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Using the RMR Geomechanical Classification Related to the Stand-Up Time Estimation in an Underground Salt Mine

Uso da Classificação Geomecânica RMR Relacionado à Estimativa de Auto Sustentação em Mina Subterrânea de Sal

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Abstract: Geomechanical classification in a salt mine (especially a potash mine) is based on the following parameters: position and angle of the stratified layer, thickness of the strata, immediate roof of the excavation, distance to the top of the overburden layer, depth, mining direction and clay thickness. There are few underground salt mines, scientific studies and publications are scarce, especially related to geomechanical classifications. This study aims to verify if the RMR (Rock Mass Rating) system proposed by Bieniawski (1973) can be adopted to correlate with the specific stand-up time in the mine. Using statistical studies and mathematical regressions, it was noticed the RMR system presented strong correlation with the maximum stand up time and it can be useful to estimate the roof self-support time in this salt mine.

Keywords: Salt Mine; Rock Mass Rating; Geomechanical Classification.

Resumo: A classificação geomecânica de mina de sal (em especial mina de potássio) baseia-se nos seguintes parâmetros: posição e ângulo da camada estratificada, espessura dos estratos, teto imediato da escavação, distância ao topo da camada de estéril, profundidade, orientação da lavra e espessura da argila. Existem poucas minas de sal subterrâneas, os estudos de cunho científico e publicações sempre foram limitados, principalmente relacionadas às classificações geomecânicas. Este estudo visa verificar se o sistema RMR (Rock Mass Rating) proposto por Bieniawski (1973) pode ser adotado para correlacionar o tempo de auto sustentação (*stand up time*) específico na mina. Com uso de estudos estatísticos e regressões matemáticas foi observado que o sistema RMR mostrou forte correlação com o tempo máximo de abertura estável, podendo ser útil na previsibilidade estimativa do tempo do auto sustentação do teto na mina de sal em estudo.

Palavras-chave: Mina de Sal; Rock Mass Rating; Classificação Geomecânica.

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1. Introduction

Work in underground mines generally involves three key macro aspects for operational feasibility: the stability of the rock mass, which focuses on the technical principles of excavation stability; safety, health, and underground environmental comfort; and operational costs, which relate to the financial sustainability of the mining enterprise. Silva (2009) states that mining methods are generally classified into two classic types: open pit, with extraction categories such as benches, quarries, and strip mining; and underground, with extraction categories such as room and pillar, open stoping, sublevel stoping, caving, cut and fill, block caving, and shaft mining.

When excavated, rock masses—whether for mining purposes or civil engineering projects—undergo changes in their original stress state, leading to a redistribution of stresses in the surrounding medium, known as induced stresses. Curi (2017) states that this stress redistribution results in concentrations and dispersions, which may cause rock mass failure due to compression, shear, and/or tensile events.

Hudson and Harrison (1997) state that the empirical approach, which combines practical experience with theoretical model approximations, plays a significant role in the development of mining and excavation projects. One of the qualitative and quantitative solutions for mining operations is the application of theoretical models for recognizing and identifying the geotechnical characteristics of the rock mass, specifically geomechanical classification. Geomechanical classification guides the understanding of rock mass behavior and quality based on specific parameters. However, its use must be carried out with caution to avoid erroneous or overly simplistic interpretations, particularly due to the heterogeneity of rock masses, as noted by Hoek (2006).

According to Franklin and Dusseault (1989), geomechanical classification systems can be grouped into uni-, bi-, and sometimes multi-parametric categories, depending on the number of variables considered. The parameters can be described as qualitative or analytical/quantitative, depending on their intended purpose and the types of variables used. Parameters and measurements that are easily quantifiable help reduce the subjectivity of a classification. It is important not to confuse characterization with classification: characterization involves considering information related to a specific issue, while classification entails interpreting relevant information for a particular problem (Figueiredo, 2023).

Bieniawski (1973) states that rock mass classification systems have been developed since Ritter (1879) to support the tunneling process and rock mechanics applied to mining. The primary outcome of geomechanical classification is to provide a parameterization of information regarding reinforcement, support, and retention in underground excavations, as exemplified in Figure 1.

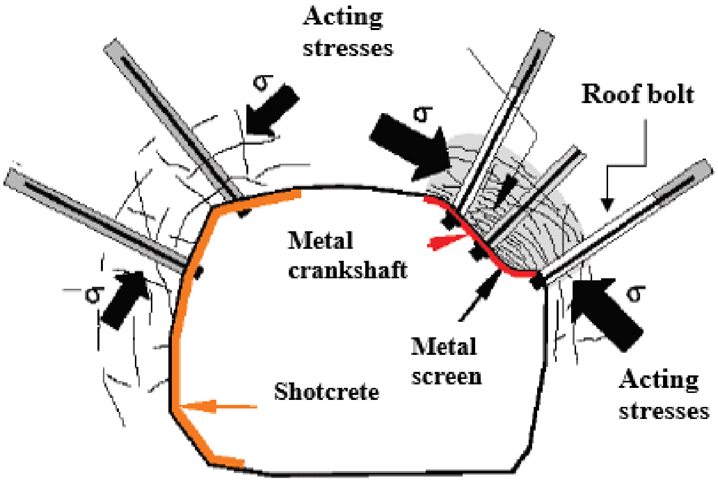


Figure 1 – Underground openings stabilization techniques.
Source: (Hoek, 1995).

