A parametric study for the effect of dip on stone mine pillar stability using a simplified model geometry

Gamal Rashed*, Brent Slaker, Morgan M. Sears and Michael M. Murphy
NIOSH, Pittsburgh, PA, USA
*Corresponding author email: Grashed@cdc.gov

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Special Extended Abstract

A parametric study was conducted using FLAC3D numerical models to examine the impact of oblique loading on the strength and yield pattern of a stone pillar using two simplified geometry types. In type-1 the side walls of the pillars were assumed to be perpendicular to the roof and the floor, while in type-2 the side walls were assumed to be vertical. These two geometries are frequently used to simplify/model the creation of pillars in dipping mines. Results from the numerical modeling indicate that dipping pillars have reduced strength compared to horizontal pillars, and they are at an elevated risk of failure. Also, an asymmetric failure propagation pattern could be obtained depending on the interaction between the pillar width/height (W/H) ratio, seam dip, in situ stresses and pillar geometry.

Introduction

As stone mining operations continue to develop deeper and in more inclined seams, more complex geometries for pillars and mining scenarios are generated. Oblique loading conditions can be caused by seam dip or by natural phenomena, such as faults and dykes [1]. The stability of stone pillars can be greatly influenced by the occurrence of geological discontinuities [2] and weak bands [3]. Discontinuity and weak-band-driven instabilities are not considered in this study because they are highly variable and site specific. Moreover, the main purpose of this work is to study more generally the response of dipping pillars to loading so that it can be applied to situations where the impact of discontinuities or weak bands are well understood.

Method

A 5 × 5 array of pillars was generated in FLAC3D to gain additional insight into the impact of seam dip on the stability of stone pillars for both type-1 and type-2 geometries. A limestone material model was calibrated based on the empirical pillar strength equations. The generalized Hoek-Brown failure criterion was selected to model the peak strength of pillars. The softening behavior was modeled by varying the geological strength index (GSI) for limestone material with the plastic strain. The study pillar is in the center of the array. The seam dip was changed from 0 to 40°. The in situ stress field was varied to account for low and high in situ stress fields, where the horizontal/vertical stress ratio (k-ratio) is 0.3, 1.0 and 3.0. The modeled W/H ratio of stone pillars varied from 0.5 to 2.5. It is uncommon to find stone pillar failures with W/H ratios greater than 2.5 [4]. The FLAC3D models were solved with and without interfaces between the roof/pillars/floor for both type-1 and type-2 geometries. Theoretically, the cases "without interfaces" mean

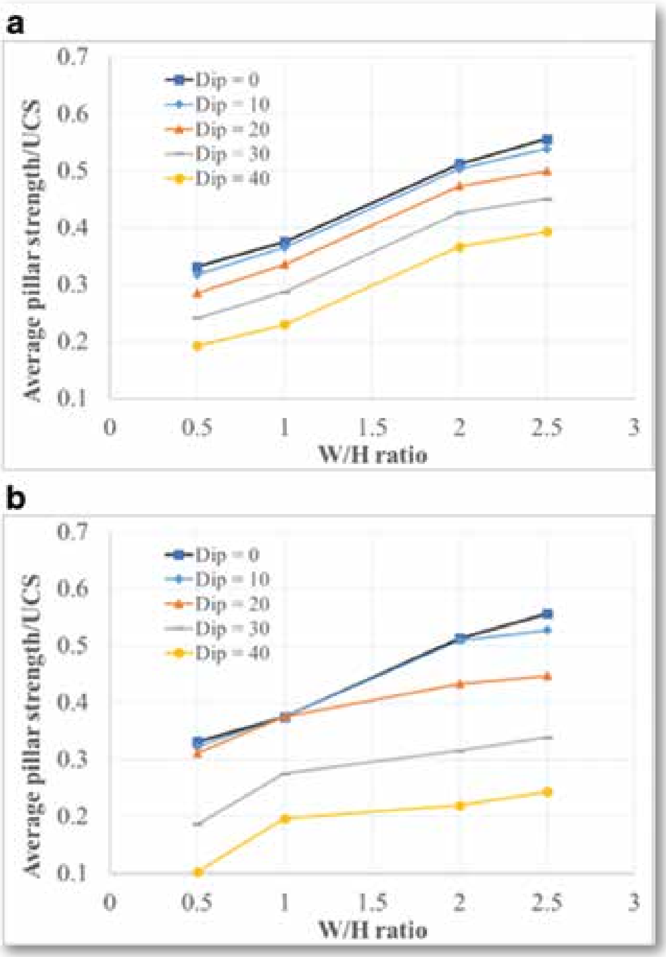

Fig. 1 Variation of average pillar strength with pillar W/H ratios without interfaces and k-ratio = 1.0 at various seam inclinations for (a) type-1 and (b) type-2 geometries.

highly strong bedding planes between pillars and roof/floor, where no sliding or separation would occur.

