Automated and digitalized web tool for open stope design

Yerkezhan Madenova
Nazarbayev University, Astana, Kazakhstan
Los Alamos National Laboratory, Los Alamos, NM, USA (Current)

Fidelis Tawiah Suorineni
Nazarbayev University, Astana, Kazakhstan

Shuai Xu
Northeastern University, Shenyang, People's Republic of China

ABSTRACT: The Stability Graph is a widely used method for open stope design to control dilution in underground mining. The method considers several factors, which are determined from different empirical graphs and require additional computations. The manual application of the Stability Graph is time-consuming and has the potential to cause computational and human subjectivity errors in open stope stability prediction. The Stability Graph is developed empirically, and its reliability increases with increased data size and quality. However, its current application does not allow data sharing between practitioners that use the method in the mining industry. This work presents the digital analogous of the Stability Graph method through a web application, which is built to ease its use and eliminate limitations. The web-based tool for open stope design is named StopeSoft and is available at openstope.com. StopeSoft provides several benefits to users compared to the traditional Stability Graph including case history data sharing.

Keywords: Open stope, Stability Graph, StopeSoft web tool, automation, digitalization.

1 INTRODUCTION

In underground mining, open stoping is one of the economic mining systems with large non-entry voids known as stopes designed for mass extraction of ore. The stability of these open stopes is of significance due to potential dilution problems. The Stability Graph was developed by Mathews et al. (1981) for managing dilution at depths below 1000 m more than four decades ago. The Stability Graph is an implicit three-dimensional plot of a stability number, either original (N) or modified (N') in a y-axis, and a shape factor (S) also referred to as hydraulic radius (HR) in an x-axis. N' and HR are defined according to equations (1) and (3). The third implicit axis is the stope surface stability states defined by the transition boundaries on the Stability Graph as Stab. Figure 1 shows a recently Refined Stability Graph (Madenova & Suorineni 2020).

$$N' = Q' \times A \times B \times C \qquad (1)$$

$$Q' = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \tag{2}$$

$$HR = \frac{Area}{Perimeter} \tag{3}$$

Where Q′ is a modified tunnelling quality index (Q) defined by Eq. (2), in which RQD is a 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 (Barton et al. 1974). Q' is the original Q assuming dry rockmass conditions and setting stress reduction factor (SRF) to unity. The letters A, B, and C are stability number adjustment factors known as a stress factor, joint defect factor, and gravity factor, respectively. The empirical charts for determining the original and modified adjustment factors can be found in Mathews et al. (1981) and Potvin (1988), respectively.

A wide industrial application of the Stability Graph method was triggered by its modification by Potvin (1988), who increased the case history data used in the development of the concept of the graph from 26 to 175 and recalibrated the stability number adjustment factors as a result. During forty years of its existence, the Stability Graph has been subjected to several changes and improvements mainly by expanding the case history data (Mawdesley et al. 2001), redefining the stope stability states transition boundaries (Nickson 1992; Trueman & Mawdesley 2003; Madenova & Suorineni 2020), calibrating existing adjustment factors and proposing new ones (Hadjigeorgiou et al. 1995; Diederichs & Kaiser 1996; Suorineni 1998; Suorineni et al. 1999a, b; Mitri et al. 2011). A comprehensive and critical review and discussion of important issues regarding the Stability Graph can be found in Suorineni (2010).

