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USE OF CEMENTED ROCK FILL FOR ENHANCED PILLAR RECOVERY IN AREA 1 OF THE DOE RUN COMPANY

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ABSTRACT

Area 1 of Doe Run Company’s Buick North Mine was selected for placement of cemented rockfill (CRF) to “trap” or encapsulate select pillars. This method of “trapping” pillars takes advantage of the passive confinement effect of CRF to increase the post-peak load bearing ability of trapped pillars so that other ore bearing pillars can be extracted while still maintaining local and global mine stability. A total of 73 pillars in this area were extracted from October 1998 thru January 2002. Thirteen of 73 pillars were totally trapped by CRF (i.e., the pillars were totally encased in CRF). Eight of the thirteen pillars trapped with CRF were instrumented with extensometers to monitor deformations that occurred during the extraction process. Of the remaining pillars, 18 were not confined in CRF; and the remaining pillars were partially trapped to some degree (one or more free faces).

Data collected from the instruments showed that the rate at which pillars deformed (or converged) slowed and that most of the instrumented pillars were virtually unaffected until the late stages of pillar extraction. Two of the instrumented pillars showed considerable initial vertical strain at the onset of pillar extraction. The rate at which these pillars converged slowed as additionally pillars were extracted. This was attributed to the passive confinement effect of CRF in which this material compacts (the density increases) as the pillar dilates, becomes stiffer, and thus provides an increase in confining pressures or stress that acts to restrict pillar dilation.

This study has provided valuable insight into the behavior of trapped roof supporting pillars during the extraction process. Future research is being undertaken to clearly develop procedures to predict the behavior CRF trapped pillars during extraction of other economically valuable pillars.

INTRODUCTION

Underground mining operations that utilize room-and-pillar techniques as the primary method of ore extraction typically leave behind significant quantities of valuable ore material as natural ground support (i.e., pillars). In many cases these pillars can exceed 50% or more of the total ore reserves. These remnant pillars are a substantial economic asset if these materials can be mined efficiently and safely and would result in an increase in mine production life, an increase in jobs and cash flow that would stimulate the local and regional economies. As can be seen in Table 1, the amount of material left in place is quite significant.

Table 1. Ore extracted using the Room-and-Pillar Mining Method (Zipf, 2000)

Material	Extract. Ratio	Value Prod.
Lead	75%	$432 mil.
Zinc	75%	$491 mil.
Soda Ash	65%	$664 mil.

Several methods have been devised in an attempt to increase ore production from areas in which the primary ore removal method of room-and-pillar mining has been exhausted. One such method, employed in the mines of the Doe Run Company of southeast Missouri, utilizes a cement “stabilized” rockfill (CRF) that is placed around selected pillars in an attempt to improve the post peak stress-deformation behavior of the encapsulated (trapped) pillars (Roberts, D.P., et al. 1998, Yanske, T.R., et al., 1999). For this method to be viable, several criteria must be met:

- economic (i.e., the extracted materials must support the cost of placement of the material),
- no critical facilities or haul roads must be impacted,
- all primary extraction has been completed (i.e., only ore remaining in the area is contained in the pillars and no material will be *stranded* after pillar extraction),
- accurate pillar tonnages and grades are known,
- the area has been accurately surveyed, and
- certain rock mechanics criteria have been met, as described below.

Pillar extraction, regardless of the use of CRF, has to meet certain rock mechanics criteria. These criteria are as follows:

- catastrophic pillar collapse does not occur (domino pillar failure),
- the work area is kept safe for personnel during the pillar extraction process,
- clear back spans resulting from pillar removal do not exceed 151 feet (46 meters)–back instability occurs with clear spans in excess of 151 feet,
- stability of critical mine areas are not affected (haul routes, active primary mining, etc.).

MINE INFORMATION

The Buick North Mine is located in south east Missouri about 5 miles south southeast of Boss, Missouri, or roughly 57 miles southeast of Rolla, Missouri (Figure 1).

