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Effect of Water Saturation Changes on the Creep and Stability of the Soil Slope Parallel to the Al-Qawasim Mountain Road of North West Libya

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ABSTRACT

The study aims to evaluate the effect of internal water saturation on the stability of the soil slope parallel to Al-Qawasem Road by testing water quantities of 60, 70, and 80 mm and assessing their impact on soil cohesion and friction angle. To achieve this, field observations, laboratory experiments, and numerical simulations using the RocPlan program were conducted. Field data revealed the inclination of tree trunks, indicating ongoing soil creep. Laboratory results showed that increasing the internal saturation ratio from 16.5% to 19.5% led to a significant decrease in cohesion and friction angle, thereby reducing soil resistance. The simulation results confirmed a decrease in the safety factor from 1.002 to 0.3, classifying the slope as being in the "choking stage" that necessitates continuous monitoring and preventive measures.

Keywords: Soil creep, cohesion, friction angle, slope stability.

تأثير تغيرات التشبع المائي على زحف وثبات منحدر التربة الموازي للطريق الجبلي القواسم شمالي غرب ليبيا

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ملخـــــــص البحــــــث

تهدف الدراسة إلى تقييم تأثير التشبع الداخلي بالمياه على ثبات منحدر التربة الموازي لطريق القواسم وذلك باختبار كميات مياه 60، 70، 80ملم، وتقييم أثرها على التماسك وزاوية الاحتكاك؛ اعتمد على الدراسة الميدانية والمعملية وبرنامج (RocPlan) وأظهرت النتائج الحقلية ميل جذوع الأشجار ما يشير إلى حدوث عملية زحف التربة، وبيّنت التجارب المعملية أن ارتفاع نسبة التشبع الداخلي من 16.5% إلى 19.5% ادت لانخفاض التماسك وزاوية الاحتكاك، مما قلل من مقاومة التربة، وأكدت المحاكاة انخفاض معامل أمان المنحدر من 1إلى 0.3، وصنفت المحاكاة المنحدر بأنه في "مرحلة الاختناق" والتي تتطلب مراقبة المنحدر بشكل مستمر.

الكلمات المفتاحية: زحـف التربــة، التماسك، زاويـة الاحتكاك، ثبـات المنحدر.

Introduction

Evaluation slope stability and minimizing the risk of material collapse are essential in geological and geotechnical engineering.[1] Slope failure can result from natural factors like rainfall or earthquakes, or human activities such as road cutting and vegetation removal.[2] When slopes Parallel to mountain roads collapse, they pose serious risks to infrastructure and public safety.[3] Material movement on slopes includes falling, sliding, toppling, and creeping, with materials such as rocks, soil, or debris involved.[4] This study focuses on Slope Stability of the Soil and soil creep, defined as the slow, shallow movement of slope materials under long-term gravitational influence.[5] Common signs include bent tree trunks, tilted poles, and surface cracks. Soil creep is affected by slope geometry, soil mechanics, and rainfall. Water infiltration raises pore pressure, increasing soil weight and reducing both cohesion and friction angle, thus promoting creep.[6,7] Additionally, changes in soil moisture or saturation levels significantly influence this process, The Soil creep is strongly affected by moisture variations in unsaturated soils.[8] Understanding it requires monitoring soil properties, pore pressure, and slope behavior before and after failure.[9] Effective risk management depends on analyzing how slope geometry and related factors contribute to collapse.[10] The research problem focuses on study soil creep observed in the field, cited in reference[11] identified slope cutting for road construction as the primary cause of this creep phenomenon. The study reported a decrease in soil cohesion from 8.2 to 2.8 t/m² as saturation increased, along with a reduction in the safety factor from 2.61 to 1.06 when saturation reached 15%.[11]

The previous study recommended further laboratory analysis to investigate soil properties under varying saturation levels. Accordingly, the current study aims to evaluate the impact of increased water content (60, 70, and 80 mm) on soil creep and to assess slope stability under different saturation ratios. This research is therefore regarded as a continuation of the previous work and a practical implementation of one of its key recommendations. The study area is located north of Gharyan city, northern edge of the AL-Qawasim Mountain, between latitudes N32°15'45" and N32°16'00" and longitudes E13°01'12" and E13°00'57", Figure 1.

