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Geotechnical Evaluation of Rock Slopes of the Ain Tobi Member Using the Rock Mass Rating System, Al-Qawasim, NW Libya

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Rock Mass Rating (RMR)
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ABSTRACT

The stability of rock slopes is a major geotechnical concern, particularly in mountainous regions where discontinuities strongly influence slope behavior. This study presents a quantitative geotechnical evaluation of the Ain Tobi Member of the Sid As Sid Formation along the old Abughaylan mountain road, northwestern Libya, using the Rock Mass Rating (RMR) system. Field investigations included lithology, discontinuity characteristics, Rock Quality Designation (RQD), intact rock strength, and groundwater conditions. The upper dolomite slopes achieved an RMRbasic value of 67, corresponding to Good Rock (Class II), whereas the lower limestone slopes yielded values of 42–45, corresponding to Fair Rock (Class III). The results demonstrate that the RMR system provides a reliable and practical approach for evaluating rock mass quality and supporting geotechnical assessment and engineering decision-making in the study area. Future studies are recommended to incorporate the Slope Mass Rating (SMR) system to provide a more comprehensive evaluation of rock slope stability by considering the relationship between discontinuity orientation and slope geometry.

التقييم الجيوتقني للمنحدرات الصخرية لعضو عين طُبي باستخدام مؤشر جودة الكتل الصخرية، القواسم، شمال غرب ليبيا

أبوالقاسم الأخضر

قسم الهندسة الجيولوجية، كلية الهندسة جادو، جامعة نالوت، نالوت،ليبيا

الكلمات المفتاحية:
عضو عين طُبي
الجيولوجيا الهندسية
مؤشر تصنيف الكتلة الصخرية *(RMR)*
تكوين سيدي الصيد
استقرار المنحدرات الصخرية

الملخص

يُعد استقرار المنحدرات الصخرية من أهم القضايا الجيوتقنية، ولا سيما في المناطق الجبلية حيث تؤثر الفواصل الصخرية بشكل كبير في سلوك المنحدرات. تهدف هذه الدراسة إلى إجراء تقييم جيوتقني كمي لعضو عين طُبي من تكوين سيدي الصيد على امتداد الطريق الجبلي القديم أبوغيلان، شمال غرب ليبيا، باستخدام مؤشر تصنيف الكتلة الصخرية. شملت الدراسة تقييم الصفة الصخرية، وخصائص الفواصل، ومؤشر جودة الصخور، ومقاومة الصخور السليمة، وظروف المياه الجوفية. أظهرت النتائج أن منحدرات الدولوميت العليا حققت قيمة بلغت 67، مما يصنفها ضمن الصخور الجيدة (الفئة الثانية)، في حين سجلت منحدرات الحجر الجيري السفلى قيماً تراوحت بين 42 و45، مما يصنفها ضمن الصخور المتوسطة (الفئة الثالثة). وتؤكد النتائج أن مؤشر تصنيف الكتلة الصخرية يُعد أداة عملية وموثوقة لتقييم جودة الكتلة الصخرية ودعم التقييمات الجيوتقنية واتخاذ القرارات الهندسية في منطقة الدراسة؛ وتوصي الدراسة بأن تتضمن الأبحاث المستقبلية تطبيق نظام تصنيف الكتلة الصخرية للمنحدرات لاستكمال تقييم استقرار المنحدرات الصخرية، من خلال مراعاة العلاقة بين اتجاهات الفواصل الصخرية وهندسة المنحدر، بما يوفر تقييماً أكثر شمولاً ودقة.

Introduction

Slopes exhibit varying characteristics depending on their formation conditions, degree of inclination, and the nature of their constituent materials, whether cohesive rock masses or loose deposits [1], which directly influence their stability behavior. Rock masses remain stable up to a critical inclination, referred to as the angle of stability, representing the maximum slope angle at which equilibrium is maintained [2]. Instability may occur when geometric conditions change or when triggering factors induce movement [3]. Rockfalls often occur suddenly and at high velocities, making them among the most hazardous geotechnical phenomena, particularly in mountainous regions. Rock slope instability is especially common in areas where rock masses are intersected by

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joints and fractures [4], increasing the likelihood of failure mechanisms such as planar sliding, wedge sliding, and toppling [5]. Within this context, the slopes of the Sid As Sid Formation, located along the old Abughaylan mountain road, represent a site of significant geological and engineering interest. According to reference [6], the area attracts numerous visitors and geology students, increasing the potential risk associated with slope instability affecting road users.

