DEVELOPMENTS IN COAL PILLAR DESIGN AT SMOKY RIVER COAL LIMITED, ALBERTA, CANADA

by

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ABSTRACT

Smoky River Coal Limited (SRCL) mines low volatile metallurgical coal by surface and underground methods in the foothills of the Rocky Mountains of Alberta. Current underground operations are confined to the 5B-4 Mine. Development of 5B-4 began in January of 1998, and production from de-pillaring sections commenced in July of the same year.

This paper briefly 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 ARMPS method is described, along with the modifications developed for calculating the ARMPS stability factor for retreat extraction of thick seams. The design criteria developed is described, as well as brief details of the geotechnical program implemented in order to verify its applicability.

INTRODUCTION

The Smoky River Coal Field is located in west central Alberta, within the inner foothills of the Canadian Rocky Mountains. The mine is approximately 20 km north of the town of Grande Cache and 360 km west of the provincial capital, Edmonton (Figure 1).

The majority of the property is contained in a block approximately 29 km long by 19 km wide. The coal leases cover some 30,000 hectares. 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 occur within the Gates Formation (of the Lower Cretaceous Luscar Group) and outcrop near the mine. The Gates Formation is subdivided into three members: the Torrens, the 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 non-marine siltstones, sandstones, mudstones and all of the significant coal seams in the area. The Grande Cache Member is overlain by the Mountain Park Member, consisting of 155 to 192 m of non-marine sandstones, mudstones, siltstones and minor coal seams.

The predominant structure of the coal field strikes north-west to south-east, comprising 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 strata dip at less than 16º, 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 north-east and south-west limits of mining.

The significant coal seams present are numbered from the lower (older) to the upper (younger), and comprise 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 economic because of thickness and low quality. Mining in 10 Seam has been attempted, including two longwall panels above 9G-4 Mine, but a weak immediate roof comprising two 0.6 m coal seams in the first 2 meters of strata has always presented stability problems.

HISTORICAL MINING METHODS AND PILLAR DESIGN

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

The original mining method was to develop three six metre wide entries on 30 m centres from the portal to the limit of mining, generally along strike, with cross cuts at 30 m centres. 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 because of the weaker roof and pervasive thrust faulting in and above the coal seam.

In the early 70’s 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), while concurrent testing by air injection investigated the development of yield and elastic zones within coal pillars (Barron, et al, 1982).

In the early 1980’s the many disadvantages of the three entry system were overcome by adopting a five entry system (Figure 4) 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 protecting the main entries from the depillared areas.

In fact, five types of pillar were recognised;

- 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 which took into account this probability of failure (Barron, et al, 1982). Favourable trials of the five entry system in 9A 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 80's and 90's 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 furthest 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 2500 m long, bounded by steeply dipping thrusted zones to the north-east and south-west, largely dictated the mining layout, which is shown in Figure 5.

During the planning stages of the mine it was soon realised 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 re-evaluation for the operation to be successful.

Although the SRCL pillar design criterion had been successfully used in a number of mines it did have 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 criteria is based on US methods that have undergone substantial modification in the past ten years.

Mining plans for 5B-4 included rectangular pillars ranging from 15 m to 36 m in width and 3.6 m in height, 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 which specifically address the strength of rectangular pillars warranted consideration of a change in design approach.

ARMPS

The most recent development out of the United States is ARMPS (**A**nalysis of **R**etreat **M**ining **P**illar **S**tability), developed by the US Bureau of Mines (Mark, et al., 1995) based on extensive case history data. ARMPS is freely available as a Windows95™ software package, and has the following advantages over previous methods used by SRCL;

- the increased load bearing capacity of rectangular pillars over square pillars of the same width is taken into consideration
- the load bearing capacity of diamond shaped or parallelogram shaped pillars is taken into consideration
- the method allows for an analysis of the stability of pillars in the Active Mining Zone (AMZ) during development, 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 inter-panel 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 the analysis of the changes in pillar stability as a result of mining progress, from development through to the extraction of coal pillars alongside a gob, or between two gobs. Mark, et al, (1995) presented a full description of the methods used to calculate pillar loading and pillar strength in the ARMPS program. The principle output of the program is the Stability Factor (SF), which is the product of the estimated load bearing capacity of pillars in the active mining zone divided by the estimated load on those pillars.

