Frontiers in Scientific Research and Technology

Online ISSN: 2682-2970
Print ISSN: 2682-2962
http://fsrt.journals.ekb.eg

FSRT J 11 (2025) 9 – 20 10.21608/fsrt.2025.350847.1146

# Evaluation of Slope Stability and Application of Rock Mass Classification on the Alagaba New Road, Northeast Sudan

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**ARTICLE INFO**

Article history:
Submitted 6 January 2025
Received in revised form 21 February 2025
Accepted 24 February 2025
Available online 4 March 2025

**Keywords**
Slope Mass Rating,
Rock Mass Rating,
Geological Strength Index,
Alagaba New Road.

## ABSTRACT

The Alagaba New Road, a crucial highway in northeast Sudan, connects the capital, Khartoum, with major Red Sea ports. Part of the road (~ 6 km) has been constructed on hilly terrain with cut and rugged topography. This study aims to characterize the rock mass and assess the stability of jointed rock slopes in seven sites along this dangerous part of the road. To achieve this aim, a comprehensive study was conducted involving the collection of 710 discontinuity readings and representative samples for laboratory testing. The scanline technique and a Brunton compass were employed for field data acquisition. The rock mass rating (RMR), slope mass rating (SMR), and geological strength index (GSI) were then calculated for the target locations. The study area comprises metavolcanic rocks and dolerite dykes in the east, metasediment rocks with less abundant metavolcanic and granodiorite in the west. The eastern rocks have higher Rock Mass Rating (RMR) values (70-77) compared to the western rocks (56-68), indicating better quality due to less weathering. Slope Mass Rating (SMR) results indicate that the eastern sites are more stable than western sites. Kinematic analysis reveals higher planar and wedge failure rates in the western sites, attributed to internal rock variations and external factors like unplanned road cutting and seismicity. The geological and engineering conditions on the eastern side offer the highest assurance of road stability and long-term sustainability. So, it is recommended that the mountain road be constructed on the eastern slope, incorporating benches and terraces to enhance stability.

## 1. Introduction

Slope failures have been identified as one of the most common natural disasters that can result in significant loss of property and human life. Mountain roads often face a severe and recurring problem of rock failures that lead to road closures and disrupt traffic, causing economic problems for the local community and travellers. Several natural factors, including topography, structural elements, composition, and climatic changes, can influence the occurrence of landslides on mountain roads. However, the presence of joints, fractures, and fissures in rocks plays a significant role in this phenomenon. Various empirical methods using rock mass classification are used to analyze slope stability. The most used methods are Rock Mass Rating (RMR) after [1,2], Geological Strength Index (GSI) after [3], Slope Mass Rating (SMR) after [4], and Continuous Slope Mass Rating (CSMR) after [5].

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These techniques are essential for evaluating the stability and conditions of slope mass and offer valuable insights into the behavior of rock slopes. The highway connecting Port Sudan and Khartoum is a vital economic and commercial route that links the Sudanese capital to key ports in eastern Sudan [6]. The new Alagaba road has numerous geological hazards and engineering problems that result in total damage in many places and partial damage in others, including rock falls, debris flows, and rock failures, due to meandering design and location in areas with severe seasonal erosion.

Assessing slope stability is critical for reducing the risk of catastrophic failures. Therefore, this study aims to evaluate the current slope stability through a comprehensive field investigation of the Alagaba New Road. Notably, no prior research has been conducted in this area, making this study the first to assess its geotechnical conditions systematically. The study proposes a new route to enhance road alignment, ensuring a straighter, safer passage in areas with sharp bends, increased durability, and reduced maintenance issues. This research will investigate the influence of various factors contributing to slope instability. To classify the rock mass and analyze potential slope failure mechanisms, we will employ several assessment techniques, including the Rock Mass Rating (RMR), Geological Strength Index (GSI), Slope Mass Rating (SMR), and Continuous Slope Mass Rating (CSMR).

## 2. Study Area

Alagaba lies at about 120 km southwest of Port Sudan in the Red Sea State in northeastern Sudan, between latitudes 18° 53' and 19° 01' E and longitudes 36° 50' and 37° 02' N (Figs.1a and b). The current study deals with the Alagaba Highway, which moves through a zone of about 25 km of rock-cut. The dominant rock types are metasediments and metavolcanic, which exhibit greenschist facies metamorphic conditions and are intruded by granitoid rocks. Syn-to-post-tectonic granites, granodiorites, tonalite, and quartz diorites comprise the plutonic rocks [7]. The Nakasib shear zone strongly affects the studied area.

Three dominant major joint systems are present (Fig. 1d): two are primarily vertical, while the third is horizontal. Although faults are typically distinct structures, many can be grouped to form a fault zone. The faults in this area are classified as normal and strike-slip types.