Although the findings presented in reference [6] provide valuable insights into fracture geometry and Rock Quality Designation (RQD), they remain insufficient without a comprehensive quantitative geotechnical classification of the rock mass. The Rock Mass Rating (RMR) system [7], is one of the most widely applied rock mass classification systems in rock engineering [8]. It integrates key geomechanical parameters, including intact rock strength, Rock Quality Designation (RQD), discontinuity spacing, discontinuity condition, and groundwater conditions into a single numerical index that represents the engineering quality of the rock mass and provides a practical basis for geotechnical evaluation and engineering design [9]. Accordingly, this study applies the Rock Mass Rating (RMR) system to field data collected from the slopes of the Sid As Sid Formation in order to quantitatively evaluate rock mass quality and assess slope stability conditions. The results provide a scientific basis for interpreting the engineering behavior of the rock mass and support decision-making related to slope stability assessment, hazard mitigation, and future engineering works in the study area.

The study area is located in northwestern Libya, northeast of Al-Qawasim city, on the northern edge of Nafusa uplift Fig.1. Geographically, it lies between latitudes 32° 15′ 88″ N to 32° 15 ′ 99″ N and longitudes 13° 02′ 17″ E to 13° 02′ 19″ E. The road starts from Ain Abughaylan at the base and ascends to the Abu abughaylan district of Al-Qawasim city, approximately 75 km from Tripoli.

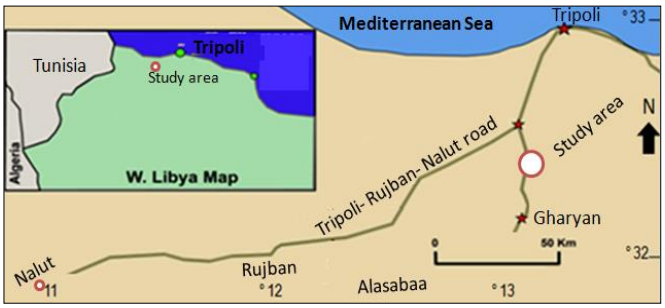


Fig.1: Location of the study area [11].

The area is part of the Nafusa uplift sequence in northwestern Libya, characterized by Mesozoic sedimentary rocks [11]. In the study area, the stratigraphic sequence terminates with the Upper Cretaceous Nalut Formation Fig. 2. The dominant rock units belong to the Sid As Sid Formation, divided into two members Upper Member (Yifran): Primarily dolomitic limestone and marl with dolomite intercalations; Lower Member (Ain Tobi): Limestone and dolomite with variable crystal sizes, yellow to grey in color, with thin marl layers. The Formation contains abundant fossils indicating Late Cretaceous (Cenomanian) age [12].

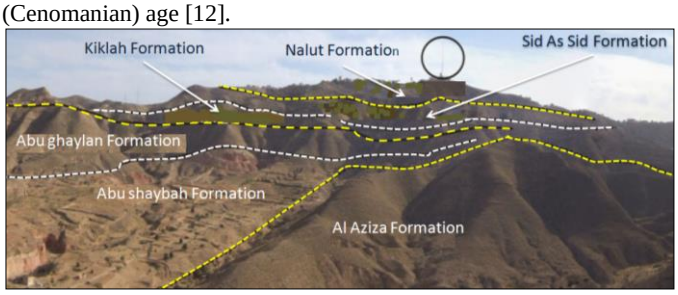


Fig. 2: Outcrop Formations in the study Area [13]

The Sid As Sid Fm comprises a carbonate succession approximately 100 m thick, deposited on an unconformity surface in a shallow marine environment in the Gharyan area. It is overlain by the Kiklah Formation to the west and the Abu Shaybah Fm to the east [14].

Methodology

Field Data: The field data required for calculating RMR used to classify and assess slope stability were obtained directly from field measurements recorded in Reference [6]. These measurements, including lithology, joint sets, roughness, continuity, spacing, infilling, RQD, intact rock strength, and groundwater conditions, are summarized in Table (1). The table compares the upper dolomite slopes with the lower limestone slopes, highlighting differences in joint characteristics and overall rock mass quality.

Table 1: Summary of Discontinuity Characteristics.

Property	Upper Slopes (Dolomite)	Lower Slopes (Limestone)
Lithology	Dolomite	Limestone
Discontinuity Sets	3 sets (S1, S2, S3)	4 sets (S1, S2, S3, S4)
Roughness	Smooth to medium	Medium to very rough
Continuity	3-10 m (medium length)	<1 m (very short)
Internal Persistence	1.3 m	0.2 m
Spacing (JS)	250 cm (extremely wide)	56 cm (moderately wide)
separation	23 mm	32 mm
Infilling	None	Rock debris, soil
Random Cracks	Few	Abundant
RQD	96% Very Good	56% Fair to Poor
Rock mass behavior	Large, stable blocks	Small, fractured blocks
Intact Rock Strength	100-200	12.5-50
Groundwater	Dry	Dry

Intact Rock Strength (IRS) was estimated in the field using the method described by Reference [15]. In the upper dolomite slopes, 30 observations indicated intact rock strengths ranging from 100–200 MPa, reflecting strong rock requiring heavy hammer blows for breakage. In the lower limestone slopes, 30 observations yielded average strengths of 12.5–50 MPa, with some samples exhibiting strengths below 1.25 MPa and disintegrating by hand, suggesting the presence of marl layers (Table 2).