The concept of the active mining zone follows from a hypothesis by the authors that pillars close to the retreat extraction line behave together as a system, i.e. that 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-like transfer of load and pillar failure.

The size of the active mining zone 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 $5\sqrt{H}$ from the gob edge.

US case history data indicates that where the SF is less than 0.75, nearly all the designs were unsatisfactory, and where the SF is greater than 1.5, nearly all the designs were satisfactory. It was found that 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 does have several drawbacks when applied to SRCL conditions;

- case histories were confined to US 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 1100 feet, 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 authors of ARMPS (Mark, 1998), it was decided that in order to confirm the applicability of ARMPS to the Smoky River Coal operations, a series of calibration analyses based on de-pillaring operations in the coal field was required.

BACK ANALYSIS OF CASE HISTORIES

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

In order to consider the extraction of thick seams as practised at SRCL, the calculation of the stability factor was modified. ARMPS allows input of a single working thickness, but in the case of most SRCL de-pillaring operations, there are two mining heights. During development, the mining height is 3.7 m (12 ft), but during de-pillaring, the mining height is 6.1 m (20 ft). 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 existing in the AMZ.

In order to take this variation in mining height into account, 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 in the following way;

(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 being the product of (b)/(a).

Table 1 gives details of the mining parameters for each of the case histories considered, as well as the stability factors obtained. Figure 6 compares the Smoky River Coal stability factors to those obtained from the published US data base (Mark, et al, 1995), and indicates that SRCL stability factors representing satisfactory conditions range from 0.47 to 1.74, with the majority (66%) being in the range 0.5 to 1.0.

Local mining conditions provided some assurance that the low stability factor values were valid. Firstly, the lowest values occurred at the greatest depth; it has been recognised 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 characterised by a strong, competent roof; under such conditions in the US acceptable pillar stability was obtained at lower values of the calculated stability factor.

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 the design of pillars at 5B-4 Mine. Appropriate engineering practice in such cases is to design to the minimum stability factor that resulted in stable conditions. Evidence suggests that a pillar design resulting in an ARMPS stability factor of 0.5 or above would be stable in Smoky River Coal Field conditions. A more conservative stability factor 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 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 analysed from the case histories. The minimum pillar size analysed was 12 m in width 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 any less than 9.7 m in width.

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

- The ARMPS Stability Factor should be maintained above 0.7.
- The maximum stress on the corner pillar should not exceed 41 MPa (6000 psi).
- Pillar widths must not be less than 9.7 m.

It was realised 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 which includes pillar stress monitoring, numerical modelling, 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, but indications are that the design criterion is applicable. Further sites will be established as mining progresses, and the results incorporated into the design criterion.

SUMMARY

Development of pillar design methods at SRCL's underground operation in the inner foothills of the Canadian Rockies has proceeded with developments in the mining method. The extension of mine workings to previously un-encountered depths at the new 5B-4 Mine has resulted in a requirement for the development of 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 behaviour information for design verification. Results from monitoring results already obtained are being analysed to improve the design criteria. Future sites will collect data from greater depth and adjacent to more extensive workings.

