XX ICongresso Brasileiro de Mecânica dos Solos e Engenharia Geotécnica
X Simpósio Brasileiro de Mecânica das Rochas
X Simpósio Brasileiro de Engenheiros Geotécnicos Jovens
24 a 27 de setembro de 2024 – Balneário Camboriú/SC

COBRAMSEG 2024
XXI Congresso Brasileiro de Mecânica dos Solos e Eng. Geotécnica
X Simpósio Brasileiro de Mecânica das Rochas
X Simpósio Brasileiro de Engenheiros Geotécnicos Jovens

DOI: 10.47094/COBRAMSEG2024/477

Open pit slope design applied to mineral reserve statement rules, SEC S-K 1300

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ABSTRACT: O dimensionamento da cava é um dos fatores que mais influenciam nas declarações de recursos e reservas minerais (MRMR). A falta de informações e a baixa confiabilidade dos parâmetros geotécnicos podem significar perdas significativas nas reservas minerais devido a um projeto de talude excessivamente conservador ou a um projeto de talude de cava inseguro e impraticável. Este artigo apresenta boas práticas para o dimensionamento de taludes de cavas, destacando o processo interativo entre o planejamento de mina e as áreas geotécnicas, que deve ocorrer de forma a garantir conceitos padronizados e rastreabilidade ao longo de todo o processo de dimensionamento da cava, desde a avaliação matemática do valor presente líquido até a operacionalização da cava. Acreditamos que esta metodologia aumentará a confiabilidade do dimensionamento de cavas, de acordo com os regulamentos da SEC (Securities and Exchange Commission) e os padrões internacionais de declarações de reservas minerais delineados pelo CRIRSCO (Committee for Mineral Reserves International Reporting Standards).

PALAVRAS-CHAVE: Dimensionamento de taludes de cavas, parâmetros geotécnicos, planejamento de mina, MRMR, SEC.

ABSTRACT: The pit slope design is one of the most influential factors in mineral resource and reserves statements (MRMR). The lack of information and the low reliability of geotechnical input can result in significant losses in mineral reserves due to either an overly conservative pit slope design or an unsafe and impractical pit slope design. This paper presents good practices for pit slope design, emphasizing the interactive process between mine planning and geotechnical areas. This process ensures standardized concepts and traceability throughout the entire pit design process, from the mathematical evaluation of net present value to the operationalization of the pit shell. We believe this methodology will enhance the reliability of pit design, in accordance with the regulations of the Securities and Exchange Commission (SEC) and the international standards for mineral reserves statements outlined by CRIRSCO (Committee for Mineral Reserves International Reporting Standards).

KEYWORDS: Pit slope design, geotechnical input, mine planning, MRMR, SEC.

1 MINERAL RESERVES AND SLOPE DESIGN

In the process of mineral reserves and resources statement, the slope design directly affects one of the main economic factors of a mineral reserve, the stripping ratio. A mining slope design study should seek a balance between operational safety and cost-effectiveness. Therefore, the reliability of information and the confidence level of geotechnical studies are fundamental factors to obtain optimal design that ensures adequate safety conditions while also seeking greater utilization of the mineral resource. The regulations of SEC - SK-1300 (2018), which adopts important criteria of CRIRSCO (2019), have led to the definition of this methodology in the cycles of resource and reserve evaluation.

The mathematical pit is a relevant basis for estimating the volume of the mineral reserve as well as the stripping ratio, a factor that has a significant impact on the calculation of the net present value (NPV), from which the viability of extracting the mineral reserve is determined. Thus, once the mathematical pit is generated, it becomes a guide for the operationalization of the pit, whose overall angles should have reasonable similarity to the overall angles of the mathematical pit.

