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Statistical analysis of the stability number adjustment factors and implications for underground mine design

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1. Introduction

The Mathews method[1] is widely used in underground hard rock mines in order to design open stopes and evaluate the stability of their geometry. The method consists in the construction of a stability graph that relates two calculated parameters: the shape factor, S and the stability number, N. The stability number N represents the ability of the rock mass to resist under a given stress condition. The shape factor S, or hydraulic radius, takes into account the size of the stope faces. The combination of these two parameters defines the stability of planned excavations. Four stability zones have been defined.[4] First, the *Stable Zone* represents the excavation which stand unsupported, or with localized support. Then, the *Failure Zone* represents the excavation where localized unravelling occurs, but a stable arch forms. Modifying the design or installing cable support may reduce the extent of the unravelling. The *Major Failure Zone* represents the cases where the extent of back or wall failure was greater than about fifty per cent of the smaller dimension of the opening. Finally, the *Caving zone* is defined. The cases falling in this zone indicate that the face of the stope under consideration is probably unsupportable and will fail and continue to fail until the void is completely filled or surface breakthrough occurs, i.e. a true caving situation.

The shape factor, S, and the stability number, N, are defined as follows:

$$S(m) = (\text{stope face area})/(\text{stope face perimeter}) \quad (1)$$

$$N = Q' \times A \times B \times C \quad (2)$$

where Q' is defined by[3]:

$$Q' = (RQD/J_n)(J_r/J_a) \quad (3)$$

and where RQD is the rock quality designation, J_n is the joint set number, J_r is the joint roughness number, and J_a is the joint alteration number. In Eq. (2), A, B, and C are respectively defined as the stress factor, the joint adjustment orientation factor, and the gravity factor. The rock stress factor, A, is a function of the ratio between the intact rock uniaxial compressive strength, σ_c, and the induced compressive stress, σ_1, estimated at the center of the stope face by

$$\text{ratio} = \sigma_c/\sigma_1 \quad (4)$$

The induced stress σ_1 can be found by numerical stress analysis or estimated from published stress distributions. The rock stress factor is determined from an empirical chart (Fig. 1a). The joint orientation adjustment factor, B, is a function of the relative difference in dip angle between the stope face and the critical joint set affecting stability (α), and is estimated using Fig. 1b. The gravity adjustment factor, C, reflects the stability of the orientation of the stope face under the influence of gravity, and it is determined from Eq. (5) or Fig. 1c.

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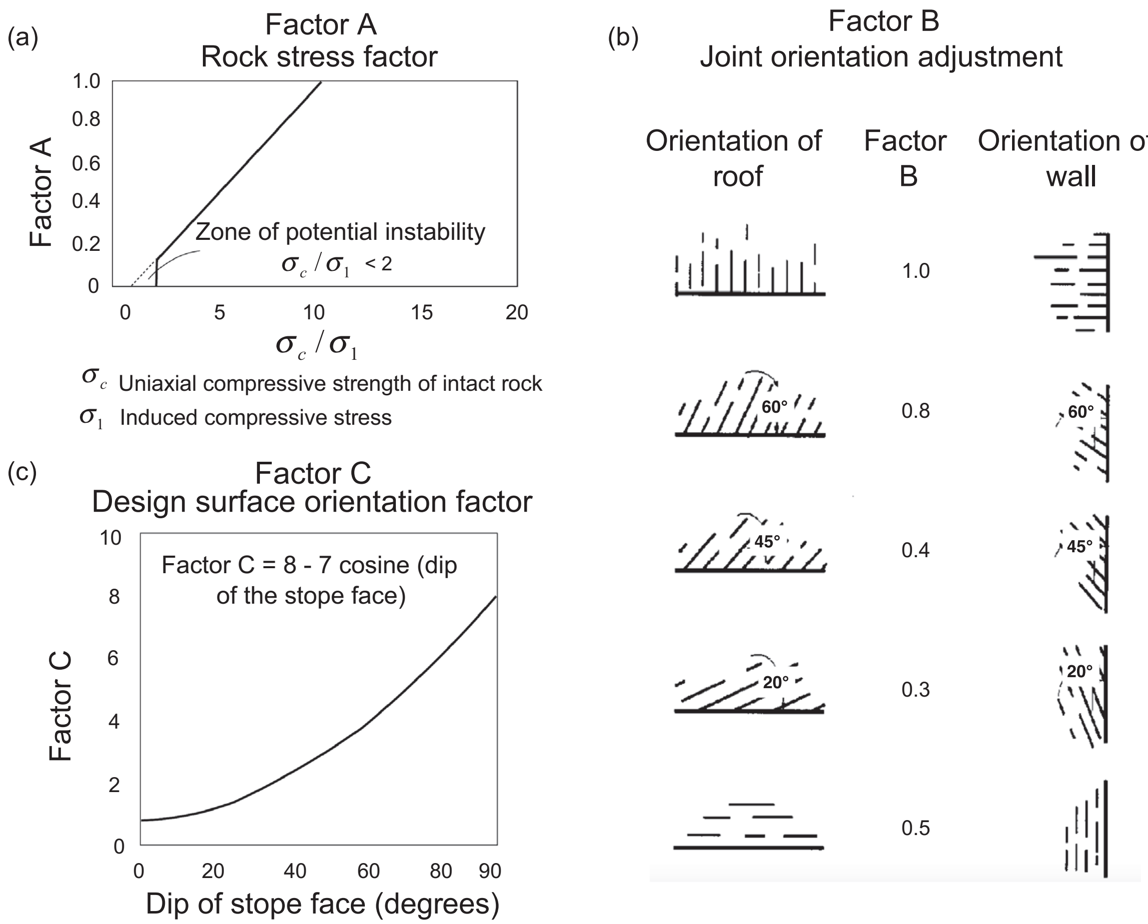