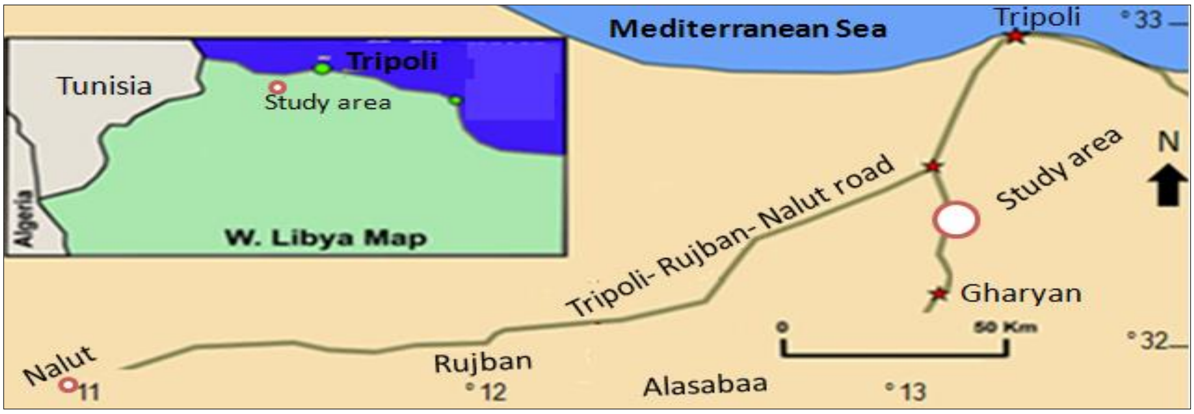

Figure 1: Location of the study area.[12]

The study area's stratigraphy is part of the broader Nafusa uplift sequence, shaped by multiple marine transgressions and regressions that led to the deposition of continental, marine, and transitional sedimentary rocks.[13] The Outcrop formations ranges from the Lower Triassic (kurrush Formation) Figure 2 to the Upper Cretaceous (Nalut Formation).[14]

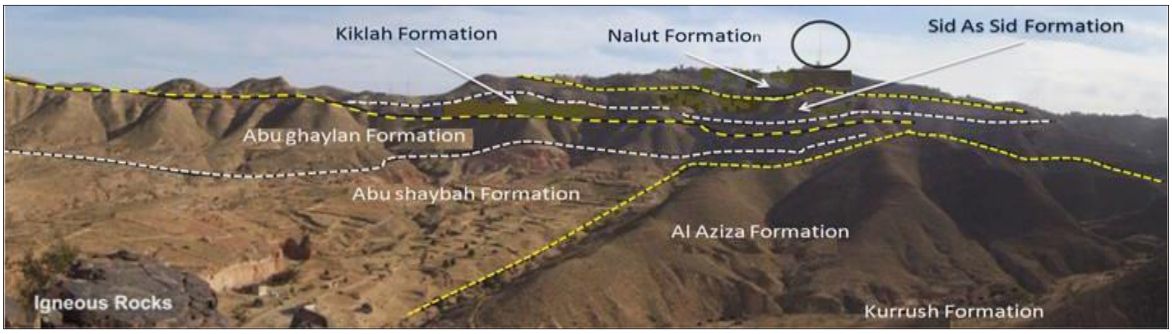

Figure 2: Outcrop formations in Gharyan Area.[13]

Materials and Methods

Field study

A field visit was conducted to collect essential data through a geological survey of the cut slope parallel to the road. Geological surveys are a fundamental method for gathering field data on slope characteristics.[15] The main data comprised slope geometry, and soil samples were obtained from a depth of 40 cm at the same location cited in reference.[11] The primary tools used during the survey included a geological compass, an inclinometer, and measuring tapes of various lengths Figure 3. Additionally, the interpretive booklet of the Tripoli geological map sheet was consulted for regional context.[16] Table1 presents a summary of the main field data collected.The field observations and measurements collected during this study align closely with the data cited in reference,[11] confirming the consistency of slope conditions at the surveyed location.