The lack of standardization in defining and terminology of pit geometry makes it difficult to apply project criteria properly for pit design. A diagnosis of the MRMR evaluation process showed that different criteria had been mistakenly applied to the design of the mathematical pit, such as applying an average angle for waste and another average angle for ore or determining the inter-ramp angle for each lithotype where there was a better understanding of geotechnical information. In both situations, significant differences were observed between the stripping ratio generated in the mathematical pit and that determined after operationalization, in which ramps, safety berms, anisotropy influence of rock mass, or some typical failure mechanisms were inserted. In each stripping ratio divergence, the process returned to the begin, and a new mathematical pit was defined, which was generally more conservative than necessary.

Our proposal was to apply a refinement in the initial phase of evaluating the economic viability of the reserve, carefully evaluating all geotechnical, geological, and structural information to preliminarily define a geometry that approximates the final operationalization condition of the pit. Additionally, we implemented a routine for assigning the geometry and sectorization in the block model used for operationalization. Figure 1 shows the typical geometry of a mine slope (Read & Stacey 2009), as well as the geometric parameters that are considered design criteria for both the mathematical pit and the operationalized pit.

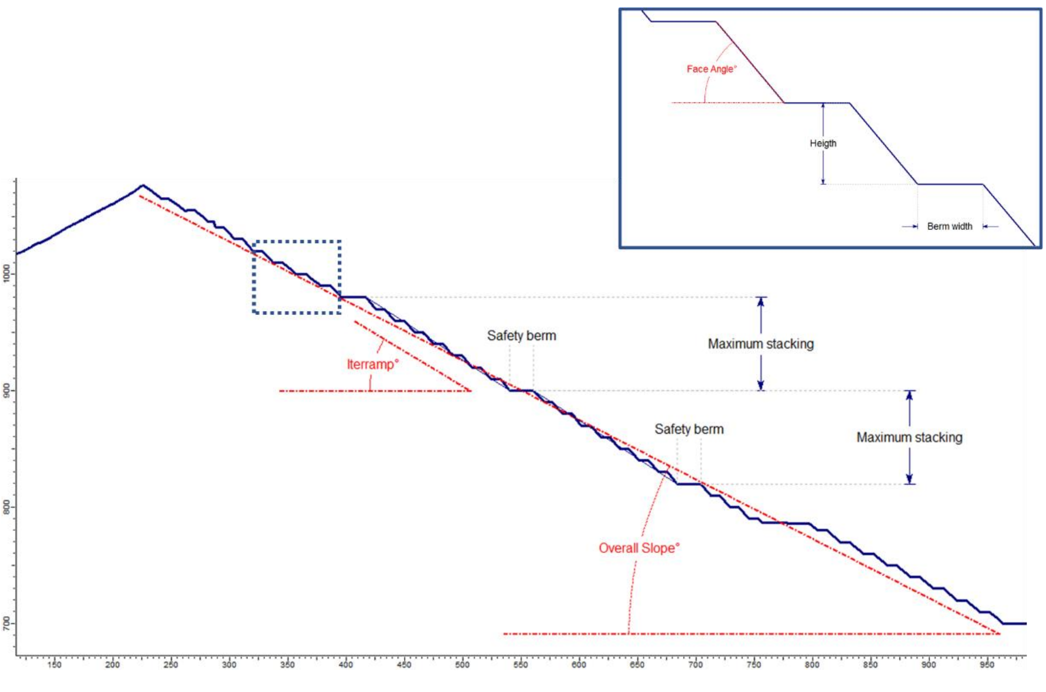

Figure 1. Typical Pit slope geometry.

2 SLOPE DESIGN INTERACTION AND FLOW CHART

The final pit evaluations are an activity jointly developed by the geotechnical and long-term mining planning teams and depend on the interaction between the teams from the definition of the mathematical pit surface to the pit shell operationalization. This activity has been divided into four stages (rows) and responsibilities (columns) as shown in figure 2.