The main applications of rock mass classification systems have been in civil construction, particularly in tunneling, and in mining. Since the development of the first classification systems, these methods have evolved significantly, incorporating new research and technological advancements. Over the years, various geomechanical classifications have been developed and continuously updated to enhance the accuracy and applicability of the methods used. These classifications not only provide a solid foundation for assessing the stability and safety of underground structures but also assist in selecting excavation methods, support types, and risk mitigation strategies. The primary geomechanical classifications are detailed in Figure 2, which provides a comprehensive overview of the different approaches and parameters used over time.

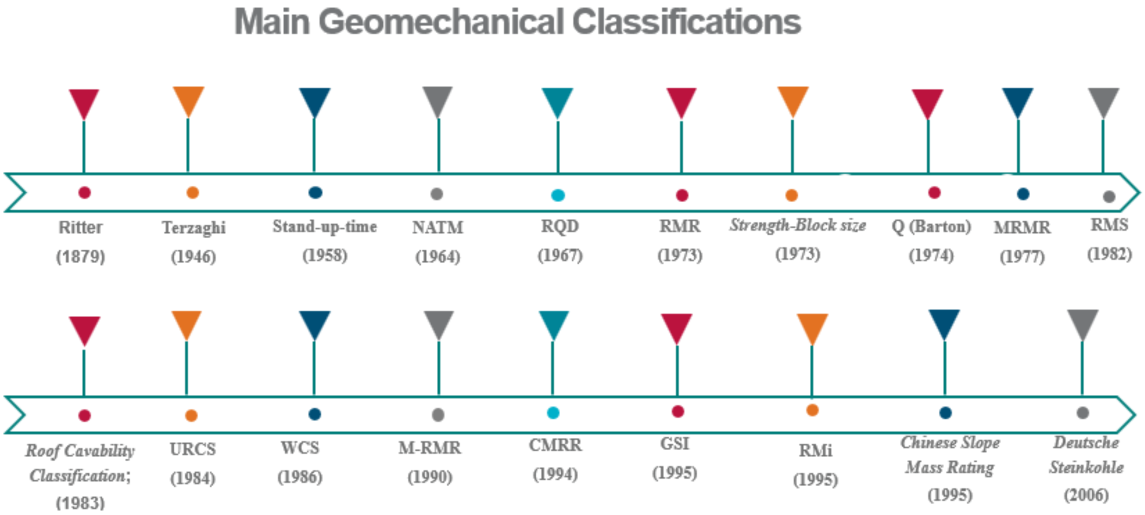


Figure 2 – Main rock mass classification systems timeline.
Source: Bieniawski (1985).

Geomechanical assessment in evaporitic deposits, particularly in salt mines, presents unique characteristics and requires specific parameters. Examples of these parameters include the position and angle of the stratified layer, stratum thickness, immediate roof characteristics, distance to the top of the waste layer, mining location and orientation, as well as the thickness of the clay layer. In the literature reviewed for this study, no specific cases of geomechanical classifications applied to salt mines were found, highlighting a significant knowledge gap and limiting the discussion of related topics, as observed by Jeremic (1994).

In a strategic mining panel, over a period of 18 months, 115 geotechnical inspections were conducted to classify the rock mass using the Rock Mass Rating (RMR) system. The objective of these inspections was to correlate the RMR value with the stand-up time of the excavation. Due to the rheological nature of the rock mass in underground salt mines, stand-up time is continuously monitored through the appearance of cracks and/or fissures, which indicate the stability of the rock mass. The geotechnical inspection model, along with the methodology employed, is detailed in Figure 3. This model illustrates how the inspections were conducted, emphasizing the importance of continuous monitoring and accurate assessment to ensure the safety and stability of mining operations in salt environments.

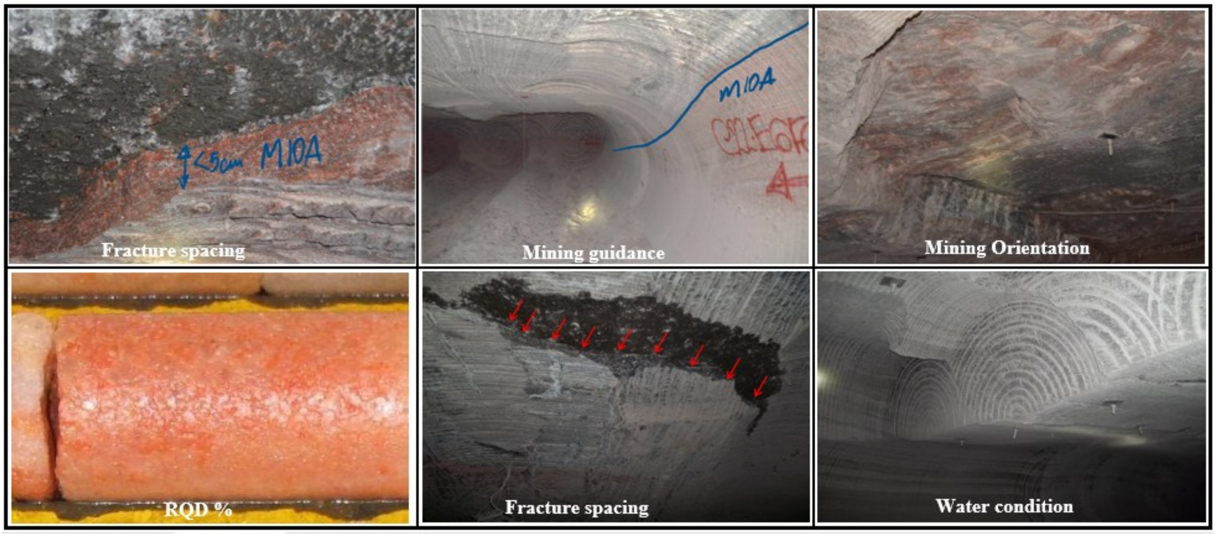


Figure 3 – RMR field data acquisition images.
Source: Authors (2023).

