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# Development of an integrated platform for stability analysis and design in sublevel stoping mines — MineRoc®

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## Abstract

*In sublevel stoping mining operations, the amount of rock overbreak from the walls plays a fundamental role in recovery and dilution control. In the case of massive orebodies, the amount of overbreak may produce interferences in the productive process and excessive wearing of drawpoints. In the case of narrow veins, the amount of overbreak may produce excessive dilution. All of these variables define the production plan of the mine. At present, a large amount of information is collected during operations. This information includes the grades and extracted tonnage, fragmentation, lithology, design of stopes and main infrastructure, geotechnical information, overbreak progress, seismicity, numerical modelling, and many other mine variables. To improve the reliability of the stability analysis design of stopes and the production plan, it is necessary to integrate the mine data in one platform. In this paper, the logic of MineRoc® is presented as an integrated technological platform for stability analysis in sublevel stoping mines. MineRoc includes an acquisition platform for mine data and geotechnical information, a geomechanical design module for stopes, and a back-analysis platform for calibrating mine design tools. The application and benefits of MineRoc are illustrated for sublevel open stope Chilean mining operations. Unified databases and updated design stability tools are developed, presented, and discussed. The platform can be used in the mine design and planning processes and is useful for reducing uncertainty in the mine design of sublevel stoping operations.*

## 1 Introduction

The potential for instability in the rock surrounding underground mine openings is an ever-present threat to the safety of both people and equipment in the mine. In order to counteract these threats, it is necessary to design measures which will eliminate or minimise any problems. The Mathews stability graph method (Mathews et al. 1981) is designed for this purpose, by leading to the design of stopes without workers entering underground mines. It is based on a stability graph relating two calculated factors: the shape factor, *S*, and the stability number, *N*, which are related to the geometry of the stope, and the characteristics of the rock mass surrounding it. The plot of these two factors defines three stability zones used to predict the stability of planned excavations:

- *The stable zone*: the excavation will stand unsupported or with localised support.
- *The failure zone (or potentially unstable zone)*: localised failure occurs, but a stable arch forms. Modifying the design or installing cable support may reduce the extent of the failure.
- *The major failure zone (or caving zone)*: excavation will fail until the void is full.

The shape factor, *S,* accounts for the geometry of the stope excavation surface and is defined by Equation 1.

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

The stability number, $N$, represents the capacity of the rock mass to remain stable under given conditions of rock stress, rock structure, and rock surfaces, and is defined by Equation 2.

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

In this expression, $Q'$ is defined as follows:

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

where:

- $RQD$ = rock quality designation.
- $J_n$ = joint set number.
- $J_r$ = joint roughness number.
- $J_a$ = joint alteration number.

In Equation 2, $A$, $B$, and $C$ are respectively defined as the rock stress factor, the joint orientation factor, and the gravity factor. The rock stress factor, $A$, is determined from the ratio of the intact rock strength (the uniaxial compressive strength (UCS), $\sigma_c$) to the induced compressive stress, $\sigma_1$, calculated at the center of the stope wall (Equation 4).

$$ratio = \sigma_c / \sigma_1 \quad (4)$$

The empirical graph leading to the definition of the rock stress factor is presented in Figure 1(a). At a value of the ratio below 2, Mathews considers that it is a zone of potential instability and does not assess the factor, $A$. At a value of the ratio between 2 and 10, $A = (0.9 / 8)\ (ratio - 2) + 0.1$. Finally, at a value of the ratio greater than 10, $A = 1$.

The joint orientation adjustment factor, $B$, is a measure of the relative difference in dip between the stope surface and the critical joint set affecting wall stability and is estimated using Figure 1(b).