Table 2: Estimation of intact rock strength [15].

Intact rock strength	Description
< 1.25 MPa	Crumbles in hand
1.25 – 5 MPa	Thin slabs break easily in hand
5 - 12.5 MPa	Thin slabs break by heavy hand pressure
12.5 – 50 MPa	Lumps broken by light hammer blows
50 – 100 MPa	Lumps broken by heavy hammer blows
100 – 200 MPa	Lumps only chip by heavy hammer blows
> 200 MPa	Rocks ring on hammer blows. Sparks fly

Method for Calculating (RMR):

The Rock Mass Rating (RMR) system, developed by Bieniawski (1974–1989), was applied to evaluate the engineering quality of the rock mass based on field observations and geotechnical characteristics. The classification integrates five key parameters, namely intact rock strength, Rock Quality Designation (RQD), discontinuity spacing, discontinuity condition, and groundwater conditions, into a single numerical index RMRbasic, according to the standard Bieniawski classification criteria [16]. The calculated RMRbasic values were subsequently used to classify the rock mass quality and assess the engineering behavior and stability of the investigated rock slopes. The RMRbasic index was calculated using the following equation (1).

$$RMR = R_1 + R_2 + R_3 + R_4 + R_5 \quad \text{.....(1)}$$

The coefficients (R_1, R_2, R_3, R_4, and R_5) were determined based on direct field measurements and detailed geological observations. Each coefficient was assigned a numerical rating according to the standard classification tables proposed by Bieniawski (1974–1989) [16]. The final Rock Mass Rating (RMR) value was obtained by summing the individual ratings of the five parameters, as presented in Table (3), resulting in a total score ranging from 0 to 100. Based on the calculated RMR value, the rock masses were classified into five main categories reflecting their overall engineering quality [16].

Table 3: RMR Parameters and Ratings [16]

Range - Description - Value	Rating
R_1 = rating for the strength of intact rock material	
UCS > 250 MPa	15
UCS 100–250 MPa	12
UCS 50–100 MPa	7
UCS 25–50 MPa	4
UCS 5–25 MPa	2
UCS 1–5 MPa	1
UCS < 1 MPa	0
R2 = rating for rock quality designation (RQD)	
90–100 %	20
75–90 %	17
50–75 %	13
25–50 %	8
< 25 %	3
R_3 = rating for joint spacing	
> 2.0 m	20
0.6 – 2.0 m	15
0.2 – 0.6 m	10
0.06 – 0.2 m	8
< 0.06 m	5
R_4 = rating for joint condition	
Not continuous, very rough, unweathered, no separation	30
Slightly rough, slightly weathered, separation < 1 mm	25
Slightly rough, highly weathered, separation < 1 mm	20
Continuous, slickensided or gouge < 5 mm, separation 1–5 mm	10
Continuous joints, soft gouge > 5 mm or separation > 5 mm	0
R_5 = rating for groundwater conditions	
Dry	15
Damp	10
Wet	7
Dripping	4
Flowing	0

The calculated RMRbasic values were classified according to the standard Rock Mass Rating (RMR) classification proposed by Bieniawski, as summarized in Table 4 [17].

Table 4: RMR Rock Mass Classes

RMR Value	Quality Class	Engineering Description
> 80	Very Good	Very Good Rock
61 – 80	Good	Good Rock
41 – 60	Fair	Fair Rock
21 – 40	Poor	Poor Rock
< 20	Very Poor	Very Poor Rock

Results and discussion

The results of the Rock Mass Rating (RMR) classification presented in Table 7 are consistent with the field observations summarized in Table 1, confirming the reliability of the RMR system in evaluating the engineering quality of the rock mass. The upper slopes, composed predominantly of dolomite, are characterized by three joint sets, moderate joint continuity (3–10 m), and very wide joint spacing (250 cm), which contributed to the maximum rating for joint spacing (R_3 = 20). Although the joint aperture reached approximately 23 mm, resulting in a joint condition rating of R_4 = 0 according to the RMR classification criteria, the high Rock Quality Designation (RQD = 96%), high intact rock strength, wide discontinuity spacing, and dry groundwater conditions produced an overall RMRbasic value of 67, corresponding to Good Rock (Class II). These results indicate that the upper dolomite slopes possess favorable engineering characteristics and good overall rock mass quality.

