https://doi.org/10.54361/ajmas.258327

Original Article

Analyzing the Stability and Safety of Artificial Slopes along the Alwadi Road in Sabratha City, Libya

Aboalgasem Alakhdar

Department of Geological Engineering, Faculty of Engineering, Jadu, Nalut University, Libya
Corresponding Email. a.alakhdar@nu.edu.ly

Abstract
This study investigates the stability of artificial slopes along the valley road in Sabratha, northwestern Libya, where quarrying activities have created unstable slopes from unconsolidated limestone debris lacking proper design. Laboratory tests measured cohesion and friction angles under varying moisture levels. Using RocPlane software, slope models were analyzed at two configurations: 40°/10 m and 20°/3 m. Results showed that increasing water content significantly reduces shear strength; at 80 mm water, the friction angle dropped to 30.9° and cohesion to 17.22 tons/m². Reducing the slope angle and height improved stability. Simulations revealed that poorly designed slopes with quarry waste have low safety factors and high collapse potential. The study underscores the need for proper engineering design to enhance slope stability and reduce geotechnical hazards.
Keywords. Safety Factor ,Artificial Slopes, Slope Stability ,Rocplane Software.

Introduction

Artificial slopes vary in terms of their shapes, types, steepness, and the materials used in their formation. They are created through drilling and cutting operations carried out by humans for various purposes, such as infrastructure development, mining, or road expansion [1]. Artificial slopes consist of rock masses, backfill materials, or compacted soil, with their stability largely depending on the nature of the materials used. Slopes made of non-cohesive materials are more prone to collapse compared to those containing cohesive components [2]. Human activities, such as quarrying operations, lead to significant changes in the natural and morphological environment, with one of the most prominent impacts being the formation of unstable artificial slopes due to the improper disposal of quarry waste on roadsides without adhering to safety standards [3]. The stability of artificial slopes depends on the properties of the materials they consist of. Some industrial slopes are highly corrosive and may quickly disintegrate when exposed to weathering and erosion factors [4]. The lack of engineering design for these slopes makes them more susceptible to repeated collapses, posing a direct threat to road users and nearby infrastructure [5], The main factors affecting slope stability in both hard and soft rocks include slope geometry, groundwater, rock properties, cohesion, internal friction angle, blasting effects, mining methods, and the equipment used [6]. The stability of artificial slopes is defined by an angle called the angle of stability, which represents the maximum inclination at which materials can remain in place without collapsing [7]. The absence of drainage systems leads to waterlogging of slope components, which reduces internal cohesion strength and increases the likelihood of sudden collapses [8]. Direct human interventions, such as deep drilling or blasting near industrial slopes, may affect their stability and increase the risk of rockfalls [9].
Climatic factors, such as heavy rainfall, also play a role in weakening the internal cohesion of slope components, particularly in cohesive materials, thereby increasing the likelihood of slope failure [10]. The research problem lies in the large accumulations of rocky debris of different sizes, mainly composed of gypsum stone debris, which were thrown beside the road and formed artificial ramps (Figure 1). Some field visits documented the collapse of rocky blocks and debris to settled on the road, making them a source of danger to the safety of road users. Based on the above, the study aimed to evaluate the stability of artificial ramps, analyze the factors affecting their stability and collapse, and propose a model (simulation) to modify the ramp to achieve the best safety factor. The study area is located within the Jifarah Plain, a relatively flat plain extending from the Tunisian coast in the west into northwestern Libya. It is bordered to the north by the Mediterranean Sea and to the south by the Nafusa uplift. The terrain gradually rises southward, reaching approximately 400 meters above sea level, with some areas reaching up to 700 meters between the Mediterranean Sea and the Nafusa uplift [11].
The Jifarah Plain can be divided into three main sections: the coastal strip in the north, the central region, and the foothills of the Nafusa uplift in the south. The coastal strip is characterized by the presence of the Gargares Formation, which forms cliffs along the shoreline, with exposures extending from Tajura in the east to the Tunisian border in the west. This formation consists mainly of Calcarenite, including shell fragments and small sand grains, interspersed with occasional clay deposits. The Gargares Formation extends inland from the shoreline for a distance ranging between 3 and 6 kilometers [12].

