THE OPTIMAL BLOCK SIZE IN THE BLOCK CAVING MINING METHOD

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ABSTRACT

Nowadays along with population growth, industry development, consumption of mineral resources and the fact that the reserves on hand are running out, the depth of surface and underground mines for further exploitation are increasing. During recent years, in underground mining, the block caving method for low-grade and large-scale deposits has shown a growing rate of application. This method is very cost effective and economically affordable. The dimensions of blocks are one of the most important parameters which should be taken into account since it has been proved to have a great deal of effect on technical issues such as commencement of caving and mine design. Proper calculation of the length and width for a block in this method leads to proper caving and discharging which are the most important stages. Therefore, in this method, the calculation of the optimized dimensions (length and width) of blocks is not only important but also directly helps the productivity of extraction. In this study, firstly for the purpose of facilitation, some assumptions were considered and having used these assumptions for estimation of optimized length and width of block, a relationship based on rock mechanics and physics was explored. Furthermore, some necessary details were added to the said relationship and finally, it was transformed into an inequality. Solving this inequality provides us with the optimized length and width of the block. The explored relationship was analyzed with MATLAB software and the graphs thereof were drawn. In these graphs, each time one of the input parameters has been drawn up in a logical range so that it could be compared with previous states.

KEYWORDS

Block-caving, Cavability, Block size, Length and width of the block, Optimal block size in block caving

INTRODUCTION

In classification of underground mining methods, caving methods are regarded as high production methods. These techniques are usually very costly and need great preparation. However, the high production rate of these methods, make them cost-effective. The Block Caving method is an example of these methods, which is similar to surface mining methods in terms of production, in that the cost of production is low. Block caving is described by Laubscher (1994) as the lowest cost underground mining method provided that the extraction layout is designed to suit the caved material and the draw horizon can be maintained for the life of the draw [4]. A wide range of minerals including Gold, Copper, Diamonds, Iron and Nickel are produced using this technique in countries such as Canada, Australia, USA, South Africa, Sweden, Zambia and China [5]. The production scheduler aims to maximize the Net Present Value (NPV) of the mining operation whilst the mine planner has control over the development rate, vertical mining rate, lateral mining rate, mining capacity, maximum number of active drawpoints and advancement direction [6]. Block caving is based on material flow as a result of gravity. Northparkes was the first mine in Australia to use a variation of the cost-effective block cave mining technique in its underground operations. Northparkes is currently mining its third block cave mine. Block caving has allowed them to achieve very low mining costs and a high productivity by industry standards, mainly through the application of efficient automated material handling and comminution systems that minimizes ore re-handle, including high speed electric load haul dump units, jaw-gyratory crushers, high-speed conveyors and shaft hoisting systems [1]. In general, three exploiting systems are assumed for this method which are: Block Caving system, Panel Caving system and Mass Caving system. One of the most important factors to consider in block caving systems is the size of the blocks (length and width). The reason for this is the fact that the length and width of the blocks have a great impact on technical issues such as the design of the mine and the commencement of caving. By calculating the proper length and width for a block, we might achieve an appropriate caving and draw in this method. The optimum block length and width are the length and width for which it has always done and will not stop caving.

DESCRIPTION

This article aims to obtain the optimal width and length needed for the caving to be carried out in a way that it does not get interrupted and stopped. In order to achieve this, forces that are applied when performing caving, should be higher than the opposite forces. The influence of dimensions of the blocks at the start of the caving makes the importance of this study two-fold. Because the weight of the block − which is an intensifier of caving − is a function of the volume of the block and the surface area of undercut and the fact that the surface area is a function of the length and width of the block. As expected, any unsupported rock mass will cave if it is undercut over a sufficient area. Caving occurs for two reasons – gravity and the stresses induced in the crown or back of the undercut or cave. The mechanisms by which caving occurs will depend on the relationship between the induced stresses, the strength of the rock mass, the geometry and strengths of the discontinuities in the rock mass [2]. Therefore, it is important to obtain the right dimensions of the block. On the other hand, if the dimensions are too big, they cause the blocks to degrade rapidly and therefore make it unstable. This is due to the natural shape of the rock mass and fractures scads and joints and cracks in the system. Furthermore, a large surface area will cause the pressure on the roof of the tunnel to be increased and therefore make it unstable. The block size must be chosen in a way that provides safety and also timely caving of blocks without stopping.

