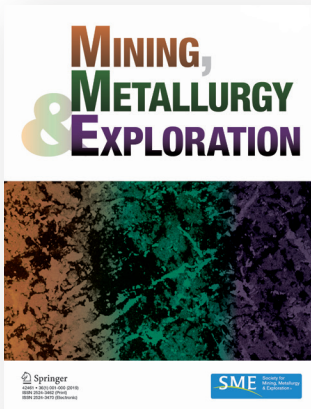


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Collection on Ground Control in Mining

Exploration of limestone pillar stability in multiple-level mining conditions using numerical models

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Keywords: Ground control, Limestone, Multiple level, Pillar stability, Interburden stability

Many underground stone mines in the United States operate on multiple mining levels. The effects of interburden thickness, pillar offset between mining levels at various depths of cover, and in situ stress conditions are poorly understood. Pillar offset is the degree to which pillars are not columnized or stacked. In this study, calibrated numerical models are used to examine limestone pillar stability in these conditions. Also, the critical interburden thickness required to minimize the interaction between mining levels is explored. The model results show that there is interaction between numerous factors that control the stability of stone pillars in multiple-level conditions. The highest degree of local pillar instability occurs when pillar overlap ranges between 10 and 70 percent. The highest degree of stability occurs when pillars are stacked.

Introduction

Recent research by the National Institute for Occupational Safety and Health (NIOSH) has led to pillar design guidelines for shallow, flat-lying deposits of single-level operations [1,2], and NIOSH is expanding that research by investigating the stability of multiple-level stone mines. The body of research for multiple-level underground limestone research is limited, while there is an abundance of research into room-and-pillar, multiple-level mining in coal mining [3,4]. Limestone mines tend to have larger roof spans, larger pillar heights, smaller and stronger pillars and less geologic stratification; pillars are usually benched in these mines and retreat mining is not used, making the interactions between levels distinctly different from what has been studied previ-

ously in coal mines. Numerical models have been used to gain some insight into how stone pillars can be affected by undermining, and some considerations for ensuring stable pillar design.

In this study, the actual jointed rock mass was replaced with a homogenous isotropic continuum model of equivalent properties. The underlying assumption of the continuum rock mass model used in this study is that rock mass behavior is not dominantly controlled by a single joint set. A stable interburden and a stable roof span were assumed.

Table 1 summarizes the parameters used in the FLAC3D models, and the values for each parameter. Numerous combinations of the study parameters were generated to determine when the interaction between the mining levels occurs and how significant the impact of these parameters could be on pillar stability.

Pillar overlap is the area of the top-level pillar that is directly overlying a bottom-level pillar. To capture a complete picture of the effect of pillar overlap on pillar stability, the bottom-level pillars were offset either in the *x* direction only

or in both the *x* and *y* directions. When pillars are offset in *x* and *y* directions, the offset distance is the same for both directions.

Results and discussion

Calibrated FLAC3D models were used to investigate the impact of pillar offset at various interburden thicknesses, depths, and in situ stress conditions. Figure 1 shows the effect of pillar offset in the *x* direction only on vertical stress distributions for 8-m interburden thickness and *k*-ratio = 0.3. Pillar offset generates asymmetric stress distribution such that stress concentration is higher on one side of the study pillar compared to the other side. These stress concentrations could be extremely high depending on the magnitude of the pillar offset and interburden thickness, which might lead to local instabilities and failures. The highest stress concentration occurs when the pillar overlap percent ranges from 67 to 33 percent.

The effect of percent pillar overlap and interburden thicknesses on percent yield when the depth of cover is 300 m (984 ft) is illustrated in Fig. 2. The pillar offset has a substantial effect on percent yield when the interburden thickness is thin. As the interburden thickness increases, the impact of pillar offset on pillar stability decreases. The lowest degree of percent yield in the study pillar (highest pillar stability) occurs when the pillars are stacked, while the highest degree of percent yield (highest local instability) occurs between 10 and 70 percent pillar overlap. The degree of interaction between the mining levels is minimal when the interburden thickness is greater than 16 m (26.2 ft), which is about 1.33 of the roof span.

Figure 3 shows the variation of percent yield at various degrees of pillar overlap and interburden thicknesses, when the depth of cover is 300 m (984 ft) for pillar offset in the *x* direction only. The pillar offset has a substantial effect on percent yield when the interburden thickness is thin. As the interburden thickness increases, the impact of pillar offset on pillar stability decreases. When the interburden thickness is 16 or 32 m (52.4 or 104.9 ft), the pillar offset has less sub-

Table 1 – Summary of the study parameters used in the FLAC3D models.

Parameter	Parameter values evaluated
Depth, m (ft)	100 (328), 200 (656), 300 (984), 400 (1,312)
Interburden thickness, m (ft)	4 (13.1), 8 (26.2), 16 (52.4), 32 (104.9)
Pillar overlap in <i>x</i> direction, %	100, 83, 67, 50, 33, 8, 0
Pillar overlap in <i>x</i> and <i>y</i> directions, %	100, 69, 44, 25, 11, 0
<i>k</i> -ratio	0.3, 3.0
Pillar width-to-height ratio	1.5
Roof span, m (ft)	12 (~40)
Material model	Linear, nonlinear