***Received**: 12-05-2025 - **Accepted**: 10-07-2025 - **Published**: 19-07-2025*

Figure 1 :An artificial slope parallel to Alwadi Road in Sabratha City

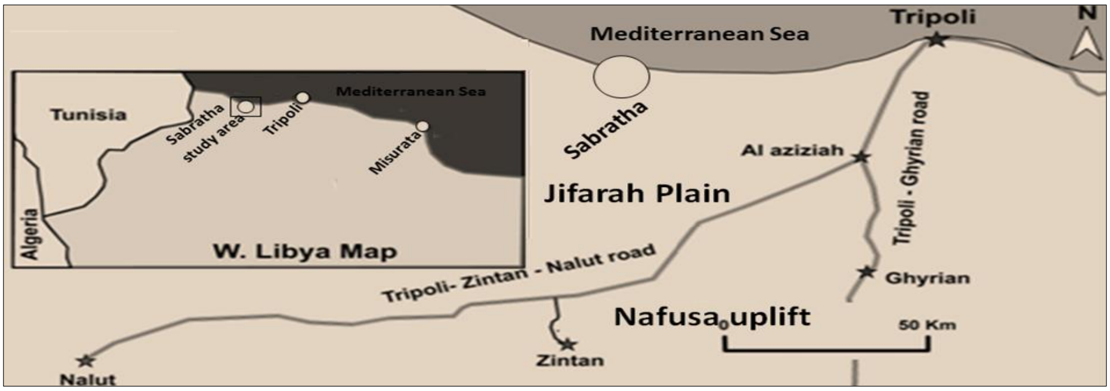

Figure 2: Location of the study area [13]

Methods

The laboratory study was conducted on a limestone sample collected from a depth of 30 cm in the field. The objective of the study was to determine the internal cohesion (C) and friction angle (Ø) of the sample under varying moisture conditions. Vertical stress, normal stress, and shear stress tests were performed using the Direct Shear Test [16], with a 36 cm² loading frame and a constant loading rate of 0.25 N/s The tests were repeated at three different loading weights: 4 kg, 8 kg, and 16 kg, using the Direct Shear Test [16], with a 36 cm² loading frame and a constant loading rate of 0.25 N/s. The tests were repeated at three different loading weights: 4 kg, 8 kg, and 16 kg. A sample was collected from the field at a depth of 30 cm and was dried in an oven at 120°C for 24 hours to ensure complete moisture removal. Vertical stress, Normal, and shear stress tests were conducted on the dry sample using a direct shear device, and the (C, Ø) values were extracted. (Table 1). The same procedure was repeated by adding 50 mm of water to the dry sample to extract the (C, Ø) values, as shown in Table 1. The procedure was then repeated with 80 mm of water, ensuring thorough mixing of the sample with the water to achieve homogeneity [17].

Table 1. Data and results obtained from the Direct Shear Test

Water Quantity	**Dry sample**	**50mm**	**80mm**
Saturation	0%	30%	50%
Friction Angle	44.2 °	35.36°	30.9°
Cohesion	28.7t/m^2	20.09 t/m^2	17.22t/m^2
Rock Unit Weight	1.5 g/cm³	2.2 g/cm³	2.5g/cm³

Slope stability analysis using RocPlane software

Slope stability is crucial in geotechnical and engineering studies, affecting infrastructure design and geohazard mitigation. RocPlane software is essential for evaluating slope stability by analyzing shear strength parameters like cohesion and friction angle (Table 2), considering factors like groundwater and seismic activity. It calculates the Factor of Safety to assess the risk of slope failure, making it vital for designing roads, dams, tunnels, and other infrastructure [18]. The software uses inputs like friction angle, cohesion, material density, and water pressure effects to compute FOS and identify failure modes such as planar, wedge, and circular slips. RocPlane also simulates dynamic loads, including seismic activity, improving geotechnical analysis [19].

***Received**: 12-05-2025 - **Accepted**: 10-07-2025 - **Published**: 19-07-2025*

https://doi.org/10.54361/ajmas.258327

Table 2. Input Data for RocPlane Software.

Water quantity	dry sample	50mm	80mm
rock of Type	limestone	limestone	limestone
Angle Slope	° 40	40°	° 40
Height Slope	m10	m10	m10
Weight Unit Rock	g/cm31.5	g/cm32.2	g/cm32.5
Angle Plane Failure	° 35	35°	° 35
Angle Face Upper	10°	10°	10°
Width Bench	m6	m6	m6
Coefficient Seismic	0.04	0.04	0.04
Friction Angle	44.2°	35.36°	30.9°
Cohesion	t/m^228.7	20.09t/m^2	t/m^217.22

In this study, data from a 40° slope angle and 10-m height, representative of an industrial slope, were analyzed. The study found that quarry debris accumulation lacked proper engineering design, increasing instability risks and posing a potential hazard to road users.

