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A comprehensive study on the effects of geometric and geomechanical parameters on crown pillar behavior during the transition from open-pit to underground mining

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ABSTRACT

Due to the deepening of open-pit mines and associated environmental concerns, the current period has been termed the 'return to underground mining era'. One of the key factors in transitioning from open-pit to underground mining is designing crown pillars based on economic and technical considerations. Due to the uncertainties surrounding this research topic, the present study uses three-dimensional numerical simulations to investigate the interactive effects of geometric and geomechanical parameters on the behaviour of crown pillars during the transition to underground mining. Pillar behaviour was evaluated based on displacement magnitude and the volume of the plastic zone of the pillar. The results of the numerical simulation showed that geometric parameters play a much more significant role than rock mechanical properties. Of the geometric parameters, the pillar dimension index (the product of the pillar's thickness and span) and the crown pillar's span play a decisive role in controlling pillar behaviour. From a geomechanical perspective, within the range of variations considered in this research, the rock elastic modulus was identified as the parameter most influential on crown pillar behaviour. This parameter controls crown pillar behaviour at a critical value of 7 GPa. Crown pillar span was identified as the second most influential parameter and can predict crown pillar displacement with a correlation coefficient of 0.83. The pillar dimension index can estimate the plastic zone volume in the pillar with 20% accuracy.

Introduction

The optimal design of the crown pillar in the transition from open-pit to underground mining is one of the key issues in deep mining operations. Previous studies on crown pillar design can generally be classified into three categories: numerical, analytical, and empirical. The inherent uncertainties and the need to balance safety and economic considerations in crown pillar design highlight the necessity for further research in this area While analytical methods are useful in the early stages due to their simplicity and speed, they cannot account for nonlinear rock behaviour or three-dimensional boundary conditions resulting from in-situ stresses and geometry. Similarly, empirical methods based on databases and data analysis are limited by the scope of available data, raising questions about their application beyond this scope. To overcome these limitations, numerical techniques have been developed that allow for more accurate modeling of geomechanical conditions and identification of failure mechanisms. Despite significant advances in crown pillar design, a review of existing research indicates that a comprehensive and systematic study examining the combined effects of geometric and geomechanical parameters on crown pillar stability is still lacking. Such a study could contribute to the establishment of a more complete framework for the optimal design of crown pillars and the reduction of existing uncertainties. In this research, the geometric and geomechanical parameters affecting crown pillar stability are identified, and the necessary experiments to evaluate the influence of these parameters on crown pillar stability are designed using the Taguchi method and analyzed through three-dimensional numerical simulations.

Materials and Methods

Identification of Influential Parameters and Taguchi Test Design

The parameters affecting the dimensions of the crown pillar in the transition from open-pit to underground mining can be categorized into two main classes: geometric parameters and geomechanical parameters. In the present study, the well-established Mohr–Coulomb failure criterion was adopted to assess rock mass behavior. The geomechanical parameters considered include the internal friction angle, cohesion, Poisson's ratio, and modulus of

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