Results and discussion

The variation of the average pillar strength versus W/H ratios for type-1 and type-2 geometries without interfaces is shown in Fig. 1. Generally, the average pillar strength decreases with increasing seam dip. The average pillar strength for the type-2 geometry is higher than for the type-1 geometry, with the reason possibly that the effective loaded area on pillars is greater for the type-2 geometry than for the type-1 geometry. For pillars of type-1 geometry, the reduction in average pillar strength is less than 5 percent when the seam dip changes from 0 to 10°, while the reduction is significant when the seam dip changes from 0° to 40°. For type-2 geometry, when the W/H ratio is less than 2.0, the impact of seam dip on pillar strength is less important at dip angles up to 30º.

The trends for the average pillar strength with and without interfaces are similar for type-1 geometry except that the pillar strength is higher when there are no interfaces. However, for the type-2 geometry the trends for the average pillar strength with and without interfaces are different, particularly at 30 and 40º.

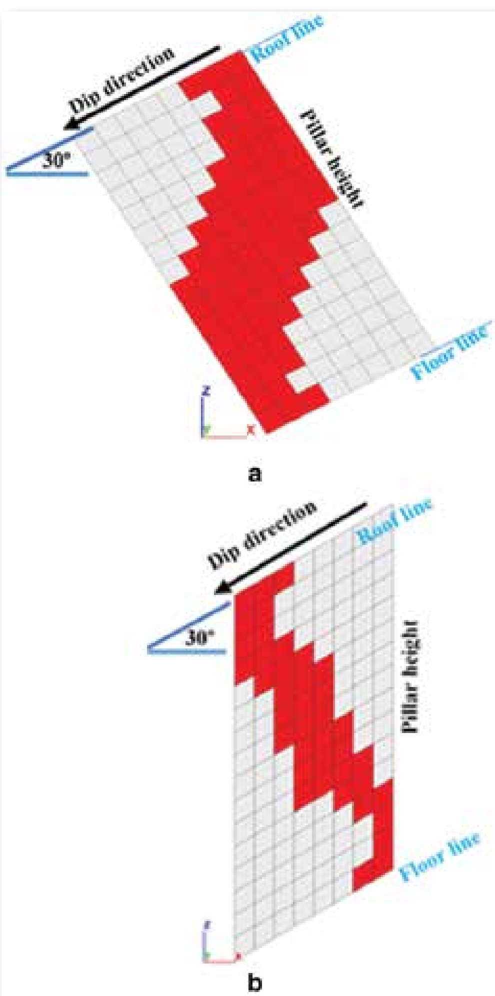

Fig. 2 Asymmetric failure propagation for W/H ratio = 0.5 with interfaces, dip angle = 30, and k-ratio = 0.3 for (a) type-1 geometry and (b) type-2 geometry (red elements are yielded).

The reduction of pillar strength with increasing seam dip is partially attributable to the reduction of the confining pressure. Hence, any increase of the k-ratio will reduce or prevent slippage along the pillar/roof and pillar/floor interfaces. To understand the mechanics of stress-induced instability in stone pillars and the measures required to control that instability, it is necessary to understand the patterns of failure propagation. For pillars in flat-lying deposits, the failure pattern starts at the pillar corners/edges and propagates uniformly toward the core of the pillar in a symmetric manner irrespective of the k-ratio, pillar W/H ratio, and interface shear strength between the pillar and the roof/floor. However, this is not the case in dipping conditions. For pillars with W/H ratio = 0.5 of the type-1 geometry, the pattern of failure propagation starts at two opposite corners and propagates down dip along the diagonal toward the pillar core as shown in Fig. 2a. The pillar diagonals are equal for type-1 geometry, which is why the failure commences at the highest point of the pillar.

Conversely, for type-2 geometry the failure pattern did not propagate along the down dip diagonal but started at the corners of the short diagonal and propagated along that diagonal toward the pillar core as shown in Fig. 2b. The load path is always looking for the stiffest, shortest direction to transfer the load.