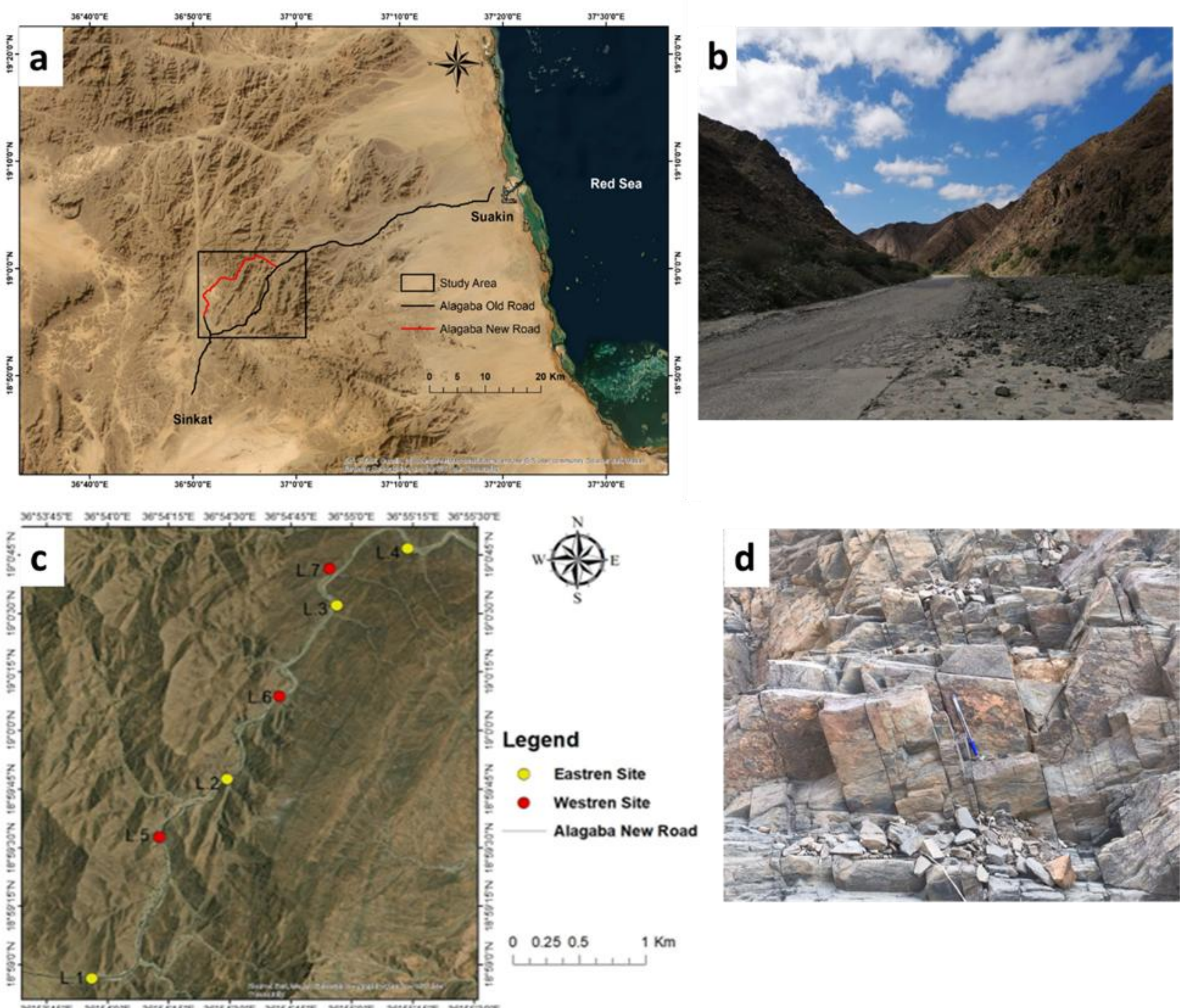


**Fig.1.** The investigated Alagaba New Road **a)** Location of the study area, **b)** The eastern and western site of Alagaba New Road, **c)** The location of seven sites of the study, **d)** Major joint systems present in the study area.

## 3. Methods

### 3.1. Field and laboratory investigations

The investigation was conducted at seven sites, as illustrated in (Fig. 1c). The sites were categorized into eastern and western sides based on the Alagaba New Road. During fieldwork, various measuring and data collection methods were used, including the scanline survey approach. The locations were assessed visually for safety and suitability, primarily to look for unstable slopes.

For the current investigation, all measurements and data related to the characteristics of the rock mass and discontinuities were collected. This covers rock quality designation (RQD), joint spacing, water effect, and the surface conditions of the joints, such as discontinuity roughness, degree of weathering, filling material, discontinuity persistence, and attitudes of various joint sets, in addition to the geometrical aspects of the slope.

Representative rock samples were collected from each site to determine their uniaxial compressive strength following the ASTM D7012-14 standard [8]. Additionally, twenty thin sections were prepared from these samples and examined using a polarizing microscope in the Geology Department at the Faculty of Science, Alexandria, university to identify mineral compositions, textures, and microstructures of the samples.

### 3.2 Rock Mass Classification

Different rock mass classification methods were applied to assess the rocky slope in the Alagaba New Road area.

#### 3.2.1 Rock Mass Rating (RMR)

The revolutionary RMR System was initially designed by [1] to analyze the stability and support needs of tunnels, slopes, and foundations. The basic RMR method includes the five fundamental parameters. After rating all the parameters, RMR was obtained using Bieniawski's Equation (1989).

$$\mathrm{RMR} = \mathrm{R1} + \mathrm{R2} + \mathrm{R3} + \mathrm{R4} + \mathrm{R5}$$

Where, R1 = UCS, R2 = RQD, R3 = discontinuity spacing, R4 = discontinuity condition, and R5 = groundwater condition. Table 1 guides the determination of RMR rocks according to [2]. The rock mass can be classified into five categories: very good (81–100), good (61–80), fair (41–60), poor (21–40), and very poor (less than 20).

**Table 1:** Classification parameters and values [2].

| Parameters | Values | | | | | | |
|---|---|---|---|---|---|---|---|
| **Point load test (Mpa)** | >10 | 10-4 | 4-2 | 2-1 | N/a | N/a | N/a |
| **Uniaxial compressive test (Mpa)** | > 250 | 250-100 | 100-50 | 50-25 | 25-5 | 5-1 | <1 |
| **Rating** | 15 | 12 | 7 | 4 | 2 | 1 | 0 |
| **RQD** | 100-90 | 90-75 | 75-50 | 50-25 | <25 | <25 | <25 |
| **Rating** | 20 | 1711 | 13 | 8 | 3 | 3 | 3 |
| **Joint spacing(cm)** | >200 | 200-60 | 60-20 | 20-6 | >6 | >6 | >6 |
| **Rating** | 20 | 15 | 10 | 8 | 5 | 5 | 5 |
| **Condition of joint** | Very rough unweathered wall rock and tight discontinuity | Rough and slightly weathered rock wall surface separation <1mm | Slightly rough and moderately to high weathered surface separation <1mm | Slick-sided wall rock surface (1-5mm) | Soft Gouge >5mm | Continuous Discontinuity | |
| **Rating** | 30 | 25 | 20 | 10 | 8 | 5 | 5 |
| **Groundwater** | Completely Dry | Dump | Wet | Dripping | Flowing | | |
| **Rating** | 15 | 10 | 7 | 4 | 0 | | |

#### 3.2.2 Geologic Strength Index (GSI)

Hoek (1994) developed the Geological Strength Index (GSI) as a tool for determining the rock mass properties of both strong and weak rock masses for use in rock engineering [3]. The GSI was developed by combining observations of rock mass conditions (Terzaghi's descriptions) with connections gained through RMR-system experience [9]. The link between rock mass structure and rock discontinuity surface conditions is obtained by calculating an average GSI value represented by diagonal contours. The geological strength index (GSI) is a simple, fast, and reliable system that can be tuned for computer simulation of rock structures. It provides a means to quantify a rock mass's strength and deformation properties. The most accurate way to measure GSI is to use a range of values rather than a single value.

### 3.3 Slope mass rating (SMR)

The Slope Mass Rating (SMR) system is a classification method for evaluating rock slope stability, initially developed based on the Rock Mass Rating (RMR) system [4]. A systematic analysis of SMR was conducted using a MATLAB-based open-source program, SMR Tool [10], which automates calculations and graphically represents slopes and discontinuities. To calculate an SMR score, adjustments are made to the RMR score by subtracting a factor based on the relationship between the slope and the joints in the rock and adding a factor based on the excavation method.

$$SMR = RMRb - (F1 \times F2 \times F3) + F4$$

Where: $RMR_b$: is the uncorrected basic RMR index derived from Bieniawski's rock mass classification.

$F_1$: represents the parallelism between the discontinuity dip direction α j, and the slope dip.

$F_2$: represents the discontinuity dip βj in the case of planar failure and the intersecting line plunge βi in the case of wedge failure. This setting is set to 1.0 for toppling failure. The rate of discontinuity shear strength is related to this parameter [11].