Figure 3: Tools used in the field study to collect geological and geometric slope data.

Table 1: Slope geometry data.

Targeted data	Value	Targeted data	**Value**
Bench width	32 m	Effect of water	**(60,70,80mm)**
Tension crack	Joint	Slope height	**9 m**
Friction angle	90°	Failure plane angle	**50°**
Distance from crust	4 m	Upper face angle	**25°**
Depth of the joints (Z)	5m	Slope face angle	**80°**

Laboratory study

The laboratory study was conducted on soil samples collected during the field survey. The primary objective was to determine the values of soil cohesion and internal friction angle. Initially, the samples were weighed and then oven-dried at 120 °C for 24 hours to eliminate

moisture content and ensure complete dryness. Subsequently, 60 mm of water was added an amount exceeding the 50 mm applied as indicated in reference.[11]
The soil was thoroughly mixed to ensure uniform distribution of moisture. Direct Shear Tests (DST) were then conducted to measure normal and shear stresses and to extract shear strength paramete .[17] At a constant loading rate of 0.25 N/S using a load frame of area 236 cm^3. The direct shear test was repeated under three different vertical loads: 4 kg, 8 kg, and 16 kg.[17] Table 2 illustrates a sample of a pre-formatted Excel sheet used for recording the parameters obtained from the device. At this stage, the water content (saturation percentage) of the soil sample was calculated by adding 60 ml of water prior to testing**.**

Table 2: An example of an Excel sheet used to enter and analyse laboratory data.

Location of sample: Al Qawasim				**Water content: 16.5%**			**Date of test: 2 / 2/ 2025**		
Weight of sample			Sample dimensions						
			Hight of Sample			Dia. Or Side of Sample			Area cm³
5ml	25ml	50ml	4Kg	8Kg	16Kg	4Kg	8Kg	16Kg	For all
153	165	175	2.5	2.6	2.6	6x6 cm²	cm²36	36cm²	36
		Volume of sample cm³			Density: γwet gm/ cm³				
		4Kg	8Kg	16Kg	60ml	70ml	80ml		
Loading rate = 0.25 mm/min				Load ring constant LRC=2.1008*10^-3					

The test was repeated after adding 70 and 80 mm of water. The internal saturation ratio was calculated following the same procedure described earlier. The objective of the test was to investigate the relationship between vertical stress and shear stress leading to specimen failure, Figure 4 in order to determine the cohesion and internal friction , Figure 5. All results obtained from the laboratory study are summarized in Table 3.

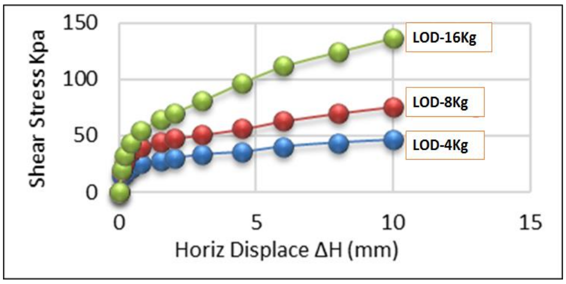

Figure 4: Variable horiz sample at loading

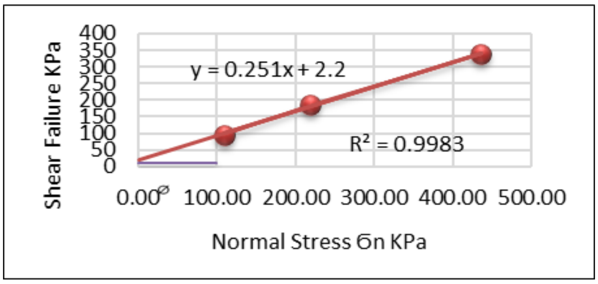

Figure5: Normal & Shear Stress Relationship

Table 3: Data and results obtained from the Direct Shear Test.