Due to the researcher's concern about the proximity of the slope and the lack of consideration for the geometric aspects of the studied slope, a new model (simulation) was proposed. This model involved reducing the slope angle from 40° to 20° and decreasing the slope height from 10 meters to 3 meters, as shown in (Table 3). As a result of these changes, the Bench Width of the slope from the top also changes, decreasing from 6 meters. A modification helps lower the height and utilizes areas behind the industrial slope where quarry waste can be placed, thereby improving the stability and safety of the slope. To determine the new slope bench width, the following procedure was followed: Calculate the new Bench Width of the slope after reducing the angle of inclination to 20°. Use the same formula to determine the new width (L_2) when the slope angle is changed to 20°.

$$.\frac{H2}{L2} = \tan(Ø2) = \qquad L2 = \frac{3}{\tan(20°)} = L2\frac{3}{0.364} = 8.24m$$

New Bench Width from the summit = 2 × L_2 = 2 × 8.24 ≈ 16.48 meters.

Table 3: Input Data for RocPlane Software at Slope Height 3m

Water quantity	Dry sample	50mm	80mm
Type of rock	limestone	limestone	limestone
Slope Angle	20°	20°	20°
Slope Height	3m	3m	3m
Rock Unit Weight	g/cm31.5	g/cm32.2	g/cm32.5
Failure Plane Angle	15°	15°	15°
Upper Face Angle	°2	°2	°2
Bench Width	16.4m	16.4m	16.4m
Seismic Coefficient	0.04	0.04	0.04
Friction Angle	44.2°	35.36°	30.9°
Cohesion	28.7t/m^2	20.09t/m^2	17.22t/m^2

Results and discussion

In the direct shear test performed, the effect of varying water quantity and content on limestone properties was evaluated at different saturation levels (0%, 30%, and 50%). These data represent the influence of adding water (50mm and 80mm) on the mechanical behavior of the specimen, specifically in terms of friction angle and cohesion, which are fundamental properties determining a material's ability to resist sliding under applied loads. Initially, the dry specimen (0% saturation) exhibited the highest values of cohesion and friction angle, with a friction angle of 44.2° and (C) of 28.7 tons/m² (Figures 3 & 4). These values indicate strong inter-particle cohesion, making the limestone more stable and less likely to slip. However, with the addition of 50 mm of water (30% saturation), a significant decrease in both properties was observed. The friction angle decreased to 35.36°, and cohesion dropped to 20.09 tons/m² (Figure 3). This change reflects the effect of water in weakening the cohesion between the limestone grains, thereby reducing the material's resistance to sliding under applied forces. As the water quantity increased to 80 mm (50% saturation) (Figures 3 & 4), the reduction in cohesion and friction continued, with the friction angle further decreasing to 30.9° and cohesion to 17.22 tons/m² (Figures 3 & 4). This continued decrease in resistance indicates a more pronounced effect of water on the stability of the sample. angle decreased to 35.36°, and cohesion dropped to 20.09 tons/m² (Figure 3). This change reflects the effect of water in weakening the cohesion between the limestone grains, thereby reducing the material's resistance to sliding under applied forces. As the water quantity increased to 80 mm (50% saturation) (Figures 3 & 4), the reduction in cohesion and friction

***Received**: 12-05-2025 - **Accepted**: 10-07-2025 - **Published**: 19-07-2025*

continued, with the friction angle further decreasing to 30.9° and cohesion to 17.22 tons/m² (Figures 3 & 4). This continued decrease in resistance indicates a more pronounced effect of water on the stability of the sample.

