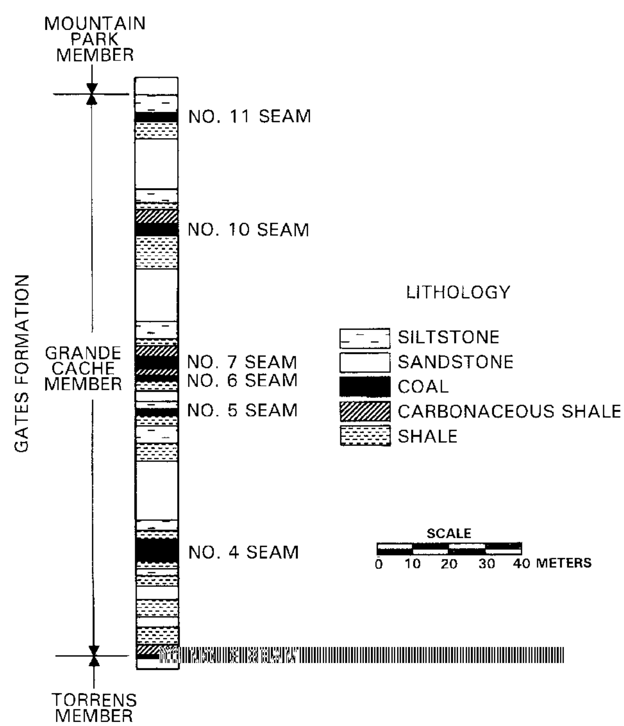

Figure 3.—Generalized stratigraphic column, Smoky River Coalfield.

HISTORICAL MINING METHODS AND PILLAR DESIGN

Underground mining at Smoky River Coal Ltd. (SRCL) commenced in 1969 in 5-4 and 2-4 Mines. The initial intent was to develop for longwall extraction; however, two early attempts at longwall mining failed and retreat room-and-pillar extraction became standard.

The original mining method was to develop three 6-m-wide entries on 30-m centers from the portal to the limit of mining, generally along strike, with crosscuts at 30-m centers. Parallel sets of entries were driven separated by 50-m barrier pillars (figure 4). On reaching the limit of mining, the road and barrier pillars were split along strike to form blocks approximately 12 m wide and mined using an open-ended "Christmas tree" method, taking 6-m passes each side with a conventional continuous miner. This method, described in more detail by Wright [1973], worked well in 2-4 Mine, but was unsuccessful in 5-4 Mine due to the weaker roof and pervasive thrust faulting in and above the coal seam.

In the early 1970s, a major geotechnical investigation program was launched to assist mine staff in planning pillar dimensions and support. Extensive load and deformation monitoring was conducted [Bielenstein et al. 1977]; concurrent testing by air injection investigated the development of yield and elastic zones within coal pillars [Barron et al. 1982].

In the early 1980s, the many disadvantages of the three-entry system were overcome by adopting a five-entry system (figure 4*B*) with short-life panels [Robson 1984]. Panels comprising five parallel entries were developed off of main development sections. This mining method depended for its success on the stability of pillars separating the panels and pillars that protected the main entries from the depillared areas. In fact, five types of pillars were recognized:

- Barrier pillars between mining panels;
- Entry pillars protecting the main entries;
- Panel pillars formed during the development of mining panels;
- Split pillars formed by splitting panel pillars prior to depillaring; and
- Remnant pillars, the diminishing remnants of split pillars formed during depillaring operations.

Tolerable probabilities of failure were estimated for each pillar type, and an empirical design criterion was developed that took into account this probability of failure [Barron et al. 1982]. Favorable trials of the five- entry system in A Mine (figure 2) resulted in its adoption in 9H and 9G Mines. Further refinement of pillar design methods, relying heavily on practical experience and a comprehensive review of pillar design methods from around the world, resulted in a design nomogram [Kulach 1989]. The method was based on the tributary area method of load calculation (considered to represent the best and safest estimate of the loads developed on pillars) and Bieniawski's [1983] method of determining pillar strength.