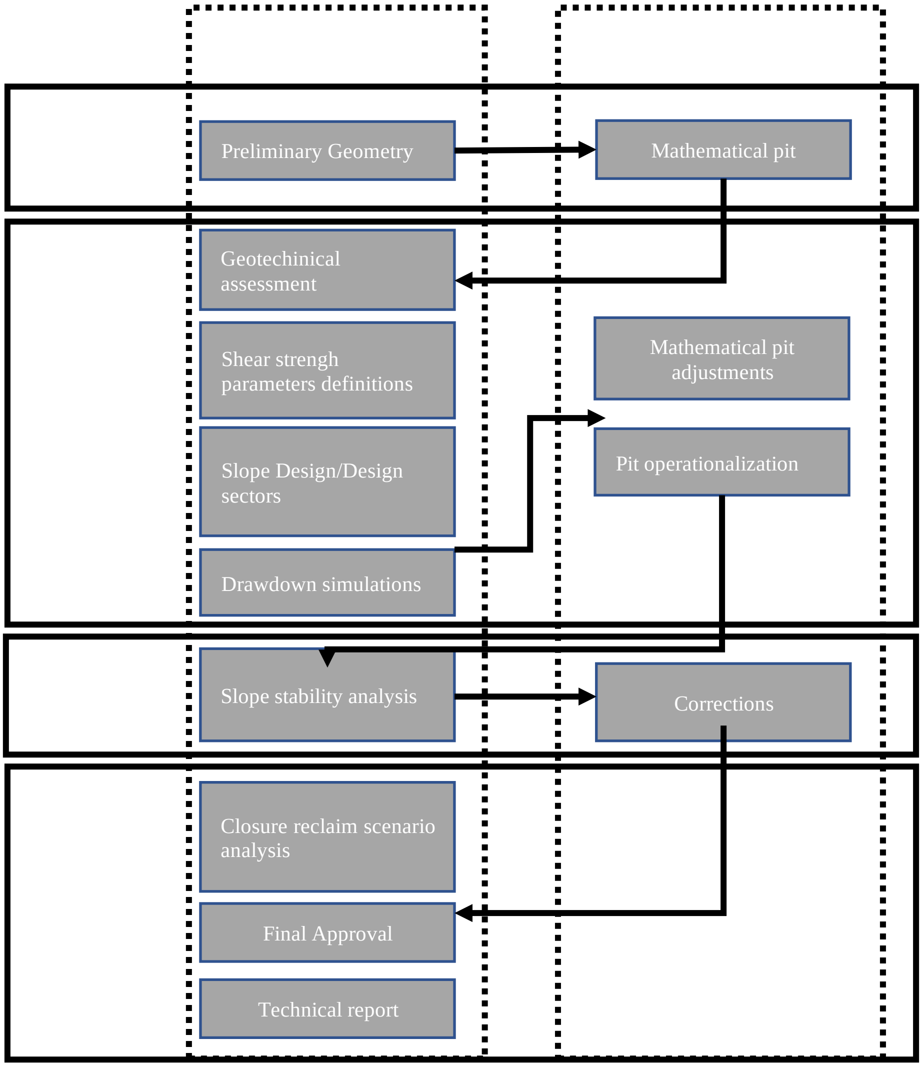

Figure 2. Flow chart for pit slope design iteration

2.1 Step 1 Design criteria for mathematical pit definition

In this step, the estimated overall angle is calculated for each geomechanical model material, which corresponds to the sequence of two maximum stackings with a geotechnical berm positioned in the middle. These estimated overall angles are defined through parametric analyses supported by extensive consolidation of technical information for each type of material, such as drilling, geotechnical tests, mapping, structural data, operational performance of the slope, and sizing of excavation and loading equipment used in the operations. This step outputs the definition of the overall angle for each lithology of the model, which is then forwarded to the long-term planning team as input for the design of the mathematical pit. The figure 3 showing an example of parametric study for overall angle definition.

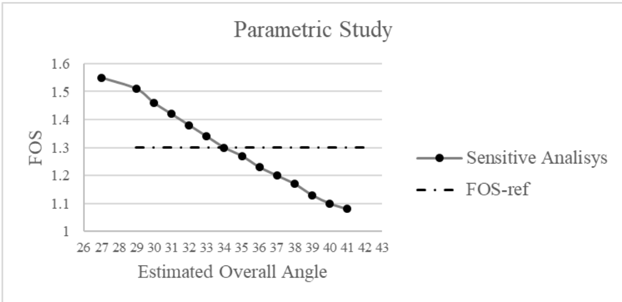

Figure 3: Parametric study shwing the FOS variation according to overall angle.