The pattern of failure propagation might be asymmetric depending on the interaction between seam dip, pillar W/H ratio, k-ratio, and pillar/roof and pillar/floor shear strength. An asymmetric fracture propagation that passes through the pillar core not only reduces the ultimate strength of the stone pillar but may also place the stone pillar at an elevated risk of instability.

Summary and conclusions

The main conclusions of the numerical modeling results can be summarized as follows:

- The strength of a stone pillar deceases as the seam dip increases, and it increases with increased k-ratio and W/H ratio. The impact of seam dip on pillar strength depends on the dip angle, the interface shear strength, the W/H ratio, and the simplified geometry used to model the actual pillar geometry. There is insignificant reduction in pillar strength (less than 5 percent) when the seam dip changed from 0 to 10º for both type-1 and type-2 geometries.
- For pillars of W/H ratio = 0.5 in oblique loading conditions, the fracture pattern is always asymmetric. It propagates along the short diagonal toward the pillar core for type-2 geometry, while for type-1 geometry it propagates down dip along the opposite corners toward the pillar core. For pillars of W/H ratio = 1.0 in oblique loading conditions, the pattern of fracture propagation is contingent on several factors, such as the seam dip, the simplified geometry used to model the pillar, the W/H ratio, the k-ratio, and the presence or absence of interfaces between pillars and roof/floor. ■

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, Centers for Disease Control and Prevention.

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Stability mechanism and control technology for fully mechanized caving mining of steeply inclined, extra-thick seams with variable angles

Wang Hongwei[1,2,3,*], Wu Yongping[1,2,3], Jiao Jianqiang[1] and Cao Peipei[4]
[1]School of Energy and Mining Engineering, Xi'an University of Science and Technology, Xi'an, China
[2]Key Laboratory of Western Mine Exploitation and Hazard Prevention, Ministry of Education, Xi'an, China
[3]State Key Laboratory of Coal Resources in Western China, Xi'an, China
4Yanbei Coal Mine, Huating Coal Industry Group, Huating, China
*Corresponding author email: Wanghw@xust.edu.cn

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Special Extended Abstract

In the fully mechanized top caving mining of steeply inclined, extra-thick seams with variable angles, the mechanisms of roof rock movement, failure, caving and filling are highly complex. This is due to the varying angle of coal seam in different areas, which makes rock–equipment stability control challenging. In this paper, the surrounding rock deformation and failure mechanisms, bearing structure of the overburden, and working characteristics of the supports are elucidated. The principle and key technologies of rock–equipment stability control are presented and applied to control the overburden of the regional failure and realize safe and efficient mining of the working face.

Introduction

Steeply inclined seams, which are buried at dip angles of 35 to 55°, are considered to be hard-excavated seams in the mining industry. With the development of rock control theory and technology, the safety and efficiency of fully mechanized caving mining of steeply inclined coal seams with a constant angle have been realized. But in top coal mining of steeply inclined coal seams with varying dip angle, the deformation and destruction and migration of the surrounding rock are evident. In particular, in the transitional-angle area of the working face, roof movement is more active, and the contact load between the supports and surrounding rock becomes complex. Moreover, the stability control of the support–surrounding rock system is challenging, the recovery rate of the top coal is low, coal wall spalling and roof falling in the front of the support are exacerbated, and the production efficiency is inconsistent and low. Therefore, research of the fully mechanized top caving mining of steeply inclined coal seams is needed.

Engineering background

The No. 2 coal seam is the primary mining seam of the No. 120210 working face in the Zaoquan Coal Mine of the Ningxia Coal Industry Group. Its average thickness and depth are 8.15 and 400 m, respectively. It is a thick and extra-thick seam with a 26° dip angle in the upper area, 30° in the middle area and 34° in the lower area. The longwall fully mechanized caving mining method is used, with a cutting height of 3.0 m and a caving height of 5.15 m.

Physical simulation for roof stability

The mining operations of the No. 120210 working face were simulated with a 1:100 physical model. The overburden caving characteristics of the working face with a large dip angle are shown in Fig. 1a. Because of the obliquity effect of the gravity field, the caving roof of the working face slips down along the floor and fills the mining space with a partition characteristic along the tendency direction. The waste filling results in an asymmetric constraint on the overburden, leading to a transitioning of the roof caving region to the upper region. In the upper area of the working face with a small dip angle, the immediate roof collapses and slips down to conversion position 1 between the upper and middle areas, forming a dense squeeze area. On the main roof of this area, a cantilever structure is formed in the same layer. In the lower area of the working face with a steep dip angle, the collapsed immediate roof slides along the floor and fills the gob; a masonry struc-