Evaluation of inclined loads in pillars stability

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ABSTRACT: In underground mining, rock pillars are frequently utilized to provide support within the deposit. Many of these pillars, either due to their geometry or the stress field acting upon them, experience inclined loads. Hence, this study aims to develop local models to analyze the impact of inclined loads on the stability of rock pillars.
The models were created using FLAC3D for various types of pillars, and the Hoek & Brown failure criterion was applied, employing equivalent parameters to simulate medium quality rock. Through these models, the influence of inclined loads on pillars and the width-height ratio were examined. The results indicate that pillars exhibit reduced resistance to inclined loads with a shear component, while the strength increases with an increased width-height ratio.

Keywords: Pillars, inclined loads, caving & numerical modelling.

1 INTRODUCTION

This study focuses on analyzing the rock pillars commonly employed as a support method in underground mining. The primary objective of these structures is to ensure local stability between tunnels or rooms, as well as overall stability of the mine, by preventing excessive displacements of the rock mass in areas affected by mining. According to Montiel et al. 2018, a pillar can be defined as a geotechnical element of rock in-situ located between two or more excavations.

Designing these pillars requires crucial knowledge of their strength under various loading conditions. However, due to the nature of mining operations, these loads can be axial, shear, or fall within an intermediate range between the two. This variation depends on the orientation and geometry of the pillar, as well as the stress field acting upon it, which can change over time as the excavation progresses.

2 INCLINED LOADS IN MINING METHODS

Caving methods are based on fracturing the surrounding rock and mineralized material to a sufficient degree to induce a controlled collapse, enabling the extraction of a large volume of ore. This process involves detaching the rock through explosive means, causing it to fall and subsequently be extracted upon reaching the deposit floor. As minerals are extracted, the stress surrounding the cavity increases, leading to the fracturing and subsequent collapse of the rock. This cycle continues in a domino effect until the extraction is complete.

As mining progresses, the cavity expands, leading to the redistribution of stresses and their concentration on the sides of the excavation, a phenomenon referred to as stress abutment. These concentrated stresses are then transmitted directly to the pillars that provide support to the extraction tunnels. It is important to note that these forces acting on the pillars are not always axial; they can also have shear components, as illustrated in Figure 1.

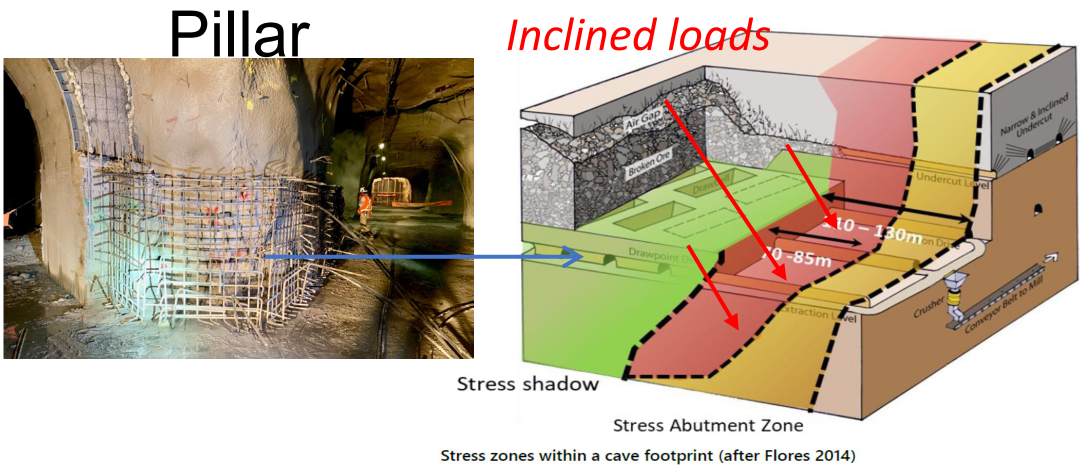

Figure 1. Pillars of caving under stress abutment (Cuello, D. & Newcombe, G., 2018).

