**Alqalam Journal of Medical and Applied Sciences**. 2025;8(3):1721-1726
https://doi.org/10.54361/ajmas.258364

*able Original Article*

# Simulation of a Marl Rock Slope Failure Parallel to the Nalut Mountain Road, Libya

**Ali Mansur[1], Aboalgasem Alakhdar*[2]**

[1]Department of Geology, Faculty of Education - Ryayna, University of Zintan, Ryayna, Libya
[2]Department of Geological Engineering, Faculty of Engineering, Nalut University, Jado, Libya
**Corresponding email.** a.alakhdar@nu.edu.ly

**Abstract**
In March 2021, a sudden rockfall occurred on the Nalut mountain road, resulting in the closure of this critical transportation route. Notably, the failure took place in the absence of rainfall or other conventional external triggers. This study aims to simulate the failure mechanism and assess the key structural factors contributing to slope instability by integrating field investigations with numerical modeling using RocPlane software. The analysis revealed that the affected slope comprises weak marl rocks and that the dominant factor in the failure was the presence of discontinuity sets, particularly Set 2 and Set 3, inclined at 45°, which intersected with the slope direction and formed a kinematically unstable wedge. This wedge was further facilitated by horizontal joints (Set 4 at 0°), creating conditions for complete structural failure. All discontinuity sets recorded a safety factor of zero, reflecting total instability. The driving force in Sets 2 and 3 was approximately 30.34 t/m, with wedge weights ranging from 42.90 to 48.43 t/m. These findings confirm that internal rock structure, rather than external environmental factors, was the primary cause of the failure. The study recommends reducing slope angles below 45°.
**Keywords**. Failure Plane Angle, Marl Rocks, Discontinuity Sets, Failure Simulation.

## Introduction

Rockfalls are geological phenomena that pose significant threats to human lives and infrastructure, particularly in mountainous regions and on both natural and artificial slopes [1]. They typically occur when rocks, debris, or soil masses lose internal stability and fail downslope. Landslides are often sudden and destructive events [2]. While they are primarily linked to natural geomorphological and geological processes, human activities such as road construction, blasting operations, and vegetation removal can significantly accelerate their occurrence [3]. These events are classified among active geological hazards, especially in terrains with steep gradients and complex geological structures [4]. Key contributing factors include the presence of discontinuities such as joints and fractures, fluctuations in pore-water saturation, and unplanned slope cuts [5].

Considering these challenges, slope stability studies have become essential, with tools like RocPlane offering effective analysis of rock mass stability, especially in wedge failure scenarios [6]. Mountain roads in Libya lack consistent monitoring by government agencies and specialists in civil engineering, road engineering, and geotechnical engineering, particularly after contractors have completed construction work. This oversight creates a critical gap that often leads to hazardous incidents due to the absence of supervision on cut slopes or those supporting the road infrastructure. The severity of such incidents is usually only recognized after material damage has already occurred [7]. The Nalut mountain road is one of the most vital routes in the western mountains, connecting the interior cities of the region with the border area of Wazen city. It serves as a major corridor for various types of motor vehicles and plays a key role in transporting water, goods, and cargo to Nalut city. In March 2021, a sudden rockfall occurred on a slope Parallel to the Road route, resulting in the road's closure (Figure 1). What makes this event particularly noteworthy is that it occurred in the absence of any rainfall, and the failure of rock masses was of varying sizes; see (Figure 2).