2.2 Step 2 — Geotechnical Model and design sectors

Geotechnical design sectors are constructed based on litogeomechanical domains (geomechanical class for each lithotype), structural domains, and hydrogeological conditions. Depending on the structural complexity of the mine, our experience has shown that 3D analyses of the mathematical pit surface are possible to individualize critical geotechnical sectors (Figure 4) in which specific geometry is defined for operationalization. The pit slope design criteria (face angle, bench height, berm width, inter-ramp angle, maximum stacking, and global angle) resulting from sectorization are consolidated Slope Design. This information, which supports the final pit design, is assigned into the block geological model used by the long-term planning team for the operationalization of the mathematical pit (figure 5).

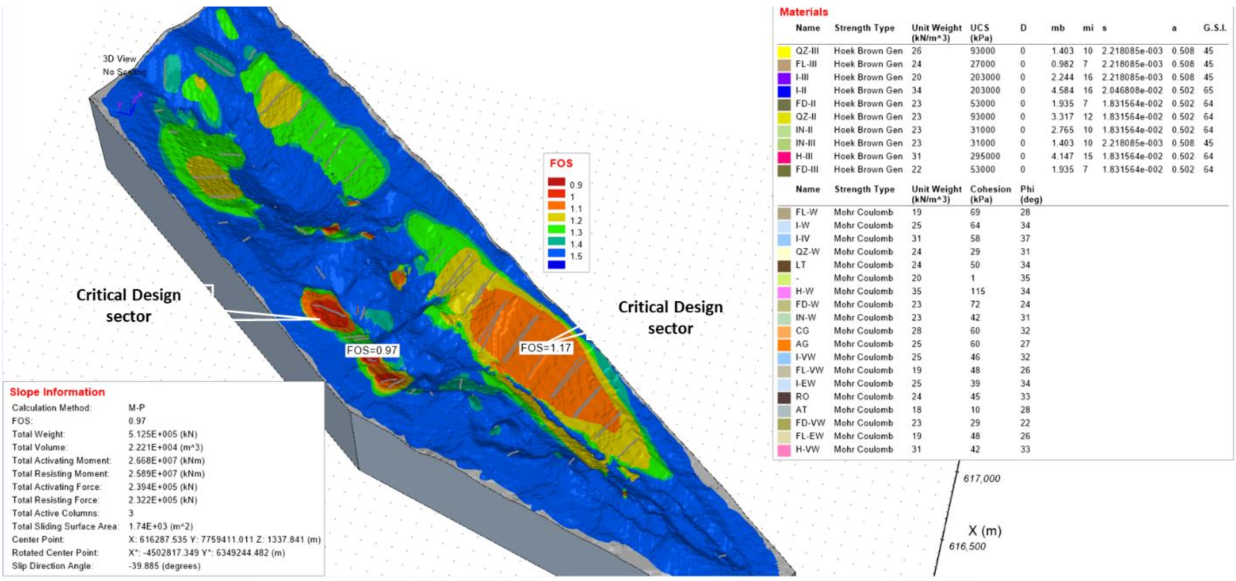

Figure 4. Mathematical pit 3D stability analysis and critical design sector definitions.

2.3 Step 3 Pit slope operationalization stability analysis

In this stage, the long-term planning team develops the final operationalized pit design, considering access ramps, operational restrictions, and other modifying factors of the reserve. Critical sections for stability analysis of the mine's geotechnical sectors are defined and the adherence between the operationalized pit design and the Slope Design parameters (figure 5) is verified. The geotechnical stability evaluation of this pit geometry is performed using deterministic limit equilibrium methods and stress-strain analysis (in specific cases) that define the factors of safety (FoS) of global and inter-ramp failure mechanisms. These values must meet the minimum acceptance criteria usually defined through international best practices (Read & Stacey

2009) or legal requirements. To achieve this, adjustments to the Slope Design parameters or other modifications that lead to geometry adequacy may be suggested. This process is iteractive, and multiple adjustments may occur until the desired FoS is achieved.