There are alternative mining methods, such as room and pillar or longwall, which are employed in mineral deposits with tabular bodies that allow for the utilization of square-shaped pillars directly within the extraction zone. While these deposits are typically horizontal (referred to as mantles), they may exhibit some degree of inclination (known as inclined mantles). Consequently, inclined loads are generated, indicating that the loads on pillars are influenced by various factors, including the geometry of the deposits, the characteristics of the pillars themselves, and the stress field acting upon them.

3 PILLAR STRENGHT

The strength and load capacity of a pillar depend on two factors: the scale effect and the shape effect. The shape effect can be analyzed by considering the height-width ratio. The strength of a pillar is determined by the width-height ratio (W/H), where the width refers to the dimension perpendicular to the direction of the load, and the height refers to the dimension parallel to the load.

According to Esterhuizen et al. (2011), the ideal W/H ratio should not be less than 0.8. A wider pillar ensures that the core remains in a state of triaxial stress, remaining mostly intact, while the walls undergo deformation caused by expansion. Conversely, a slender pillar lacks this additional confinement. Therefore, it can be concluded that greater width and lower height result in greater strength. However, in methods like room and pillar, the ratio generally ranges from 1 to 2. In panel caving, on the other hand, the ratio is usually greater than 2.

As the size of pillars increases, their compressive strength decreases. This is due to the increased likelihood of containing discontinuities as the size grows. These discontinuities can weaken the structure, making it more prone to failures. To obtain accurate results, it is ideal to conduct laboratory tests on larger samples, which helps reduce the scale effect. However, practical limitations may prevent the feasibility of such tests. In such cases, empirical relationships between the strength of laboratory samples and the real scale of the geotechnical element can be used. The Hoek & Brown model, which incorporates the Geological Strength Index (GSI), is an example of such a relationship (Brady & Brown, 2005; Oke & Kalenchuk, K., 2017).

4 METHODOLOGY

The model was elaborated in a program of finite differences ($FLAC^{3D}$), the mesh was constructed by means of primitives with the Hoek-Brown criterion. In addition, the model was developed for a medium quality rock with GSI of 50, σ_{ci} 75 MPa and m_i 18, as well as an initial stress state of 1 MPa in an isotropic stress state. As for the boundary conditions, the attached method of reflection was used, is imposed on the edges of the roof and floor of the pillar, which simulates pillars systematically around the model accommodated as a grid, also this condition allows torsions to exist in presence of inclined loads.

To do the tests of control deformation in finite differences a velocity criterion was developed that maintained a constant velocity modulus ($|\bar{e}|$=constant = $2.5x10^{-5}$ m/s) in this way only the inclination of a vector contained in the xy plane varied and the resulting vectors were placed at the head of the pillar. Finally, for all tests, vectors with a plunge of 0°, 15°, 30°, 45°, 60°, 75° and 90° were used. Both the development of the criterion and an explanation of the boundary condition carried out are found in more detail in Bustamante E., 2023 and in Bustamante E. & Montiel E., 2022.

4.1 Validation

For validation, the results of square pillars with W/H ratios of 0.5, 1, 1.5 and 2 were compared to empirical formulas (Figure 2). Upon graphing the results, it is noticeable that the Sheorey, Salomón & Munro and González formulas exhibit trends like the$FLAC^{3D}$ model. The first two formulas are for coal, and since this rock has similar parameters, we can consider the results to be realistic. On the other hand, the Gonzalez formula, which is the most recent, considers the quality of the rock mass and simple compression, although they have a discrepancy in the values for W/H ratios greater than 1.5 (Bustamante E., 2023).