***Figure 1: The mountain road of Nalut***

***Figure 2: Rockfall on Nalut Road***

Despite the abundance of studies on landslides and mass movement, the geological and engineering literature, particularly within the Libyan context, lacks quantitative field-based analyses that investigate


***Received**: 12-06-2025 - **Accepted**: 09-08-2025 - **Published**: 16-08-2025*

https://doi.org/10.54361/ajmas.258364

structural failures in slopes composed of weak marl rocks using specialized tools such as RocPlane. Moreover, landslides that are not associated with obvious external triggers, such as rainfall or seismic activity, receive insufficient attention despite their potential severity and the possibility of being caused solely by internal structural factors. This study makes a significant contribution toward addressing this gap by simulating an actual slope failure event and analyzing the role of discontinuity sets in the loss of slope stability. Accordingly, the primary objective was to simulate the failure, identify the discontinuity sets and Dip Failure Plane Angle influential in slope failure, based on field measurements and slope geometry, and offer practical recommendations to mitigate the risk of similar events in the future. The study area is located within the Nafusa uplift, approximately 270 km SW of Tripoli. Astronomically, between latitudes 31°52′62″N - 31°52′78″N, and longitudes 10°59′22″E 10°59′14″E; see (Figure 3) [9].

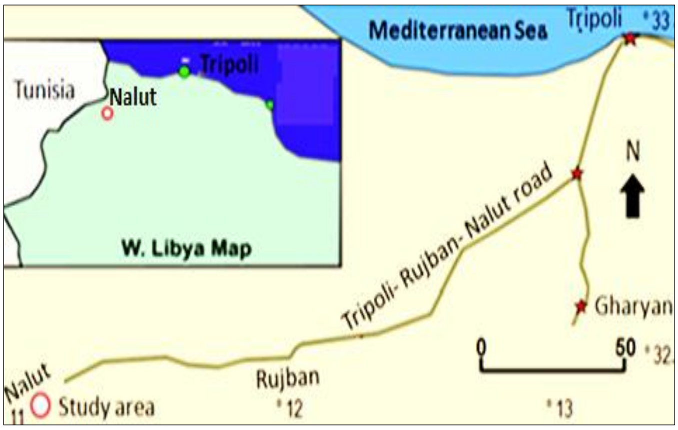


***Figure 3. Location of the study area***

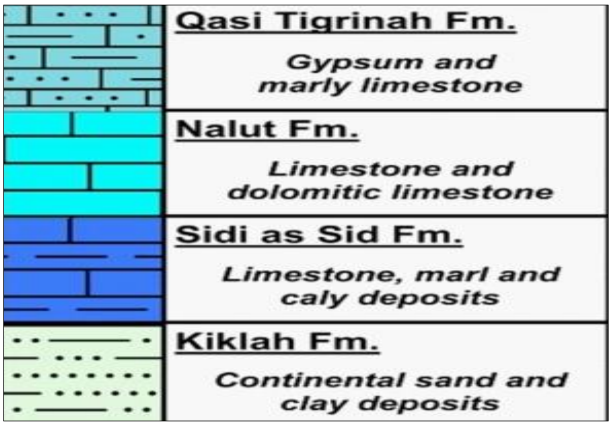


***Figure 4. Formations at Nalut Road***

Geologically, the study area lies within the stratigraphic sequence of the Nafusa uplift, which begins with the Kurrush Formation, dated to the Lower Triassic period, and extends up to the Zamam Formation of the early Cenozoic era [10]. The stratigraphic units exposed along the mountain road leading to the city of Nalut begin at the base with the Kikla Fm; see (Figure 4), followed by the Sidi as Sid Formation, which comprises the Ain Tobi Member dolomite and the Yafran Member marl, marly limestone, and clay within gypsum. This formation forms the slopes parallel to the road near the Ain Tala site, while the Nalut Formation is exposed in the upper sections of the road toward Nalut.

## Methods

### *Field Study*

The first phase of the study involved detailed field investigations aimed at identifying structural and geotechnical weaknesses within both the failure-affected area and the adjacent stable zone. This was accomplished through the examination of rock outcrop and slope geometry. Particular attention was given to slope geometry and the key factors influencing its stability, such as Dip angle, slope height, and slope width, as well as discontinuity sets [11]. Field measurements (Table 1) revealed a significant geometric modification: the slope's Dip changed from approximately 55° before cutting to 90° after cutting. The slope is approximately 9 m in height and 10 m in width. A tension crack forming a right angle (90°) was observed, and the estimated Failure Plane Angle dips at approximately 45°, suggesting a potential slip surface. Furthermore, joint depth was recorded at up to 5 m, while the measurement point was located just 2.5 m (Distance from Crust).