2. Methodology

This study is directly linked to field inspections conducted in excavated and mined areas from January 2021 to June 2022, resulting in 115 inspections within a specific mining panel, as illustrated in the map in Figure 4. During these field inspections, geomechanical assessments were performed using the Rock Mass Rating (RMR) system. Subsequently, correlations were sought between the RMR value, the excavation span, and the stand-up time. The inspections were carried out by a single technical professional, which helped reduce qualitative variability in the assessments, ensuring greater consistency in the collected data. This factor is particularly important in geomechanical studies, where the accuracy and uniformity of observations can significantly influence the results and conclusions.

The analysis of the collected data provided valuable insights into the relationship between rock mass quality, measured by the RMR, and excavation stability. Determining the stand-up time was essential for assessing the safety and operational feasibility of excavations, particularly in underground salt mines, where the rheological nature of the rock mass presents unique challenges. Furthermore, this study highlights the importance of continuous and rigorous monitoring of geomechanical conditions in salt mines, contributing to the literature by addressing a relatively unexplored area. The methodology detailed in Figure 3 and the data analysis in the map in Figure 4 provide a solid foundation for future research and improvements in geomechanical classification and monitoring techniques in evaporitic deposits.

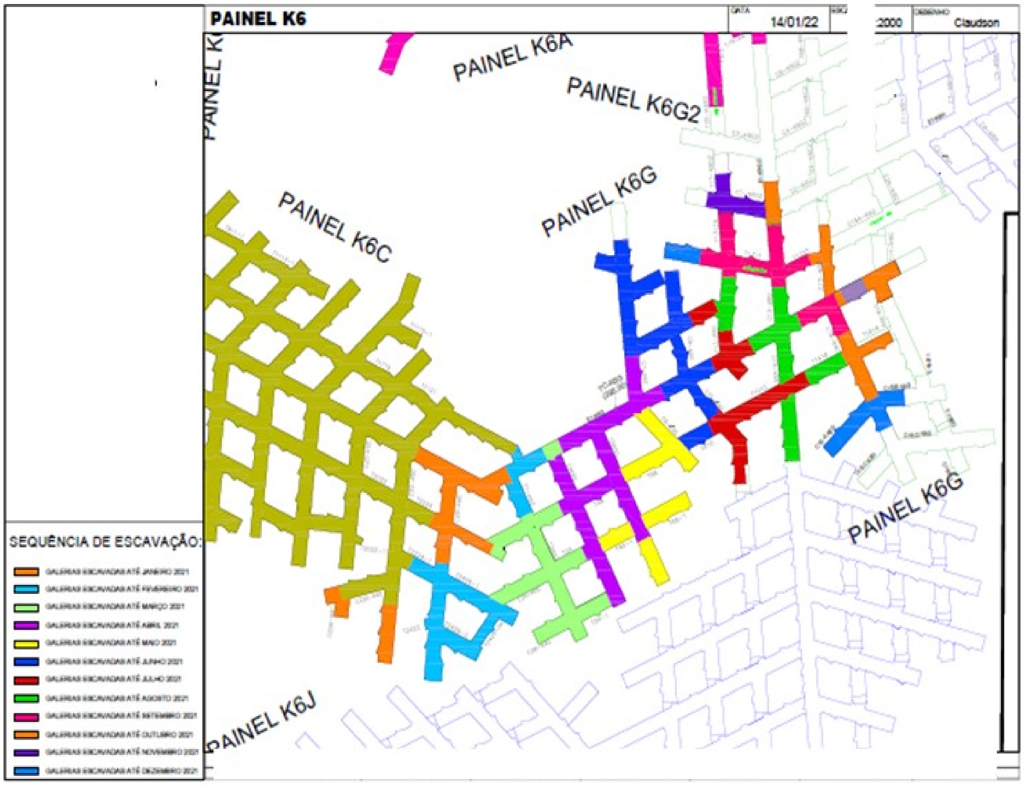


Figure 4 – Excavations during 2021.
Source: Authors (2021).

Fig.5 shows an inspected area, where the following qualitative and quantitative data where registered:

- Mining panel: excavation area consisting of subdivisions of the type of chamber-crosscuts.
- Future ventilation or access shaft: permanent or temporary.
- Crown: outcropping geological structure after excavation (qualitative variable)
- Excavation geometry: excavated area in square meter; length x width (qualitative variable)
- Structure and drive crown relative position, being wedge condition (called D); crown condition < 1m (called C); crown condition > 1m (called B); condition 1 wall (called A) (qualitative variable).
- Excavation geometry: section with drive intersection (called I); drive section with ramp (considered II); section with opening (called III); drive section without support (called IV) (qualitative variable).
- Stand up time: time from excavation until first inspection (quantitative variable).