ASSUMPTIONS

The first step to achieve the above aim is to make some assumptions. Based on these assumptions, in order to perform the caving method, the original relationship has been proposed. This relationship simply states the caving condition. Then, known influencing factors and boundary conditions were added to the equation. Sensitivity analysis was then carried out using the MATLAB software in order to analyze the obtained relationship.

The assumptions are as follows:

1. There is only one rectangular block length (x), width (y) and height (z) in the mine (Figure 1).
2. The whole block is assumed to be integrated. The rules of physics have been used to solve the equations. Figure 2 shows the way in which these rules have been applied in order to balance the forces involved.
3. All the results are related to the final shape of mines after fracture and caving at the end of the mine's life.
4. It is assumed that the subsidence has taken place at the end of the mine's life. Subsidence spreads in the long term with a slope of 45 degrees from the extracted blocks to the ground surface.
5. Fraction of the rectangular block is mineral with γ_1 density and the remaining is composed of γ_2 density.

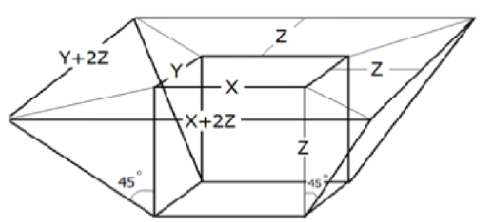

Figure 1 – Three-dimensional scheme of a Block

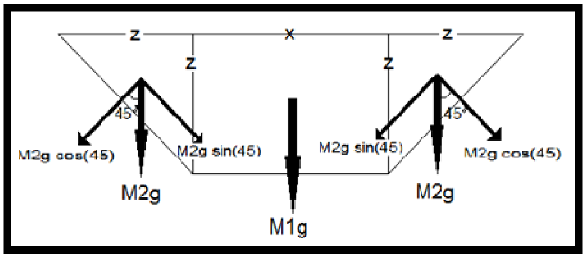

Figure 2– Vertical cross section of the block and the balance of forces

CALCULATION

In order to perform the caving method, the weight of the frustum (Figure 1) has to be more than the cohesion forces that exist on the four sides of the block which prevent it from falling. This is because apart from the weight of the block, the tailings above and around the block, there is no force to contribute to the collapse and caving is determined only by gravity. Therefore, in order to cave the block we have:

$$W_0 + W_c = W > \sum_{i=1}^{4} F_i \tag{1a}$$

$$F = C + \sigma_n . tan(\varphi) \tag{1b}$$

where, W_0 is the weight of the block, W_c is the weight of the tailings, C is the cohesion, σ_n is the horizontal normal, φ is the angle of internal friction and F is the Shear strength.

In the next step, the variables are added to equation (1). Block volume was calculated using geometric relationships; its density was multiplied to obtain the total weight of the block and the destructive forces. In order to make the dimensions equal, the cohesion factor was multiplied to the surface which it is applied to. The weight of the block is then used instead of the horizontal normal stress in order to convert all the relationships so that they are written according to Newton's laws. The above equation could now be modified as follows:

$$W > \sum_{i=1}^{4} F_i$$

$$x.y.h.\gamma_1 + x.y.\gamma_2(z-h) + 2\left(\frac{z^3}{3} + \frac{x.z^2}{2}\right).\gamma_2.\frac{\sqrt{2}}{2} + 2\left(\frac{z^3}{3} + \frac{y.z^2}{2}\right).\gamma_2.\frac{\sqrt{2}}{2} > 2\left[\sqrt{2}C.z.(z+x) + \left(\frac{z^3}{3} + \frac{x.z^2}{2}\right).\gamma_2.\frac{\sqrt{2}}{2}.tan(\varphi)\right] + 2\left[\sqrt{2}C.z.(z+y) + \left(\frac{z^3}{3} + \frac{y.z^2}{2}\right).\gamma_2.\frac{\sqrt{2}}{2}.tan(\varphi)\right] \tag{2}$$