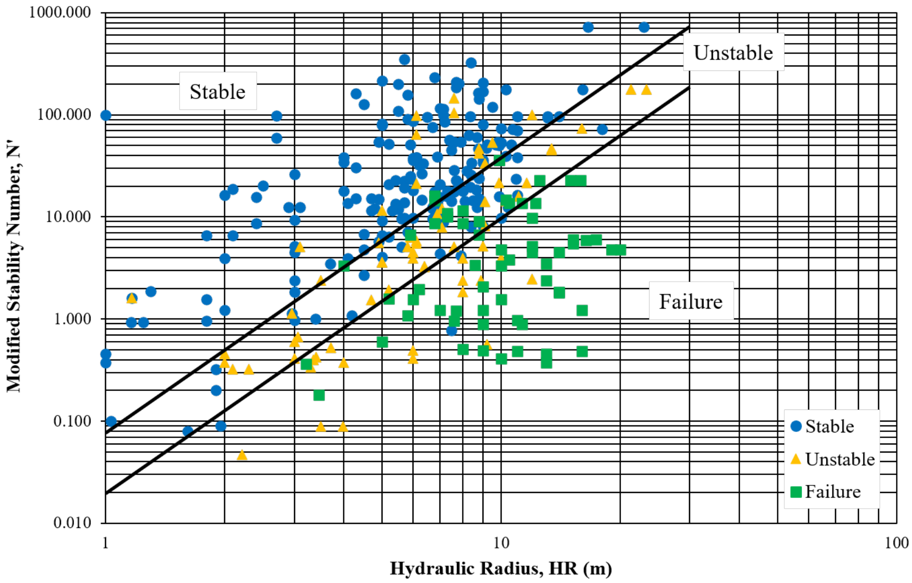

Figure 1. The Refined Stability Graph (Madenova & Suorineni 2020).

Despite the numerous improvements made to the Stability Graph since its inception, it still has some limitations. The challenges associated with the present form of the Stability Graph include the following: 1) Each stope surface requires an independent stability assessment, which is time-consuming; 2) The use of multiple adjustment factor charts prior to the stability number computation might include human subjectivity, that affect the stope stability prediction outcome. 3) Two schools of thought exist in the use of the Stability Graph. One school prefers using the original factors by Mathews et al. (1981), while the other favors the modified stability number adjustment factors by Potvin (1988). Several versions of the Stability Graph also exist. There are no guidelines for users on which version of the Stability Graph or factors to use. 4) The Stability Graph is an empirical method, in which reliability and accuracy are directly proportional to the data size and quality. The current form of the Stability Graphs limits case history data sharing among its users. 5) Adjustment factors such as the fault factor (Suorineni 1998) and time factor (Tannant & Diederichs 1997) were proposed to account for their effect on the open stope stability, but remain unpopular despite their significant impact on open stope stability. This paper presents an automated and digitalized web tool that was developed with the aim of eliminating these limitations of the Stability Graph in open stope design.

2 AUTOMATED AND DIGITALIZEDWEB TOOL FOR OPEN STOPE DESIGN

The Stability Graph constitutes the base of the web tool that is herein referred to as StopeSoft. The web nature of StopeSoft enables to tackle the current drawbacks in the use of the Stability Graph and provides a versatile and solid solution for a wide audience in the mining industry and academia. The key function of StopeSoft, which is to predict open stope surface stabilities efficiently and reliably, can be accessed from the home page and consists of multiple components. This digital analogous of the Stability Graph has several advantages over its manual counterpart. These can be explored in the next section. Besides the primary part, StopeSoft includes the general information part, contact page, and data sharing module. The general information provides the background on the Stability Graph, its components, and variations as well as the logic behind all computations of the open stope stability prediction. The contact page can be used to reach out to the authors for technical support and feedback. The data sharing module allows users to contribute towards the stability graph database expansion by sharing their case history data.

3 THE KEY COMPONENTS OF STOPESOFT

The primary part of StopeSoft is intuitively structured based on of the Stability Graph, namely, it consists of computations of HR, modified Q, stress analysis, adjustment factors, and the probabilistic prediction of the open stope surface stability as shown in Figure 2.