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Figure 1: Location of Smoky River Coal Limited

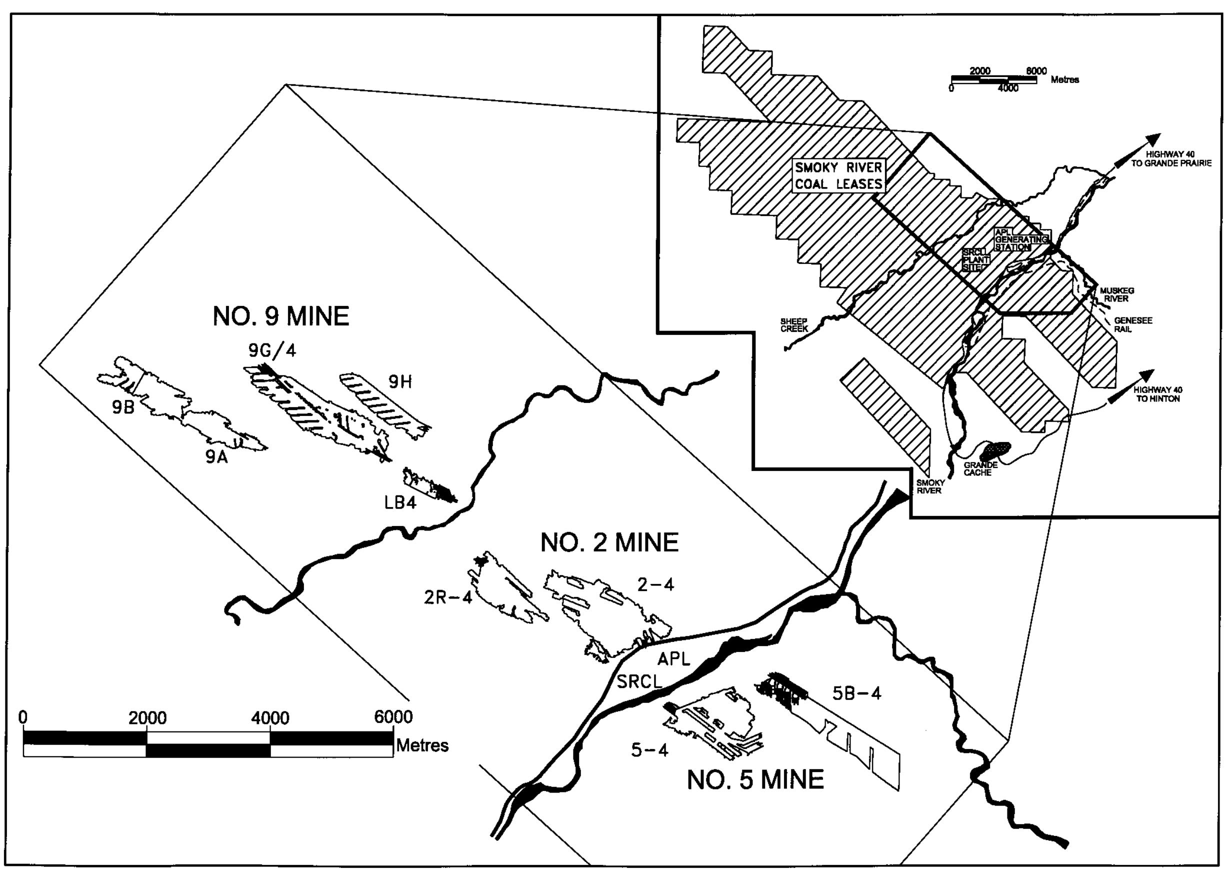