The gravity adjustment factor, $C$, reflects the effect of orientation of the stope surface on its stability, under the influence of gravity, and is determined from Equation 5 and Figure 1(c):

$$C = 8 - 7\ cosine(angle\ of\ dip) \quad (5)$$

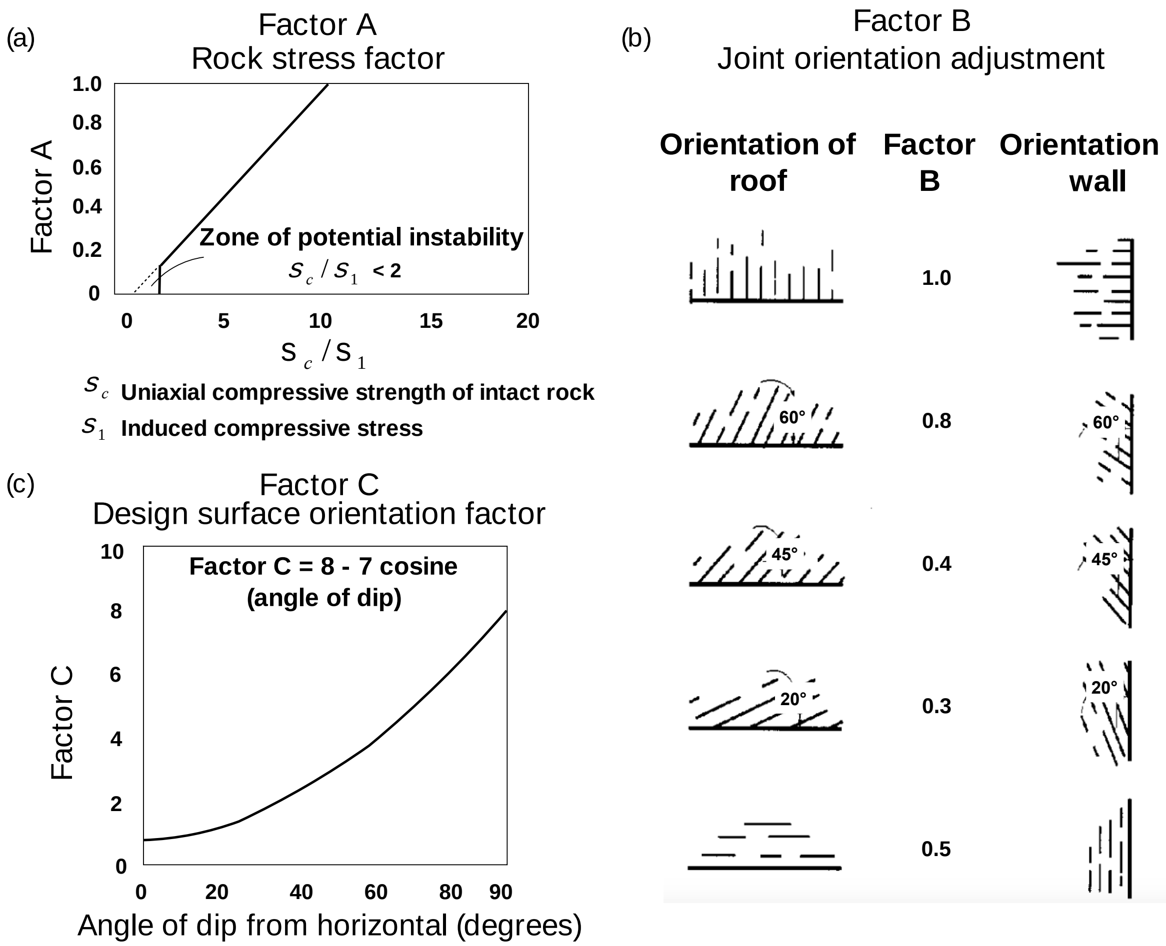



**Figure 1 Adjustment factors for determination of Mathews' stability number (after Mathews et al. 1981)**

The method was first introduced by Mathews et al. (1981), three decades ago, for mining at depths below 1,000 m. Its initial formulation was based on the study of 26 cases in 1980, which have been extended over the years (Mitri et al. 2011; Nickson 1992; Potvin 1988; Stewart & Forsyth 1995; Trueman et al. 2000), and it incorporates into mine design an estimation of the equivalent linear overbreak slough (ELOS) of the walls (Clark & Pakalnis 1997).

The more recent database proposed by Mawdesley (2002) contains 465 case studies, mainly from Canada and Australia. Logistic regression was used in order to statistically determine the boundaries between the three states of stability. The stability graph corresponding to this analysis is presented in Figure 2 and is considered as a reference in this paper.