***Table 1. Slope Geometry Data Based on Field Observations***

| **Slope Face Angle Before Cut (Slope Face Angle)** | **°55** | **Slope Face Angle After Cut (Upper Face Angle)** | **°90** |
|---|---|---|---|
| Slope Height | 9 m | Bench Width | 10 m |
| Tension Crack | 90° | Failure Plane Angle | 45° |
| Seismic Coefficient | 0.04 | Upper Face Angle | 55° |
| Distance From Crust | m2.5 | Joints Depth | 5 m |

### *RocPlane Software*

The RocPlane software was utilized in this study as an interactive analytical tool to assess the influence of structural discontinuities, specifically the angle of the failure plane, on the likelihood of rockfall. The objective was to identify the critical failure plane angles that significantly contributed to the rockfall event. RocPlane is one of the most advanced and widely used programs for failure analysis in rock slope engineering


***Received**: 12-06-2025 - **Accepted**: 09-08-2025 - **Published**: 16-08-2025*

https://doi.org/10.54361/ajmas.258364

[11]. It provides a robust graphical interface that enables precise modeling and visualization of potential failure scenarios, thereby facilitating a deeper understanding of slope behavior under various engineering conditions. Key input parameters required for the analysis include slope angle, slope height, joint surface orientation, and slope geometry [12] (Figure 5).

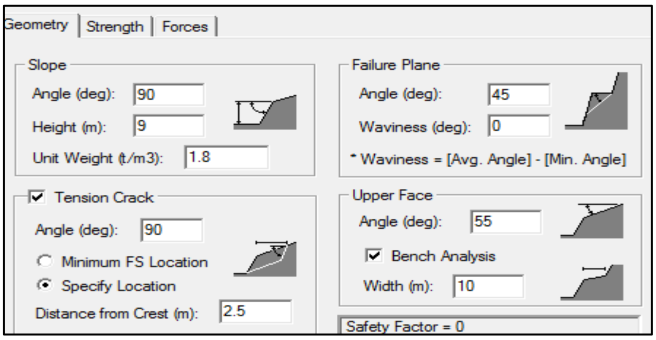



***Figure 5. Inputs Geometry Slope***

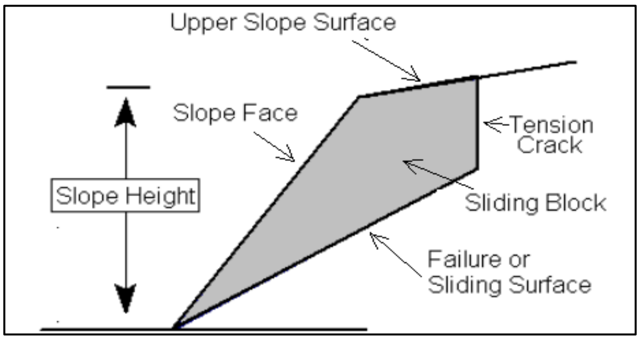



***Figure 6. Structure of slope***

The software conducts its analyses and simulations based on mathematical models rooted in rock mechanics, particularly in calculating shear resistance along potential failure surfaces. In this study, the Mohr–Coulomb failure criterion was adopted to describe the relationship between shear strength and effective normal stress acting on the failure plane [13]. This model incorporates key parameters such as shear strength, cohesion, effective normal stress, and the angle of internal friction. Furthermore, the program relies on accurate input data collected during the fieldwork [14] (Table 1), including other geometric and structural features illustrated in Figure 6. The integration of these detailed inputs enhances the reliability and realism of the simulation results, ensuring that they closely reflect the actual site conditions [15].