Figure 2: Site Layout

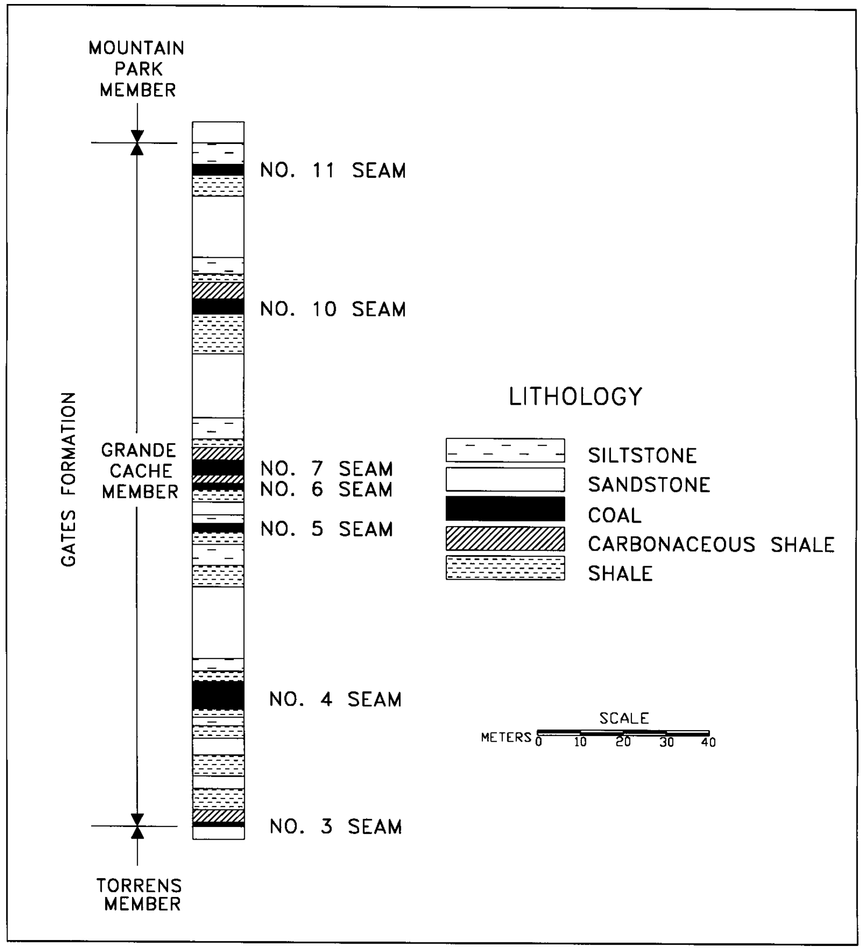

Figure 3: Generalised Straitigraphic Column, Smoky River Coalfield

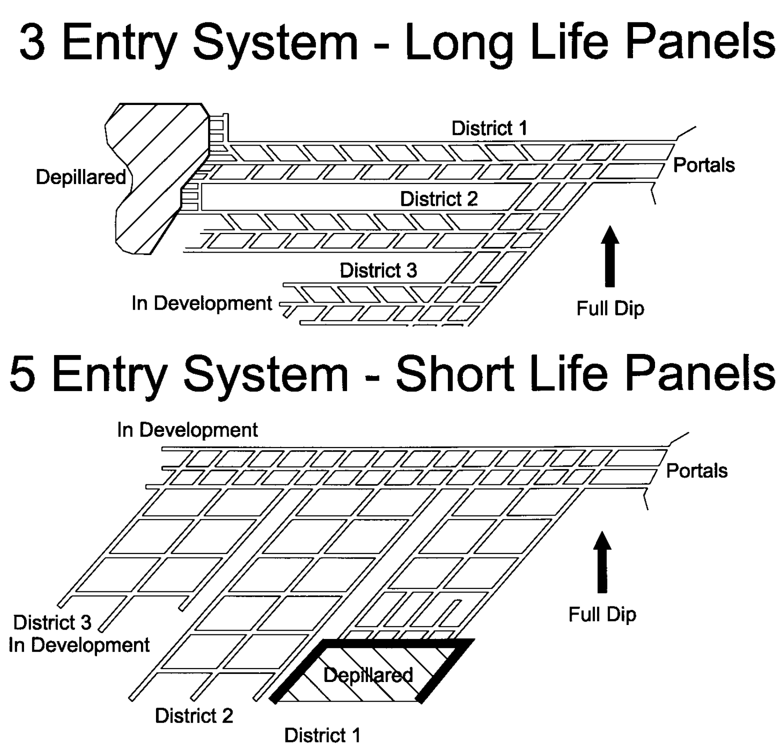