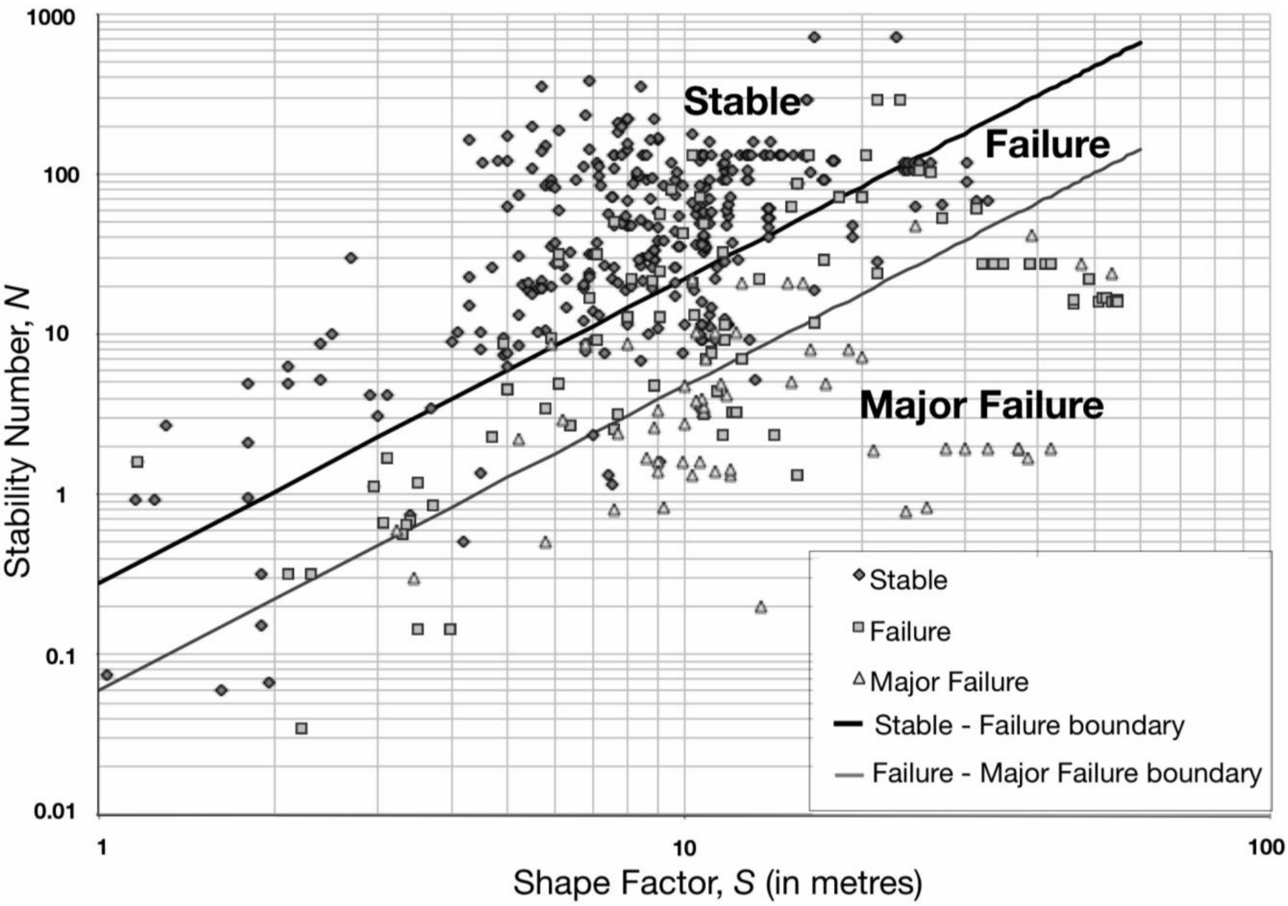



**Figure 2 Extended Mathews stability log-log graph based on logistic regression (Mawdesley 2002)**

The case histories collected in the extended Mathews database are from mining operations from different countries, which may lead to differences in the stability evaluation of the stope. In addition, the geotechnical, operational, and design standards are different. In order to improve the performance of the stability graph method it is essential to store all the information related to the case histories on a single data-management platform. To accomplish this, MineRoc was developed as a software design tool. In this paper the logic of MineRoc is presented as an integrated technological platform for the stability analysis of sublevel stoping mines. The application and benefits of MineRoc are illustrated for sublevel open stope Chilean mining operations. Unified databases and updated design stability tools are developed, presented, and discussed.