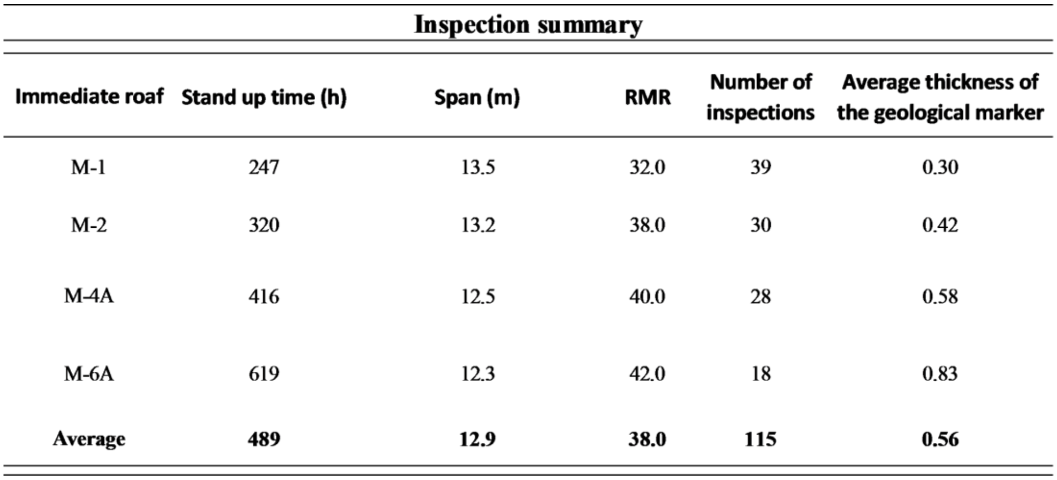
Figure 5 – Crack found in geotechnical survey.
Source: Authors (2023).

3. Results and discussion

In this study, data related to the stand-up time of the immediate roof (measured in hours) and the geomechanical classification using the RMR (Rock Mass Rating) system were compiled. These data were collected from 115 geotechnical inspections conducted from January 2021 to June 2022 and were organized and summarized in Table 1.

Figure 6 presents a synthesis of the results obtained, enabling a detailed analysis of the relationship between the RMR classification and the stand-up time of the immediate roof in the excavations. Analyzing this data is crucial for understanding the behavior of the rock mass in salt mines and developing effective support and reinforcement strategies to ensure the safety of underground operations.

The collected data were essential in identifying patterns and significant correlations, contributing to the development of predictive models that can be applied in future excavations. The comparative analysis between the RMR and stand-up time provides a better understanding of the geomechanical conditions of the rock mass, facilitating informed decision-making in the planning and execution of mining activities.



Inspection summary

Immediate roof	Stand up time (h)	Span (m)	RMR	Number of inspections	Average thickness of the geological marker
M-1	247	13.5	32.0	39	0.30
M-2	320	13.2	38.0	30	0.42
M-4A	416	12.5	40.0	28	0.58
M-6A	619	12.3	42.0	18	0.83
Average	**489**	**12.9**	**38.0**	**115**	**0.56**

Figure 6 – Panel in field survey based on RMR.With stand-up time; span; number of surveys and geological sedimentary structure thickness
Source: Authors (2023).

After the 115 field surveys data analysis, shown in Table 1 and Fig. 6

- 4 geological areas were observed outcropping in the excavation: M-1, M-2, M4A and M6-A. Where the number regards the surveys; for instance, M-1 had 39 surveys performed, M-2 had 30.
- RMR mean value was 38, being considered "poor" regarding the quality classification.
- The geological area with higher RMR was M-6A, with an average value of 42, being considered as "fair"
- The geological area with higher stand-up time was M-6A, showing that the thicker the sedimentary bedding (m), higher the beam effect which increases layer strength.
- M-1 showed the lower RMR value, 32, considered as "poor".

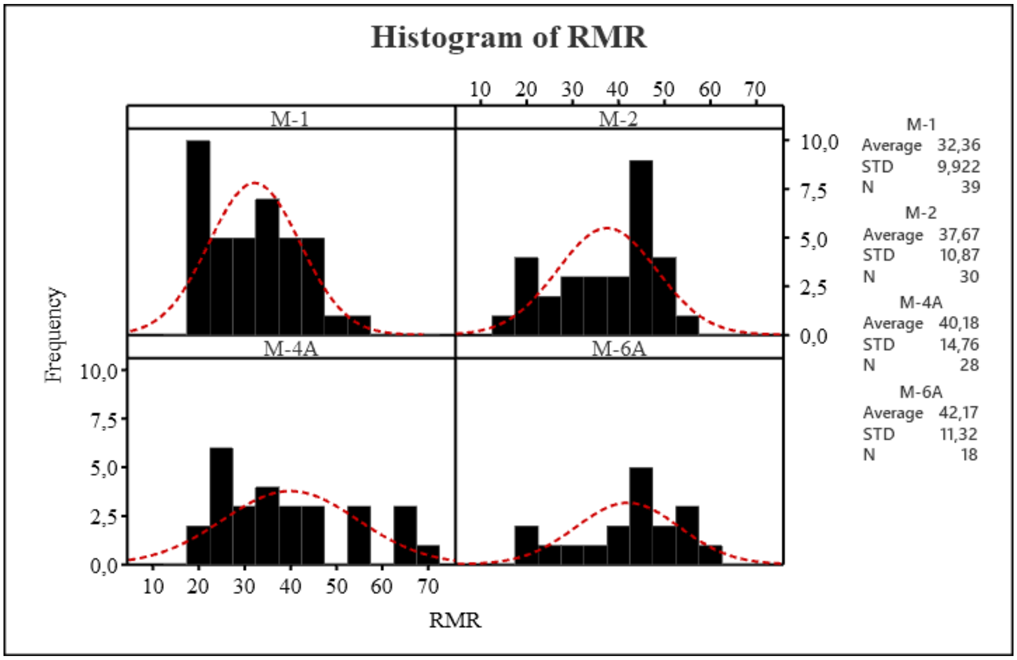


Figure 7 – RMR values histogram
Source: Authors (2023).