F3: depending on the slope βs, discontinuity βj, dips (toppling or planar failure cases) or the plunge of the intersecting line (wedge failure case).

F4: is a correction factor that varies according to the excavation method.

The Continuous Slope Mass Rating (CSMR) method provides a more accurate slope stability evaluation than the SMR method [12]. The CSMR is calculated using the same equation as SMR but with different adjustment factors (F1, F2, and F3).

### 3.4. Kinematic analysis

Kinematic analysis was conducted with commercial software to assess slope stability in high-risk areas. The sites were selected based on their high-risk nature, with long faces preferred for accessible data collection. Additionally, they were based on the simplicity of measurement, ensuring that the analysis focused on areas where slope instability is most likely.

## 4. Results and Discussion

### 4.1. Lithology

The main rock units in the study area comprise metavolcanic rocks, and dolerite dykes dominated in the eastern sites and metasediment rocks with less abundant metavolcanic and granodiorite at the western sites. The metavolcanic encompasses metadacite, metaandesite, metarhyolite, and metabasalt (Fig 2).

The metasediments dominated on the western side are represented by light grey to black and fine to medium-grained biotite schist, chlorite schist, and marbles. These rocks are composed mainly of biotite and quartz, along with less abundant muscovite and feldspar (Fig. 3). The most notable feature of the metasediment rock is its well-developed schistosity foliation, which gives it a tendency to split into distinct layers.

### 4.2. Rock Mass Classification

The analysis of the data presented in Tables 2 and 3 and Figure 4 shows that the rock mass rating at the eastern sites ranges from 70 to 77, with Geological Strength Index (GSI) values between 65 and 70, classifying the rock mass as Class II or good rock. This suggests that the rock mass is relatively competent, with favorable slope-cutting conditions and stability. The higher Rock Mass Rating (RMR) and GSI values imply that the rock mass is strong, with favorable discontinuity arrangements and orientations.

In contrast, at the western sites, Station 5 has an RMR Basic value of 68 and a GSI range of 55-60, maintaining its classification as Class II or good rock. However, Stations 6 and 7 have RMR Basic values of 56 and GSI ranges of 45-50, classifying the rock mass as Class III or fair rock. This indicates that the rock mass conditions at these locations are slightly inferior compared to the eastern sites, with lower rock strength, higher discontinuity density, and the presence of unfavorable joints with significant persistence.

The analysis reveals that the rock mass conditions are generally better at the eastern stations (1 to 4) compared to the western stations (5 to 7). The disparity in RMR values between the two sides is attributed to the susceptibility of the western metasediments to weathering processes, which reduce the strength and hardness of the rocks over time through physical and chemical weathering. According to [13], mica schists are highly anisotropic metamorphic rocks often exhibiting weaknesses in strength and construction applications. The lower RMR values at the western sites are primarily due to high joint densities and regular joint sets with moderate to smooth roughness surfaces [14]. Conversely, the rock mass at the eastern sites features relatively strong rock walls, larger spacing, and good joint surface conditions, contributing to higher RMR values.

Higher values of RMR, GSI, and RQD are observed in competent (hard rock) and massive (thick) lithologies. In contrast, less competent (soft rock) and thinly bedded rocks display lower values [16]. In the study area, the rocks on the eastern side are mostly thick and massive, while the rocks on the western side are dominantly thin with a foliated and schistosity nature. Therefore, the schist rock masses have poor quality with lower RQD and GSI values, as shown in Fig. 5.

### 4.3. Slope Mass Rating

The results of SMR (Table 4) indicate that the eastern sites were mostly normal to completely stable (60-92). On the other hand, the stability of the western sites varied from very bad to unstable in sites 6 and 7, with values of 20 and 30, respectively. Site 5 is stable, with a value of 74, which is attributed to the lithology, orientation of the discontinuities, slope angle, weathering, and condition of discontinuity surfaces.

According to [4], If the F3 is less than −50°, unfavorable conditions occur, such as the planar failure in site No. 6 with 56 RMR and 20 SMR and site No. 7 with 58 RMR and 31 SMR.

The CSMR values (Table 5) showed that the stability ratings were nearly identical to those of SMR. In general, the CSMR system allows a more conservative estimate of these instabilities as a better indicator than the SMR system [17]. It was noted that all rock failures within the study area were primarily influenced by joint systems (Table 6).

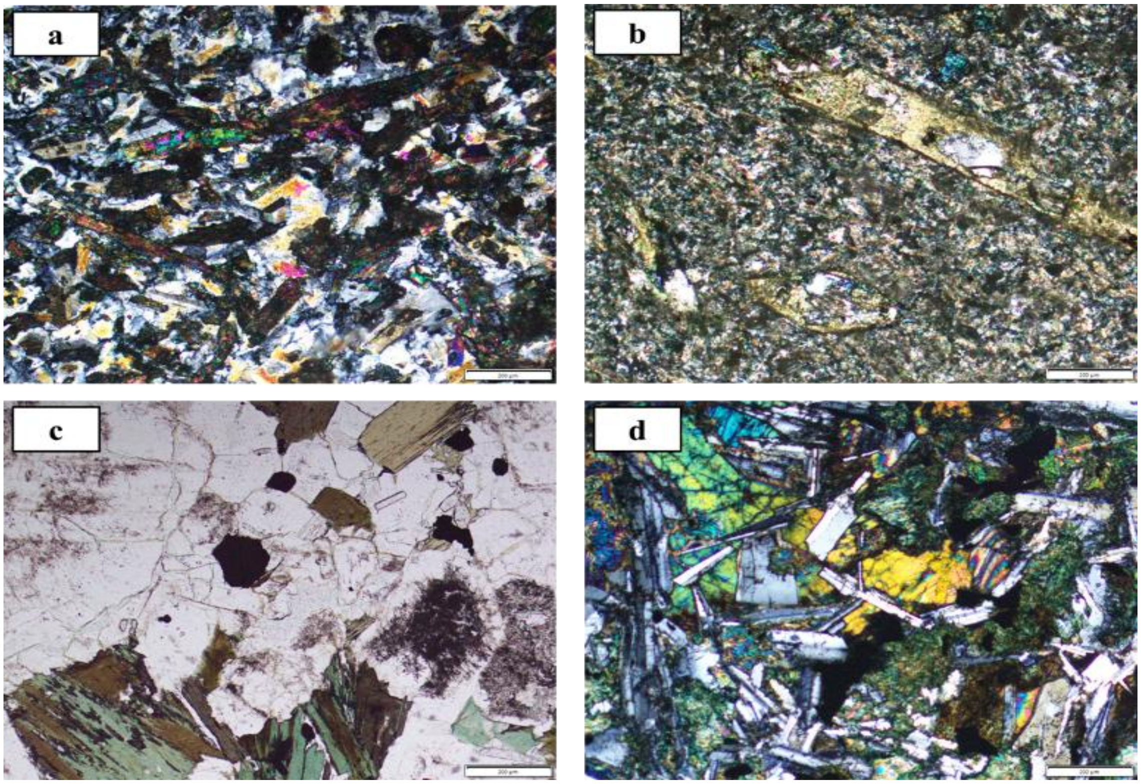

**Fig. 2** Photomicrographs of eastern side rock varieties. **(a)** Metabasalt with abundant epidote (of high interference color) and chlorite (of blue interference color) and plagioclase (of low interference color) – XPL. **(b)** Meta-andesite with relict hornblende and feldspar phenocrysts in fine-grained groundmass rich in chlorite – XPL. **(c)** Granodiorite with K-feldspar (of clayey alteration) plagioclase, quartz, biotite and chlorite – PPL. **(d)** Dolerite dyke with subophitic texture composed of augite and plagioclase laths – XPL. Scale bar = 200 µm

