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Illumination of parameter contributions on uneven break phenomenon in underground stoping mines

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ABSTRACT

One of the most serious conundrum facing the stope production in underground metalliferous mining is uneven break (UB: unplanned dilution and ore-loss). Although the UB has a huge economic fallout to the entire mining process, it is practically unavoidable due to the complex causing mechanism. In this study, the contribution of ten major UB causative parameters has been scrutinised based on a published UB predicting artificial neuron network (ANN) model to put UB under the engineering management. Two typical ANN sensitivity analysis methods, i.e., connection weight algorithm (CWA) and profile method (PM) have been applied. As a result of CWA and PM applications, adjusted *Q* rate (AQ) revealed as the most influential parameter to UB with contribution of 22.40% in CWA and 20.48% in PM respectively. The findings of this study can be used as an important reference in stope design, production, and reconciliation stages on underground stoping mine.

1. Introduction

In underground metalliferous mining, stoping is the most commonly utilised mining method among various others. Adoption of stoping method has been steadily increased due to the ability to mechanisation into larger scale and the flexible applicability to various ground conditions. Many researchers have been reporting the popularity of stoping method. According to Pakalnis et al. [1], open stoping method accounts for half of underground metalliferous mine production in Canada. Once again, Pakalnis and Hughes [2] noted that in excess of 60% of underground mine production in North America relies on sublevel stoping method. Additionally, after investigation on major metalliferous underground mines in Australia, Jang et al. [3] reported that over 85% are operating by various stoping methods.

In spite of the popularity of stoping method, most of the mines are suffering from excessive dilution and ore-loss. Dilution and ore-loss can be simply defined as unwanted influx and remaining materials into planned ore production and in stope even after the production. These phenomena can be broadly classified into planned and unplanned which have been illustrated along with the stope production procedures in Fig. 1. As shown in Fig. 1b and d, planned dilution and ore-loss are determined at the stope planning stage while unplanned dilution and ore-loss can be confirmed after stope production.

Both planned and unplanned dilutions are basically unavoidable. Indeed, planned dilution and ore-loss can be minimised on the stope planning stage by thorough consideration to maximise net profit but not completely eliminated. Likewise, unplanned dilution and ore-loss are inevitable as long as stope is excavated by drilling and blasting method. In fact, the most important task to maximise the productivity of stope production is reducing unplanned dilution and ore-loss. To minimise the unplanned dilution and ore-loss, the causing mechanism and contributions of influencing parameters must be comprehensively investigated in preference.

The aim of this study is to illuminate the causing mechanism of unplanned dilution and ore-loss (uneven break: UB) based on a published uneven break prediction artificial neural network (ANN) model by Jang et al. [3]. The ANN model has been developed through comprehensive investigations on 1067 stope production results from underground mines in Western Australia. Justifications of choosing the uneven break prediction ANN model are; the model achieves the statistical significant with the correlation coefficient of 0.719 with ten major UB causative factors and is the unique model that covers both unplanned dilution and ore-loss simultaneously.

The remainder of this paper is divided into four sections. Section 2 reviews previous studies on uneven break phenomenon.

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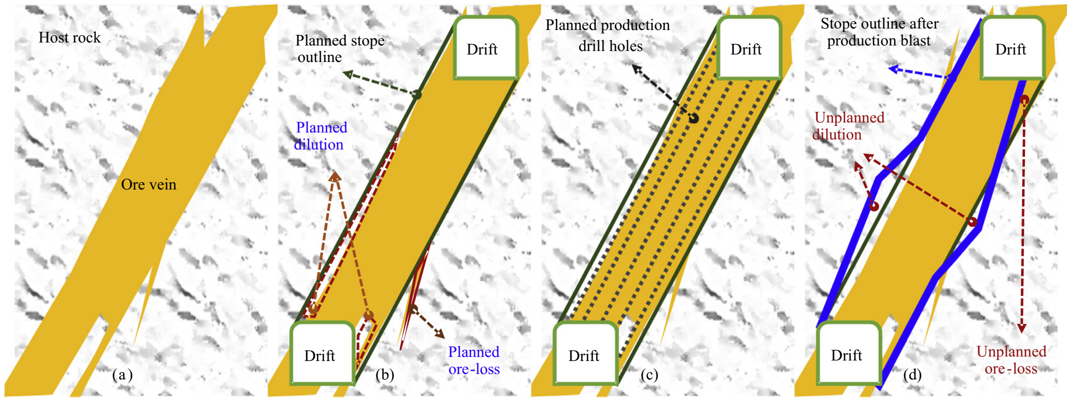

Fig. 1. Schematic view of dilution and ore-loss throughout stope production stages (a) an example of ore vein shape, (b) stope production plan, (c) production drilling plan, (d) stope after production.

