ABSTRACT

Analysis of the Brittle Failure Mechanism of Underground Stone Mine Pillars

Jimenez, Rosbel

The most used method for extraction of minerals that are found in flat-lying stratiform is called the room and pillar mining method, and it is developed in most of the underground stone mines in the US (Esterhuizen et al., 2011), for that reason, it is a main topic of study. If a set or layout of pillars is not stable it can lead to a major collapse due to the fall of the roof, and it can result in not only the destruction of the underground mine since in addition to that, it can produce air blast, subsidence, convergence of the mine opening, mostly if they happen in a short period of time (Esterhuizen et al., 2011).

In the last few years, a lot of research studies have been taking place in order to address the pillar collapses that are occurring in the Eastern and Midwestern U.S. This research is mainly led by the National Institute for Occupational Safety and Health (NIOSH), and some research performed by universities as well. From these research studies, Esterhuizen et al. (2011) developed the software S-Pillar that is the base for underground stone mine pillar design today, and it was based in a statistical study of 34 mines in the U.S.

This software's outputs include suggested width-to-height ratios, pillar strength, and Factor of Safety. Since S-Pillar software offers data on how well a specific configuration of pillars is performing, the industry has experienced an increase in its utilization (Rumbaugh et al., 2022). However, the industry as a whole is unable to utilize it to its full potential due to the constraints it offers.

In the works that have provided more information for the use of the software S-Pillar, Escobar (2021) derived the cell equations for applying the empirical stone mine pillar strength equation using the software LaModel (a BEM software), which is used successfully in coal mining. Süner (2021), developed a statistical study from the S-Pillar database to find the most accurate distribution of parameters for making use in numerical simulations, and the effect of the natural fractures on the pillars was studied using the parameters derived from the S-Pillar database. To analyze the mechanical behavior, he implemented a UDEC model, and the results show that the strength of the pillars with low intact rock strength was greater than those with high intact rock strength in comparison with the S-Pillar equation (Süner, 2021). Later, Ates (2022) developed a code for the automation of the implementation of the equations derived by Escobar (2021) into LaModel software incorporating the use of the LDF factor defined by Esterhuizen (2011). He proposed the use of a Local Large Discontinuity Factor to assess the performance of a pillar. LLDF examines the safety factor of a single pillar intersected by a large discontinuity instead of applying it to the whole pillar layout, which allows to better quantify the influence in a specific area (Baris ATES, 2022).

On the other hand, the consideration of brittle behavior has been studied in less intensity. In the attempts to find the influence of the brittle behavior an S-Shaped failure envelope had been proposed by Kaiser & Kim (2015), the envelope was the result of a fit to the Boltzmann Sigmoid

Function with data collected from Hoek's database. The results show the use of a UCS and an Apparent UCS (AUCS) that are clue factors for providing the shape of the failure envelope for hard-brittle rock. Also, Rafiei Renani & Martin (2018), explained how the mobilization of the strength parameters worked for hard-brittle rock, and equations for their values were proposed.

In this research a numerical simulation is performed for having deeper analysis of the brittle behavior and the implementation of the S-Shaped failure envelope is developed. The strength of the underground stone mine pillars is found using the Boundary Element Software FLAC 3D, developed by Itasca Consulting Inc. The approach is carried out by considering the previous statistical studies on the S-Pillar parameters and previous implementations of the brittle behavior in underground stone mines, with procedures similar to how Esterhuizen (2008) and Rashed et al (2023) proceeded. The model is applied doing variations of the width-to-height ratio of the pillar and the results are compared to the empirical equation derived by Esterhuizen et al (2011). The S-Shaped envelope and Cohesion Weakening Friction Strengthening theory is applied for accounting on unification of the approaches in one model.

Keywords: Limestone Pillars, Pillar Strength, Numerical Models, FLAC 3D, Brittle failure, Brittle behavior, CWFS

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