In this study, the primary objective was to simulate a rockfall event that had already occurred at the site. To accurately reflect the failure conditions, both the cohesion and friction angle of the marl rock were assumed to be -0, representing a complete loss of shear strength along the failure surface. As a result, laboratory testing to determine these parameters was deemed unnecessary, since the analysis aimed to model a worst-case scenario in which shear resistance had been entirely lost.

## Results and Discussion

### *Discussion of Field Study Results*

The area under study covers approximately 180 m². Field observations of weak zones affecting the adjacent, parallel, and lower slopes revealed that the prevailing rocks in the area belong to the Nalut Formation and the Yafran Member, as illustrated in Figure 7. The failure, however, occurred specifically within the marl rocks of the Yafran Marl Member. The geological cross-section shown in Figure 7 depicts a rock profile adjacent to the failure site, consisting of two main stratigraphic units: the Nalut Formation in the upper part and the Yafran Marl Member in the lower part. The affected slope exhibits a significant engineering modification; the slope angle changed from 55° before cutting to 90° after cutting**.**

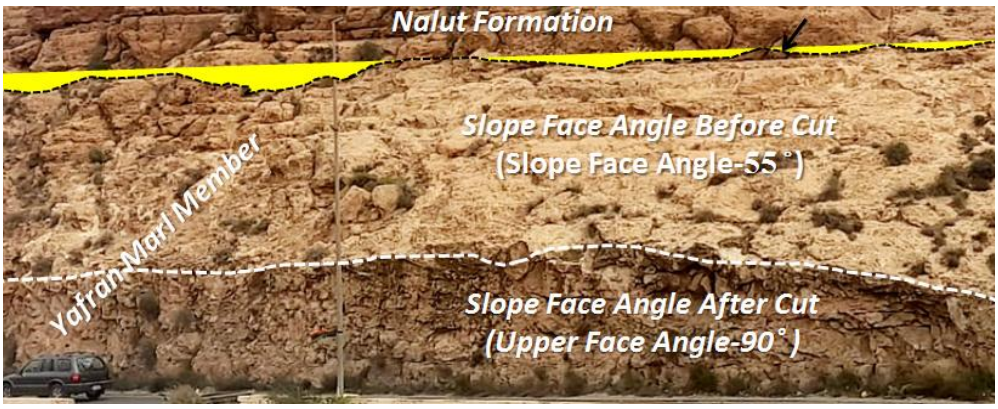



***Figure 7. Cross-Section of Nalut Formation and Yafran Marl Member***

The Yafran Marl Member is composed of marl, a fragile sedimentary rock consisting of a mixture of clay and carbonate materials. These rocks are characterized by high structural weakness, significant susceptibility to cracking, and a strong tendency to absorb water. As a result, they are highly prone to disintegration and failure, particularly when subjected to excavation activities or exposed to varying climatic conditions. From a geotechnical perspective, adjusting the dip angle to 90° in marl rocks is unsafe, as it reduces the stability of rock masses and increases the likelihood of failure. This is due to several interrelated factors, most


***Received**: 12-06-2025 - **Accepted**: 09-08-2025 - **Published**: 16-08-2025*

https://doi.org/10.54361/ajmas.258364

notably: The prevalence of structural joints and fractures in marl rocks, which form potential slip paths, along with the variation in mechanical properties between the two formations, where the interface between dolomite and marl forms a weak separation plane that may act as a slip layer. The effects of water and weathering also play a pivotal role in the deterioration of marl properties, as rainwater seepage contributes to reducing the cohesion of these rocks, accelerating their failure under the influence of natural or artificial loads.

The field study identified five main discontinuity sets within the marl rocks (Figure 8), representing failure plane orientations, with dip angles ranging between 0° and 90°. Notably, two joint sets with an inclination of approximately 45° (S2 and S3) are considered critical, as their orientation aligns with the slope direction; this discontinuity significantly contributed to the occurrence of the mass failure. In addition, horizontal joints (0°) act as potential basal slip surfaces, particularly under conditions of low internal cohesion and reduced friction angles. Vertical joints (90°), especially set S5, which nearly coincides with the slope face (Figure 9), contribute to the fragmentation of rock masses and enhance for failure.