# 2 MineRoc platform

MineRoc is a three-dimensional software application developed as a tool for the design and back-analysis of the performance of stopes in sublevel stoping mines. The systematic use of MineRoc permits:

- Adaptation of design parameters to the geological, geotechnical and operational conditions of the mine.
- The standardisation of stope design.
- Back-analysis of stability and overbreak of stopes.
- Improvements in the design, leading to an increase in productivity and decrease in the operational costs.

The MineRoc platform includes three modules:

- Acquisition and management of the geological and geotechnical data.
- A module for stope design using stability curves from the literature or locally calibrated.
- A module for back-analysis of overbreak and stability performance of the stope.

The interaction between the modules and their basic functions are shown in Figure 3. The following sections briefly describe the logic of the modules associated with the information required and generated by each of them.

## 2.1 Module for acquisition of the geotechnical data

The module for acquisition of the geotechnical data (Figure 3(a)) allows storage of the geotechnical information of multiple case studies on a single platform. It is documented in independent libraries, and the generated information is available for the design of new stopes or the back-analysis of mined stopes. The following information is defined as an input in the module:

- *Intact rock*: $UCS_{50}$, Young's modulus (E), Hoek–Brown peak envelope parameters (sc, mi).
- *Structural patterns*: orientation and characteristics.
- *Rock mass classification*: rock quality designation (Deere et al. 1967), rock mass rating (Bieniawski 1976), the geological strength index (Hoek & Brown 1997), and the Barton classification system, Q (Barton et al. 1974).
- *In situ stresses*: measurements and tendencies of in situ stresses for mine design are stored. If such information is not available, it is possible to use regional models that have been calibrated using databases from Chile (Galarce 2014) and Canada (Arjang & Herget 1997; Galarce 2014).