After simplification, the above equation can be written as follows:

$$x.y\left(h\gamma_1 + \gamma_2(z-h)\right) - \begin{Bmatrix} 2\sqrt{2}C.z(2z+x+y) + \\ \sqrt{2}.\gamma_2\left[\frac{2z^3}{3} + \frac{z^2}{2}(x+y)\right](\tan(\varphi) - 1) \end{Bmatrix} > 0 \tag{3}$$

where, x is the length of the block, y is the width of the block, h is the thickness of the mineral, z is the depth of the mineral, γ_1 is the Specific gravity of mineral, γ_2 is the special gravity of the tailings, c is the cohesion and φ is the angle of internal friction.

This relationship is an inequality with two unknowns. Therefore, we need to define a condition in order to solve it. In the block caving method, it is always tried to design blocks as square shaped. However, rectangular blocks tend to be better designs for other applications, including transportation and draw points. Sometimes, the reserves also provide a way to design a rectangular block that is economical. Therefore, in order to solve the inequality, the ratio of width to length was assumed to be a constant parameter that depends on the designer's choice. Obviously, whenever this ratio becomes zero, the block is squared shape and the hydraulic radius is increased thus the caveability is increased as a result. The hydraulic radius is a term used in hydraulics and is a number derived by dividing the area by the perimeter. The hydraulic radius required to ensure propagation of the cave refers to the unsupported area of the cave back, that is, space into which caved material can move. No pillars can be left and caved material must be removed [3]. When the hydraulic radius (K) equals to 1, then caveability is at maximum.

$$k = \frac{y}{x} \rightarrow y = k.x$$

$$x.y\left(h\gamma_1 + \gamma_2(z-h)\right) - \left\{\begin{matrix} 4\sqrt{2}C.z^2 + 2\sqrt{2}C.z(x+y) + \\ \frac{2\sqrt{2}}{3}.\gamma_2.z^3.(\tan(\varphi)-1) + \frac{\sqrt{2}}{2}.\gamma_2.z^2(x+y)(\tan(\varphi)-1) \end{matrix}\right\} > 0 \quad (4)$$

$$k.x^2\left(h\gamma_1 + \gamma_2(z-h)\right) - \left\{x.\left(\frac{1+k}{2}\right)\left[4\sqrt{2}C.z + \sqrt{2}.\gamma_2.z^2(\tan(\varphi)-1)\right]\right\} - \left[4\sqrt{2}C.z^2 + \frac{2\sqrt{2}}{3}.\gamma_2.z^3.(\tan(\varphi)-1)\right] > 0 \quad (5)$$

And each square is equal in length and width and we have:
K=1

$$x^2\left(h\gamma_1 + \gamma_2(z-h)\right) - x\left[4\sqrt{2}C.z + \sqrt{2}.\gamma_2.z^2(\tan(\varphi)-1)\right] - \left[4\sqrt{2}C.z^2 + \frac{2\sqrt{2}.\gamma_2.z^3}{3}(\tan(\varphi)-1)\right] > 0 \quad (6)$$

THE ULTIMATE RELATIONSHIP

Relationship number (7) shows the overall calculation of the optimal block size with respect to the conditions above:

$$k.x^2\left(h\gamma_1 + \gamma_2(z-h)\right) - \left\{x.\left(\frac{1+k}{2}\right)\left[4\sqrt{2}C.z + \sqrt{2}.\gamma_2.z^2(\tan(\varphi)-1)\right]\right\} - \left[4\sqrt{2}C.z^2 + \frac{2\sqrt{2}}{3}.\gamma_2.z^3.(\tan(\varphi)-1)\right] > 0 \quad (7)$$

The above equation is a quadratic inequality unit age length where the ratio of width to length has also been considered. For any one mine, conditions such as depth, thickness, mineral and gangue mineral density, cohesion and internal friction angle could be added into the above equation and as a result, the optimal block length for the mine can be achieved.