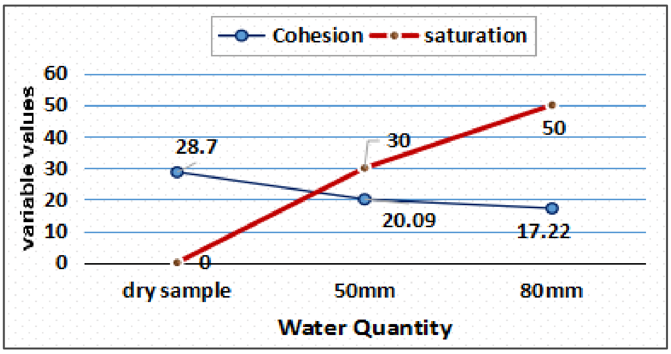

Figure 3: relationship between saturation & c

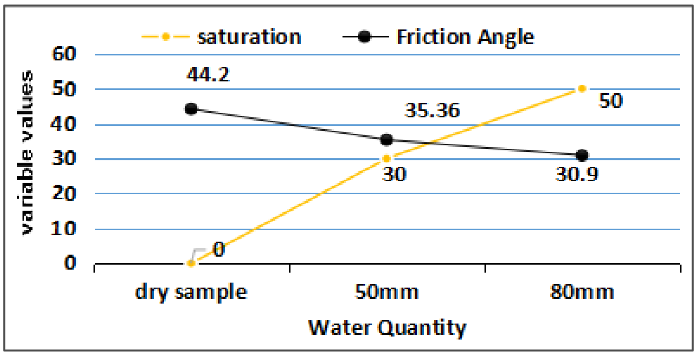

Figure 4 :relationship between saturation & Ø

With higher saturation, the limestone grains become more widely spaced, reducing the bonds between the grains and weakening the load-bearing capacity of the specimen. From these results, it is evident that the addition of water significantly reduces the material's slip resistance, making it more susceptible to detachment under mechanical loads. This suggests that the properties of limestone are highly dependent on water content, and these effects must be considered when evaluating the material's stability.
The results of the Rocplane analysis (Table 4) indicate that slope stability is significantly influenced by changes in cohesion(C) and friction angle (Ø), which are, in turn, affected by the water content (saturation) within the sample. As water content increases, the factor of safety decreases, leading to a higher likelihood of failure and collapse. In the dry state of the limestone sample, where water does not affect the slope (Figure 5), the slope remains highly stable, exhibiting the highest safety factor 45.2404 (Table 4).

Table 4: Rocplane software output

Water Quantity	Dry Sample	50mm	80mm
Saturation	0%	30%	50%
Factor Of Safety	45.2404	21.3944	0
Resisting Force	483.287t/m	334.627t/m	0t/m
Driving Force	10.6826t/m	15.6409t/m	18.9152t/m
Normal Force	14.0277t/m	9.07217t/m	0t/m

This stability is attributed to a significant resisting force 483.287 t/m and a high friction angle 44.2°, which minimizes the likelihood of collapse. Additionally, the high cohesive strength 28.7 t/m² enhances rock consolidation, further preventing failure.