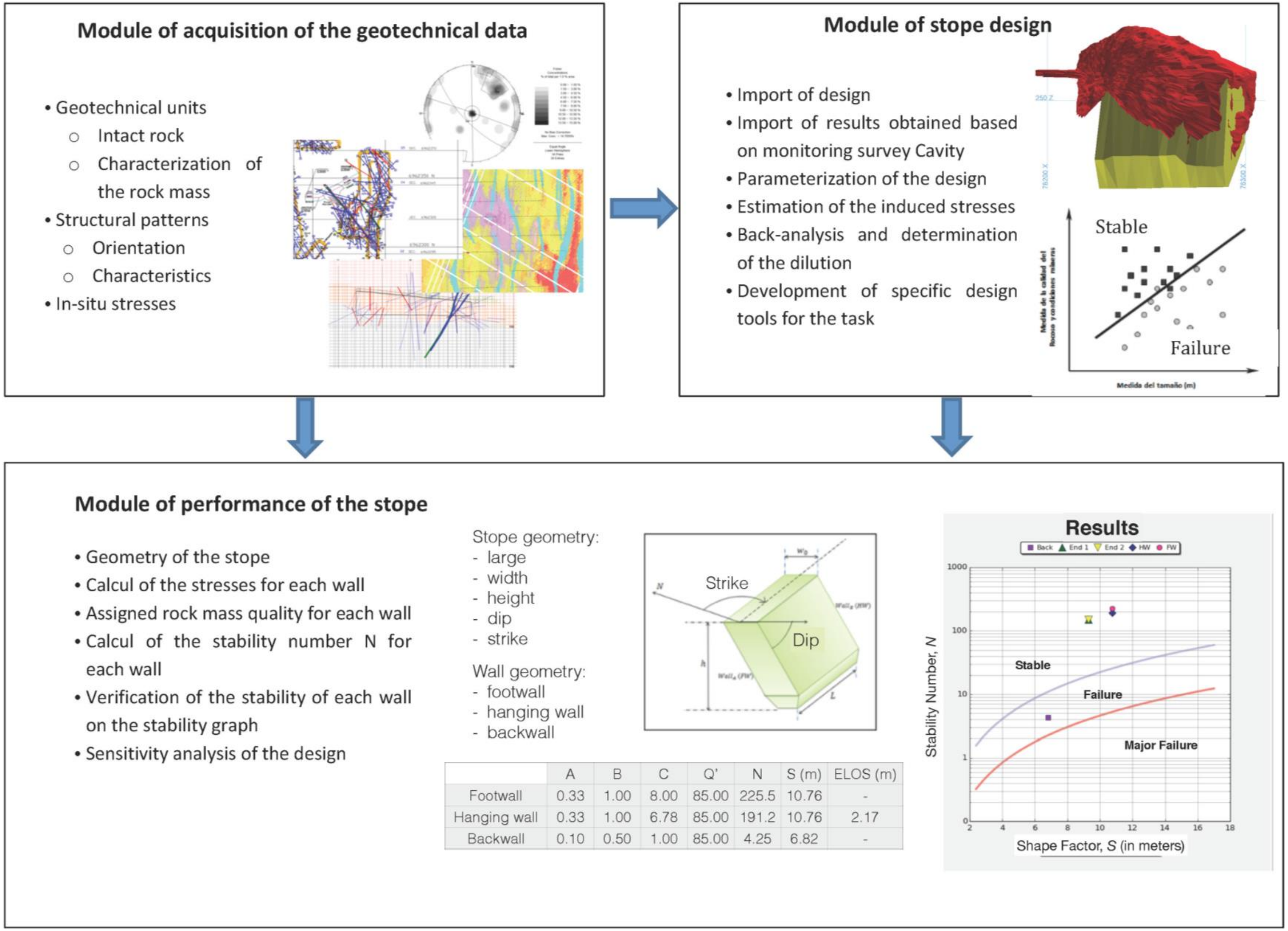
## 2.2 Stope performance module

The objective of the stope performance module (Figure 3(b)) is to generate stability tools based on the back-analysis of mined stopes. The following information is defined as an input in the module:

- Design of the stope.
- Stresses in the zone or depth.
- Geotechnical and geological information of the zone generated by the module for acquisition of geotechnical data.
- Cavity monitoring survey results.

The geometry of the stope design is parameterised and the width (w), length (L), height (h), dip, and strike of the walls are calculated. The geotechnical information, parameterised geometry, and cavity-monitoring survey results are used to estimate the associated volume of overbreak volume ($V_{OB}$), the shape factor (S), the adjustment factors (*A, B, C*), and the stability number (N) associated with each of the stope walls. The ELOS is calculated and the stability condition is assigned to each wall. Once enough case histories have been collected, a local stability boundary can be established. The developed stability tool represents in a better manner the standards and operational conditions of the mine.

More details on this module are presented in Section 3.




| | A | B | C | Q' | N | S (m) | ELOS (m) |
|---|---|---|---|---|---|---|---|
| Footwall | 0.33 | 1.00 | 8.00 | 85.00 | 225.5 | 10.76 | - |
| Hanging wall | 0.33 | 1.00 | 6.78 | 85.00 | 191.2 | 10.76 | 2.17 |
| Backwall | 0.10 | 0.50 | 1.00 | 85.00 | 4.25 | 6.82 | - |

**Figure 3** Logic of the MineRoc platform and the interaction between modules

### 2.3 Stope design module

The stope design module (Figure 3(c)) allows the geotechnical data to be transformed into information that is useful for the mine design. This module assists the user in the process of the design of the basic unit of exploitation of the stopes. The following information is used to evaluate the stability number and shape factor for each wall (back, hanging wall, footwall and ends) of the stope:

- The information generated by the module for acquisition of geotechnical data.
- In situ stress.
- The geometry of the stope: w, L, h, dip and strike of the walls.

The following outputs are obtained from this module:

- The values of the adjustment factors proposed in the stability number method:
    - The rock stress factor, A. The stresses at each wall are calculated using the charts provided in Mawdesley (2002).
    - The joint orientation factor, B. The true solid angle is calculated using the orientation of the joints and the walls.
    - The gravity factor, C.
- The stability number, N.
- The shape factor per wall, S.
- The condition of stability of each wall and the ELOS for the hanging wall. The condition of stability is verified using the stability chart proposed by Mawdesley (2002) or a stability chart calibrated using the back-analysis and stope performance module for the site conditions of the mine. In a similar manner, the ELOS is calculated using the curves proposed in Castro (2014) or curves calibrated for the conditions of the mine using the back-analysis and stope performance module.