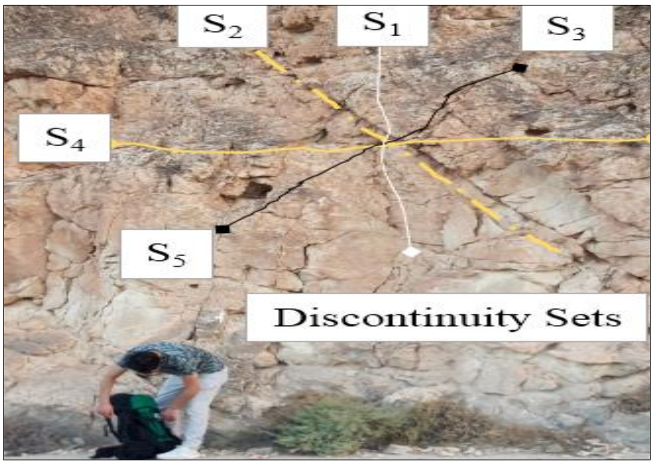



***Figure 8. Discontinuity Sets in the Marl***

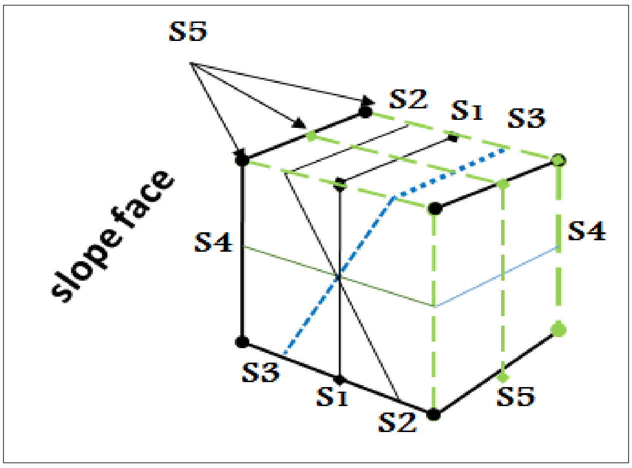



***Figure 9. Sets Orientation***

***Discussion of RocPlane outputs***

The results of the failure analysis using the RocPlane program (Table 2) provided a detailed assessment of five sets of rock discontinuities by identifying the failure plane angles most influential in the failure process. The analysis also included the evaluation of acting forces such as the driving force, resisting force, vertical force, and wedge weight. The findings indicated that the factor of safety (FOS) for all discontinuity sets was zero, which strongly suggests a definitive failure and complete instability of the rock mass under the current condition.

***Table 2. RocPlane software output***

| Discontinuity Sets | Set 1 | Set 2 | Set 3 | Set 4 | Set 5 |
|---|---|---|---|---|---|
| Failure Plane Angle | 90° | 45° | 45° | 0° | 90° |
| Factor Of Safety | 0 | 0 | 0 | 0 | 0 |
| Resisting Force | 0 t/m | 0 t/m | 0 t/m | 0t/m | 0 t/m |
| Driving Force | 1.30t/m | 30.3t/m | 30.3t/m | 0.84t/m | 1.30t/m |
| Normal Force | 0.02 t/m | 30.3 t/m | 30.3 t/m | 48.42t/m | 0.022t/m |
| Wedge Weight | 1.30t/m | 42.9t/m | 42.9 t/m | 48.43 | 1.30t/m |

When examining Set1, which represents vertical joints (failure plane angle 90°), the analysis shows a small driving force (1.30 t/m) (Figure 10) with no resistance and a similar wedge weight. Although vertical joints typically do not serve as primary sliding surfaces, their presence can contribute to the detachment of small rock blocks; the low vertical force (0.022 t/m) reflects the limited role of friction along this direction.