Using Minitab software, linear, quadratic, log-linear, and log-quadratic regressions were performed to relate the excavation opening time (Y) with the obtained RMR values (X), aiming to observe if there is a pattern between these two variables, as shown in Figure 8.

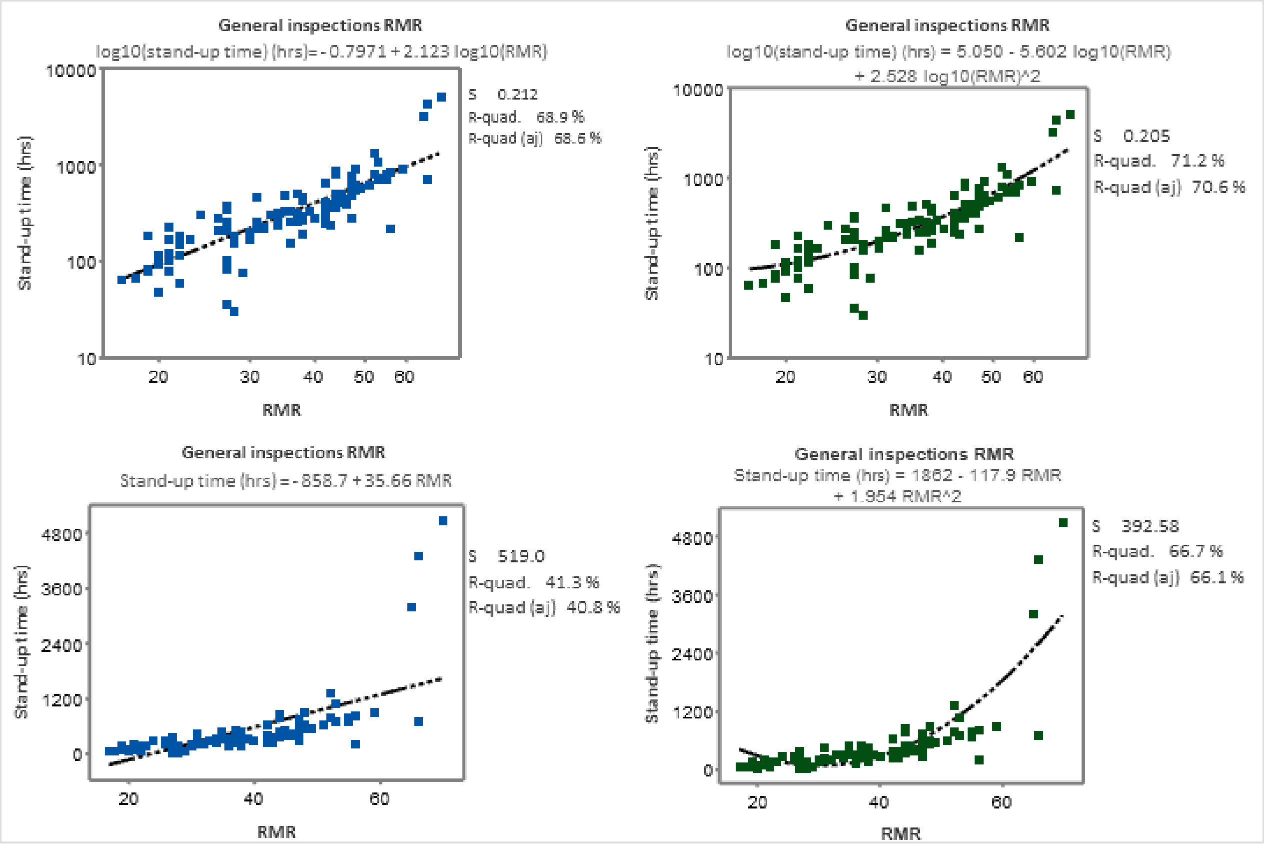


Figure 8 – RMR value and stand-up time correlations.
Source: Authors (2023).

The regression that showed the highest correlation was the logarithmic equation, with a value of approximately 71.2%, indicating a strong correlation between the opening time data and the Rock Mass Rating (RMR), according to the regression coefficient described by Larson (2015). This result suggests that the logarithmic equation is effective in modeling the relationship between these variables, providing a more accurate understanding of the influence of RMR on the stand-up time of geotechnical structures.

Additionally, a heat map was developed with the primary goal of offering a visual management tool for the correlation between the RMR value and the stand-up time. This heat map, presented in Figure 9, allows for an intuitive and immediate interpretation of the data, highlighting that the higher the RMR value, the longer the stand-up times of the excavation roof.