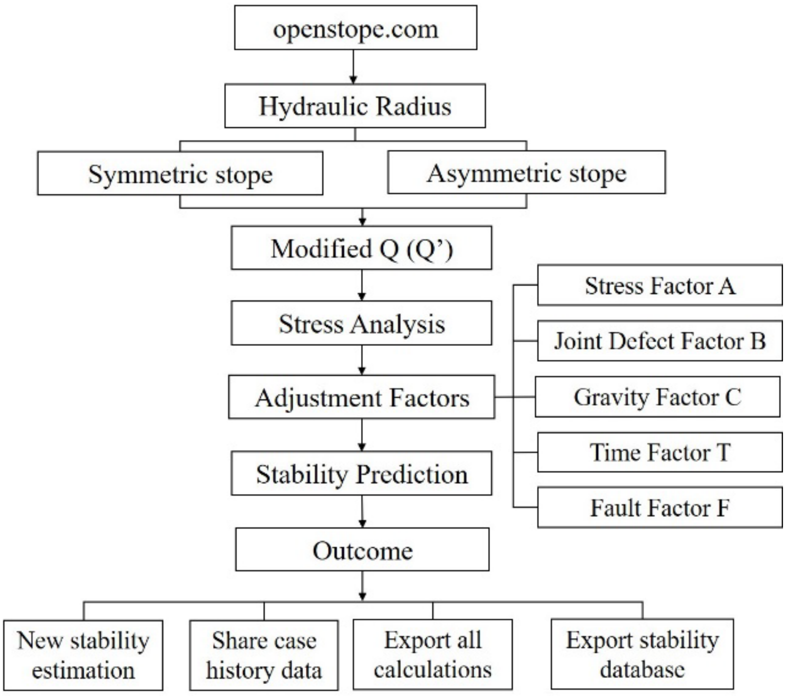

Figure 2. StopeSoft structure for the open stope stability prediction.

3.1 Hydraulic radius and modified Q

Open stope stability assessment starts from the HR calculation in StopeSoft. One of two stope geometries can be selected to calculate the HR of stope surfaces. Symmetric stope implies a rectangular prism, while asymmetric stope assumes a trapezoidal prism. Providing the dimensions of the selected stope allows to calculate the HR of each stope surface simultaneously. Irregular trapezoidal stope option gives users an alternative because in underground mines, stopes can deviate from the regular rectangular forms. After the calculation of HR, modified Q is estimated according to Eq. (2). Depending on the users' need, modified Q can be calculated either for a single stope surface (i.e., crown or hangingwall) or for all stope surfaces. If the rock properties of each stope surface are different, modified Q' for all stope surfaces is calculated separately by adding a new stope surface and corresponding rock properties, otherwise, one can choose the same rock characteristics for all stope surfaces. Thus, StopeSoft enables the calculation of HR and modified Q for each stope surface instantly and simultaneously, which makes it more versatile compared to the classical application of the Stability Graph, which is limited to a single stope surface evaluation at a time.

3.2 Stress analysis

Stress analysis is a prerequisite for calculating the stress factor A and it follows the modified Q calculation in StopeSoft. Two options are provided to estimate the induced stresses at the stope faces: directly providing in-situ stresses or calculating them using Young's Modulus and stope depth below ground surface. The latter is more applicable at the initial stages of the mining projects when stress tensors from in-situ measurements are not readily available. The stress analysis in StopeSoft is based on Mathews et al. (1981) and requires vertical and horizontal stresses and stope surface span to height ratio to evaluate the induced stress at mid-surfaces of the stope. Automation of the induced stress calculation at each stope surface through the integration of the multiple stress analysis equations into the StopeSoft greatly reduces the potential human error. The synchronous calculation of the induced stress for each surface also facilitates the stope stability prediction process consuming less time. It should be noted that more than 75% of all hangingwall and footwall data in the refined database come from the stress environment where the major principal stress is in the horizontal direction. Thus, caution should be taken when using the StopeSoft with data derived from environments where the maximum stress is vertical. More details on this issue are discussed in Suorineni (2010).

3.3 Stability number adjustment factors

Upon finding the induced stresses at the stope surfaces, stope stability prediction process proceeds with the stability number adjustment factors. In StopeSoft, the original, modified, and additional adjustment factors are included. Both original and modified stability number adjustment factors were integrated into the StopeSoft in spite of the negligible differences between these factors (Madenova & Suorineni 2020). This is because one school of thought prefers to calculate the stability number using the original adjustment factors, while others favor the modified stability number adjustment factors. To meet users' preferences, both original and modified adjustment factors are included into the StopeSoft.