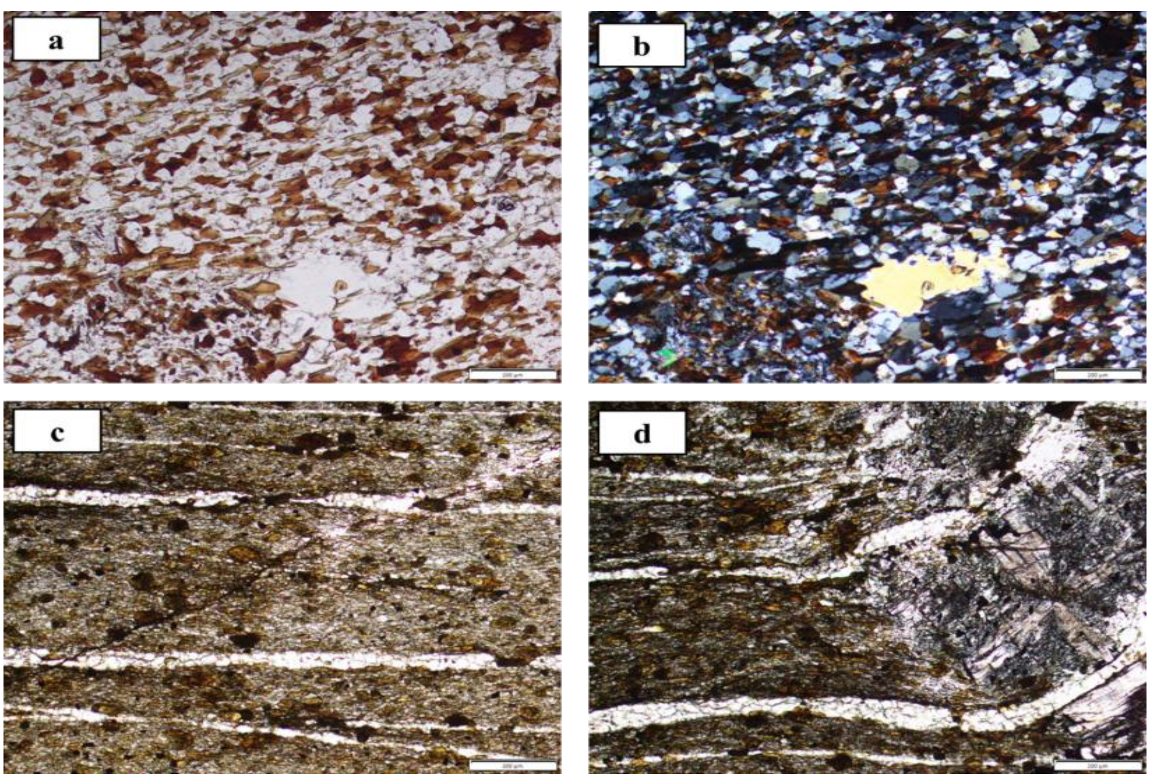

**Fig. 3** Photomicrographs of western side metasediments showing **(a & b)** Biotite schist with aligned biotite and abundant quartz – **a** under PPL, **b** under XPL; **(c & d)** Quartz microbands in foliated and deformed metasediment - PPL. Scale bar = 200 µm.

**Table 2:** Parameters of Rock Mass Rating (RMR)in the studied location.

| Location | | | R1 | R2 | R3 | R4 | | | | | R5 | RMR | Remark |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Description | | UCS (MPa) | RQD | Spacing (cm) | Persistence (m) | Aperture (mm) | Roughness | Infilling | Weathering D. S | G. W | -- | -- |
| Eastern | 1 | Meta-andesite | 65 | 82% | 20-60 | <1 | 1 | Rough | None | Slightly weathered | Dry | | |
| | | Rating | 7 | 17 | 10 | 6 | 4 | 5 | 6 | 5 | 15 | 75 | Good |
| | 2 | Meta-andesite | 70 | 73% | 20-60 | 2.5 | 1 | Rough | None | Slightly weathered | Dry | | |
| | | Rating | 7 | 14 | 10 | 4 | 4 | 5 | 6 | 5 | 15 | 70 | Good |
| | 3 | Meta-andesite | 70 | 82% | 20-60 | 3 | 4 | Rough | None | Unweathered | Dry | | |
| | | Rating | 7 | 17 | 10 | 4 | | 5 | 6 | 6 | 15 | 74 | Good |
| | 4 | Meta-dolerite | 70 | 95% | 20-60 | 3 | 1 | Rough | None | Unweathered | Dry | | |
| | | Rating | 7 | 20 | 10 | 4 | 4 | 5 | 6 | 6 | 15 | 77 | Good |
| western | 5 | Meta-andesite | 74 | 75% | 20-60 | 2 | 2 | Rough | Hard filling < 5mm | Slightly weathered | Dry | | |
| | | Rating | 7 | 17 | 10 | 4 | 1 | 5 | 4 | 5 | 15 | 68 | Good |
| | 6 | Schist | 50 | 60% | 20-6 | 3 | 3 | Smoot h | Hard filling < 5mm | moderately weathered | Dry | | |
| | | Rating | 7 | 13 | 8 | 4 | 1 | 1 | 4 | 3 | 15 | 56 | Fair |
| | 7 | Schist | 45 | 60% | 20-6 | 3 | 1 | Smoot h | None | moderately weathered | Dry | | |
| | | Rating | 4 | 13 | 8 | 4 | 4 | 1 | 6 | 3 | 15 | 58 | Fair |

*R1, R2, R3, R4, R5 = ratings of the RMR1989 classification system referred to, respectively, UCS, RQD, spacing of discontinuities, condition of discontinuities, and groundwater. RQD = value for the Rock Quality Designation.*