ANALYSES OF THE DIAGRAMS

Changes In Length Versus Depth According To Cohesion Variation

In the diagram of Figure 3, it is assumed that all parameters are fixed. However, the depth and the cohesion can be changed. It should also be noted that the ratio of length to width is considered to be 1 (k=1). In this diagram (Figure 3), the horizontal axis shows the depth and the vertical axis shows the block length. Each line presents a value of the cohesion that is drawn from 1–1.5 MPa. As it can be seen, proposed length to a depth of 600 m with a 1.3 MPa cohesion is about 55 m and proposed length to the 1.4 MPa cohesion is more than 10 0 m.

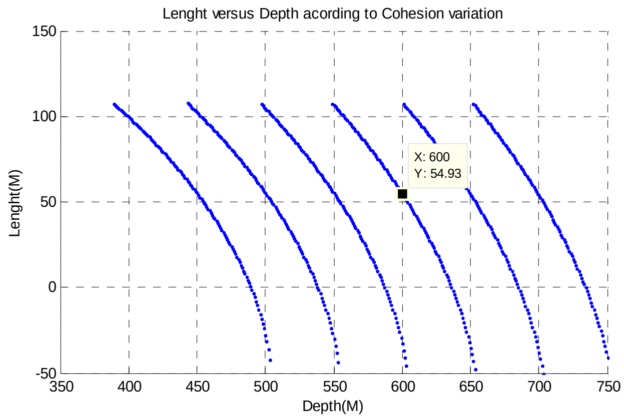

Figure 3 – Changes in length vs. depth according to cohesion variation

Changes in length vs. depth according to y/x variation (K)

In Figure 4 below, each line illustrates a ratio of width to length − which varies in the range of 0 to 1− with distance of 0.2 (which is changeable). It is observed that when the ratio is closer to zero, the block length is larger because the block has changed its shape to a rectangular shape and therefore it is less destructible. Therefore, the length should be greater so that as a result the weight of the blocks becomes heavier and caving is carried out.

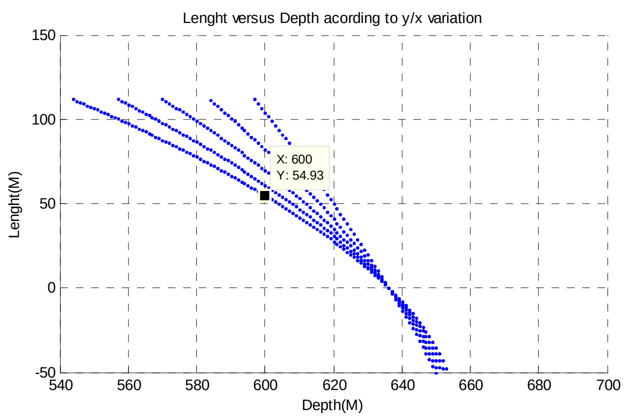

Figure 4 – Changes in length vs. depth according to y/x variation (K)

Changes in length vs. depth according to the angle of internal friction variation

In Figure 5, the internal friction angle varies between 20 and 30 degrees, which shows that it is directly related to the length of the block. This means the proposed length is increased with an increase in the internal friction angle, and vice versa. The reason for this is that the resistance forces are increased as a result of an increase in the internal angle of friction. Therefore, in order to overcome these forces, the block weight becomes heavier.

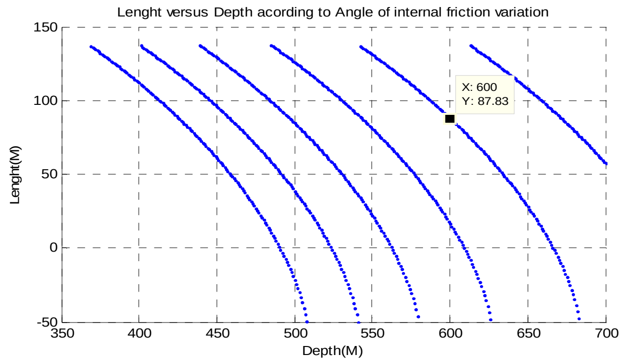

Figure 5 – Changes in length vs. depth according to angle of internal friction variation

Changes in length vs. depth according to mineral density variation

Figure 6 shows that the mineral density does not influence the length of the block. Furthermore, there were no significant changes in the proposed length. This can be due to the small proportion of mineral blocks as weights. Because in this example, it is assumed that the mineral thickness is 100 m and the depth is 600 m. Therefore, the impact of mineral density is far less. It should be noted that in this diagram, mineral density changes between 25–50 KN/m^3.