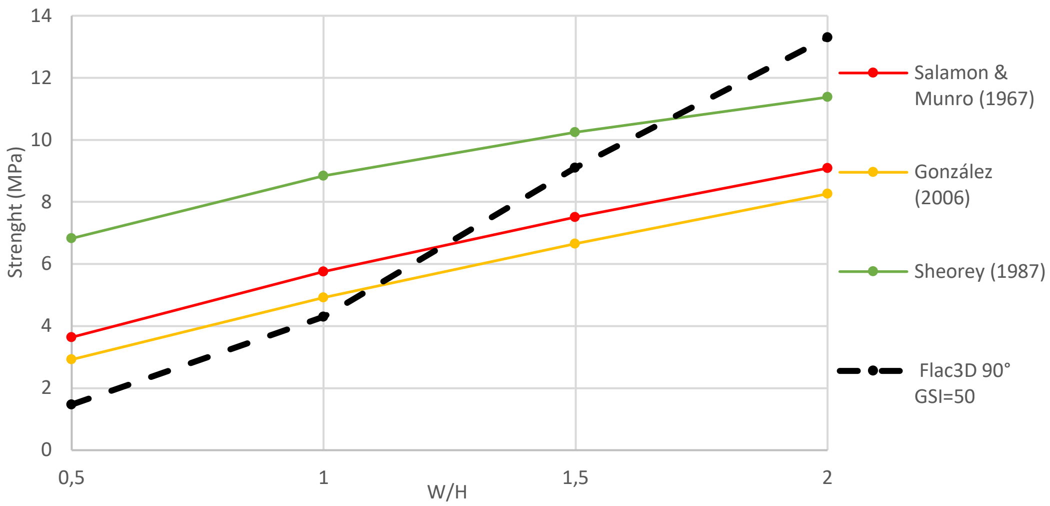

Figure 2. Validation between empirical equations and numerical model in finite differences with axial load.

5 RESULTS

The initial tests were conducted on self-supported methods square pillars with W/H ratio of 1 and dimensions of 10x10 m. The effect of inclined loads on the pillars was analyzed, obtaining the following increment of maximum deformations. As shown in Figure 3, pillars subjected to inclined loads between 0° to 60° usually exhibit roof displacements, generating torsions in the corners affecting the core. However, when the inclined load reached a plunge of 75°, the pillar bulges, this means that the walls are dilating; therefore, the core is damaged to a lesser degree.

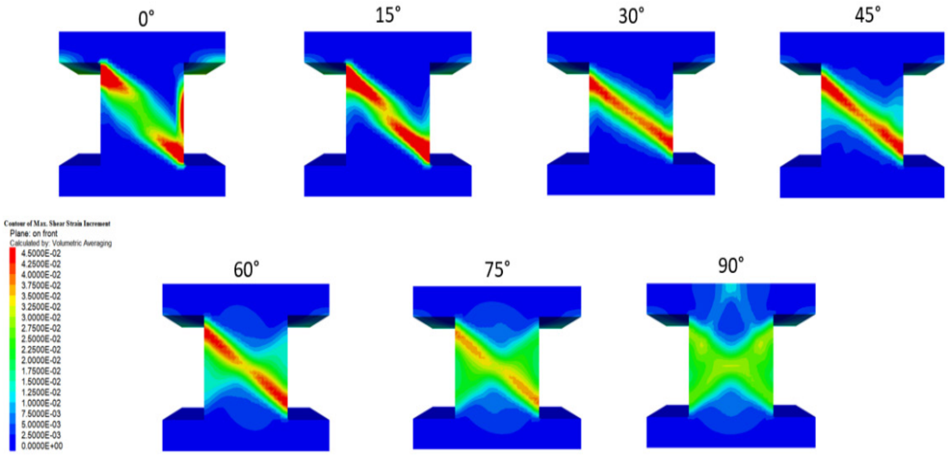

Figure 3. Contour of Max. Shear Strain Increment for pillar (W/H=1) with different plunge.

The results indicate that in pure shear there is minimal strength, as both the core of the pillar and a wall are affected; compromising the structure for 15°, 30°, 45° and 60°, the core continues to be affected, and observed mechanism is that of shear failure. However, as the axial load component increases, the formation of the typical cross of compression failure can be seen. At 75°, the maximum strengths are presented, and the failure mechanism resembles that of simple compression, forming a well-defined cross at 90°. This is supported by Figure 4, where a strength envelope is observed depending on the plunge of the load. This is standardized with respect to the vertical load; representing 100% of what a pillar could withstand.