**Table 3:** Rock Mass Classification results

| Station. No | RMR Basic | GSI | Rock mass class |
|---|---|---|---|
| 1 | 75 | 65-70 | Class II good rock |
| 2 | 70 | 65-70 | Class II good rock |
| 3 | 74 | 65-70 | Class II good rock |
| 4 | 77 | 65-70 | Class II good rock |
| 5 | 68 | 55-60 | Class II good rock |
| 6 | 56 | 45-50 | Class III fair rock |
| 7 | 58 | 45-50 | Class III fair rock |

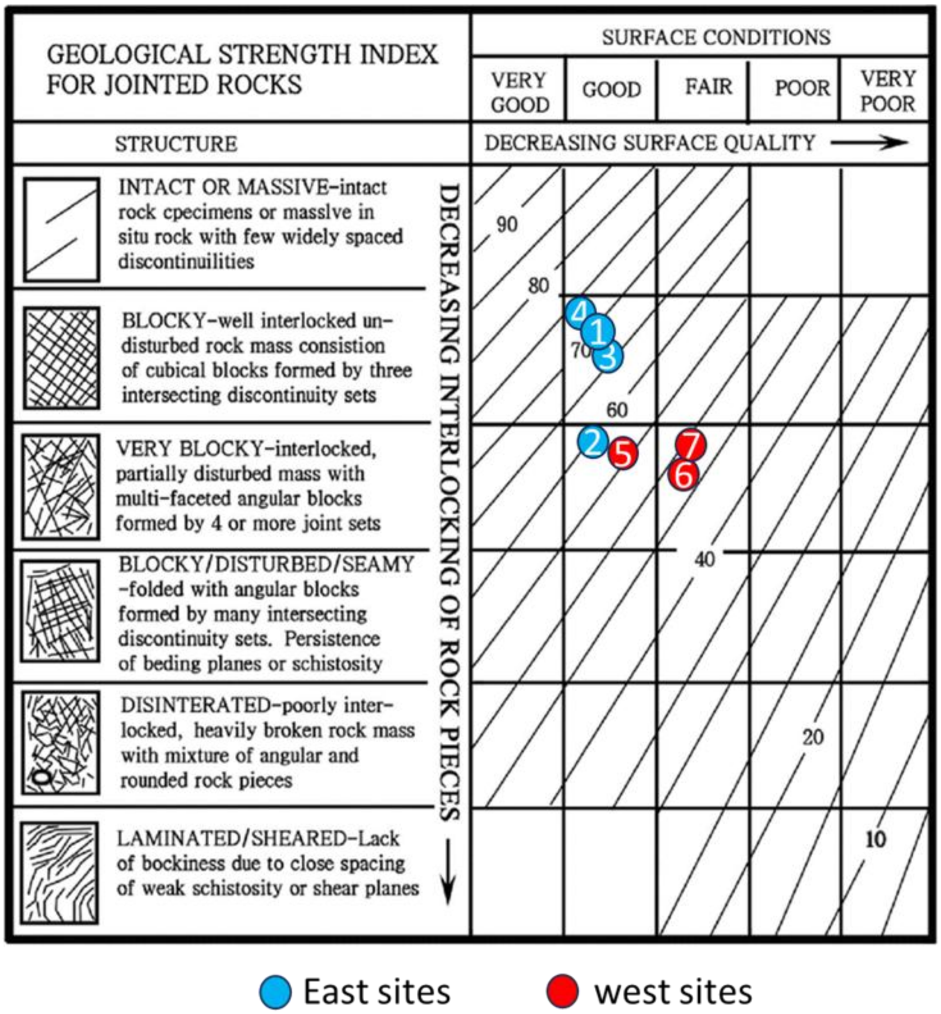


**Fig. 4** GSI chart [15] and distribution of GSI values from the observations in the field

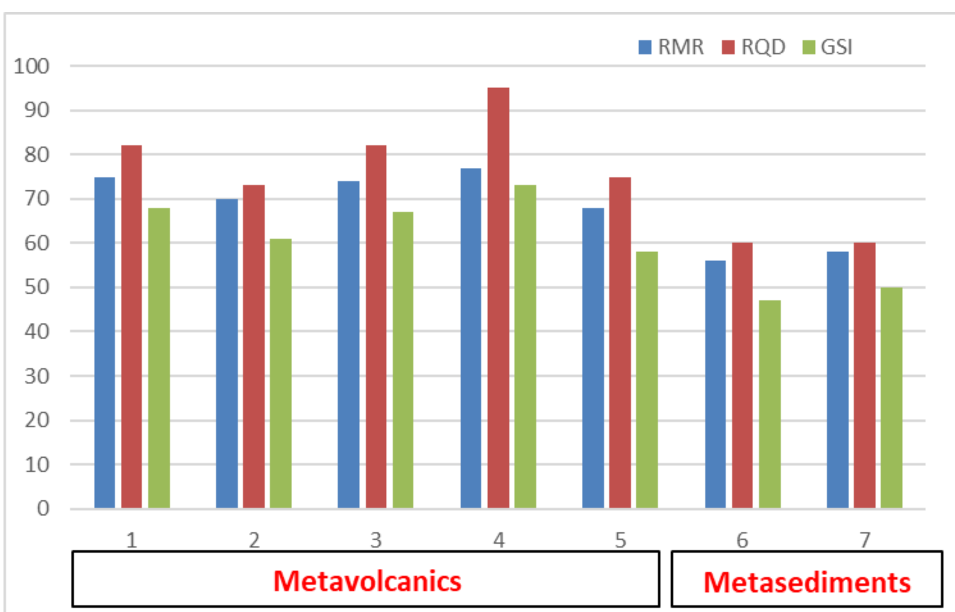


**Fig. 5** Bar diagram showing RMR, RQD, GSI and lithology in the study area

**Table 4:** Slope Mass Rating SMR values.

| Site | | $RMR_b$ | Kinematic | F1 | F2 | F3 | F4 | Calculated SMR | Class/Stability | Support |
|---|---|---|---|---|---|---|---|---|---|---|
| Eastern | 1 | 75 | Toppling | 0.15 | 1.00 | - 25 | 0 | 71 | II/Stable | Occasional |
| | 2 | 70 | Toppling | 1 | 1.00 | - 25 | 15 | 60 | III / Normal | Occasional |
| | 3 | 74 | Toppling | 0.85 | 1.00 | - 25 | 15 | 67 | II / Stable | Occasional |
| | 4 | 77 | Plane/wedge | 0.15 | 1.00 | 00 | 15 | 92 | I/ Completely Stable | Occasional |
| western | 5 | 68 | Planar | 0.15 | 0.4 | - 50 | 10 | 74 | II / Stable | Occasional |
| | 6 | 56 | Plane/wedge | 0.85 | 1.00 | - 60 | 15 | 20 | V/ very bad | Re-excavation |
| | 7 | 58 | Plane/wedge | 0.85 | 1.00 | - 60 | 15 | 30 | IV/ Unstable | Important/ corrective |