Figure 4: Development of Mining methods

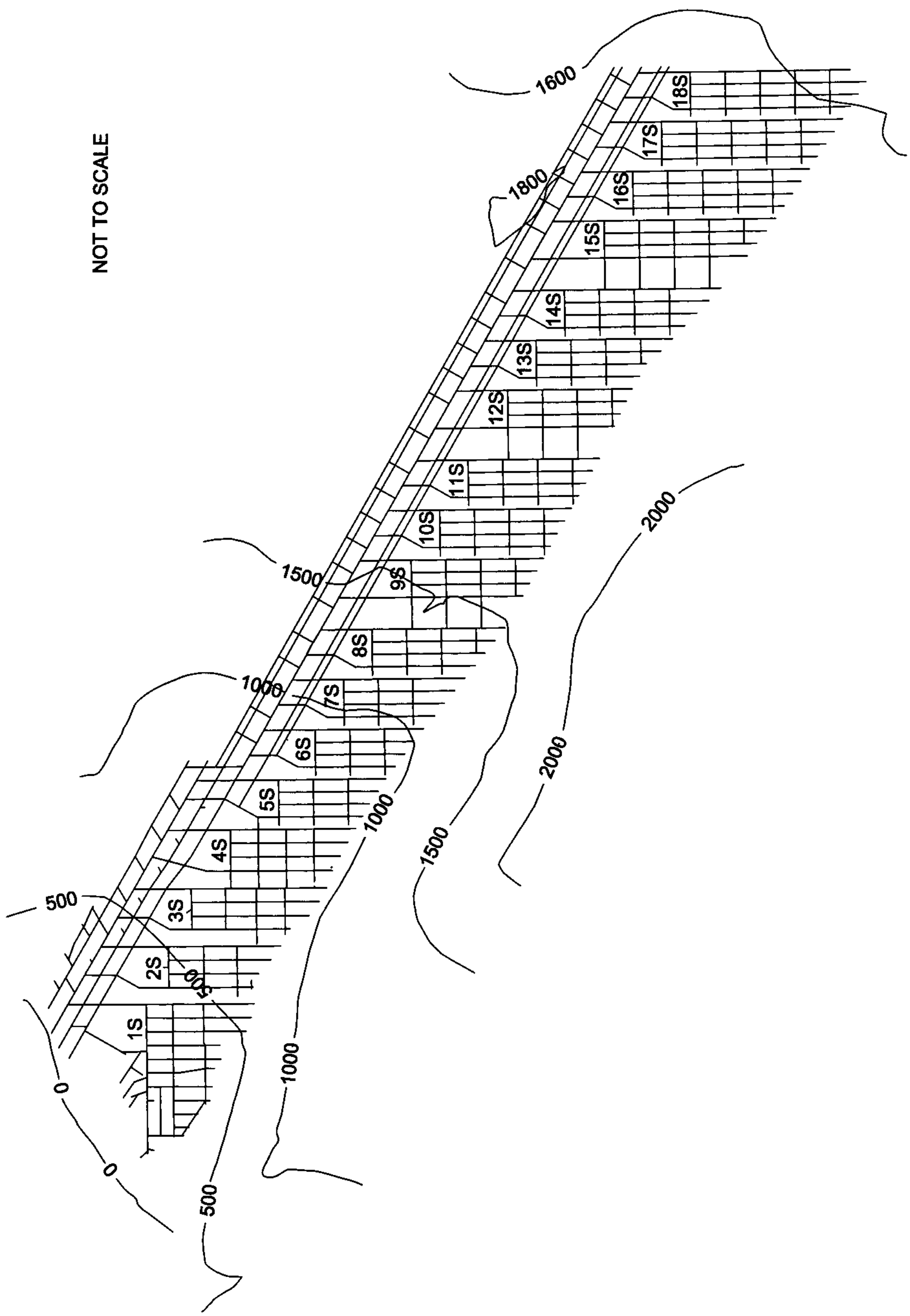

Figure 5: Layout of 5B-4 Mine
(overburden contours in feet)