In contrast, in (Figure 11).

Set 4 represents a horizontal discontinuity joint system (failure plane angle = 0°). Although its contribution to direct driving force and sliding is minimal (0.84 t/m), it shows the highest wedge weight among all sets (48.43 t/m). This suggests that it corresponds to a thick horizontal layer that may contribute to the detachment of overlying blocks or reduce the overall cohesion of the rocks, particularly when interacting with active inclined joints. Set 4 represents a horizontal discontinuity joint system (failure plane angle = 0°). Although its contribution to direct driving force and sliding is minimal (0.84 t/m), it shows the highest wedge weight among all sets (48.43 t/m). This suggests that it corresponds to a thick horizontal layer that may contribute to the detachment of overlying blocks or reduce the overall cohesion of the rocks, particularly when interacting with active inclined joints.


***Received**: 12-06-2025 - **Accepted**: 09-08-2025 - **Published**: 16-08-2025*

https://doi.org/10.54361/ajmas.258364

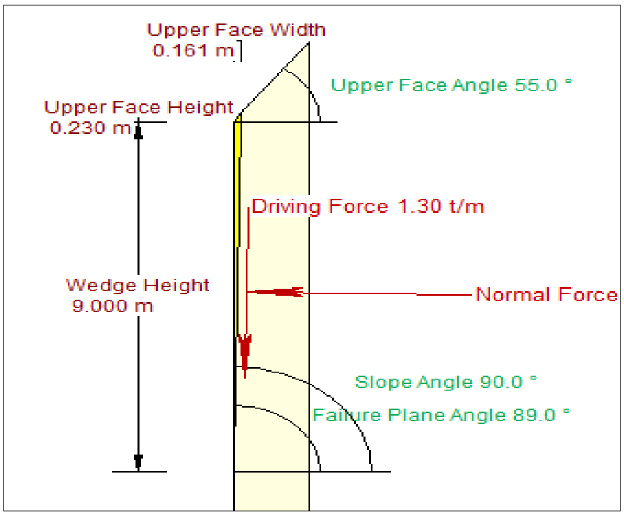



*Figure 10. Simulation of 90° Failure Plane*

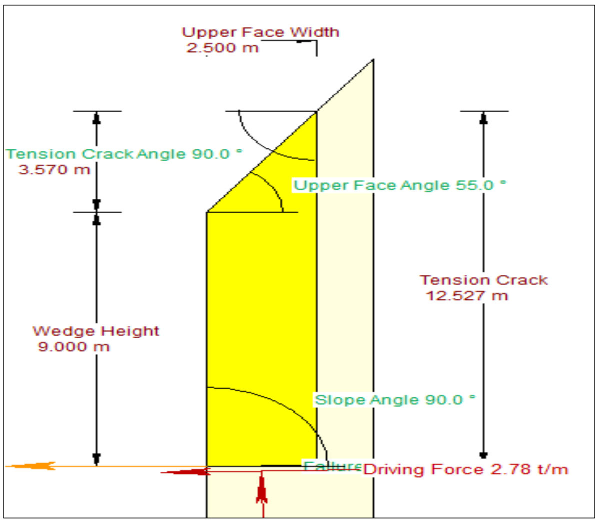
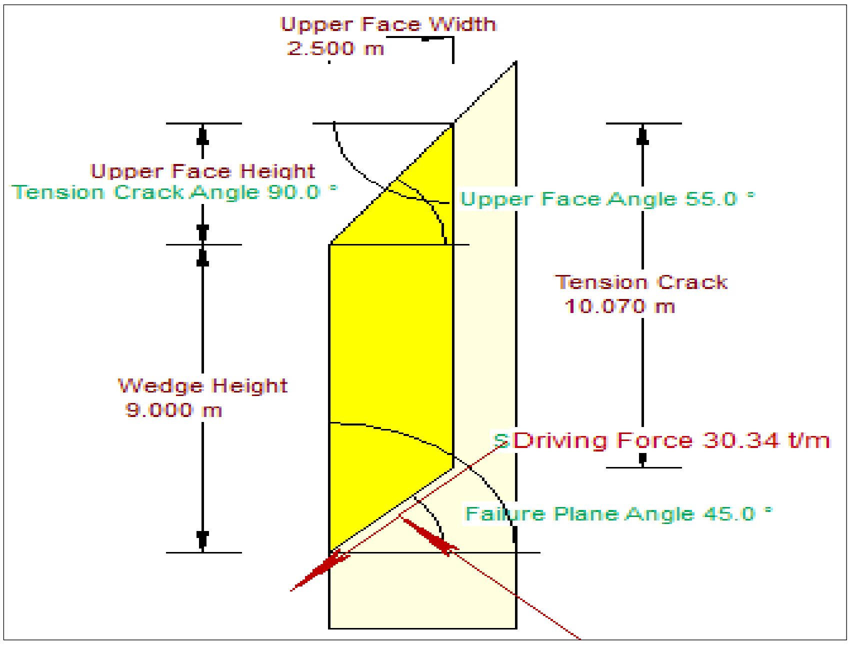