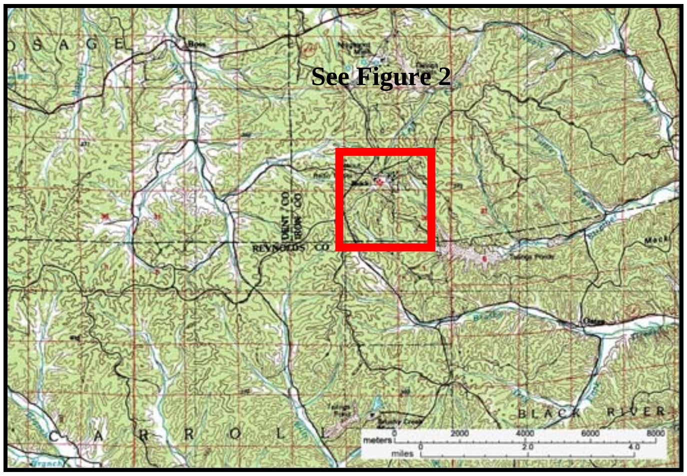

Figure 1. Map of Buick Mine

Figure 2, is a survey (supplied by John Carmack of the Doe Run Company) of the location of Area 1. The red highlighted region in the southern middle of the map is the locations of CRF placement.

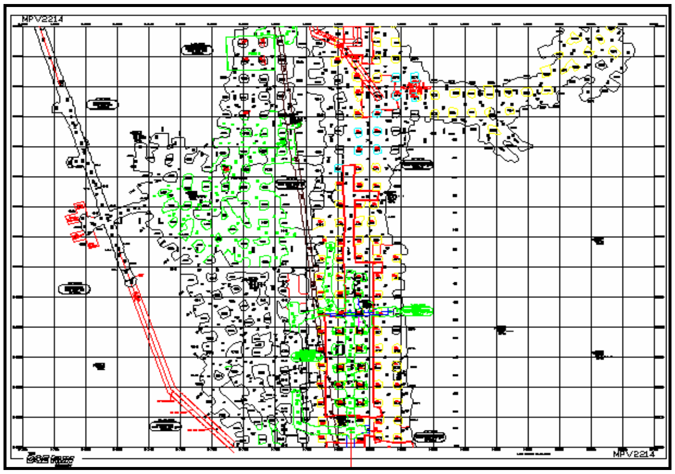

Figure 2. Mine Map of Area 1

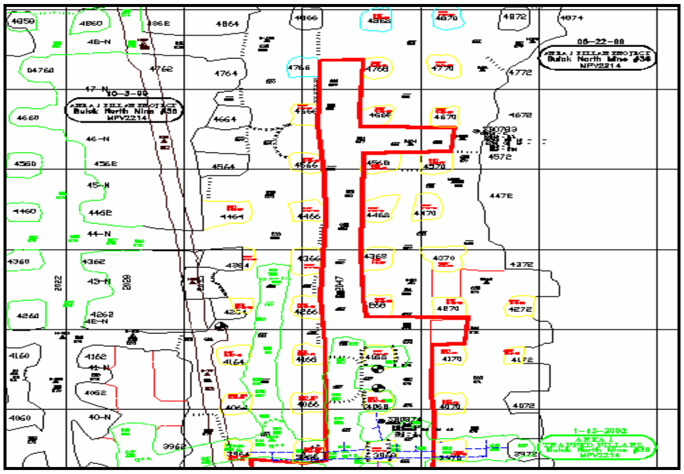

Figure 3. Blowup of Northern Half of Area 1 Extraction

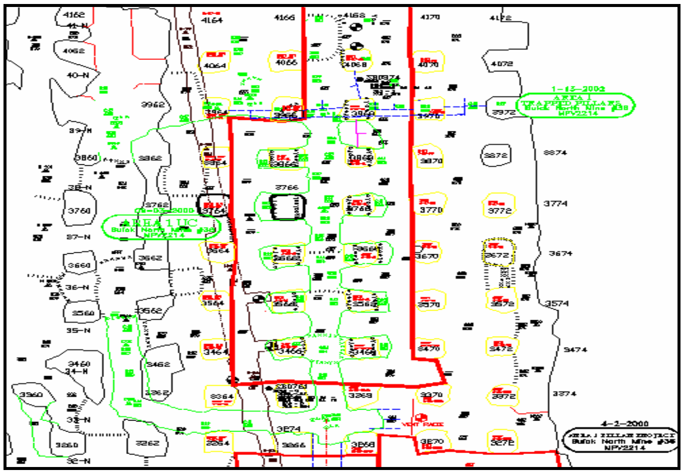

Figure 4. Blowup of Southern Half of Area 1 Extraction

Figures 3 and 4 represent the red highlighted region expanded to a scale that can be visually observed.

Eight of the thirteen pillars encapsulated (commonly referred to as *trapped*) in CRF were instrumented with multi-point extensometers. Two measurements were recorded per station, one for sill deformations and the other for the combined sill/pillar deformations. The difference between the two readings was used to calculate pillar deformation. For a typical extensometer setup, refer to Figure 5.