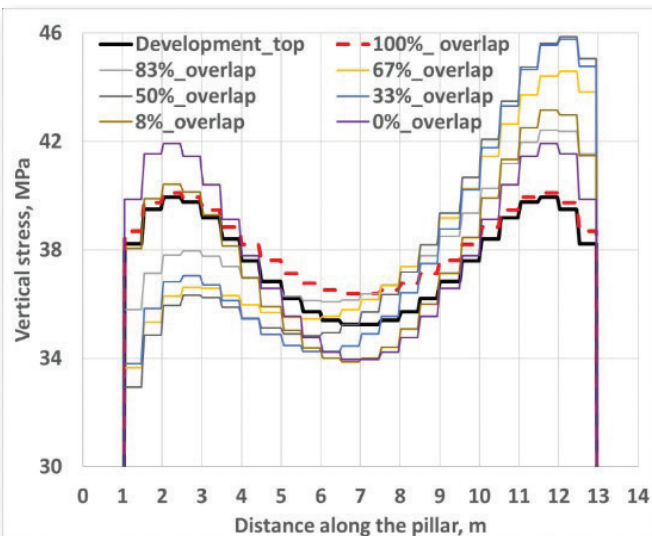


Fig. 1 Variation of vertical stress distributions with pillar overlap percent for 8-m interburden thickness, *k*-ratio = 0.3 and depth of cover = 400 m.

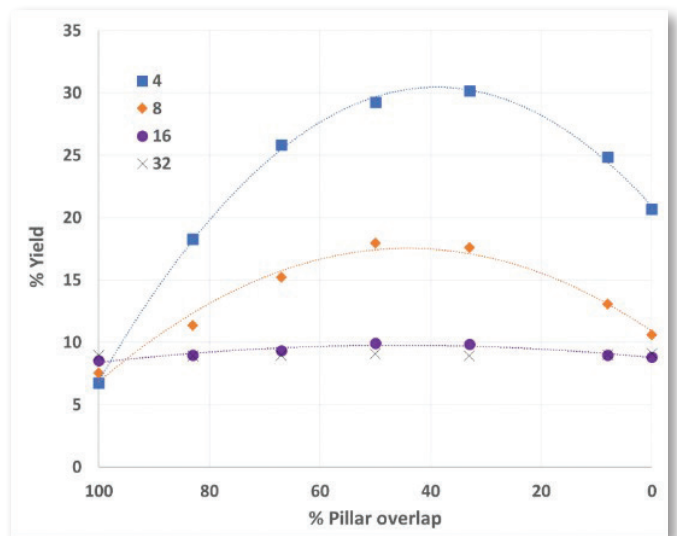


Fig. 2 Influence of interburden thickness on percent yield at various pillar offsets for pillar offset in the *x* direction only and depth of cover = 300 m.

stantial effect on pillar percent yield. It is obvious that the lowest degree of percent yield in the study pillar (highest pillar stability) occurs when the pillars are stacked, while the highest degree of percent yield (highest local instability) occurs between 10 and 70 percent pillar overlap.

Conclusion

Many mines are operating in multiple-level environments, and an understanding of the interactions between levels is critical to ensuring pillar stability. Modeling results show that pillar overlap can have a significant impact on pillar stability, becoming less stable in a range of 10 to 70 percent overlap, at decreasing interburden thicknesses and at increasing depth. The model scenarios here are idealized, but the mechanisms underlying these findings may be generalizable to a variety of geometries and stress states, improving our understanding of how pillars and interburden interact.

Disclaimer

The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC). Mention of any company name or product does not constitute endorsement by NIOSH. ■

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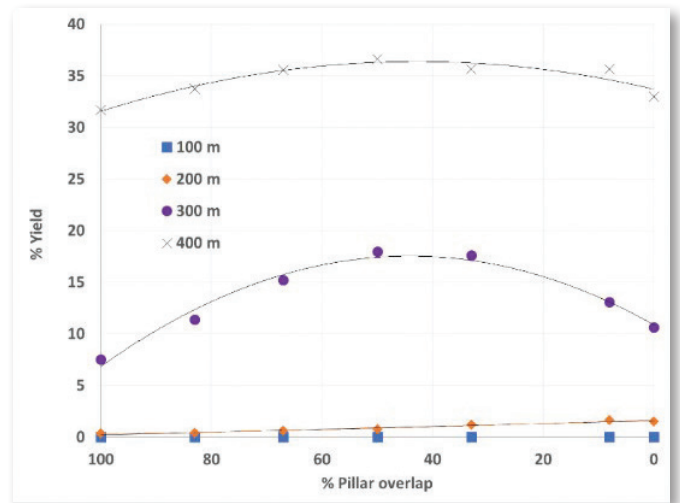


Fig. 3 Influence of depth on percent yield at various pillar offsets for pillar offset in the *x* direction only.

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Purification of molybdenite concentrates by a continuous sulfation-leaching process

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Keywords: Molybdenite, Purification, Sulfation, Reactor design

The current processes that aim to purify molybdenite concentrates are not able to dissolve some copper compounds, hence limiting the processes. Typically, the copper content results are from 2 up to 4 weight percent in the last concentrate. Such values are still too high for the molybdenite concentrate to be further processed to molybdenum trioxide by roasting. In order to achieve lower levels of copper — but also avoid excessive molybdenite losses — a continuous sulfation-leaching process is investigated and applied successfully on a pilot scale. Additionally, a reactor prototype and its process parameters are proposed for a commercial plant.

Background

Molybdenite concentrates are usually produced as a by-product of porphyry copper concentrates, leading to over-

all molybdenite recoveries generally below 70 percent. To reduce the copper content, molybdenite concentrates are generally leached using a ferric chloride solution or cyanide — although ferric chloride does not dissolve some species, such as enargite (Cu_3AsS_4), and cyanidation does not dissolve chalcopyrite (CuFeS_2) as well.

In the 1970s, U.S.-based Kennecott Copper Co. applied sulfation with sulfuric acid to purify low-grade molybdenite concentrates with high copper contents [1,2], but severe corrosion of the equipment used hampered further development of the technology.

Methods and technology development

The purification of molybdenite concentrate from copper concentrates was performed by sulfation. The sulfation