## 3 Logic involved in the stope performance module

The objective of the stope performance module is to generate stability tools based on the back-analysis of mined stopes using the stope designs and the result of the monitoring survey in the drawing exchange format (DXF). Figure 4 presents the general procedure:

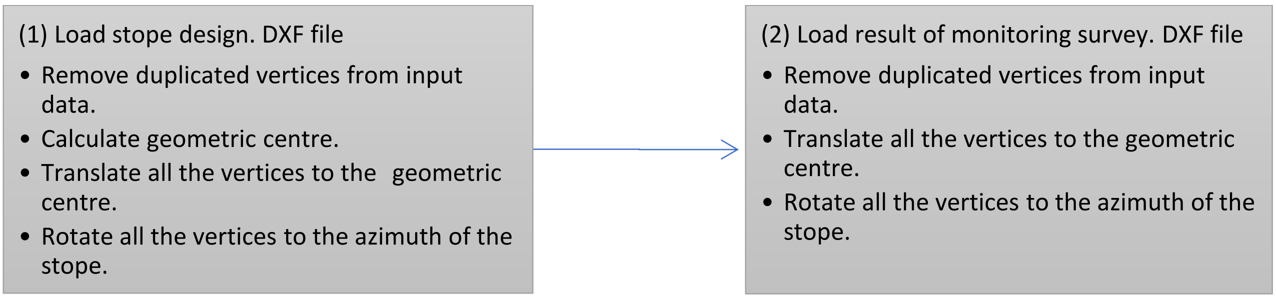



**Figure 4 Pre-processing of input data**

### 3.1 Volume calculation from DXF file

The main objective of the platform is to use actual data to improve the boundary of the stability graph method based on local case histories and the calculation of the volume of overbreak, geometry and stability number per wall. In this version of MineRoc the volume of underbreak is not calculated which is most likely caused by a drill/blast issue. However, the estimation of the volume of underbreak is an important parameter from an operational perspective and it will be incorporated into MineRoc in future versions.

For calculating the volume overbreak the boundaries between the stope design and the result of the monitoring survey are used to estimate the volume per wall. These boundaries are created using the dip of each wall to generate a plane. These planes separate the triangulation vertices that belong to the overbreak of each wall (Figure 5).

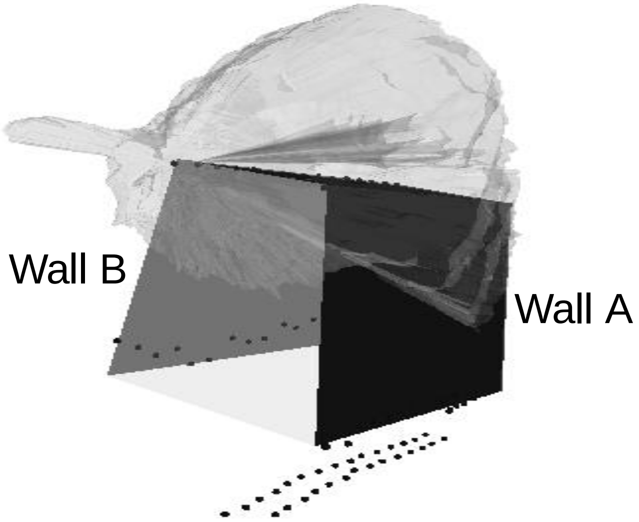



**Figure 5 Isometric view with the stope exploited and the stope design**

Next, the triangles that belong to each wall are projected over the plane created for each wall (Figure 5). Using this projection the overbreak volume of the triangle is estimated. This procedure is repeated for every triangle.

One of the problems of calculating the overbreak volume is the overlapping between triangles' projections and sub-triangles, which can affect the final calculation (Figure 6). To fix this problem, an algorithm for checking and filtering all the overlapping triangles and their respective volumes is implemented. After this procedure, we subtract the overlapping volume from the total overbreak volume. This filter is implemented by checking that the projected triangle in each wall of the stope does not cross the plane created by another triangle (Figures 7 and 8). This iteration process is the most computationally expensive part of the performance process.