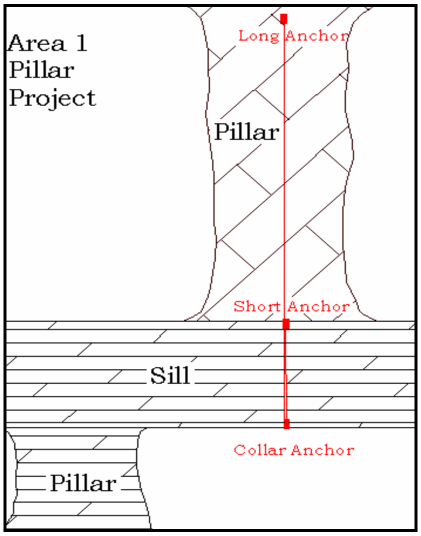

Figure 5. Typical Extensometer Installation

Extensometer installation and data collection was performed according to the following schedule.

Table 1. Ore extracted using the Room-and-Pillar Mining Method (Zipf, 2000)

Pillars	Installation Date	Pillar Height	Sill Thickness
3866	10/26/98	36.0 feet	23.0 feet
3968		31.5 feet	29.0 feet
4068		37.0 feet	32.0 feet
3766	05/27/99	47.5 feet	21.0 feet
3768		46.4 feet	22.6 feet
3868		45.0 feet	25.0 feet
3666	11/18/99	50.0 feet	20.0 feet
3668		32.8 feet	19.9 feet

Pillars with extensometers installed, ranged in height from 36 feet (10.97 meters) up to 50 feet (15.24 meters), sill heights ranged from 20 feet (6.1 meters) to 32 feet (9.75 meters) thick. All other pillars in Area 1 extraction ranged in height from 20 feet (6.1 meters) up to 60 feet (17.5 meters).

Most pillars that were either partially confined or unconfined were extracted during roughly a one year period of time from late 1998 to early 2000. All of the trapped pillars were extracted from Area 1 from late 2001 thru early 2002. No other in-situ rock mass measurements were in this area. Pillar extraction sequence followed no readily identifiable pattern, instead timing and sequence was based on visual inspection and pillar grading with subsequent numerical modeling. No more than two pillars were removed on any one extraction sequence. Typically, pillars slated for removal were undertaken in two to four week intervals. This provided several benefits; 1.) ensures the safety of mine personnel during ore retrieval operations, and 2.) all remaining pillars are visually inspected and rated according to a numeric scale that ranged from a value of one (no visible signs of pillar distress) to a value of six (failure occurred or imminent). This information is used to empirically quantify (and adjust) the rock mass properties of an individual pillar (i.e., Young's Modulus, strength, etc.) which would then be compared with results obtained from numerical modeling. The numerical models would then be re-calibrated as necessary to ensure proper comparison between model and actual field observations. At this point, additional modeling would be performed to determine the next likely subject pillars for removal, Lane, et al. (2001).

EXTENSOMETER DATA

The extensometer data was collected from the eight instrumented pillars from October 27, 1998 through December 30, 1999, the data is plotted in the following graphs. Readings taken from extensometers ended abruptly on December 30, 1999 at which point, during the normal course of mine operations, the wire leads to the instruments were severed and/or lost. Pillar extraction continued through early January of 2002, extraction was carried out during this time period on *trapped* or encased pillars, unfortunately no additional data was collected during this time period for reasons stated above. Figures 6 thru 13 are graphical representations of the data collected from the extensometers (both sill and pillar deformation are plotted). Dates in red represent pillar extraction that appear to have a significant influence on pillar/sill deformations, dates in blue represent pillar extraction that do not appear to have a clear influence on measured deformations. Note not all pillar extraction dates have been plotted on the following graphs.

