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A MODIFICATION LIMIT EQUILIBRUM SOLUTION FOR MINE BACKFILL ANALYSIS IN SEMI CUBE STOPE

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ABSTRACT

Mine backfill is a material that is used to fill the empty stope in an underground mine for ground control stability and to reduce ore dilution. Generally, the backfill consists of mining waste materials and ore tailings, which are added to a binder such as cement. Problems that often appear in the mining cycle using stope and backfill are the stability of the backfill on the primary stope when exposing the secondary stope. Previous researchers suggested analyzing the stability of the backfill on the narrow stope. In some cases, a semi-cube stope is often found. Obviously, the potential failure dimension, which acts as the driving force of the backfill in the semi-cube stope, is smaller than the narrow stope. This study was meant to develop a method for analyzing the stability of the backfill on the semi-cube stope by calculating the driving force according to the failure potential dimensions that could potentially occur and simulating it with numerical modeling using FEM.

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BACKGROUND

Extraction of mineral resources from the ground has caused surface subsidence and caving in many areas. Post caving problems due to underground mining have sponsored more responsible regulations, but the recognition that base minerals are depleting resources has produced a demand higher extraction ratio with less ore left underground to support mine openings (Mitchell et al., 1983). Mine backfilling is a method that has been used for decades in Canada and across the world. This method has several advantages such as stabilizing the drifts and stope of a mine and increasing worker safety (Levesque et al., 2017).

The type of backfill used an underground mine operation is dependent on several factor: the configuration of the mining process, the stope sequences, and excavation size determined by mining method, the depth and orientation of the orebody, and the materials available to use as backfill, focusing on tailings management requirements over the life of the orebody (Yilmaz & Fall, 2017).

Materials used as mine backfill or components of a fill mass are five types: run of mill concentrator tailings, used with a cementing agent to form paste fill; deslimed mill or concentrator tailings, or sandfill; natural sands; aggregates, development mullock and similar coarse, cohesionless media; and cementing agents of various types (Zhang et al., 2016).

To improve the ground stability conditions (as well as increase the ore recovery rate and reduce the ore dilution), mine stope are usually divided into primary and secondary stope. When the orebody is extracted from the primary stope, the voids created should be filled before the secondary stope are mined. Playing the role of man-made pillar or working space, the fill body in the primary stope must have a minimum strength to remain stable when one confining wall is removed during secondary stope mining operations (Li, 2014).

The proposed backfill analysis begins with the model of Mitchell (Mitchell et al., 1983) based on a validated boundary equilibrium analysis with a stability test box on a laboratory scale. The last modification (Li & Aubertin, 2014) by adding some validated parameters with a three-dimensional numerical simulation.

The solution of backfill analysis still considers that the stope analyzed is a narrow stope ($H \geq B \tan \alpha$) or high aspect ratio (HAR). In fact, some stopes are also lower dimensions or can be called semi cube stope ($H \leq B \tan \alpha$) or low aspect ratio (LAR). Li and Aubertin (2012) and Li (2014) have discussed solutions for analysis on LAR stope. However, in Li and Aubertin (2014) the previous proposal was modified without including a solution for analysis on LAR stopes. In this paper, wedge models have been proposed by (Mitchell et al., 1983). The methods proposed by Mitchell et al. (1982) and Li and Aubertin (2014) will be modified for use in the analysis of LAR or semi-cube stopes (Li & Aubertin, 2014; Mitchell et al., 1982).

NUMERICAL MODELLING

Numerical simulations have been performed using Finite element method with Rocscience program Phase2 to investigate the mechanical failure of backfill if the front wall exposed. The shear strength reduction method has been applied for this simulation to show the sliding plane when the backfill is failure. The stope geometry is height =13.6 m, width = 5.6 m and length = 10.8 m. The backfill properties-based Mohr-Coulomb failure criteria with plastic model are cohesion 33 KPa, frictional angle 30°, young's modulus 11.5 MPa, poison's ratio 0.3, tensile strength peak 0.0135 MPa and residual 0.01 MPa, dilation angle 0° and unit weight 0.016 MN/m3. The rock mass is considered plastic, with the properties is young's modulus 28 GPa, poison's ratio 0.26, cohesion peak 3.98 MPa and residual 2.98 MPa, friction angle 38°, tensile strength peak 0.04 MPa and residual 0.03 MPa, dilation angle 10°, and unit weight 0.027 MN/m^3.