Mining continued in the late 1980s and 1990s in 9H and 9G Mines using this method of pillar design. The small resource block exploited by the LB-4 Mine necessitated a change in method, with entries developed to the farthest extent and retreated back, but all three mines were successful from a pillar stability standpoint.

In 1997, plans were developed to exploit a previously untouched parcel of coal to the north of the old 5-4 Mine. The shape of the resource block, 370 m wide by 2,500 m long, bounded by steeply dipping thrusted zones to the northeast and southwest, largely dictated the mining layout, which is shown in figure 5.

During the planning stages of the mine, it was soon realized that conditions would be very different from the more recent underground operations, which were carried out at shallow to moderate depths under a competent sandstone roof. The proposed 5B-4 Mine would operate at depths of up to 550 m and beneath a roof affected by pervasive thrust faulting. Both pillar design and roof support requirements necessitated reevaluation for the operation to be successful.

Although the SRCL pillar design criterion had been used successfully in a number of mines, it had some obvious disadvantages with respect to its application in 5B-4 Mine:

- The nomogram is restricted to 12-m-wide by 3.6-m-high pillars and 6-m-wide roadways.
- The method is based on a strength calculation for square pillars and severely underestimates the strength of rectangular pillars.
- The design criterion is based on U.S. methods that have undergone substantial modification in the past 10 years.

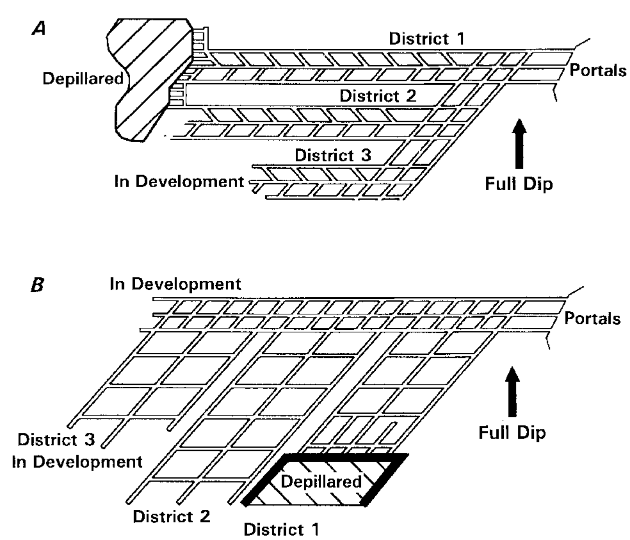

Figure 4.—Development of mining methods. *A*, three-entry system, long-life panels; *B*, five-entry system, short-life panels.