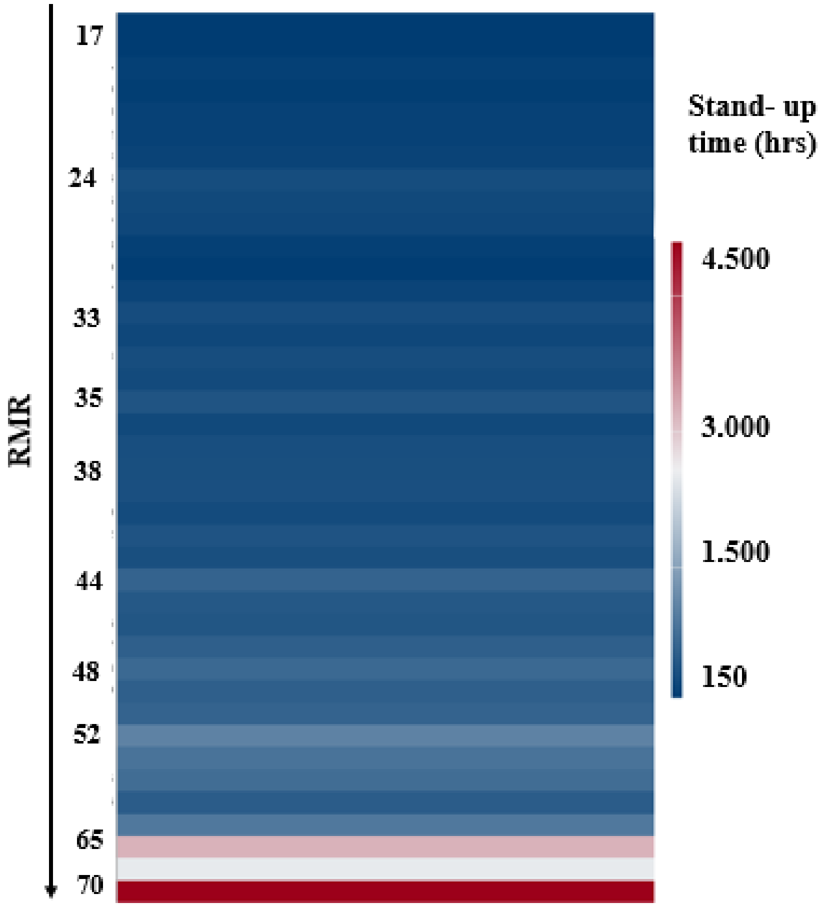


Figure 9 – Heat map between stand-up time and RMR values.
Source: Authors (2023).

The data collected during the field inspections were organized and grouped based on the four different geological markers identified (M-1, M-2, M-4A, M-6A). This grouping allowed for a more detailed analysis of the correlations between the Rock Mass Rating (RMR) classification and the excavation opening time.

For each of the geological markers, specific correlations were determined, providing a clear view of how geological characteristics influence the stand-up time behavior. Figure 10 illustrates this specific correlation for marker M-2, using both linear and logarithmic equations as examples. This figure highlights the ability of different regression forms to capture the relationship between the RMR and the opening time, with the intention of identifying the most effective approach to predict the structural behavior of rocks under varying conditions.

The analysis revealed that logarithmic equations demonstrate greater accuracy and fit to the observed data, showcasing the robustness of this model compared to linear equations. This result is crucial for a detailed understanding of the geotechnical dynamics present in the different geological markers, enabling a more precise and reliable prediction of stand-up time based on the RMR.

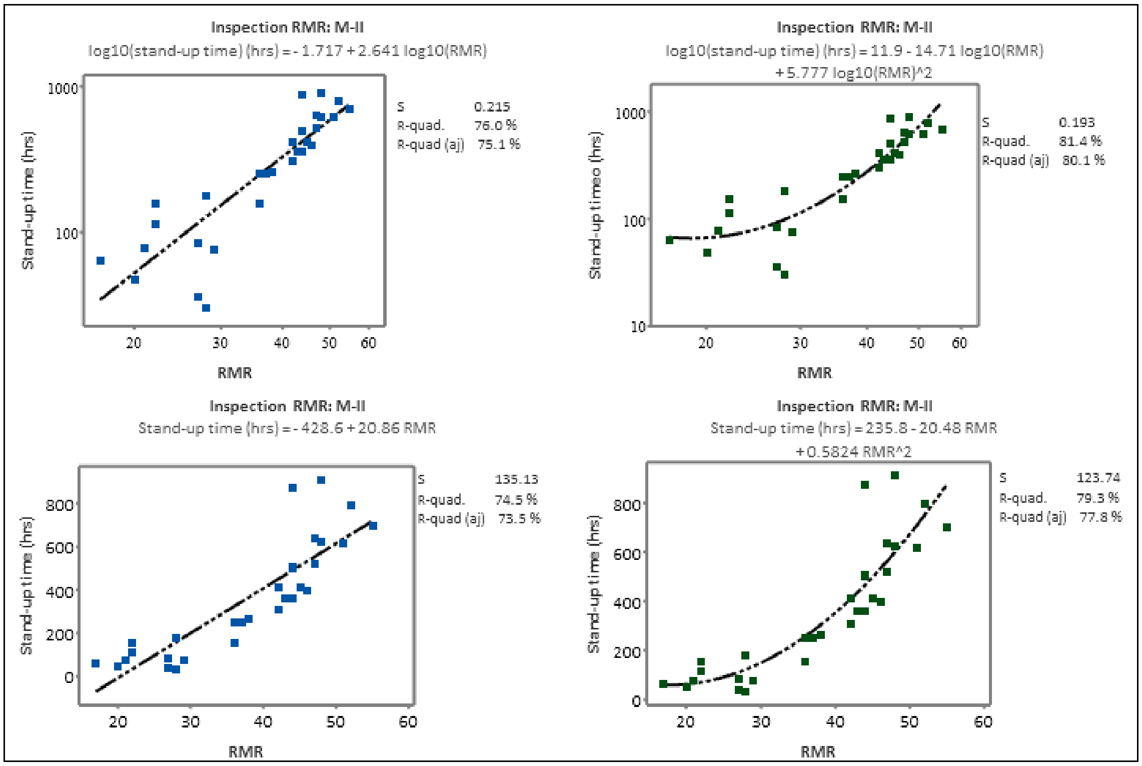


Figure 10 – RMR value x stand-up time correlations for M-2A.
Source: Authors (2023).