Section 3 expounds the published UB prediction ANN and analyse the parameter contributions with representing essential findings. Subsequently in Section 4, the study will be concluded with comments on proper UB management system in underground stoping mines, and future works.

2. Uneven break management in underground stoping mines

Minimising uneven break (UB) in stope production is one of the most challenging tasks but cannot be abandoned. Because it is directly influencing not only to the productivity of stope production but also the profitability throughout whole mining operations. For instance, the inflexed low grade and waste material contaminate and downgrade the planned ore stream that burdens production cycles with extra mucking and hauling. Also, the remaining ore-loss in stope directly causes a diminution in productivity and often requires secondary blasting. The uneven break is difficult to manage because of its highly complex causing mechanism that is associated with most of all conditions of underground stoping, such as geological and geotechnical characteristics of ore and host rock, physical shape of stope, blasting plan and geometry, stope production sequences, and human errors during planning and production.

Since the uneven break is considered as an inevitable phenomenon, the aim of uneven break management in underground stoping mine is its minimisation but not complete prevention. Notwithstanding the contributions of numerous researchers, most of mines still rely on experienced engineers' intuitions and/or previous stope reconciliation results. Some of empirical models have been introduced however these models consider either the unplanned dilution or ore-loss with a few particular causative factors. As the phenomenon occurs under a highly complex mechanism, the majority of studies has been limited to unplanned dilution but not ore-loss.

In 1997 at the Louvicourt underground mine in Canada, Germain and Hadjigeorgiou [4] attempted a linear regression analysis to examine relations of unplanned dilution in stope production with a stope blasting related parameter (powder factor) and a geotechnical parameter (Q-value [5]). The result only reconfirmed the complexity of the mechanism with less than 0.3 of correlation coefficient.

Stewart et al. [6] investigated the stress effects on unplanned dilution at the Kundana gold mines in Western Australia. After observing 410 stope productions, authors founded that more than 50% of over break had happened in where the stress had exceeded the damage criterion. The study found the significant influence of stress on unplanned dilution.

A quantitative unplanned dilution prediction model was introduced by Pakalnis [7] based on 133 observations on an open stoping mine located in Northern Manitoba, Canada. The model predicts the percentage of potential unplanned dilution on stope wall based on two geotechnical parameters, i.e., hydraulic radius and rock mass rating (RMR) [8,9] within three different stope domains i.e., isolated, adjacent rib, and echelon. However, the model cannot be practically adopted due to several crucial drawbacks, such as the insufficient coverage of dilution causing parameters and the limitation on using regional datasets.

Another empirical method, 'the critical span cave', was introduced by Lang [10] to analyse the stope stability. The critical span curve method was first introduced for back stability analysis in cut and fill stoping mines. The initial method has been improved upon by researchers at the University of British Colombia by expanding the datasets up to 292 case studies. The definition of the 'critical span' is the diameter of the largest circle of unsupported back in the stope and the stability of the stope back is related to the designed unsupported span. The stability of a stope back is classified as stable, potentially unstable, and unstable by plotting designed critical span of stope with the rock mass rating (RMR) system. The method has been limitedly adopted in some Canadian mines. However, application of this method required a careful consideration with extensive pre verification processes as a consequence of its foundation with regional data and does not accounts blasting and stress related conditions.

The most frequently used unplanned dilution management system is the stability graph method [11–13]. This method is used to estimate the stability of stope wall by plotting a stability number (N) against a hydraulic radius (HR: area/perimeter of the stope wall). The stability number is an integrated geotechnical factor that has been modified by Potvin [12] and is defined as:

$$N' = Q' \times A \times B \times C \tag{1}$$

where N' presents the modified stability number, Q' is the modified Q-value, and A, B, and C are factors that stand for the stress, the joint orientation, and the gravity respectively.

The stability graph method has been widely adopted due to the simplicity of its management. Nevertheless, the capability of managing unplanned dilution is mostly unreliable as it only counts for few geotechnical factors but no other universal factors, i.e., blasting and far field stress factors [14,15]. Fig. 2 shows stability graph method analysis of 134 stope walls in an underground stoping mine in Western Australia.

In Fig. 2, although the vast majority of data points are located in the stable zone of supported transition line, unplanned dilutions are chaotically tracked. In other words, the unplanned dilution