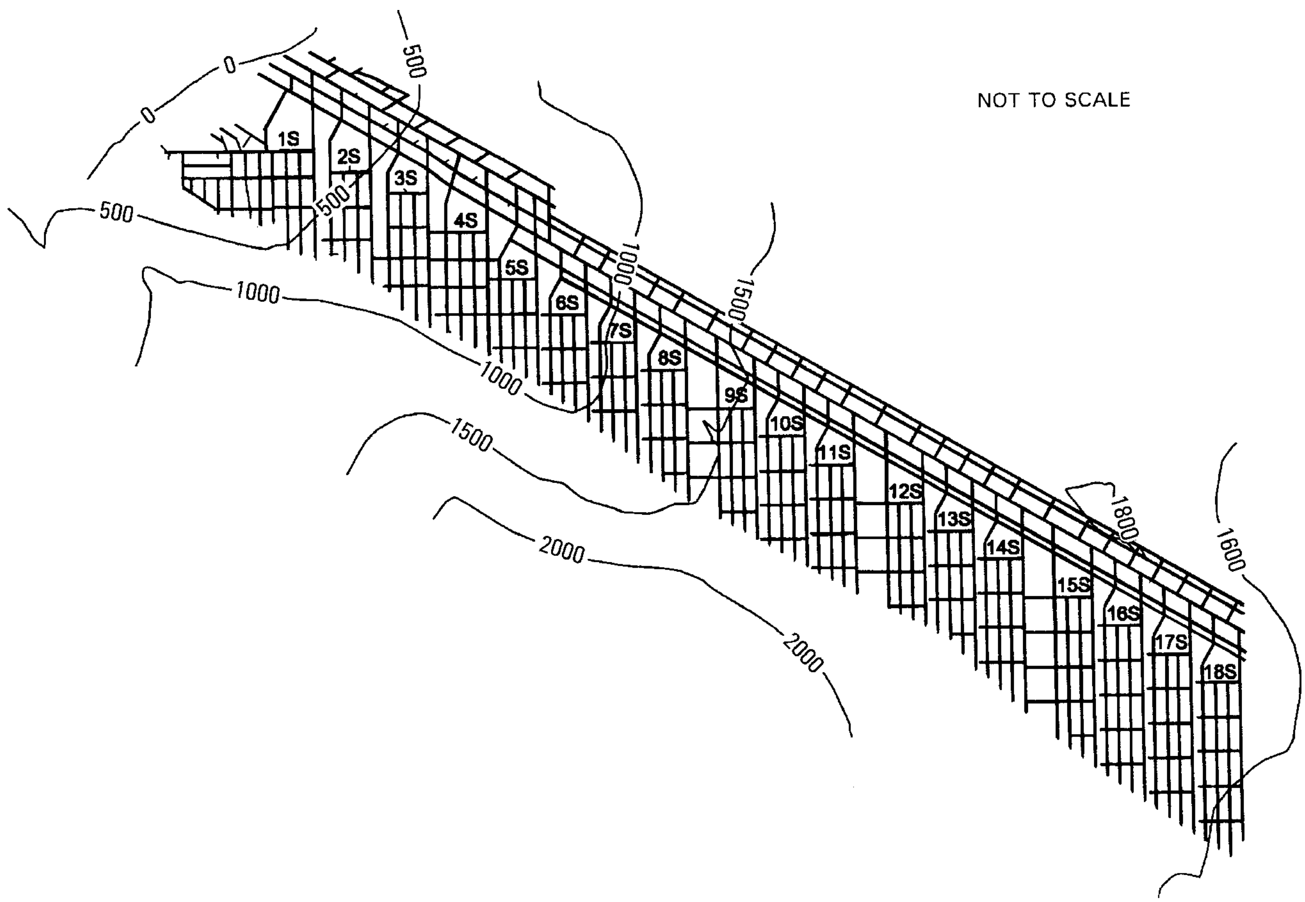

Figure 5.—Layout of 5B-4 Mine. ***(Elevation in feet.)***

Mining plans for 5B-4 included rectangular pillars ranging from 15 m to 36 m wide and 3.6 m high, standing between 4.9-m-wide roadways, which lay outside the empirical basis of the design nomogram. Although a nomogram for 5B-4 parameters could have been developed, the availability of more recently developed design methods that specifically address the strength of rectangular pillars warranted consideration of a change in design approach.

ANALYSIS OF RETREAT MINING PILLAR STABILITY (ARMPS)

The most recent development in pillar design in the United States is the Analysis of Retreat Mining Pillar Stability (ARMPS). ARMPS was developed by the former U.S. Bureau of Mines [Mark and Chase 1997] based on extensive case history data. ARMPS is available as a Windows 95™ software package and has the following advantages over previous methods used by SRCL:

- The increased load-bearing capacity of rectangular pillars over that of square pillars of the same width is taken into consideration.
- The load-bearing capacity of diamond- or parallelogram-shaped pillars is taken into consideration.
- ARMPS allows for an analysis of the stability of pillars in the active mining zone (AMZ) during development, during retreat, and with gobs on one or both sides.
- The effect of depth on abutment loading, based on angles of caving, is considered.
- The effect of slabbing the interpanel pillar on pillars in the AMZ is considered.