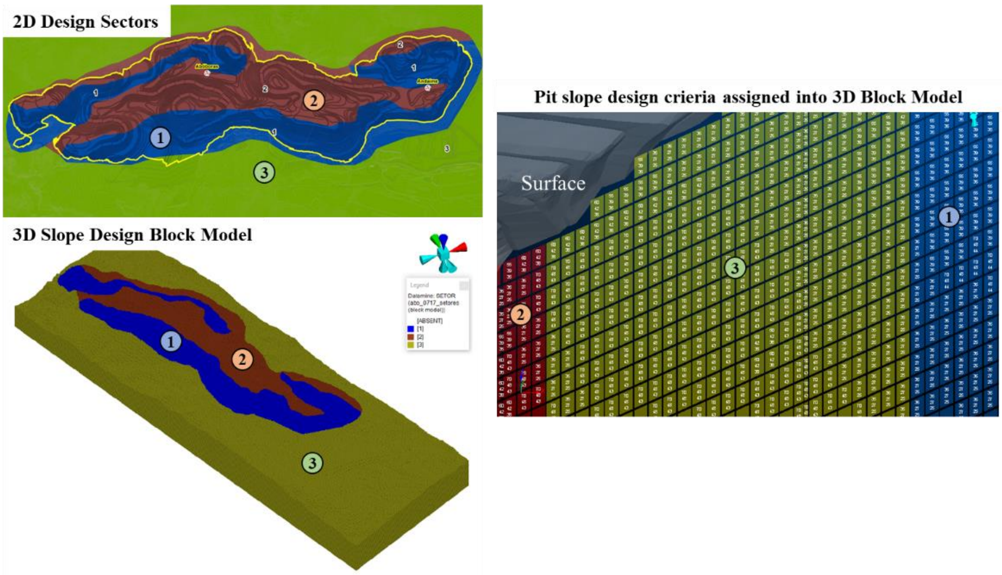

Figure 5. Pit slope design criteria.

2.4 Step 4 Final validation and closure condition outlines

This stage corresponds to the final validation of the operationalized pit, in which the corrections requested in the previous stage are verified. Once it is certified that all geotechnical assumptions are met, the geometry is approved. After approval, verification is carried out for closure condition, considering the scenario of recovered water level and the pseudo-static condition.

3 CONCLUSIONS

The MRMR process requires constant interaction among the various technical teams within a company. The modifying factors are extremely relevant and directly influence the viability of the reserve. Currently, with the new SEC SK-1300 code rules, it is understood that a minimum level of maturity of a pre-feasibility study is required to support a mineral reserve declaration.

The methodology presented comprises the aspects mentioned above. The work is performed with close interaction between the Long-Term Planning Group, which performs the pit design, and the Geotechnical Group, which performs the geotechnical evaluations and recommendations. That interaction is represented in the flow chart shown in Figure 2.

It is possible to ensure that the design criteria for the final pit have been understood by the mine planning team and properly applied during the design of the mathematical and operationalized pits. The parametric analyses and the application of the overall angle by lithology allows the definition of a mathematical pit with greater adherence to the operationalization.

3D stability analyses have proven to be applicable for verifying critical sectors even in the mathematical pit, particularly in mines where complex regional geological structures influence the stability of the final pit slope.

Stability analyses of critical sections aim to guarantee the minimum safety factors required by internal standards and best market practices.

A conceptual closure plan is developed for reserve evaluations. The objectives of this plan are to ensure compliance with the regulatory requirements and international standards during the closure and post-closure phases; secure long-term physical, chemical and ecological stability, so that the potential environmental and social impacts are controlled; design water management structures so as to avoid and/or control potential impacts on the soil and water resources and downstream users in the long-term; and ensure minimum or no maintenance requirement in the post-closure period.

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