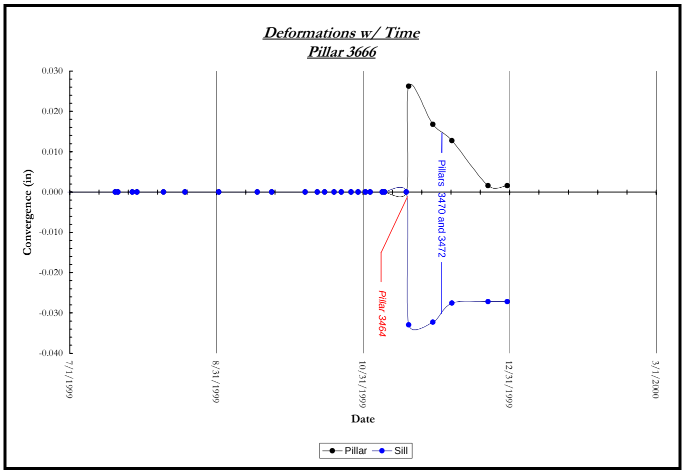

Figure 6. Pillar 3666 Extensometer Data

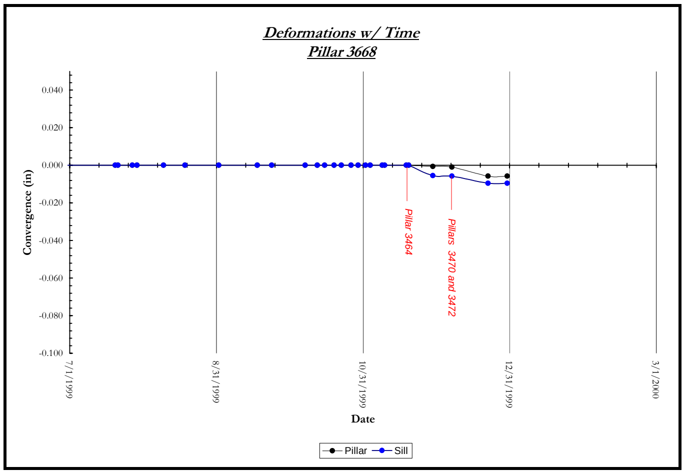

Figure 7. Pillar 3668 Extensometer Data

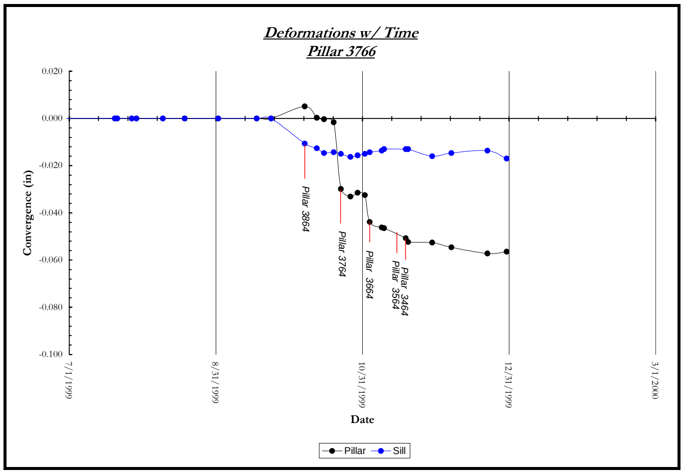

Figure 8. Pillar 3766 Extensometer Data

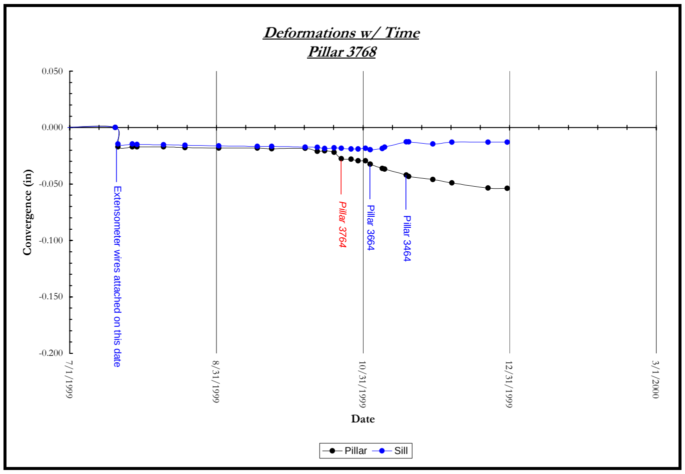

Figure 9. Pillar 3768 Extensometer Data

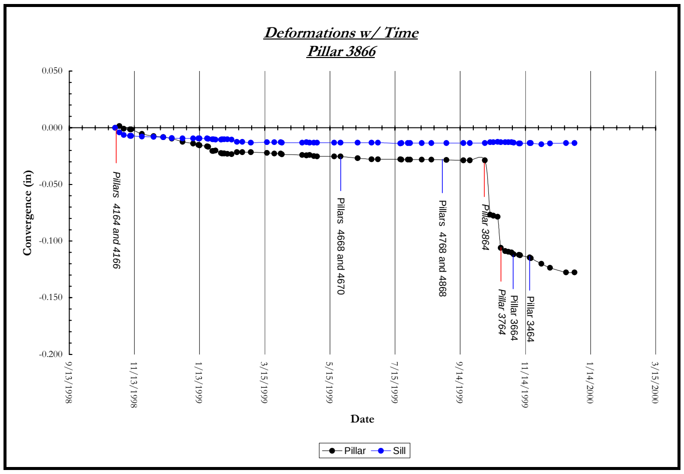

Figure 10. Pillar 3868 Extensometer Data

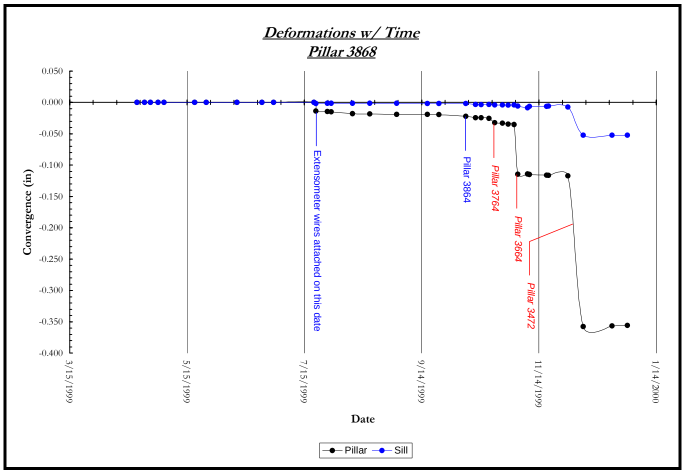

Figure 11. Pillar 3868 Extensometer Data

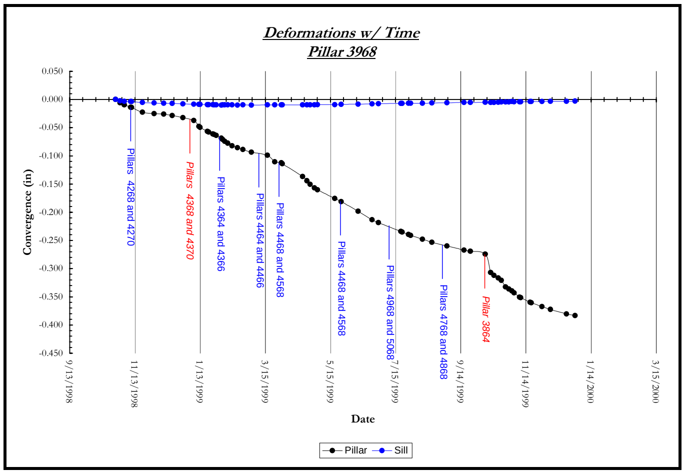

Figure 12. Pillar 3968 Extensometer Data

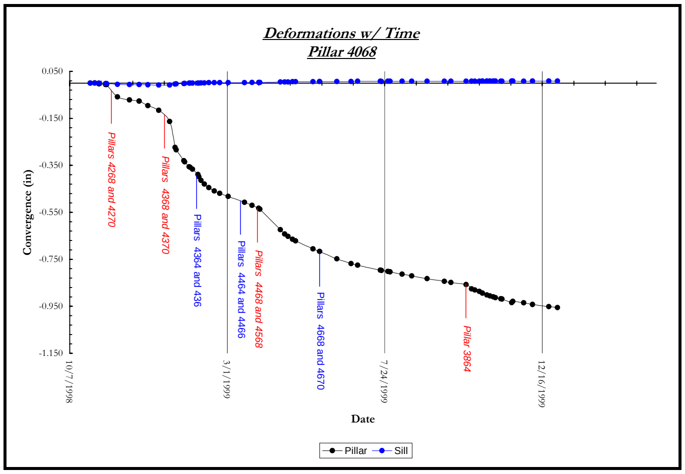

Figure 13. Pillar 4068 Extensometer Data

ANALYSIS

Deformations for sills ranged from -0.008 inches to -0.052 inches with an average value of 0.0203 inches. Pillar deformations ranged from 0.006 inches to 0.955 inches with an average value of 0.246 inches. As would be expected, the general behavior of pillars under these loading conditions would be that trapped pillars would undergo axial shortening, which was observed in all cases in some form. The only exceptions were with pillars 3666 and 3766, in which an initial period of axial extension was observed in the data. But after review of the data, this may be attributed to seating issues associated with the extensometer anchors such as initial slippage or incomplete bonding of grout with the anchor and/or the surrounding rock mass.