ARMPS is a very flexible method of analysis. The software allows the user to input all of the major parameters relating to layout, mining, and pillar dimensions and location of any worked-out, caved areas. It also allows analysis of changes in pillar stability as a result of mining progress, from development to the extraction of coal pillars alongside a gob or between two gobs. Mark and Chase [1997] present a full description of the methods used to calculate pillar loading and pillar strength in the ARMPS program. The principal output of the program is the stability factor (SF), which is the product of the estimated load-bearing capacity of pillars in the AMZ divided by the estimated load on those pillars.

The concept of the AMZ follows from a hypothesis by Mark and Chase [1997] that pillars close to the retreat extraction line behave together as a system, i.e., if an individual pillar is overloaded, load is transferred to adjacent pillars. If these are of adequate size, the system remains stable, otherwise the pillars fail in turn, resulting in a domino-type transfer of load and pillar failure.

The size of the AMZ is a function of depth, H, based on measurements of abutment zone widths conducted by Mark [1990], which showed that 90% of abutment loads fall within a distance $2.8\sqrt{H}$ from the gob edge.

U.S. case history data indicate that where the ARMPS SF is <0.75, nearly all of the designs were unsatisfactory; where the SF is >1.5, nearly all of the designs were satisfactory. For the deeper case histories, there was some evidence that stability factors can be lower and still ensure overall pillar stability. In addition, case histories with less competent roof rock were more stable than those with stronger roof strata, as this promoted pillar squeeze or burst activity.

Despite its utility and comprehensive analytical method, ARMPS has several drawbacks when applied to SRCL conditions:

- Case histories were confined to U.S. mines. As with any empirically based design method, this presents problems in application outside the case history environment.
- The case history database extends only to depths of about 1,100 ft, and only a few case histories were obtained at this depth of cover.
- None of the case histories matched the seam thicknesses mined at SRCL (up to 6 m).

After discussions with the developers of ARMPS [Mark 1998], it was decided that in order to confirm the applicability of ARMPS to SRCL operations, a series of calibration analyses based on depillaring operations in the coalfield was required.

BACK-ANALYSIS OF CASE HISTORIES

Mine plans from 9G, 9H, and LB-4 Mines (figure 2) were reviewed, and relevant mining data were extracted to develop a series of case histories. Each case history was then analyzed using the ARMPS method, and safety factors were recorded and compared to the existing U.S. case history database.

In order to consider the extraction of thick seams as practiced at SRCL, the calculation of the SF was modified. ARMPS allows input of a single working thickness; in most SRCL depillaring operations, however, there are two mining heights. During development, the mining height is 3.7 m; during depillaring, the mining height is 6.1 m. This variation in mining height has a marked effect on pillar stability through the height/width ratio of the pillars. Rationally, load shed to the AMZ from the 6.1-m-high pillars in the mined-out area is more effectively controlled by the pillars of 3.7-m height in the AMZ.

In order to take into account this variation in mining height, ARMPS stability factors and details of pillar loading were calculated for extraction heights of both 3.7 m and 6.1 m. The SRCL stability factor was derived as follows:

(a) The pillar load transferred to pillars in the AMZ for a mining height of 6.1 m was determined using ARMPS.

(b) The load-bearing capacity of pillars in the AMZ for a mining height of 3.7 m was determined using ARMPS.

A stability factor was calculated as: (b) divided by (a).

Table 1 presents details of the mining parameters for each of the case histories considered, as well as the stability factors obtained. Figure 6 compares the SRCL stability factors with those obtained from the published U.S. database [Mark and Chase 1997] and indicates that SRCL stability factors representing satisfactory conditions range from 0.47 to 1.74, with the majority (66%) in the range of 0.5 to 1.0.

Local mining conditions provided some assurance that the low SF values were valid. Firstly, the lowest values occurred at the greatest depth; it has been recognized that acceptable stability factors appear to be lower at depth, perhaps due to the influence of horizontal stresses in reducing the pillar loading. Secondly, the SRCL case histories are characterized by a strong, competent roof; under such conditions in the United States, acceptable pillar stability was obtained at lower values of the calculated SF.