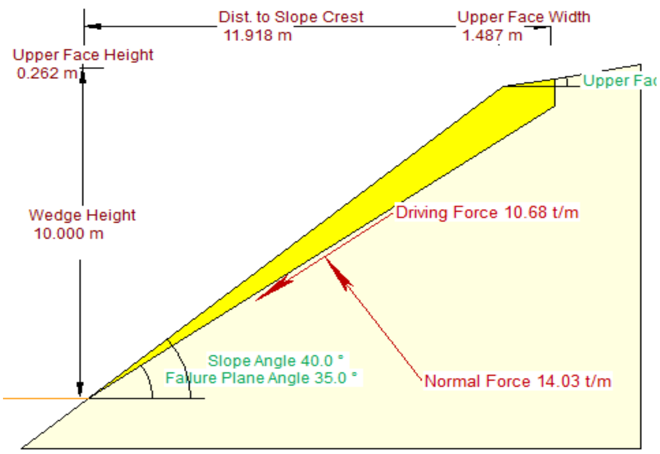

Figure 5. Slope simulating unaffected by water

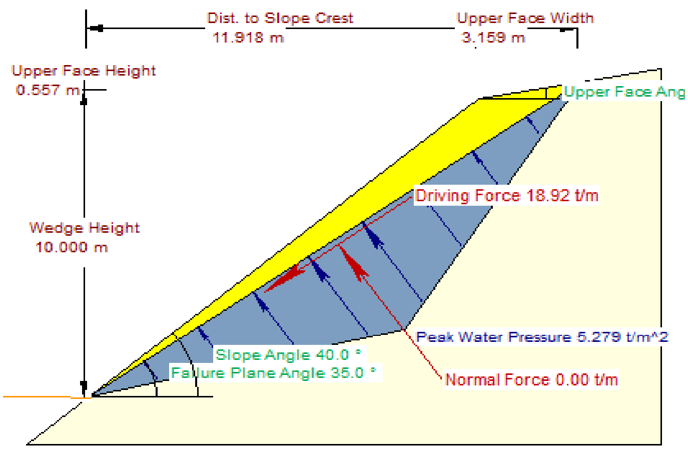

Figure 6. Slope simulation affected by 80mm of water

When 50 mm of water was added, the factor of safety decreased significantly to 21.3944, indicating reduced slope stability due to increased moisture or structural changes in the soil or rock. The resisting force dropped to 334.627 t/m, showing a reduced ability to resist sliding, while the driving force increased to 15.6409 t/m.

***Received**: 12-05-2025 - **Accepted**: 10-07-2025 - **Published**: 19-07-2025*

Alqalam Journal of Medical and Applied Sciences. 2025;8(3):1444-1450
https://doi.org/10.54361/ajmas.258327

Despite this, the factor of safety remained above 1, suggesting the slope was still stable, though cohesion between rock particles decreased to 20.09 t/m² (Table 3), weakening resistance to failure. At 80 mm of water (Figure 6), the system reached a state of complete failure, with cohesion almost disappearing, 17.22 t/m², and the friction angle dropping to 30.9°. This resulted in a loss of resistance, with the resisting force reduced to 0 t/m² and the safety factor dropping to 0, indicating inevitable collapse. The relationship between variables shows that increased water reduces friction angle and cohesion, decreasing resistance and increasing driving forces.
The combination of high slope height and steep inclination makes the slope sensitive to environmental changes, increasing collapse risk under high water saturation. While the seismic coefficient remained constant at 0.04, the main factors influencing stability were water content, friction angle, cohesion, and inclination angle. The relationship between variables shows that increased water reduces friction angle and cohesion, decreasing resistance and increasing driving forces. The combination of high slope height and steep inclination makes the slope sensitive to environmental changes, increasing collapse risk under high water saturation. While the seismic coefficient remained constant at 0.04, the main factors influencing stability were water content, friction angle, cohesion, and inclination angle.
The results of the slope stability analysis using RocPlane highlight the significant impact of reducing the inclination angle from 40° to 20° and lowering the slope height from 10 m to 3 m on enhancing overall stability (Figure 7). The calculated values indicate a substantial increase in the factor of safety across all cases (Table 5).

Table 5: Rocplane software output: Rocplane software output

Water Quantity	Dry Sample	50mm	80mm
Factor Of Safety	171.404	82.0421	60.8618
Resisting Force	352.236t/m	247.276t/m	208.453t/m
Driving Force	2.05501t/m	3.01401t/m	3.42501t/m
Normal Force	6.60168t/m	7.33389t/m	1.60851t/m

With the dry condition, reaching 171.404 (Table 5) is significantly higher than the values recorded at a 40° inclination. Even with an increase in water content to 50 mm, the factor of safety remained high at 82.0421 (Table 5), demonstrating that the modifications to the slope's geometry reduced the adverse effects of water on stability. At 80 mm of water (Figure 8), the factor of safety decreased to 60.8618, yet it still indicates a high level of stability compared to the previous results at a steeper slope.

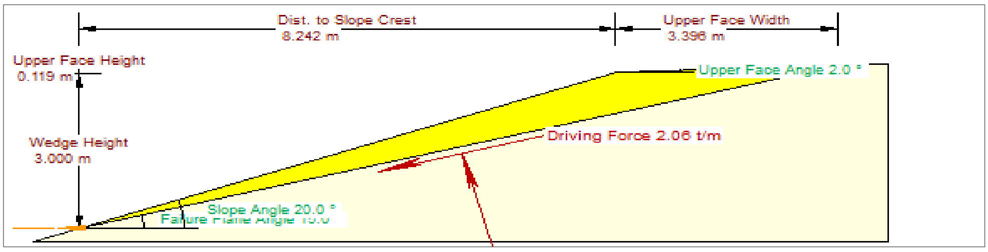

Figure 7: Simulation of a dry slope with a 20° slope angle and a height of 3 m.