*Figure 11. Simulation of 0° Failure Plane*

Set 5 is similar to Set 1 and represents a vertical joint system. It is characterized by low wedge weight and a limited driving force (1.30 t/m), which reduces its direct impact on slope failure. However, the presence of such vertical joints may compromise the structural integrity of the rock mass and increase its susceptibility to disintegration.

Figure 12 illustrates a simulation of the effect of a 45° failure plane angle on slope instability. The analysis reveals that Set 2 and Set 3 are the primary contributors to the observed failure, as they represent steep, intersecting discontinuity planes that align with the slope direction, enabling rock mass movement. The driving force (30.34 t/m) and wedge weight (42.90 t/m), confirm the instability of these planes.




*Figrue 12. Simulation of 45° Failure Plane*

This destabilizing effect is further exacerbated by Set 4, which forms a weak horizontal base that facilitates block separation even in the absence of groundwater. Notably, failure occurred in the model despite dry conditions, indicating that the high joint continuity, zero cohesion, and low internal friction angle were sufficient to cause failure purely under gravitational stress, Set 2 and Set 3 are considered the most critical, as they consist of 45° inclined joints that directly contributed to the wedge-type failure, with a driving force of 30.34 t/m and a wedge weight of 42.90 t/m. Set 4, despite being horizontal, played a significant role in weakening the base of the rock mass due to its substantial wedge weight (48.43 t/m). Vertical joints (Set 1 and Set 5) had a secondary effect by promoting block disintegration and detachment.

## Conclusion

This study highlights the critical importance of accurate geotechnical analysis of joint systems in evaluating the stability of rock slopes. The outputs from the RocPlane program demonstrated that the structural


***Received****: 12-06-2025 -* ***Accepted****: 09-08-2025 -* ***Published****: 16-08-2025*

configuration of the rock mass, particularly the intersection of inclined joints, played a direct role in creating conditions conducive to failure. Field investigations confirmed that joints dipping at approximately 45° constituted a primary weakness, as their orientation coincided with the slope direction in a manner that directly triggered an actual rock failure. This underscores the inherent hazard posed by such geological features, even in the absence of typical triggering factors such as rainfall or groundwater infiltration. The findings reaffirm the necessity of integrating detailed field observations with numerical modeling in geological hazard assessments, emphasizing the importance of joint characteristics, dip, strike, spacing, and persistence in accurately identifying failure mechanisms. Based on these insights, the study proposes a systematic methodological framework for slope stability analysis that can be applied to similar geological contexts, thereby supporting improved infrastructure protection and risk mitigation in complex mountainous terrains. In light of the failure event and analytical results, the study recommends urgent engineering interventions, including reducing slope angles to below 45° and removing detached or unstable rock blocks. Furthermore, it advocates for replicating such integrated assessments in other high-risk locations with comparable geological settings to develop proactive and effective preventive engineering measures.