Pillars 3968 and 4068 displayed the highest deformation of 0.383 inches and 0.955 inches, respectively. All the other monitored pillars ranged between 0.01 inches and 0.356 inches. This can be explained by two factors, the first and probably the most important is that these two pillars have less confining material present than the other pillars monitored, (Figure 4). Secondly, these two pillars accept most of the load shed into Area 1 trapped pillars. Finally, these pillars were monitored for the longest period of time, in comparisons with the others, such that deformations that might have occurred during this time period were not accounted for.

Pillars 3968 and 4068, and to some extent pillar 3866, show the greatest benefit of having backfill provided passive confinement (Figures 10, 12, and 13). From these figures it can be seen that the rate of deformation decreases with time, both in the short term (i.e., between any individual pillar extractions) and long term, in which the trend is for the overall deformation rate to decrease. This is not as evident in the other instrumented pillars because the monitoring period was not as extensive as in pillars 3866, 3968, and 4068.

A simple analytical solution was determined for convergence of pillar 3766 as extraction operations were undertaken. The deformations obtained through extensometer readings were then compared with those obtained from the analytic calculations in an effort to quantify the benefits of using CRF. Pillar strains and deformation were then calculated at pillar configuration to simulate pillar extraction utilizing the simple linear elastic relationship between stress and strain (i.e., Hooke's Law). Subsequently, pillar loads were calculated utilizing the tributary area method. Figure 14 is a drawing of the pillar(s) in question. Calculations of load and deformation were based on the extraction of pillar 3764, directly west of the trapped pillar under investigation. Extensometer readings show a convergence reading during the extraction of pillar 3764 of 0.028 inches. The analytic solution predicted a change of 0.458 inches. Even though a more rigorous investigation is necessary, this simple analysis justifies the use CRF to trap select pillars and that further study is warranted.

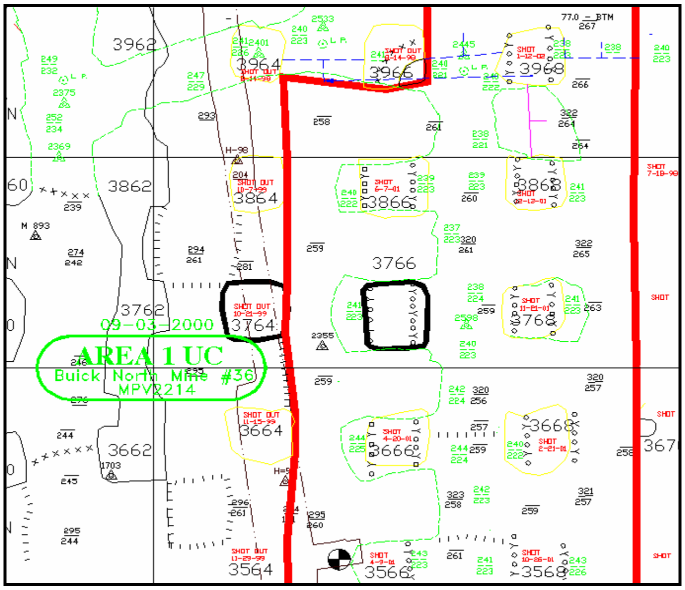

Figure 14. Example Pillar Location

CONCLUSIONS

This study shows the possible benefits of using passive confinement on the stress/strain properties of underground pillars. This study does show that pillar deformations do appear to decrease with time as extraction proceeds, but additional research and pillar monitoring is warranted. Such as the use of extensometers in unconfined pillars such that a comparison can be made between confined and unconfined. A more quantative model is needed to explain the mechanism of reinforcement of pillars by backfill. Such model should give the answer to what physical properties of backfill have the greatest impacts on providing the reinforcement to the stressed pillar(s). The knowledge about the required physical properties of backfill needed would allow for the design of better pillar extraction strategies to maximize the entrapment effect of pillars and also to maximize cost associated with mix components (i.e., cement, fly ash, etc). To these ends, research is currently underway by one of the authors in which a single artificial pillar/backfill system will be fully instrumented and tested, both in the laboratory setting and numerically, to determine what effect backfill has on the stress-strain characteristics of the pillar.

Ultimately, the model would allow for an increase in the extraction ratios at the room and pillars mines which would increase the mineable ore reserves. This could extend the lives of many mining based economies and could revitalize many abandoned mines, which still hold substantial ore reserves left in the remnant pillars. At some currently operating mines, pillar extraction operations are the only economically viable means of ore extraction.

ACKNOWLEDGEMENTS

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