1) ***Re-excavation, Important/Corrective”:*** *Reshaping or benching the slope, changing the slope angle, or implementing extensive retaining structures. Involves removing additional material and installing permanent support systems such as retaining walls or anchors.*
2) ***Systematic Support*** *for slopes exhibiting moderate instability where consistent reinforcement includes installing rock bolts, shotcrete, or mesh across the slope.*
3) ***Occasional Support*** *is applied selectively when the overall slope is relatively stable but has localized weak zones requiring reinforcement, such as spot bolting, targeted shotcrete application, or localized drainage improvements.*

**Table 5:** Calculated Continuous Slope Mass Rating CSMR values

| Sites | | $RMR_{basic}$ | F1 | F2 | F3 | F4 | CSMR | Class/Stability |
|---|---|---|---|---|---|---|---|---|
| Eastern | 1 | 75 | 0.16 | 1.00 | - 25.67 | 0 | 70 | II/ Stable |
| | 2 | 70 | 0.99 | 1.00 | - 25.67 | 15 | 59 | III / Normal |
| | 3 | 74 | 0.94 | 1.00 | - 25.58 | 15 | 64 | II / Stable |
| | 4 | 77 | 0.148 | 0.99 | -1.46 | 15 | 91 | I/ Completely Stable |
| Western | 5 | 68 | 0.83 | 0.99 | - 51.14 | 10 | 68 | II / Stable |
| | 6 | 56 | 0.94 | 0.95 | - 59. 04 | 15 | 17 | V/ very bad |
| | 7 | 58 | 0.94 | 0.99 | - 56.23 | 15 | 20 | IV/ very bad |

**Table 6:** A summary of the fundamental discontinuity characteristics

| Site | | Slope orientation | Slope Height (m) | Joint sets dip /dip direction | | | | Mechanism of failure | Type of failure in the field |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Set 1 | Set 2 | Set 3 | Set 4 | | |
| Eastern | 1 | 70/355 | 25 | 7º/52º | 79º/103º | 82º/147º | | Structurally controlled | Some Blocks |
| | 2 | 79/280 | 15 | 13º/172º | 79º/151º | 78º/229º | | | Some Blocks |
| | 3 | 70/226 | 30 | 13º/43º | 80º/41º | 87º/299º | | | Toppling |
| | 4 | 85/060 | 20 | 14º/171º | 79º/117º | 83º/148º | | | None |
| Western | 5 | 70/085 | 20 | 87º/096º | 85º/151º | 30º/122º | 18º/284º | | Wedge/Planar |
| | 6 | 80/141 | 20 | 90º/208º | 84º/98º | 84º/180º | 85º/260º | | Big Wedge/Planar |
| | 7 | 70/133 | 20 | 26º/130º | 86º/094º | 89º/024º | 80º/126º | | Big Wedge/Planar |

### 4.4. Kinematic analysis

The kinematic analysis was performed using the internal friction angle of rock discontinuities and the orientations of slopes and discontinuities to identify potential failures controlled by structural factors. The potential failure zone is pink in stereography (Fig.6). Kinematic analysis of slopes reveals that the planar and wedge failure in eastern sites was relatively insignificant. However, the third site shows a slight discrepancy between the results obtained from the kinematic analysis and slope mass rating. While the kinematic analysis shows a relatively high rate of toppling failure in site No. 3 (Fig. 6), the slope mass rating indicates that the site is stable. This is because the two methods are based on different principles, and their outcomes cannot be easily compared [18]. Nevertheless, we can attribute the difference between the data of site No. 3 and the other sites to the difference in the discontinuity's orientation and the slope.