Table 7: RMR Ratings for Dolomite and Limestone Slopes

Parameter	Symbol	Dolomite Upper Slopes	Limestone Lower Slopes
Intact rock strength	R_1	Rating 12	Rating 4–7
RQD	R2	Rating 20	Rating 13
Joint spacing	R_3	Rating 20	Rating 10
Joint condition	R_4	Rating 0	Rating 0
Groundwater Conditions	R_5	Rating 15	Rating 15
(RMR basic score)	—	67	42–45
RMR Class	—	II	III
Rock Mass Quality	—	Good Rock	Fair Rock

Figure 3 compares the ratings of the five RMR parameters (R_1–R_5) for the upper dolomite and lower limestone slopes. The comparison clearly demonstrates the superior geomechanical quality of the dolomite slopes, particularly in terms of intact rock strength, Rock Quality Designation (RQD), and discontinuity spacing, which resulted in a

higher overall RMRbasic value than that of the limestone slopes.

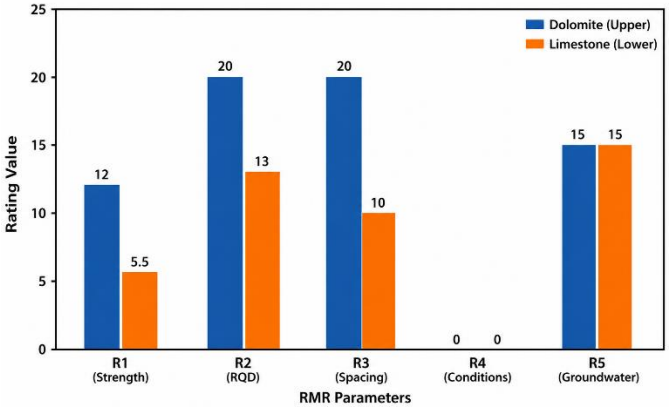


Fig. 3: RMR Parameters Comparison for Slopes

In contrast, the lower slopes composed of limestone exhibit less favorable geomechanical characteristics than the upper dolomite slopes. As summarized in Table 1, the limestone slopes are characterized by four discontinuity sets, short joint continuity (<1 m), relatively close joint spacing (56 cm), and the presence of rock debris and soil infilling. These conditions adversely affected the RMR ratings, particularly the joint spacing rating (R_3 = 10) and the joint condition rating (R_4 = 0), indicating poorer rock mass conditions and a greater degree of discontinuity development.

The lower Rock Quality Designation (RQD = 56%) resulted in an R2 rating of 13, while the estimated intact rock strength (12.5–50 MPa) corresponded to an R_1 rating ranging from 4 to 7. Dry groundwater conditions produced an R_5 rating of 15 for both slope sections. Consequently, the calculated RMRbasic values ranged from 42 to 45 for the limestone slopes, classifying the rock mass as Fair Rock (Class III) according to the Bieniawski RMR classification system.

By comparison, the upper dolomite slopes achieved an RMRbasic value of 67, corresponding to Good Rock (Class II). This higher classification reflects the combined influence of excellent rock quality (RQD = 96%), high intact rock strength (100–200 MPa), very wide discontinuity spacing, and dry groundwater conditions. Although the relatively large joint aperture reduced the joint condition rating (R_4 = 0), the overall engineering quality of the dolomite rock mass remained significantly higher than that of the limestone slopes. The comparison between the two slope sections demonstrates that rock mass quality is primarily controlled by the combined effects of intact rock strength, rock quality designation, discontinuity spacing, and joint conditions. The lower engineering quality of the limestone slopes indicates a greater susceptibility to localized instability and progressive weathering, whereas the dolomite slopes exhibit more favorable engineering characteristics, indicating better engineering performance and more favorable conditions for long-term slope stability.

Conclusions

This study presented a comprehensive geotechnical evaluation of the rock masses of the Ain Tobi Member within the Sidi As Sid Formation along the old Abughaylan mountain road, northwestern Libya, using the Rock Mass Rating (RMR) system. The field investigations and rock mass characterization demonstrated that the RMR system is a practical and reliable tool for evaluating rock mass quality and supporting engineering geological investigations. The findings provide valuable information for infrastructure planning, slope management, and engineering decision-making in the study area and in similar geological settings. Future studies are recommended to

incorporate the Slope Mass Rating (SMR) system to provide a more comprehensive assessment of rock slope stability by considering the relationship between discontinuity orientation and slope geometry. Furthermore, integrating rock mass classification with numerical modeling and long-term field monitoring would improve the understanding of slope behavior and contribute to more accurate geotechnical assessments and safer, more sustainable engineering practices in mountainous regions.

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