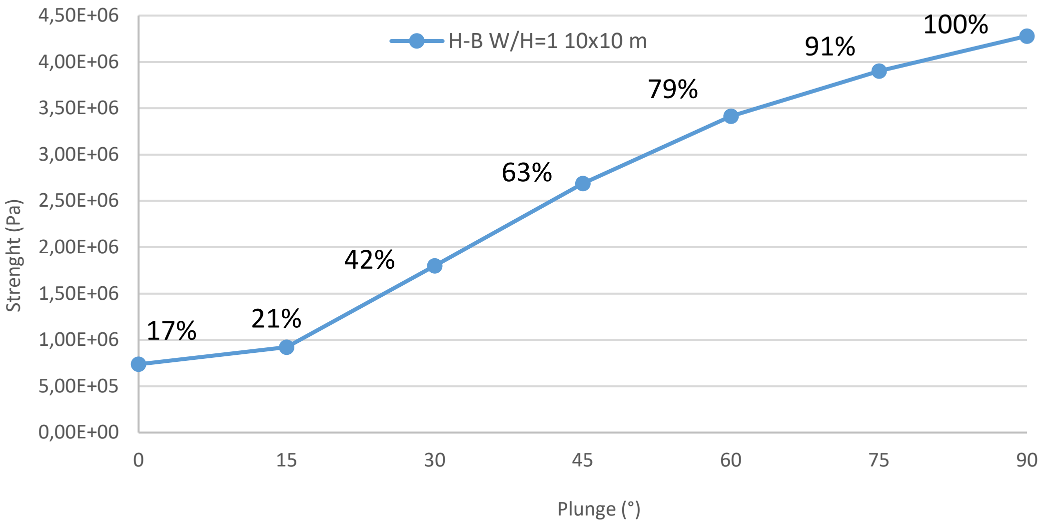

Figure 4. Strength envelope depending on the plunge for pillar of W/H 10x10 m.

5.1 Width height ratio

To analyze the impact according to the W/H ratio, 4 pillar models with the same width (area) of 10 m were used but varying the height to achieve this ratio of 0.5, 1, 1.5 and 2. With the same parameters of rock mass were used for all models. From the results of this case Fig. 6 was plotted, showing the strength envelope for each.

We can see in Figure 5 that all the curves start at the same point at 0°, due to the equal shear strength resulting from having the same area. As the axial load component is increased, the pillars with greater W/H ratios exhibit increased strength, forming an "S" shaped curve. The failure mechanisms for ratios greater than 1 were consistent with those observed in Figure 3.

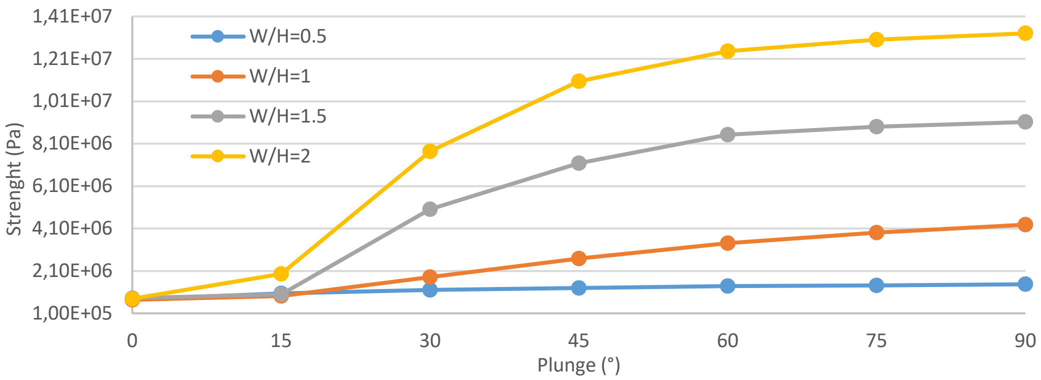

Figure 5. Strength envelope depending on the plunge for pillars of W/H de 0.5, 1, 1.5 y 2.