***Conflict of interest.*** Nil

## References

1. Dahiya N, Pandit K, Sarkar S, Pain A. Various aspects of rockfall hazards along the mountain roads in India: A systematic review. Indian Geotechnical Journal. 2025; 55(3):2007-29.
2. Amarasinghe MP, Kulathilaka SA, Robert DJ, Zhou A, Jayathissa HA. Risk assessment and management of rainfall-induced landslides in tropical regions: A review. Natural Hazards. 2024 Feb;120(3):2179-231.
3. Alakhdar A. Analyzing the Stability and Safety of Artificial Slopes along the Alwadi Road in Sabratha City, Libya. AlQalam Journal of Medical and Applied Sciences. 2025 Jul 19:1444-1450.
4. Lin J, Chen W, Qi X, Hou H. Risk assessment and its influencing factors analysis of geological hazards in typical mountain environment. Journal of Cleaner Production. 2021;309:127077.
5. Blower T, Preene M. Chapter 9 Managing groundwater in practice. Geological Society, London, Engineering Geology Special Publications. 2025 Oct 1;31(1):egsp31-2024.
6. Sengani F, Muavhi N, Mulenga F. Advanced analysis of road-slope stability in a brittle and faulted rockmass terrain by several techniques. Transportation Geotechnics. 2021 May 1;28:100545.
7. Alakhdar A, Albarshani M. Analyzing the Effect of Water on Stability of Rocky Slopes and Simulating Collapse: A Case Study of the Debris Slope Parallel to Rujban Mountain Road–NW Libya. InSebha University Conference Proceedings 2024 Oct 16 (Vol. 3, No. 2, pp. 28-33.
8. Yi Z, Yin Y, Zhang Z, Wang X, Zhang N, Yin B, Zhang S, Zhang Y, Gao S, Chen L, Zeng Y. A review and summary of the classification system, triggering factors, and global distribution of high and steep dangerous rocks. Environmental Earth Sciences. 2024 Dec;83(24):671.
9. Khalifa A. The geologic contribution to the mountain slopes instability and its effect on rockfall hazards: a case study to the Zintan Road. Conference for Engineering Science; 2022; Jadu, Libya.
10. Almagtuf R, Alakhdar A. Analysis of the Stability of Nalut Formation Outcrops Parallel to Al-Rujban Mountain Road-NW Libya. AlQalam Journal of Medical and Applied Sciences. 2025, 3:213-20.
11. Alakhdar A. Effect of Fault on the Physical Properties of the Ain Tabi Member: A Case Study of Al-Qwasim Mountain Road Slopes. University of Zawia Journal of Engineering Sciences and Technology. 2024 Dec 15;2(2):197-207.
12. Alakhdar A. Effect of Water Saturation Changes on the Creep and Stability of the Soil Slope Parallel to the Al-Qawasim Mountain Road Sharwes Journal,2025; 6, 338-331.
13. User's Guide for Rocplane software. (2001). Rocscience Inc, pp. 1-88. https://www.u-cursos.cl/ingenieria/2011/2/GL5201/1/material_docente/bajar?id=390028&lsar=1&file=45
14. Lepakshi R, Reddy B. Shear strength parameters and Mohr-Coulomb failure envelopes for cement stabilised rammed earth. Construction and Building Materials. 2020;20;249:118708.
15. Azarafza M, Akgün H, Feizi-Derakhshi MR, Azarafza M, Rahnamarad J, Derakhshani R. Discontinuous rock slope stability analysis under blocky structural sliding by fuzzy key-block analysis method. Heliyon. 2020 May 1; 6(5).


***Received**: 12-06-2025 - **Accepted**: 09-08-2025 - **Published**: 16-08-2025*