The equations derived from the regressions performed are presented in detail in Table 2. These results highlight a strong correlation between the Rock Mass Rating (RMR) value and the excavation opening time, also known as "stand-up time." The statistical analysis demonstrates that, with increasing RMR values, there is a clear trend towards prolongation of the stand-up time of the rock structures.

These equations are fundamental for predictive modeling in the field of geotechnics, providing a robust quantitative basis to estimate the behavior of excavations under different geological conditions. The high degree of correlation observed suggests that the RMR is a highly effective and reliable parameter for predicting the initial stability time of excavations without additional support.

Furthermore, Figure 11 provides a comparative view of the different equations obtained from various regression forms, such as linear, logarithmic, and power. This comparison allows for a critical evaluation of the methodologies employed, highlighting the relative efficiency of each approach in capturing the dynamics between the RMR and excavation opening time.

Imediatte Roaf Geologic	**Regression model**	**Stand-up time (hrs)**	**R^2 (%)**	**R^2 aj (%)**
M-I	Linear	Y= -393.9 + 21.59 * (RMR)	61.13	60.1
	Quadratic	Y= 676.3 - 47.71 *(RMR) + 1.026 * (RMR)^2	74.5	73.1
	Linear logarithmic	log10(stand-up time)= -0.6138 + 1.998 * log10 (Roof spam(m))	74.3	73.6
	Quadratic logarithmic	log10(stand-up time)= 4.380 - 4.805 * log10 (Roof spam (m)) + 2.297 log10 (Roof spam (m))^2	75.9	74.5
M-II	Linear	Y= -428.6 + 20.86 * (RMR)	74.5	73.5
	Quadratic	Y= 235.8 - 20.48 * (RMR) + 0.5824 * (RMR)^2	79.3	77.8
	Linear logarithmic	log10(stand-up time)= -1.717 + 2.641 * log10 (Roof spam (m))	76.0	75.1
	Quadratic logarithmic	log10(stand-up time)= 11.19 - 14.71 * log10 (Roof spam (m)) + 5.777 log10 (Roof spam (m))^2	81.4	80.1
M-4A	Linear	Y= -1.765+ 62.50 * (RMR)	53.1	51.3
	Quadratic	Y= 3.297 - 192,4 * (RMR) + 2,855 * (RMR)^2	74.6	72.6
	Linear logarithmic	log10(stand-up time)= -0.5364 + 2.013 * log10 (Roof spam (m))	62.8	61.4
	Quadratic logarithmic	log10(stand-up time)= 11.36 - 13.13 * log10 (Roof spam (m)) + 4.775 log10 (Roof spam (m))^2	71.0	68.7
M-6A	Linear	Y= - 162.3 + 16.02 * (RMR)	72.7	71.0
	Quadratic	Y= 368.7 - 13.29 * (RMR) + 0.3711 * (RMR)^2	77.6	74.6
	Linear logarithmic	log10(stand-up time)= 0.6229 + 1.275 * log10 (Roof spam (m))	78.5	77.1
	Quadratic logarithmic	log10(stand-up time)= 3.369 - 2.306 * log10 (Roof spam (m)) + 1.157 log10 (Roof spam (m))^2	79.5	76.8

Figure 11 – Correlation equations for different shapes, and for different geological areas.
Source: Authors (2023).

- (M-I): The equation that exhibits the best behavior is the logarithmic regression ($R^2 > 75.9$ and R^2adj > 74.5), showing a strong correlation coefficient for both R^2 and R^2adj. Additionally, it is observed that stand-up times increase as the RMR values rise. The span variation (m) also influences the different stand-up times of the excavation. The quadratic linear regression also presented good correlation of the data.
- (M-II): The equation that exhibits the best behavior is the logarithmic regression ($R^2 > 81.4$ and R^2adj > 80.1), showing a strong correlation coefficient for both R^2 and R^2adj. It was observed that the increase in RMR values is associated with longer stand-up times of the roof, demonstrating that the RMR indicator can be a good source for data interpretation.
- (M-4A): The equation that exhibits the best behavior is also the quadratic linear regression ($R^2 > 72.1$ and R^2adj > 69.8), demonstrating a strong correlation coefficient for both R^2 and R^2adj. It is noted that for this geological marker,

there was a reduction in the excavated span (m) and a greater thickness of the rock strata compared to M-1 and M-2, resulting in a thicker rock layer. The quadratic logarithmic equation shows a good apparent correlation with the data.

- (M-6A): The equation that exhibits the best behavior is again the logarithmic regression ($R^2 > 79.5$ and $R^2adj > 76.8$), showing a strong correlation coefficient for both R^2 and R^2adj. The interpretation was similar to that of M-4A, where higher RMR values are associated with longer stand-up times. This geological marker has the greatest thickness among those evaluated in the field. It is also noted that the linear equation presents good correlations.

Figure 12 presents an analysis map (span x opening time x RMR) for a quick visualization of the variations in the studied parameters, indicating that the higher the RMR value, the longer the excavation opening time.