Water quantity	Saturation	Friction angle(φ)	Cohesion(C)
60mm	16.5%	34.0°	2.2 t/m²
70mm	18.0%	32.8°	1.7 t/m²
80mm	19.5%	31.5°	1.3 t/m²

RocPlane software

The RocPlane is an easy-to-use, interactive tool designed to evaluate the stability of rock slope components. It enables users to estimate the support capacity required to achieve a specified safety factor. The software is also employed to analyze slope performance and configuration by generating both 2D and 3D, facilitating reliable engineering analysis and interpretation.[17] One of the key input parameters is the slope geometry Figure 6, illustrated in Figure6 and detailed inTable 1.Additionally, the software integrates shearstrength parameters (**C**) and (**φ**) extracted from laboratory tests, Figure 7 and presented in Table 3.

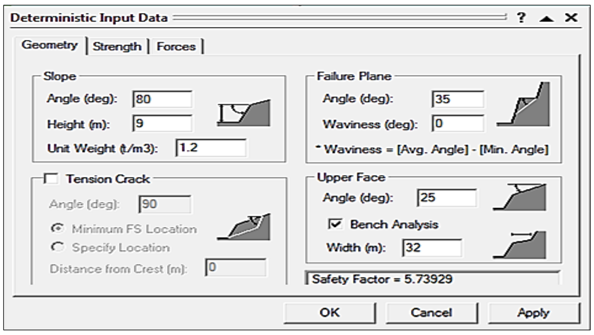

Figure 6 : Inputs Geometry Slope

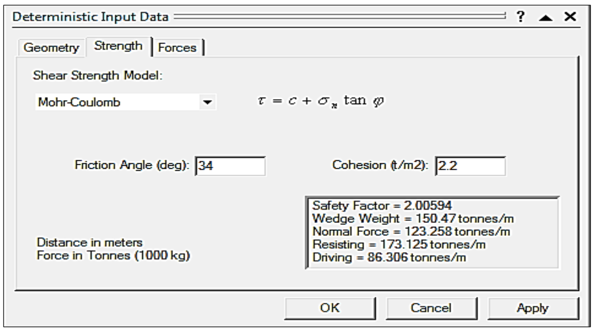

Figure7: Inputs C & Ø Angle.

Results and Discussion

Discussion of Field Study Results

The field study revealed that the soil slope rests on the Kiklah Formation, composed of poorly sorted and chemically weathered sandstone, which forms the slope's base. This base is overlain by a mixed layer of gravel and clay. The slope surface is irregular, featuring drainage channels oriented northwest aligned with the natural slope's average inclination of 25°, while the overall slope orientation is N 35° W. Large boulders were observed on the slope surface, some near the edge of the artificial cut, adding extra pressure to this weakened zone. Human interventions, including tree planting for soil stabilization, were also noted. To irrigate these trees, rainwater collection basins were constructed Figure 8, but these basins allow water to slowly infiltrate the upper and middle slope zones, increasing water saturation. This rise in saturation elevates pore water pressure, reducing soil internal cohesion and friction angle. The Field evidence such as tree trunks bending perpendicular to the cut slope face indicates soil creep directed toward the artificial slope Figure 8, contrary to the natural downslope movement. The curvature of tree trunks on a slope indicates that the soil is slowly moving in a certain direction. Trees adapt to this gradual soil movement by tilting their trunks accordingly.At the same time, tree roots form a strong stabilizing network within the soil, anchoring soil particles and reducing their tendency to slide, which helps slow down or even halt the creeping movement. Therefore, although the curvature of the trunks reflects ongoing soil movement, the presence of trees and their roots plays a crucial role in stabilizing the slope and lowering the risk of collapse. This behavior is to increased water saturation, the weight of boulders Figure 8, and the sharp increase in slope angle from 25° to 80°, due to the cutting process, which weakens the slope's natural structure. These observations align with findings reported by (Alakhdar, 2024).[11]