Table 1.—Summary of SRCL case histories analyzed using the ARMPS method

Mine	District	Depth, ft	ARMPS SF (6.1 m)	Load shed to AMZ, tons	ARMPS SF (3.7 m)	Capacity of AMZ, tons	SRCL SF	Load condition
LB-4	Mine	580	1.35	5.83E+6	1.99	1.16E+7	1.56	2
9H-4	SW2	390	1.23	1.18E+6	1.80	2.05E+6	1.74	3
9H-4	SW3	485	1.35	1.69E+6	0.92	1.63E+6	0.96	3
9H-4	SW4	575	0.73	2.44E+6	1.12	2.49E+6	1.02	3
9H-4	SW5	660	0.56	3.43E+6	0.89	2.69E+6	0.78	3
9H-4	SW6	715	0.49	4.05E+6	0.77	2.77E+6	0.68	3
9H-4	SW7	755	0.61	4.71E+6	1.04	4.14E+6	0.87	3
9H-4	SW8	832	0.50	6.11E+6	0.79	4.35E+6	0.71	3
9H-4	SW9	932	0.35	4.60E+6	0.53	2.30E+6	0.50	3
9G-4	SW2	560	0.85	2.05E+6	1.27	2.46E+6	1.20	3
9G-4	SW3	650	0.58	3.26E+6	0.94	2.65E+6	0.81	3
9G-4	SW4	730	0.49	4.10E+6	0.80	2.83E+6	0.69	3
9G-4	SW5	745	0.51	3.98E+6	0.85	2.83E+6	0.71	3
9G-4	SW6	780	0.51	4.01E+6	0.88	2.90E+6	0.72	3
9G-4	SW7	840	0.41	5.21E+6	0.69	2.97E+6	0.57	3
9G-4	SW8	885	0.37	5.84E+6	0.62	3.05E+6	0.52	3
9G-4	SW9	920	0.34	6.56E+6	0.51	3.11E+6	0.47	3
9G-4	SW10	915	0.34	6.49E+6	0.53	3.10E+6	0.47	3