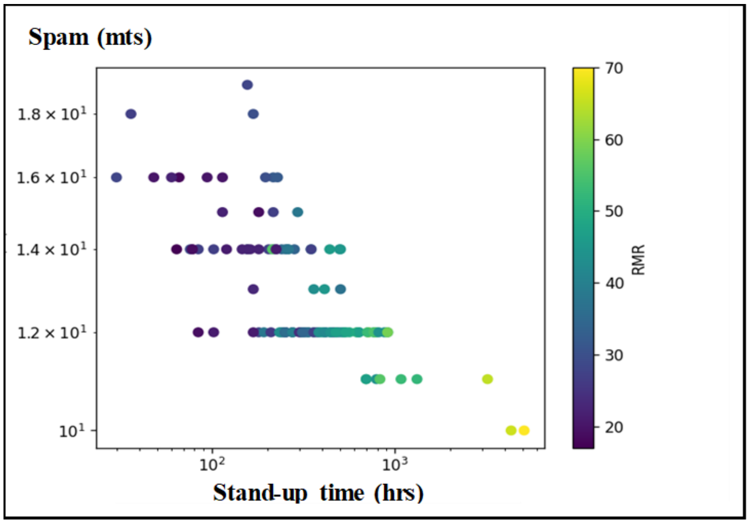
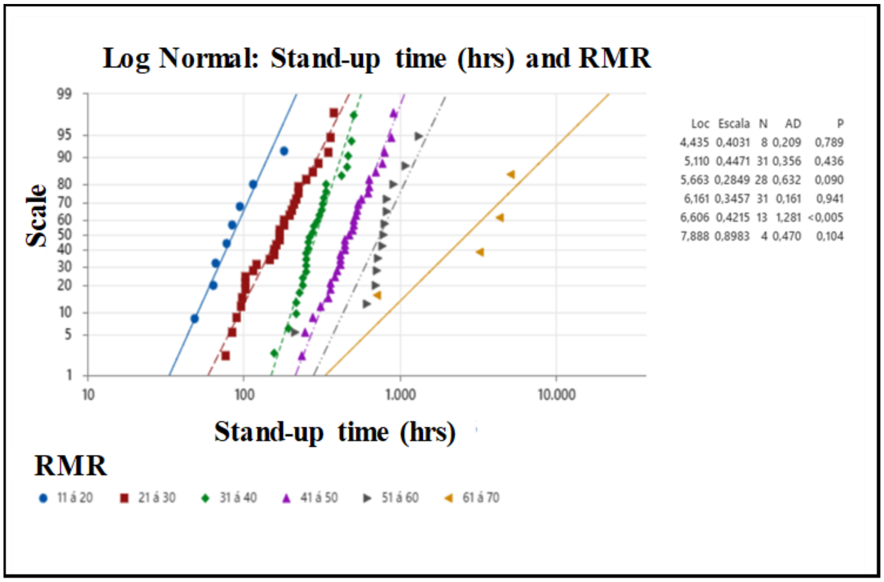


Figure 12 – Stand-up time (h) x RMR value x span (m)
Source: Authors (2023).

The similarity of the regression curves for each class of Rock Mass Rating (RMR) in relation to the stand-up time was analyzed. The results show a clear trend: the better and higher the geomechanical classification of the RMR, the longer the stand-up time of the rock structures. This relationship is visually represented in Figure 12. The analysis of the regression curves revealed that all RMR classes follow a consistent pattern, where an increase in the RMR value is associated with an extension of the stand-up time. This pattern reaffirms the validity of RMR as a robust and reliable indicator of excavation stability.

Figure 13 illustrates a trend in the regression curves for different RMR classes. Visualizing these curves provides an intuitive and immediate understanding of the interactions between the geomechanical quality of the rocks and the initial stability time. This knowledge is crucial for decision-making in geotechnical engineering projects, where safety and efficiency depend on accurate predictions of rock behavior. The observation of this similarity in the regression curves also provides a solid foundation for generalizing the results. It suggests that the developed regression equations can be reliably applied to a wide range of geological conditions, increasing the practical utility of the predictive models derived from the RMR classification.



Loc	Escala	N	AD	P
4,435	0,4031	8	0,209	0,789
5,110	0,4471	31	0,356	0,436
5,663	0,2849	28	0,632	0,090
6,161	0,3457	31	0,161	0,941
6,606	0,4215	13	1,281	<0,005
7,888	0,8983	4	0,470	0,104

Figure 13 – RMR value correlation with stand-up time for RMR gap values.
Source: Authors (2023).

4. Concluding remarks

Although not commonly used in underground salt mines, the Rock Mass Rating (RMR) classification was applied during field inspections to evaluate its applicability in this type of mine. The choice of RMR was based on its established use in geotechnical literature, as well as its design for sedimentary deposits, though it is rarely used in salt mines.

The results indicated that the average RMR classification was 38, suggesting a poor-quality rock mass. Despite this classification, the RMR system yielded significant results in the correlation equations with the stand-up time, with correlation values ($R^2 \geq 71\%$) for the logarithmic quadratic equations. Strong correlations were also observed for the four identified geological markers. These findings suggest that the adoption of the RMR system can be useful in predicting the stable opening time of the excavation.

The relationship between RMR classification and stand-up time indicates that higher RMR values are associated with longer stand-up times for the immediate ceiling in the salt mine. Therefore, the use of RMR classification can provide valuable support in scheduling and transitioning from corrective geotechnical activities to preventive ones. The ability to predict ceiling support needs before instability occurs can result in a more proactive and efficient approach to safety management in excavations. Additionally, RMR offers the possibility of establishing a systematic geomechanical classification applicable to salt mines.

Furthermore, it was observed that the longest stand-up times were associated with geological markers that had thicker rock strata, suggesting greater apparent beam resistance and consequently longer stand-up time.

It is important to note that this study was conducted in only one location/mining panel, covering four geological typologies found in the excavation. Despite promising results, caution is recommended in interpreting and using the obtained data. There is a need for continued data collection, with more structured and modeled analyses, to validate and refine the application of this geomechanical classification model to salt mines. Future studies should focus on expanding the data set and applying RMR in different geological and operational conditions to verify the robustness and generalizability of the results obtained.

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