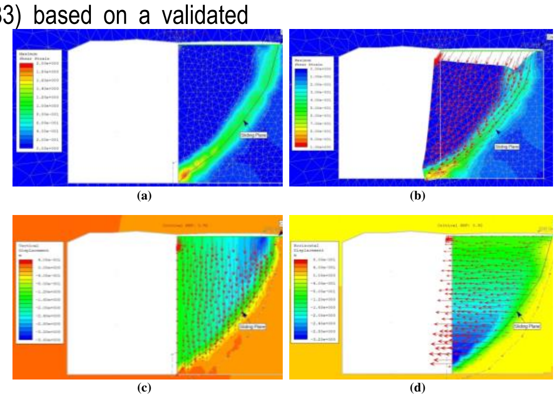

Figure 1. Numerical simulation results of backfilled semi cube stope with front wall exposed

Figure 3 shows the numerical simulation results using FEM with shear strength reduction has applied. The sliding plane can be determined by higher contour (Fig. 3a and 3b) which shows the maximum shear strain conditions have occurred in that area. The displacement showed by red arrow (total displacement for Fig 3b, vertical displacement for Fig 3c and horizontal displacement for Fig 3d) which the displacement only happened above the sliding plane. Examinations of the sliding plane indicates that it makes angle of about α≈55° to the horizontal. This value is somewhat lower than the value 60° given by the commonly used relationship (i.e. α=45°+30°/2=60°). From the figure above, the movement of the sliding block only happens in one zone, the triangular wedge block (lower block) and the crest is formed in front of back wall.

Based on the numerical simulations presented above and on recent experimental observations, the following assumptions are adopted to modify limit equilibrium solution for semi cube backfilled stope with front wall exposed:

a. The stope is low, and the shape resembles semi cube, i.e. H ≤ B tan α.
b. The sliding plane formed an angle α=45°+φ/2 with the horizontal.
c. Based on the dimension of block, weight of block in the semi cube stope lower than in the narrow stope.
d. The sliding plane doesn't cut the back wall, and the crest is formed in front of the back wall.
e. The modification is only based on dimension of block failure and the forces acting in the block failure is follow the previous researcher.

PROPOSE MODIFICATION SOLUTION

1. MODIFICATION MITCHELL SOLUTION

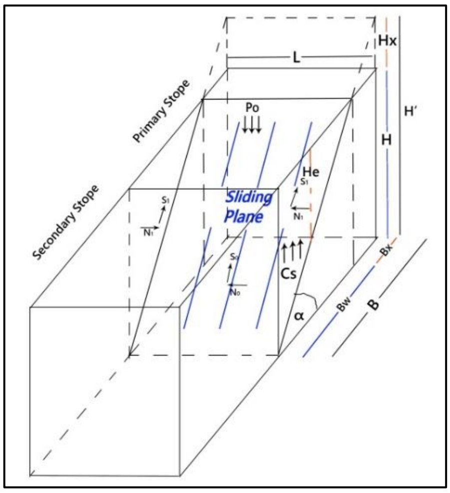

Figure 2. The modification Mitchell et al. solution for semi cube backfilled stope

Figure 4 shows the failure material backfill scheme of Mitchell et al.'s proposal for semi-cube stope. From the scheme it can be seen that the height of the stope filled by the backfill material dimensions smaller than the horizontal length multiplied by the Kristi's angle tangent (H ≤ L tan α) and the formation of the crest in front of the back wall (Lx) thus causing the dimensions of block failure on the semi-cube stope smaller than on the upright stope because the working field is only the field in front of the crest.
The following is an equation of Mitchell et al. solution modification:

$$H_x = B\tan\alpha - H \qquad (1)$$

$$B_x = \frac{H_x}{\tan\alpha} \qquad (2)$$

$$B_w = B - B_x \qquad (3)$$

$$H_e = H - \frac{B_w \tan\alpha}{2} \qquad (4)$$

$$\text{Weight of Block} = B_w \times H_e\,(\gamma L - 2C_s) \qquad (5)$$

$$FS = \frac{\tan\phi}{\tan\alpha} + \frac{2\,C\,L}{H_e\,(\gamma L - 2C_s)\sin 2\alpha} \qquad (6)$$

$$\text{UCS Minimum} = \left(\gamma - 2\frac{C}{L}\right)\left(H - \frac{B_w \tan\alpha}{2}\right)\sin\alpha\ (FS) \quad (7)$$

$$C = \frac{\gamma H}{2(\frac{H}{L} + \tan\alpha)} \quad (8)$$

2. MODIFICATION LI AND AUBERTIN SOLUTION

At semi-cube stope, the potential failure of mine backfill is only a wedge block so that the styles previously (Li & Aubertin, 2014) work only the styles found in wedge blocks (Figure 3). Therefore, the authors developed Li and Aubertin's proposal so that it can be used to analyze backfill material on semi-cube stope as follows:

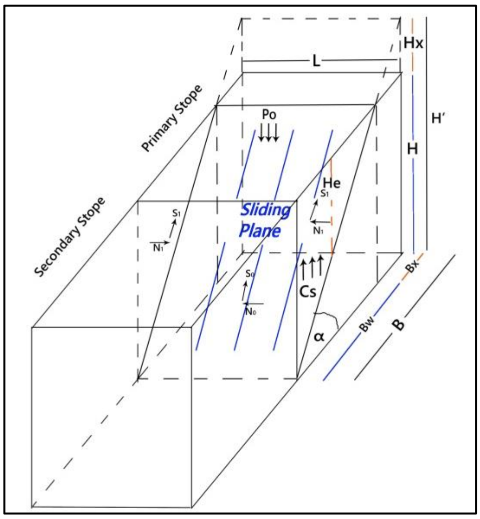

Figure 3. The modification Li and Aubertin solution for semi cube backfilled stope

$$H_x = B\tan\alpha - H \quad (9)$$

$$B_x = \frac{H_x}{\tan\alpha} \quad (10)$$

$$B_w = B - B_x \quad (11)$$

$$H_e = H - \frac{B_w \tan\alpha}{2} = \frac{1}{2}H \quad (12)$$

$$W_0 = \gamma\, B_w\, L\, H_e \quad (13)$$

$$K = \frac{1-\sin\phi}{1+\sin\phi} = \tan^2\left(45° - \frac{\phi}{2}\right) \quad (14)$$

$$M = 2K\left({B_w}^{-1} + L^{-1}\right)\tan\delta \quad (15)$$

$$N_1 = \frac{K}{M\tan\alpha}\left\{\left(\frac{\gamma}{M} - P_0\right)\left(\frac{1-\exp(-H\,M)}{M} - H\right) + \frac{\gamma H^2}{2}\right\} \quad (16)$$

$$S_1 = C_s\frac{H^2}{2\tan\alpha} + N_1\tan\delta \quad (17)$$

$$N_0 = (P_0\, B_w\, L + W_0)\cos\alpha \quad (18)$$

$$S_0 = \frac{C\,H\,L}{\sin\alpha} + N_0\tan\alpha \quad (19)$$

$$FS = \frac{S_0 + (2S_1)}{(P_0\, B_w\, L + W_0)\sin 2\alpha} \quad (20)$$

$$\text{Cminimum} = \frac{(D'P_0) + \left(\frac{A'\gamma H}{2}\left(1+\frac{L}{B_w}\right)\sin\alpha\right) - \left(\gamma\left(\frac{C'}{M} + \frac{H}{2}\right)\right)}{B'\left(1+\frac{L}{B_w}\right)} \quad (21)$$

$$A' = FS - \frac{\tan\phi}{\tan\alpha} \quad (22)$$

$$B' = \frac{1}{\cos\alpha} + r_s\frac{H}{L} \quad (23)$$

$$C' = \left(\frac{1-\exp(-M\,H)}{M\,H} - 1\right) \quad (24)$$

$$D' = A'\left(1 + \frac{L}{B}\right)\sin\alpha + C' \quad (25)$$

GRAPHICAL RESULT USING MODIFICATION SOLUTION

Figure 3 shows graphical correlation between factor of safety and curing time of backfill using modification Mitchell et al. solution for semi cube stope. The backfill has 19% cement content with several curing times and stope dimensions.

Figure 4 shows graphical correlation between factor of safety and curing time of backfill using modification Li and Aubertin solution for semi cube stope. The backfill has 19% cement content with several curing times and stope dimensions.