The forces acting on the slope exhibit noticeable changes, with a significant increase in resistive force compared to the driving force, leading to improved stability. In the dry state (Figure 7), the resistive force reached 352.236 t/m, indicating a very low probability of sliding. As water content increased to 50 mm, the resistive force decreased to 247.276 t/m but remained significantly higher than the driving force, which did not exceed 3.01401 t/m (Table 5). At 80 mm of water (Figure 8), the resistive force further decreased to 208.453 t/m, yet it remained sufficient to prevent collapse, as the driving force stayed below 3.42501 t/m. Meanwhile, the vertical force was also affected by increased water content, rising from 6.60168 t/m in the dry state to 7.33389 t/m at 50 mm of water, before dropping to 1.60851 t/m under full saturation (80 mm). This decline at high saturation levels reflects the effect of water in reducing the effective weight of the rock mass, leading to lower internal friction. However, the slope remained highly stable due to the substantial resistive force (Table 5) and the lower inclination angle.
In general, reducing the inclination angle and lowering the slope height positively affected slope stability. These modifications reduced the effect of driving forces and increased the resistive force, making the impact of water on stability less damaging compared to previous cases with a steeper slope. Based on these results, adjusting the inclination angle and elevation proves to be an effective engineering strategy for reducing the risk of collapses, particularly in areas susceptible to environmental changes like water intrusion or heavy rainfall.

***Received**: 12-05-2025 - **Accepted**: 10-07-2025 - **Published**: 19-07-2025*

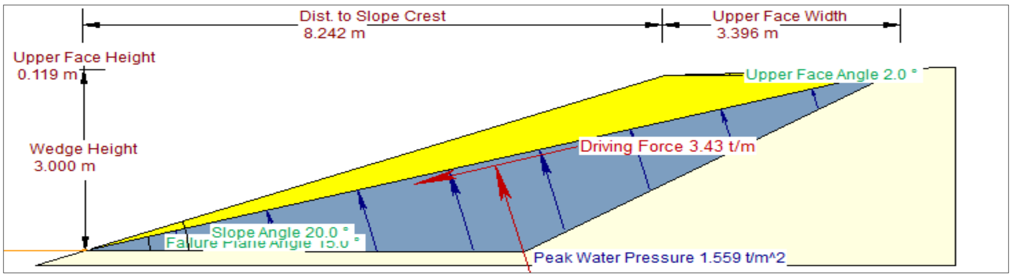

Figure 8: Slope Simulation with a 20° slope and 3 m height, affected by 80 mm of water.

Conclusion

The results of the analysis indicate that the stability of artificial slopes is significantly affected by environmental and human factors. Changes in water content, friction angle, and cohesion play a crucial role in determining slope stability. The study shows that increased water content significantly reduces stability by lowering the friction angle and cohesion between rock particles, which in turn increases the likelihood of slippage and collapse. Modifying the slope angle and height can substantially improve stability and reduce the water's impact on the slopes. In the studied area, large accumulations of limestone rock debris improperly disposed of along roadsides pose a clear threat to road user safety. The lack of proper engineering design for these slopes increases the risk of frequent collapses. Based on these findings, the study recommends improving the stability of industrial slopes by adjusting the slope angle and reducing the height to 3 meters, along with implementing periodic monitoring of industrial slopes parallel to the valley road.