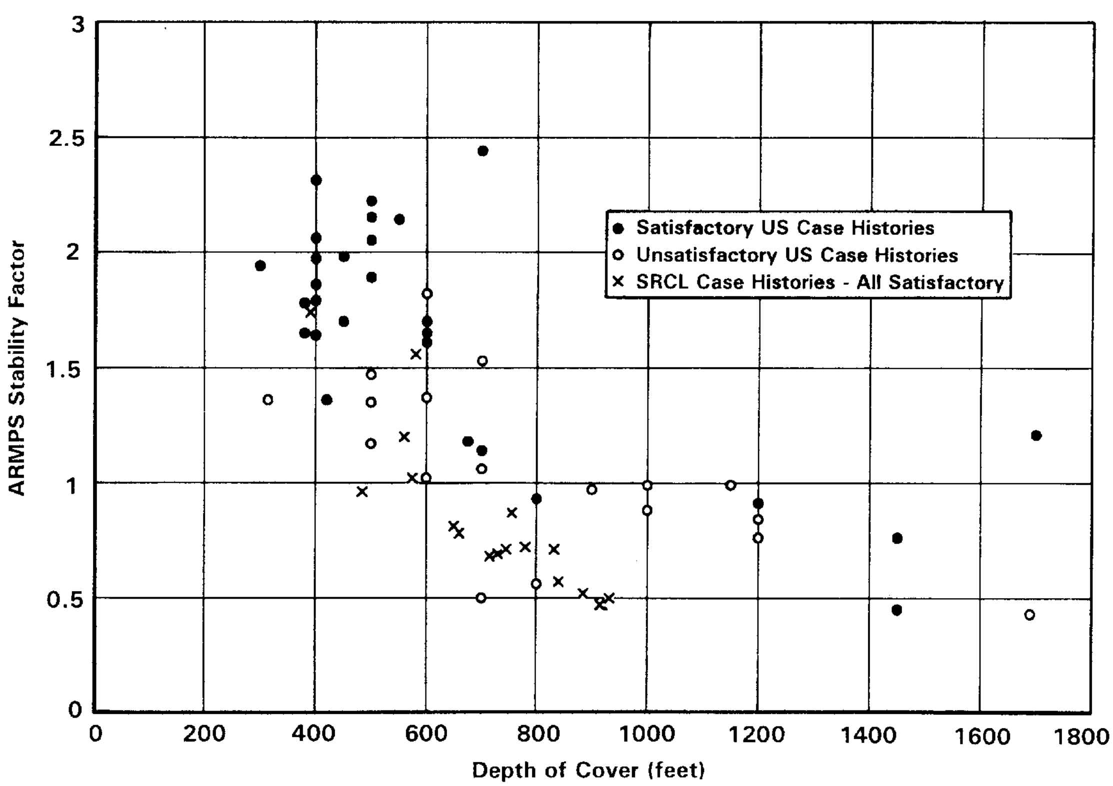

Figure 6.—Comparison of U.S. and SRCL stability factors.

DEVELOPMENT OF A DESIGN CRITERION

After considering the results of the case history analysis, it was decided to use the ARMPS method to assist in pillar design at 5B-4 Mine. Appropriate engineering practice in such cases is to design to the minimum SF that resulted in stable conditions. Evidence suggests that a pillar design resulting in an ARMPS SF of $0.5 would be stable in Smoky River Coalfield conditions. A more conservative SF of 0.7 was established.

A further limitation was imposed after an analysis of the pillar stresses on the gob corner pillar. This pillar, located adjacent to both the active retreat section gob and the barrier pillar between the active panel and the old gob, is subjected to the highest stresses and is therefore more prone to failure. The primary concern in this case is the threat of coal bumps or pillar burst, resulting in the transference of loads to adjacent pillars in the AMZ and possibly massive failure.

ARMPS analyses of SRCL case histories revealed that the maximum stress experienced on any gob corner pillar was about 41 MPa. At this stress level, the pillar proved to be stable.

A third criterion was adopted based on the size of pillars analyzed from the case histories. The minimum pillar size analyzed was 12 m wide between 6-m roadways. Maintaining this extraction ratio for the 4.9-m-wide roadways employed at 5B-4 Mine precluded the use of ARMPS for pillars <9.7 m wide.

Based on the ARMPS output from the case history data compiled from previous pillar retreat mining in the Smoky River Coalfield, the following design criterion for pillars is suggested:

- The ARMPS SF should be maintained above 0.7.
- The maximum stress on the corner pillar should not exceed 41 MPa (6,000 psi).
- Pillar widths must not be <9.7 m.

It was realized that the ARMPS-derived design criterion was also limited in application, specifically to the depths encountered in the case history analysis. With depths of cover projected to exceed those of the case histories by 50%, there was an element of uncertainty with respect to the applicability of the design criterion. This is currently being addressed by a geotechnical program that includes pillar stress monitoring, numerical modeling, and continuing assessment of the design criterion.

Vibrating wire stress cells, electronic convergence meters, and an I. S. Campbell data logger have already been deployed at three monitoring sites to collect data on the effects of mining on pillar stability. Two of the sites monitored stress changes while the site was being "mined by" during the development phase. It is hoped that these two sites will provide valuable information on the strength of the coal pillars monitored.

Results are still being evaluated; however, indications are that the design criterion is applicable. Further sites will be established as mining progresses, and the results will be incorporated into the design criterion.

SUMMARY

Development of pillar design methods at SRCL's underground operation has proceeded with developments in the mining method. The extension of mine workings to previously unencountered depths at the new 5B-4 Mine has resulted in a requirement to develop pillar design methods to match the new mining environment.

Pillar designs are currently being based on the results of a back-analysis of case histories using the recently developed ARMPS method. As with any empirical method of design, prudent engineering practice dictates the collection and analysis of pillar behavior information for design verification. Monitoring results already obtained are being analyzed to improve the design criteria. Future sites will collect data from greater depth and adjacent to more extensive workings.

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