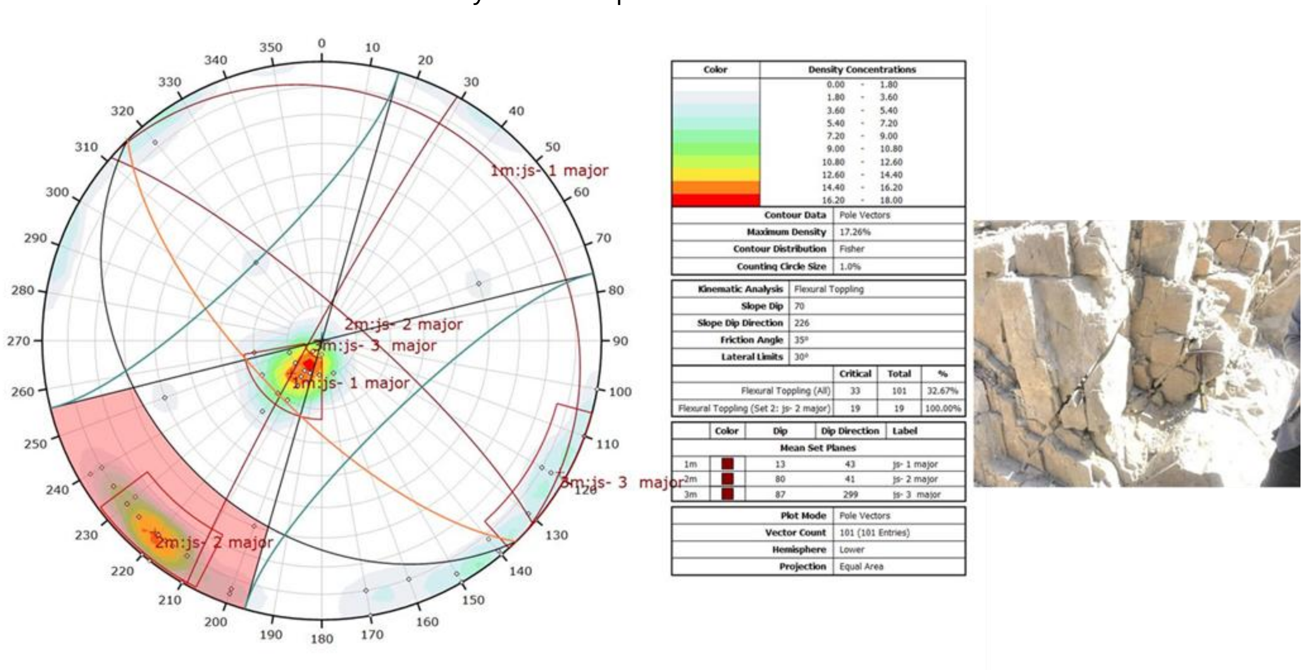


**Fig. 6** Stereo plots and photographs of slope potential for a toppling failure in site 3

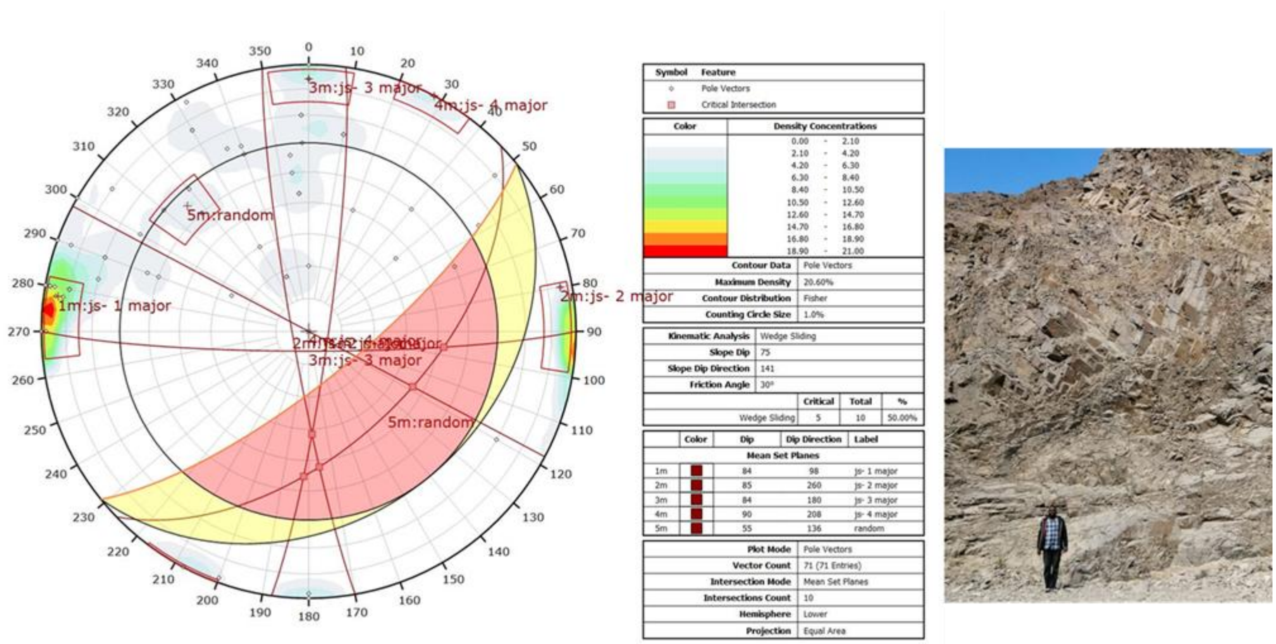


**Fig. 7** Stereo plots and photographs of slope potential for Wedge failure on sites 6

On the other hand, the rate of planar failure was higher in the western sites than in the eastern sites. The wedge failure was also expected to occur in site No. 6, causing a messy and significant feature in the field (Fig. 7). These differences are mainly due to internal factors such as rock variation and different engineering parameters like deformation, shear resistance, and weathering. To a lesser extent, external factors such as unplanned road cutting, seismicity, and heavy precipitation also contribute.

Rockslide volume and intensity are significantly influenced by the persistence length of critical joints within the rock mass. Longer, more persistent joints generate greater potential sliding surfaces making the event more extensive and intense with rockslides. Hence an evaluation of joint persistence has been deemed crucial in determining the extent and intensity of likely rockslides. This understanding is crucial in formulating efficient hazard risk reduction measures and slope stability in geotechnical engineering practice. In station 3, on the eastern side, the persistence of the critical joints is diving in the slope, and the persistence length is less than 2.5 meters, while in stations 6 and 7, on the western side, the persistence of critical joints is daylight to the slope generally and the persistence length is bigger than 3 meters (Fig. 8).

Based on the findings, it is recommended that the mountain road be constructed on the eastern side slope utilizing benches and terraces. Numerous designs for these benches and terraces are documented in the literature, often in conjunction with gravity walls in areas with high loose material to maximize lateral pressure. The geological and engineering conditions on the eastern side provide the greatest assurance of road stability and long-term sustainability. Therefore, it is suggested that the mountain road be built on the east side slope, as the geological and engineering parameters indicate the highest probability of road stability and sustainable development.

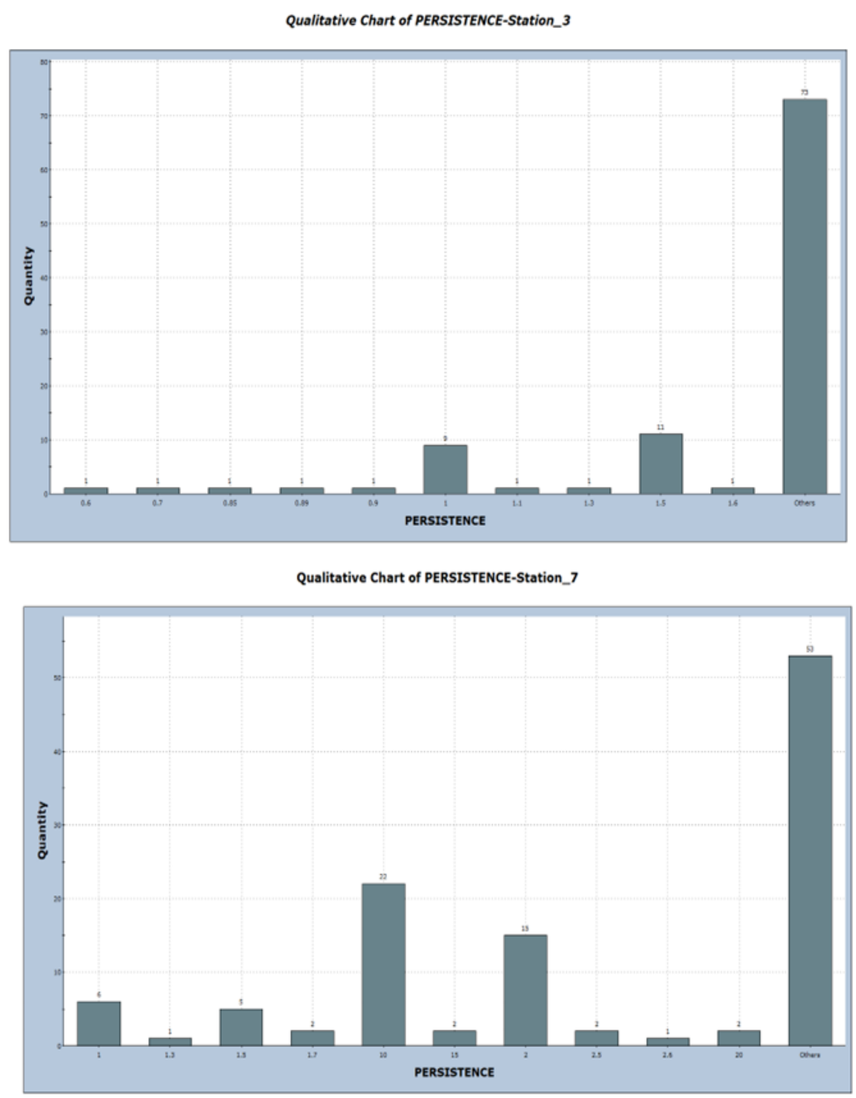


**Fig. 8** The effectiveness of persistence in rock failure at sites 3 and 7

The height of the road or the height of the cut must be determined according to surveying considerations, as the vertical alignment of the proposed road must be considered, in addition to reducing the severe curvature of the road by making the horizontal alignment of the road. It is also preferable for the cutting of the road to be mechanical, which is much better than cutting by blasting, as priority must be given to excavators such as buckling and jackhammers to make cuts in the rocks where the joints intersect completely so that these rocks can be extracted and used in filling operations. Mechanical rock cutting operations are possible in the rocks of the eastern side in a good way, except for the dolerite rocks (site 4), as these rocks require regular and smooth blasting operations to reduce random fractures (lunching feature) that may cause serious subsequent rock failures. The slope angles for artificial slopes should then be established, with consideration of the stability of the rocks, as shown in Table 7. These values are extracted from Dips software. A proper drainage and isolation system of rainwater and its effects on the longevity of the proposed road should be developed. Assess the impact of seismicity and how this will affect the design of the road structure.