Conflict of interest. Nil

References

1. Chaulya, Kolapo, P.; Oniyide, G.O.; Said, K.O.; Lawal, A.I.; Onifade, M.; Munemo, P. An overview of slope failure in mining operations. Mining 2022, 2(2), pp. 350–384. https://doi.org/10.3390/mining2020019
2. Islam, M.S.; Begum, A.; Hasan, M.M. Slope stability analysis of the Rangamati District using geotechnical and geochemical parameters. Natural Hazards 2021,Volume 108, pp 1659–1686. https://doi.org/10.1007/s11069-021-04750-5
3. Kolapo, P.; Oniyide, G.O.; Said, K.O.; Lawal, A.I.; Onifade, M.; Munemo, P. An overview of slope failure in mining operations. Mining 2022, 2, pp. 350–384. https://www.mdpi.com/2673-6489/2/2/19
4. Auty, K.M.; Zaman, R.U.; Kamal, N.N. Innovative Approaches to Stability of Embankment A Role of Chemical Stabilization in Erosion Mitigation. Doctoral Dissertation, Department of Civil and Environmental Engineering (CEE), Islamic University of Technology (IUT), Board Bazar, Gazipur-1704, Bangladesh, 2024.pp 1-119.https://www.researchgate.net/publication/384649087
5. Naghadehi, M.Z.; Jimenez, R.; KhaloKakaie, R.; Jalali, S.M.E. A probabilistic systems methodology to analyze the importance of factors affecting the stability of rock slopes. Engineering Geology 2011, 118(3–4), pp. 82–92. https://doi.org/10.1016/j.enggeo.2011.01.003
6. Gundewar, C. Application of Rock Mechanics in Surface and Underground Mining; Indian Bureau of Mines: Nagpur, Maharashtra, India, 2014; pp. 62–66.https://library.niti.gov.in/cgi-bin/koha/opac-detail.pl?biblionumber=77932&shelfbrowse
7. Kayusi, F. Analysis of the Effects of Artisanal Soapstone Mining on Slope Stability in Nyamarambe Division, Kisii-County Kenya. Doctoral Dissertation, Pwani University, Kenya, 2024. https://journal.utripoli.edu.ly/index.php/Alqalam/article/view/773
8. Ekinci, E.; Arslankaya, E. Factors affecting stability and slope failure of landfill sites: A review. In Proceedings of the EurAsia Waste Management Symposium, Istanbul, Turkey, October 2022; pp. 24–26.https://www.eurasiasymposium.com
9. Alakhdar, A. Effect of fault on the physical properties of the Ain Tabi Member: A case study of Al-Qwasim Mountain Road slopes. Univ. Zawia J. Eng. Sci. Technol. 2024, 2(2), pp. 197–207 https://doi.org/10.26629/uzjest
10. Riaz, M.T.; Basharat, M.; Ahmed, K.S.; Sirfraz, Y.; Shahzad, A.; Shah, N.A. Failure mechanism of a massive fault–controlled rainfall–triggered landslide in northern Pakistan. Landslides 2024, 21(11), pp. 2741–2767 .https://doi.org/10.1007/s10346-024-02342-5
11. Riad, A.S.G.P.; Gad, M.A.; Rashed, K.A.; Hasan, N.A. Impact of pumping rate on seawater intrusion in Jefara Plain, Libya. J. Am. Sci. 2016, 12(3), pp. 81–88 https://doi.org/10.7537/marsjas12031611
12. Khomiara, S.B. Ichnology of the carbonate aeolianites of the Quaternary Gargaresh Formation, western Libyan coast. Journal of Academic Research2018, 11, pp. 11–30.https://lam-journal.ly/index.php/jar/article/view/1054
13. Almagtuf, R.; Alakhdar, A. Analysis of the stability of Nalut Formation outcrops parallel to Al-Rujban Mountain Road–NW Libya. AlQalam J. Med. Appl. Sci. 2025, pp. 213– 220. https://doi.org/10.54361/ajmas.258133
14. IRC. Geological map of Libya, 1:250,000 sheets Tarabulus, explanatory booklet. Industrial Research Centre, 1992.

***Received**: 12-05-2025 - **Accepted**: 10-07-2025 - **Published**: 19-07-2025*

15. Goudarzi, G.H. Geology and Mineral Resources of Libya—a Reconnaissance; US Government Printing Office: Washington, DC, USA, 1970; Volume 660, pp. 1–112.
16. TolouKian, A.R.; Sadeghi, J.; Zakeri, J.A. Large-scale direct shear tests on sand-contaminated ballast. Proc. Inst. Civ. Eng.—Geotech. Eng. 2018, 171(5), pp. 451–461 https://doi.org/10.1007/s42452-019-1459-3
17. Alakhdar, A. Effect of water saturation changes on the creep and stability of the soil slope parallel to the Al-Qawasim Mountain Road. Sharwes J. 2025, 6, pp. 331–338 https://doi.org/10.26629/ssj.2025.18
18. 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 LibyaIn Sebha University Conference Proceedings, Vol. 3, No. 2, 2024; pp. 28–33 https://doi.org/10.51984/sucp.v3i2.3118
19. Rocscience Inc. User's Guide for RocPlane software. 2001; pp. 1–14. https://www.rocscience.com/downloads/rocplane/R ocPlaneReference

***Received**: 12-05-2025 - **Accepted**: 10-07-2025 - **Published**: 19-07-2025*