There is sufficient evidence (Suorineni et al. 2001; Suorineni 2010; Le Roux & Bentley 2017) showing the influence of several factors on the stope stability, which are not accounted for in the Stability Graph. These factors include faults, backfill, blasting effect, and stope exposure time (Suorineni 2010). Two critical factors, namely, fault factor and time factor are integrated into StopeSoft. Fault factor calculation is based on the fault factors charts developed by Suorineni (1998) for different scenarios of stope-fault interaction. Although fault factor use is optional in the web tool, it should be used with caution in stope backs. Stope backs were not directly included in the development of the fault factor. Time factor incorporation into StopeSoft is based on the values of modified Q proposed by Tannant and Diederichs (1997).

3.4 *Open stope stability prediction*

The completion of adjustment factors' estimation enables one to jump to the ultimate part of the stope surface stability assessment process. The stope stability prediction part involves three components: the major stability graph versions, probabilistic prediction of open stope surface stabilities, and sensitivity analysis. Three major Stability Graphs can be identified based on the database and original and modified adjustment factors used to build these graphs. These include the Potvin-Nickson Stability Graph, Extended Mathews Stability Graph, and the Refined Stability Graph. The latter is derived from revising the databases of the previous two graphs and using the modified adjustment factors to make the stability graph variations consistent. Madenova and Suorineni (2020) showed that there is no significant difference between the use of the original and modified stability graph factors. Hence, it is for the user to decide on which factors to use based on their familiarity. Considering the varying preferences of users, the web tool provides the flexibility to choose between the modified, extended (with mixed data from both entry and non-entry type mining systems), and refined (with cleaned up data only from the open stope mining system) stability graphs. It should be noted that the stope surface stability state may fall on different stability zones, depending on which version of the stability graph is used. Users and practitioners should make decisions regarding the stability outcome from the various stability graphs they used, relying on their engineering judgement.

In StopeSoft, stope surface stability is predicted probabilistically using the refined (cleaned) database and the multinomial logistic regression algorithm. Statistical assessment of the stope surface stabilities eliminates the false feeling of absolute stope performance. Characterizing the stope stability states probabilistically is more realistic compared to the qualitative and deterministic descriptions on the standard stability graphs to avoid misleading confidence and human subjectivity. The relatively limited data size also encourages the statistical treatment of the open stope data.

The open stope stability prediction stage incorporates the sensitivity analysis of hydraulic radius versus the likelihood of stope surface stability. Sensitivity evaluation is undertaken through recursive calculations. It is aimed to provide mining engineers with possible stope surface stability conditions given a specific range of the stope hydraulic radius, which is helpful in optimizing the stope geometry.

3.5 *Data Sharing*

After assessment of the stope surface stabilities, users can navigate to the final outcome page, where all previous results are displayed on a single page to provide access to all calculated stope stability parameters. Upon completion of the work, one can either start a new stability estimation, download the refined stope database or stope stability report, which contains all calculation results, or share inputted data through the data sharing form. The latter plays a significant role in improving the Stability Graph because the rigidity and credibility of the empirical method increase with the data volume and quality. Thus, by sharing the case history data, mining engineers and web tool users can contribute towards the stability graph database extension and enhanced workability. The web nature of StopeSoft provides worldwide access to the web tool and makes data sharing possible.

4 CONCLUSION

The Stability Graph in its current form presents some limitations that pose challenges to its application. The main drawbacks include the increased time due to a separate stability estimation for each stope surface, possible prediction errors in the use of multiple charts of adjustment factors, variations of the stability graphs, lack of consideration for critical factors that influence the stope stability, and non-sharing of data. To tackle these limitations, the automated and digitalized web tool for open stope design was developed. The web application for open stope stability prediction is named StopeSoft and is available at openstope.com. Key features of StopeSoft are instant computations, integration of additional critical adjustment factors for fault and time, optional use of major stability graphs, probabilistic prediction of open stope surface stabilities, sensitivity analysis, and data sharing capabilities. StopeSoft facilitates the speed of open stope stability assessment lowering the risk of unintended errors due to the integrated computations. The web nature of StopeSoft gives an opportunity to further development and enhancement of the web tool in the future by adding other practical features and expanding the stability graph database.