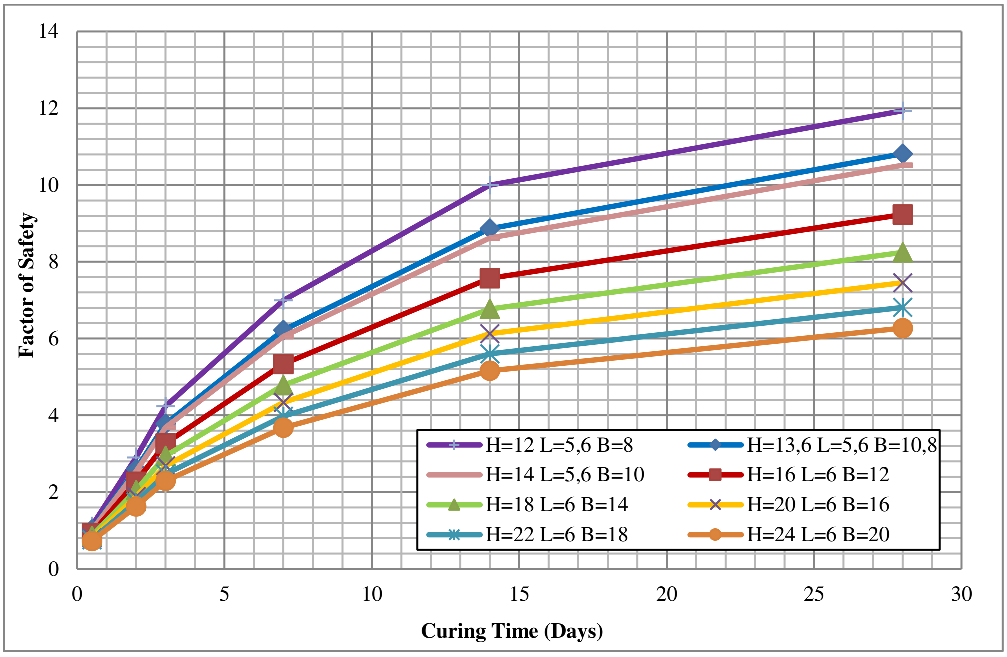

Figure 4. Graphical correlation CT and FS using modification Mitchell et al. solution

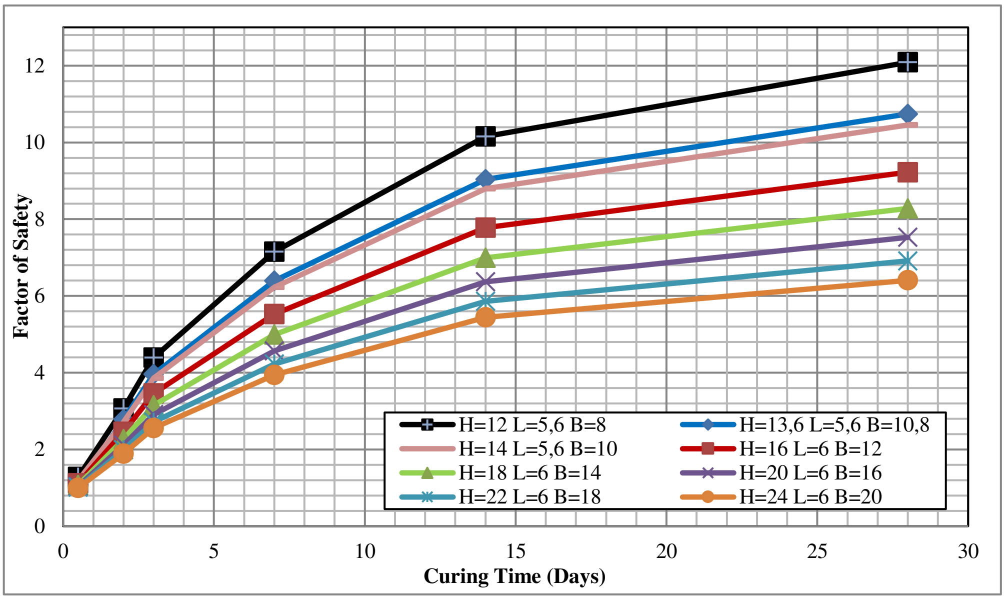

Figure 5. Graphical correlation CT and FS using modification Li and Aubertin solution

CONCLUSION

In this paper, the factor of safety obtained using the development of Li and Aubertin proposals tends to be higher and the minimum cohesion needed using the development of Mitchell et al. proposals tends to be higher because the forces that work on the potential block failure of li and Aubertin proposals have been considered and calculated as the role of these forces, while the development of Mitchell et all's proposal only focuses on the intrinsic properties of the CPB and the weight of the block failure that has the potential to occur

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