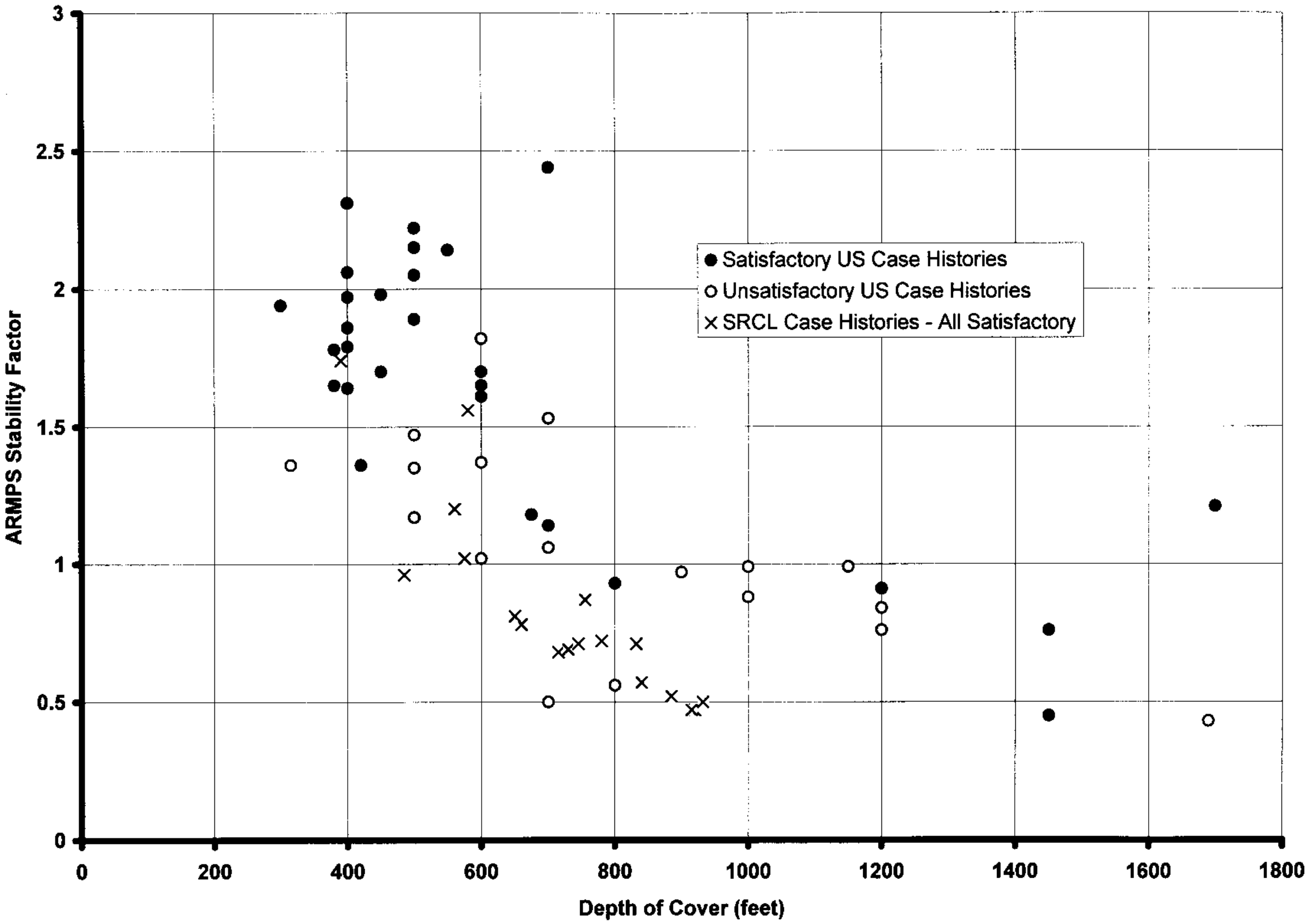

Figure 6: Comparison of US and SRCL Stability Factors

Mine	District	Depth (ft)	ARMPS SF, (20 ft)	Load shed to AMZ (tons)	ARMPS SF (12 ft)	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

Table 1: Summary of SRCL Case Histories Analyzed using the ARMPS Method