ACKNOWLEDGEMENTS

The financial support by Nazarbayev University through the Faculty Development Competitive Research Grant No. 240919FD3920 and ThinkRox Inc. advice are highly acknowledged. The authors also acknowledge funding by the National Science Foundation of China (Nos. 51874068, 52074062).

REFERENCES

Barton, N., Lien, R. and Lunde, J. 1974. Engineering classification of rock masses for the design of tunnel support. *Rock mechanics*, 6(4), pp.189-236.

Diederichs, M.S. and Kaiser, P.K. 1996. Rock instability and risk analyses in open stope mine design. *Canadian geotechnical journal*, 33(3), pp.431-439.

Hadjigeorgiou, J., Leclair, J. and Potvin, Y. 1995. An update of the stability graph method for open stope design. *CIM Rock Mechanics and Strata Control session*, Halifax, Nova Scotia, pp.14-18.

Le Roux, P.J. and Brentley, K.R. 2017. Time-Dependent Failure of Open Stopes at Target Mine. In *ISRM Rock Mechanics for Africa*. International Society for Rock Mechanics and Rock Engineering.

Madenova, Y. and Suorineni, F.T. 2020. On the question of original versus modified stability graph factors–a critical evaluation. *Mining Technology*, 129(1), pp.40-52.

Mathews, K.E., Hoek, E. Wyllie, D.C. and Stewart, S.B.V. 1981. *Prediction of stable excavation spans at depths below 1000m in hard rock mines*. CANMET Report, DSS Serial No. OSQ80-00081.

Mawdesley, C., Trueman, R. and Whiten, W.J. 2001. Extending the Mathews stability graph for open–stope design. *Mining Technology*, 110(1), pp.27-39.

Mitri, H.S., Hughes, R. and Zhang, Y. 2011. New rock stress factor for the stability graph method. *International journal of rock mechanics and mining sciences* (1997), 48(1), pp.141-145.

Nickson, S.D. 1992. *Cable support guidelines for underground hard rock mine operations*. PhD dissertation, University of British Columbia, Vancouver, Canada.

Potvin, Yves. 1988. *Empirical open stope design in Canada*. PhD dissertation. University of British Columbia, Vancouver, Canada.

Suorineni, F.T. 1998. *Effects of faults and stress on open stope design.* PhD thesis. University of Waterloo, Ontario, Canada.

Suorineni, F.T., Tannant, D.D. and Kaiser, P.K. 1999a. Determination of fault-related sloughage in open stopes. *International Journal of Rock Mechanics and Mining Sciences*, 36(7), pp.891-906.

Suorineni, F.T., Tannant, D.D. and Kaiser, P.K. 1999b. Fault factor for the stability graph method of open-stope design. *Transactions of the Institution of Mining and Metallurgy* Section A-Mining Industry, 108, pp. A92-A104.

Suorineni, F.T., Tannant, D.D., Kaiser, P.K. and Dusseault, M.B. 2001. Incorporation of a fault factor into the stability graph method: Kidd mine case studies. *Mineral resources engineering*, 10(01), pp.3-37.

Suorineni, F.T. 2010. The stability graph after three decades in use: experiences and the way forward. *International journal of Mining, Reclamation and Environment*, 24(4), pp.307-339.

Tannant, D.D. and Diederichs, M.S. 1997. *Cablebolt optimization in# 3 Mine*. Report to Shawn Seldon, Kidd Mine Division, Timmins, Ontario, Canada.

Trueman, R. and Mawdesley, C. 2003. Predicting cave initiation and propagation. *CIM bulletin*, 96(1071), pp.54-59.