5.2 Inclined loads in panel caving pillars

Using the same rock parameters, a panel caving pillar of W/H = 2.5 was generated, and failure mechanisms were analyzed. Results showed that at 0° and 15°, the failure mechanism was primarily shear; while from 30° to 45°, it was a combination of shear and compression. From 60° onwards, the mechanism was more characteristic of compression failure. Finally, an increase in axial load component led to a concentration of shear deformations in tunnels (Figure 6).

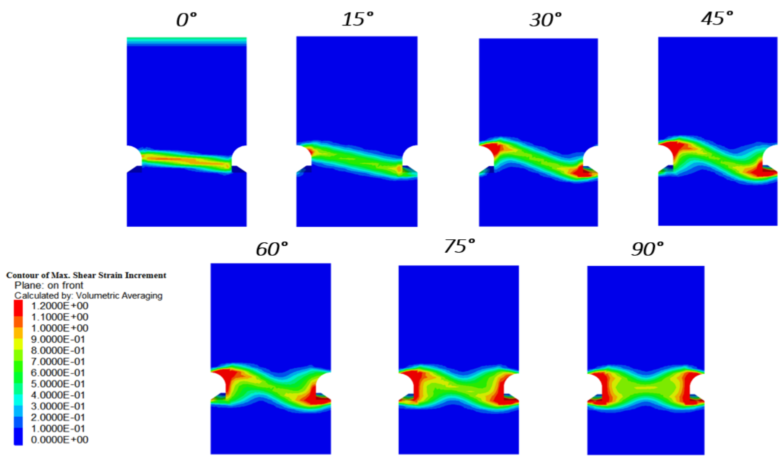

Figure 7. Contour of Max. Shear Strain Increment for pillar of panel caving with different plunge.

Finally, we can note that the fault envelope in Figure 7 shows that caving pillar experiences a significant drop in strength with low plunge angles. However, due to the W/H ratio used in these structures, the pillar is less susceptible to inclined loads and has greater confinement. Furthermore, there is an increase in the strength of the pillar from 45° onwards, reaching 90% of its maximum load capacity.

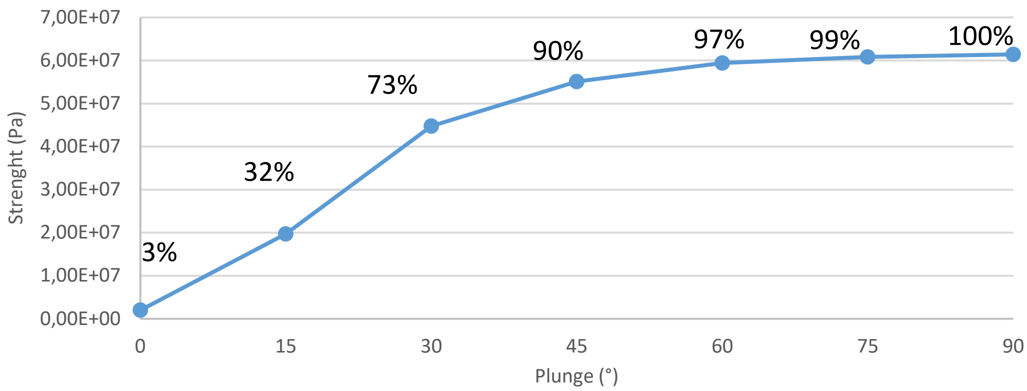

Figure 7. Strength envelope depending on the plunge for pillars of W/H de 0.5, 1, 1.5 y 2.

6 CONCLUSIONS

Throughout the article it was shown that at shear load (0° plunge) the pillars have the minimum strength and in axial load (90° plunge) the maximum. Also, that if the plunge is greater than 45 ° the strength will be at least 60% of the maximum load. It was also determined that the higher the W/H ratio there will be a substantial increase in strength because the confinement in the core is greater, something that favors the caving pillars. We can determine that a crucial factor for pillar stability is core confinement.

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