Fig. 1. Adjustment factors for determination of the Mathews stability number.[1]

$$C = 8\text{–}7\ \cos(\text{dip of stope face}) \tag{5}$$

As an empirical method, the stability graph presents some limitations. The most significant ones are[4]: the subjectivity in the definition of the stability zones, the absence of standardization of the extended database,[5] the non-representation of the rock stress factor, *A*, for instabilities caused by low confinement conditions, and the poor representation of the sliding failure modes by the gravity adjustment factor *C*. In the past three decades, several studies have addressed these limitations. Redefinition of the transition zones[2,6] and statistical analysis using a Bayesian likelihood statistic[7] have been proposed. The extension of the stability database[1] allowed to define statistically the Stable/Failure and Failure/Major-Failure boundaries using logistic regression.[8]

Modifications of the *A*, *B*, and *C* factors have also been proposed.[2,9–11] However, none of these studies have evaluated the impact of the proposed modifications on the performance of the method. Thus there is no evidence that the modifications are statistically significant.

Stewart and Trueman[12] investigated the goodness of the fit of logit models for different versions of the rock stress factor *A* for low stresses. Five rock stress factors were included in the analysis: the original Mathews stress factor, the Diederichs and Kaiser modified stress factor,[13] a reflected stress factor, Stewart's modified stress factor, and a fixed stress factor of 0.5.[5] This study concluded that the alternative stress factors did not improve the performance of the stability boundaries defined relative to the original stress factor.

Mawdesley et al.[18] used logistic regression to improve the definition of the stability boundaries. Three stability zones were defined: stable, failure and major failure. In a further study, Mawdesley[5] concluded that the failure – major failure boundary could not be correctly determined from the statistically analysis. Therefore, only the stable state from the other states of stability can be properly identified.

In this paper, statistical analysis is used to evaluate the performance and significance of the factors *A*, *B*, and *C* leading to the calculation of the stability number *N*. Based on a literature review and to the author's knowledge several adjustment factors are tested. The impact of these factors on the performance of the stable boundary is evaluated using a contingency matrix and a performance metrics analysis. The indicator of performance (Peirce Skill Score[14]) of the model, obtained for different combination of factors of adjustment, is maximized to define the most representative boundary of stability. The extended Mathews database[8] is considered as the reference for the analysis. The results lead to the proposal of a new rock stress factor that is less conservative than the original one for high stress conditions. The performance evaluation of different *B* and *C* factors did not improve the significance of the stability graph method compared to the original. The implications for underground mine design are evaluated and discussed in the last part of the paper.

2. Modifications to the stability number

The first modification of the stability graph method was proposed by Potvin[9] after collecting a significant amount of case histories for a range of mining depths (175 cases histories from 34 mines). The rock stress factor, *A*, is based on the proposal of