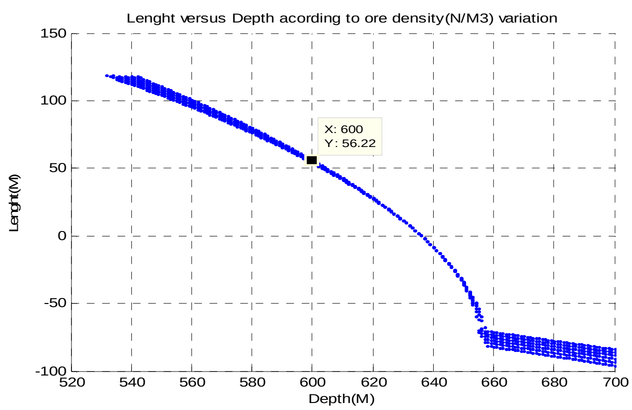

Figure 6 – Changes in length vs. depth according to mineral density variation

Changes in length vs. depth according to gangue density variation

Unlike Figure 6, in Figure 7 it is evident that the variation of gangue density plays an important role in the proposed block length. This is because of the fact that a large proportion of the blocks weight is composed of gangue. Whenever the gangue density becomes higher, the length of the block becomes smaller. These changes in the following diagram are between 25 and 35 KN/m^3.

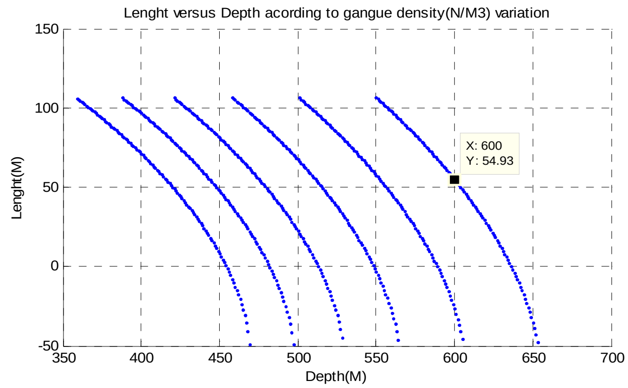

Figure 7 – Changes in length vs. depth according to gangue density variation

Changes in length versus depth according to thickness of the mineral variation

The thickness of the block does not have a big influence on the length of the block. In Figure 8, the thickness of the mineral varies between 100 and 200 m.

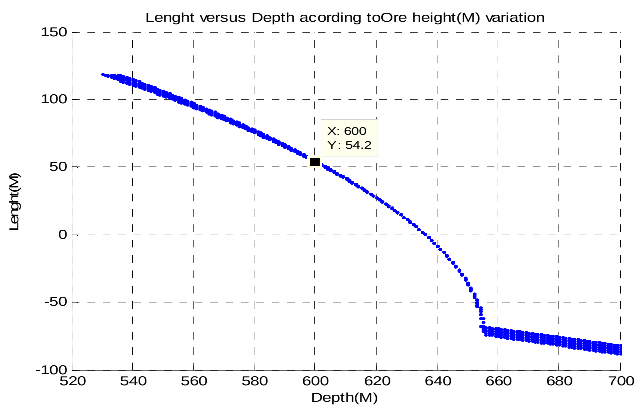

Figure 8 – Changes in length vs. depth according to thickness of the mineral variation

CONCLUSIONS

In order to perform caving, instability forces should always be greater than stability force. Thus, based on this, the length and width of the block can be achieved by solving the inequality that has been presented in this paper. Regarding the presented relationships, sensitivity analysis was carried out on various parameters such as cohesion, internal friction angle, mineral thickness, density and mineral gangue. The analysis showed that mineral thickness and density had the least effect. The impact of hydraulic radius on caving showed that square blocks are best suited for caving. While using square blocks, the relationship becomes a quadratic inequality with one unknown which is easy to be solved. However, in the case of rectangular blocks, the ratio of length to width (parameter K) is calculated graphically which has been presented in this paper in different lengths according to the depth of the block which comes in various widths.

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