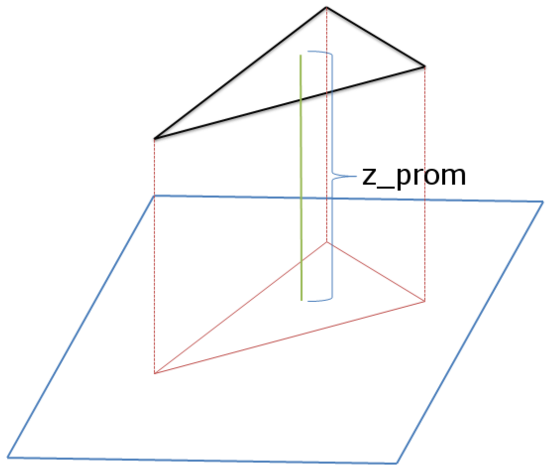



**Figure 6 Projections from the triangle to the plane associated with the wall of interest**

**Figure 7 Three-dimensional visual representation of overlapping triangles**

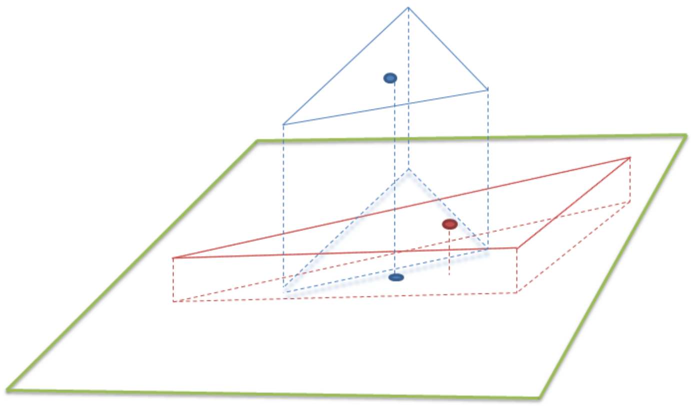


**Figure 8 Projections from the triangle to the plane associated with the wall of interest with overlapping**

# 4 Application of MineRoc

As presented in the previous part, the MineRoc software is an integrated technological platform for the stability analysis in sublevel stoping mines. MineRoc includes an acquisition platform for mine data and geotechnical information, a geomechanical design module for stopes, and a back-analysis platform for calibrating mine design tools. In this section, a case study is presented to highlight the benefits of the software. Twenty stopes mined in the north region of Chile have been analysed. The study was conducted in order to appreciate the differences between the stability curve proposed in the literature and the stability curve adapted to the site-specific conditions of the mine developed using the MineRoc software.

First, the module for acquisition of geotechnical data was used to provide information relating to the various geotechnical units present in the studied sectors. Second, the module of performance of the stope was used to obtain the factors of adjustments of the Mathews method for each stope and to specify its stability. The ELOS has been also calculated for each wall of the stopes studied.

Once the historical cases are processed, an admissible amount of overbreak is defined by the mine. The boundaries of the stability curves are readjusted to the local conditions (Figure 9). It can be observed that the boundary between the stable zone and the failure zone proposed in the literature (Figure 9(a)) is changed by using the historical cases (Figure 9(b)). The implication is that these results indicated that the boundaries proposed in the literature require local calibration for a definition of stability given by the standards of the mine.