**Table 7:** Summary of slope save angle

| Site No. | Slope save angle |
|---|---|
| 1 | 50° |
| 2 | 50° |
| 3 | 40° |
| 4 | 45° |
| 5 | 40° |
| 6 | 55° |
| 7 | 70° |

## Conclusion

The study revealed that the eastern part of the area is composed of metavolcanic rocks that show high resistance to weathering and shear resistance on the discontinuity surfaces. On the other hand, the western side is characterized by biotite schist rocks, which exhibit low resistance to weathering and shear resistance on the discontinuity surfaces due to the schistosity structure that causes them to split into layers and fall. Based on the rock mass rating results, it was found that the rocks on the eastern side (metavolcanic rocks) of the New Alagaba Road are of higher quality than those on the western side, with RMR values ranging from 70 to 77 and 56 to 68, respectively.

The SMR and CSMR values showed that Eastern sites had stable slopes with a low probability of rock failure due to the orientation of discontinuities with the slopes. In contrast, the western sites showed higher planar and wedge failure rates and a high probability of failure, with sites No. 6 and 7 particularly unstable due to the low shear strength of the discontinuities and the orientation of discontinuities with the slope, while site No. 5 showed lower probability of failure due to that the rocks are mainly meta-andesite relative to the schist rocks in sites No. 6 and 7

Kinematic analysis revealed that the eastern sites exhibited a low planar/wedge failure occurrence. In contrast, the western sites showed higher planar and wedge failure rates, indicating unstable geological conditions.

It is recommended to construct the mountain road on the eastern slope by utilizing benches and terraces to enhance stability. Mechanical rock cutting is preferred over blasting to minimize random fractures. Additionally, it is important to develop effective drainage and isolation systems to manage rainwater and ensure the longevity of the road. Consider the impact of seismic activity on the road's design and structure.

## List of Abbreviation

| | |
|---|---|
| RMR | Rock Mass Rating |
| SMR | Slope Mass Rating |
| GSI | Geological Strength Index |
| CSMR | Continuous Slope Mass Rating |
| RQD | Rock Quality Designation |
| UCS | Uniaxial Compressive Strength |

**Funding:** This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

**Acknowledgements:** We sincerely appreciate the collaboration of the staff from the Geology Department, Faculty of Science and Technology, Al Neelain University, Sudan, for their assistance and cooperation during the laboratory testing stages.

### References

1. Bieniawski ZT. Engineering classification of jointed rock masses. Civil Engineering= Siviele Ingenieurswese. 1973 Dec 1;1973(12):335-43.

2. Bieniawski ZT. Engineering rock mass classifications: a complete manual for engineers and geologists in mining, civil, and petroleum engineering. John Wiley & Sons; 1989 Aug 24.

3. Hoek, E. Strength of rock and rock masses: International Society of Rock Mechanics New Journal,v. 2.1994

4. Romana, M., New adjustment ratings for application of Bieniawski classification to slopes, in Proceedings Proceedings of the international symposium on role of rock mechanics, Zacatecas, Mexico1985, p. 49-53.

5. Tomás R, Delgado J, Serón JB. Modification of slope mass rating (SMR) by continuous functions. International journal of rock mechanics and mining sciences. 2007 Oct 1;44(7):1062-9.

6. Ali, E., and Rahamt Allah, E. K., Assessment of Geological Hazards Along Alagaba Highway-Red Sea State, Sudan. In Recent Advances in Geo-Environmental Engineering, Geomechanics and Geotechnics, and Geohazards: Proceedings in Proceedings 1st Springer Conference of the Arabian Journal of Geosciences (CAJG-1), Tunisia, 2018, Springer International Publishing, p. 377-380.

7. Embleton, J. C., Hughes, D. J., Klemenic, P. M., Poole, S. T., and Vail, J. R. A new approach to the stratigraphy and tectonic evolution of the Red Sea Hills, Sudan. (1984):101-112

8. ASTM, 2014, D7012-14e1 Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures. West Conshohocken, PA.

9. Singh B. Rock Mass Classification–A Practical Approach in Civil Engineering. Elsevier; 1999.

10. Riquelme AJ, Abellán A, Tomás R, Jaboyedoff M. A new approach for semi-automatic rock mass joints recognition from 3D point clouds. Computers & geosciences. 2014 Jul 1; 68:38-52.

11. Romana MR. A geomechanical classification for slopes: slope mass rating. InRock testing and site characterization 1993 Jan 1 (pp. 575-600). Pergamon.

12. Sharma M, Sharma S, Kumar M, Singh SK. Analysis of slope stability of road cut slopes of Srinagar, Uttrakhand, India. Int J Appl Eng Res. 2019;14(3):609-15.

13. Zhang XP, Wong LN, Wang SJ, Han GY. Engineering properties of quartz mica schist. Engineering geology. 2011 Aug 10;121(3-4):135-49.

14. Goel RK, Mitra S. Weathering and its Influence on Rock Slope Stability in Hilly Areas. Journal of Rock Mechanics and Tunnelling Technology (JRMTT). 2021;27(1):49-62.

15. Hoek E, Brown ET. Practical estimates of rock mass strength. International journal of rock mechanics and mining sciences. 1997 Dec 1;34(8):1165-86.

16. Singh JL, Tamrakar NK. Rock mass rating and geological strength index of rock masses of Thopal-Malekhu river areas, Central Nepal lesser Himalaya. Bulletin of the Department of Geology. 2013 Oct 11; 16:29-42.

17. Dahiya N, Pandit K, Sarkar S. A comparison of slope stability assessment techniques using different rock mass classification systems and finite element method (FEM): A case study from the Garhwal Himalayas, India. Journal of Earth System Science. 2022 Nov 24;131(4):242.

18. Yeh PT, Chen IH, Lee KZ, Chang KT. Graphical comparison of numerical analysis, slope mass rating, and kinematic analysis for the effects of weak plane orientations on rock slope stability. Engineering Geology. 2022 Dec 20; 311:106900.