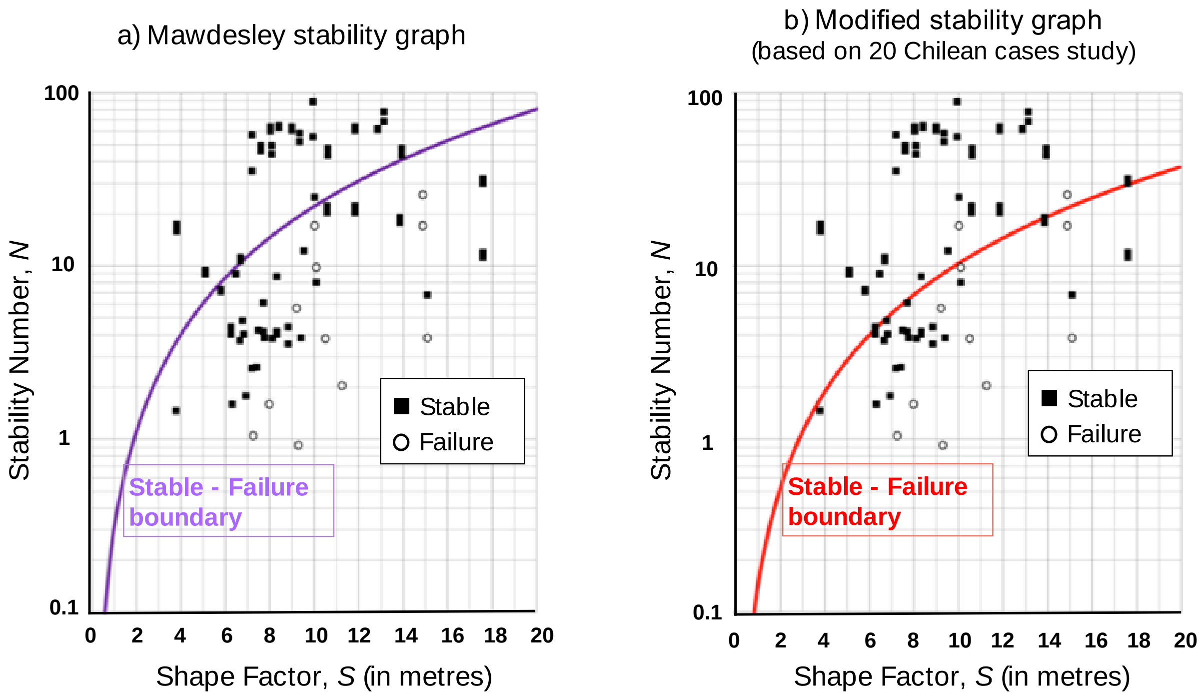



**Figure 9** **Stability graphs proposed by (a) Mawdesley (2002) and (b) locally developed chart for a mine in Chile**

This example (Figure 9) illustrates the impact of the design tools on the dimensions of the stope using the stope design module. Given the geotechnical information of the mine and the proposed length of the stopes (L = 70 m), the mine manager is interested in the maximum width of the stope. Using the stope design module, the dimensions of the stope are changed and the results are immediately updated in the locally developed stability chart. Using the stability graph proposed by Mawdesley (2002), the maximum width of the stope is estimated as 20 m. When the locally developed chart is used, an admissible width of 40 m is obtained.

## 5 Discussion

Given the dynamics of sublevel stoping mines and the need to control their production costs, it is necessary to:

- Standardise the design of the stopes.
- Develop site-specific design tools.
- Estimate in advance and more precisely the overbreak behaviour of stope walls.

In practice, these requirements make it possible to establish site-specific guidelines for stability based on the back-analysis of local case histories. This gives more reliability to the mine design parameters. The continuous updating of empirical design methods makes it possible to increase the productivity of the mining system and to decrease the production costs. In this context, MineRoc is a technological platform developed as a tool for the design and performance of stopes in sublevel stoping mines.

The main advantages of using MineRoc are:

- Management of data:
  - Consolidation of geotechnical information in a single platform.
- Design process:
  - Sensitivity analysis of mine design parameters.
  - Tabulated results stored in a local database.
  - Updated tools for mine design based on back-analysis of local conditions.
  - Proper definition of stability based on mine standards, which may vary across the industry.

The Mathews method, which is included in this version of MineRoc, is currently under review in order to represent the operational and acceptability conditions of Chilean mines in a better manner. The empirical approach is currently being combined with mine-scale modelling, which will lead to better design guidelines.

# 6 Conclusion

The objective of this paper was to present the logic involved in MineRoc software and an example of its application. This software has been developed as a tool for the stope design in underground mines. To date, the design of the stopes is mainly based on the use of the empirical stability graph developed by Mathews (1981). In its initial formulation, the method was based on the study of 26 cases which have been extended over the years up to 465 cases as from today. These case studies are mostly based on experience of operations in Canada and Australia, which do not reflect the Chilean conditions. Moreover, the sustainable growth of mining requires a review and standardisation of the design methods. This standardisation would lead to an increase of the safety and the productivity of the mine. The MineRoc software allows the mine design to be improved based on local case studies. It also proposes to store all the geotechnical data and stope information on a single database, which ensures the possibility of performing statistical analysis, leading to the improvement of the stability graph method.

# Acknowledgement

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