Figure 8: Field evidence of human activity and soil erosion affecting the slope

Discussion of Laboratory Results

The results presented in Table 4 indicate that increasing the amount of water added to the soil leads to a corresponding rise in water saturation, from 16.5% at 60 mm to 19.5% at 80 mm. This increase in saturation has a clear negative impact on the soil's mechanical properties. Specifically, the internal friction angle gradually decreases from 34° to 31.5°, reflecting a reduced resistance to sliding forces between soil particles. This reduction is attributed to the weakening of internal bonds caused by higher water content, which facilitates the breakdown of molecular bonds. Simultaneously, the soil's internal cohesion declines markedly from 2.2 tons/m² to 1.3 tons/m², indicating weaker bonding between particles and an increased susceptibility to sliding as saturation rises. This deterioration of fundamental soil properties directly compromises slope stability, heightening the risk of slow creep or sudden collapse. These findings align with the study's objective of understanding how changes in water saturation affect soil slope creep and stability.The data demonstrate that rainwater accumulation and deep infiltration increase pore pressure, reducing both cohesion and friction angle, thereby weakening the natural slope structure. Field observations, such as the bending of tree trunks perpendicular to the cut slope, further support these conclusions, indicating active creeping movements toward the artificial slope caused by these processes. It is also noteworthy that the soil sample did not reach full saturation but remained relatively saturated, highlighting the significant role of the internal saturation ratio on the soil's mechanical properties. The most influential factor was not simply the volume of water added, but rather the internal saturation ratio, which reflects the actual water absorption by the soil. The decrease in cohesion is explained by the initially dry state of the soil with the addition of 60 mm of water, saturation reached 16.5%, and then increased to 18% at 70 mm and 19.5% at 80 mm. Each rise in saturation corresponded to a further reduction in cohesion. "This process replicates field conditions where water reduces soil cohesion and friction. Saturation, not total water volume, is the main driver of creep, as water in sandy soils penetrates deeper layers."

Discussion of the Results of the Rocplane software

The simulation results presented in Table 4 using RocPlane software demonstrated the impact of varying water quantities (60, 70 and 80 mm) on slope stability through several geotechnical indicators. The water content increased gradually from 16.5% at 60 mm to 18.0% at 70 mm and 19.5% at 80 mm, indicating higher soil saturation and reduced shear strength. The normal force remained stable at approximately 43.35 t/m for both 60 mm and 70 mm water levels but dropped significantly to 6.78 t/m at 80 mm, suggesting a reduction in effective stress due to elevated pore water pressure.

Table 4: Rocplane software output.

Water quantity	60mm	70mm	80mm
Water content (%)	16.5%	% 18.0	19.5%
Normal force	43.3523 t/m	43.3523 t/m	6.78072 t/m
Driving force	51.6653 t/m	51.6653 t/m	58.0211 t/m
Resisting force	51.7859 t/m	45.3593 t/m	17.4769 t/m
Factor of safety	1.00234	0.877947	0.301217
Shear strength	51.78t/m^2	45.35 t/m^2	17.47t/m^2

The driving force rose from 51.67 t/m at 60 mm and 70 mm to 58.02 t/m at 80 mm, reflecting the increased weight of the saturated soil mass. Conversely, the resisting force declined from 51.79 t/m at 60 mm to 45.36 t/m at 70 mm, and dramatically to 17.47 t/m at 80 mm, indicating a substantial deterioration in the soil's resistance to sliding as saturation increased. According to Table 4, the Factor of Safety recorded a marginally safe value of 1.002 at 60 mm of water, suggesting that the slope remains stable under these conditions. However, the FOS decreased to 0.877947 at 70 mm below the critical threshold of 1.0 indicating increasing instability. At 80 mm, the safety factor dropped drastically to 0.301, signaling a high risk of imminent failure if conditions persist. This trend aligns with the corresponding reduction in shear strength, which declined from 51.78 t/m² at 60 mm to 45.35 t/m² at 70 mm, and further to 17.47 t/m² at 80 mm. Despite the clear evidence of declining stability, the simulation consistently reported a collapse probability of 0% across all cases. Overall, the results indicate that water levels exceeding 60 mm mark the beginning of slope destabilization, with conditions deteriorating significantly at 80 mm. These findings highlight the critical importance of monitoring water infiltration and its effects on slope behavior, particularly in areas vulnerable to heavy rainfall or subsurface leakage. Figure 9 illustrates the simulated slope model under initial conditions based on the input parameters. Under these conditions, the slope appears stable, with minimal influence from driving forces due to the presence of internal cohesion. However, as internal saturation increases Figure 10, the effect of driving forces becomes more pronounced. This is due to elevated pore water pressure and the mobilization of forces along the potential failure plane.

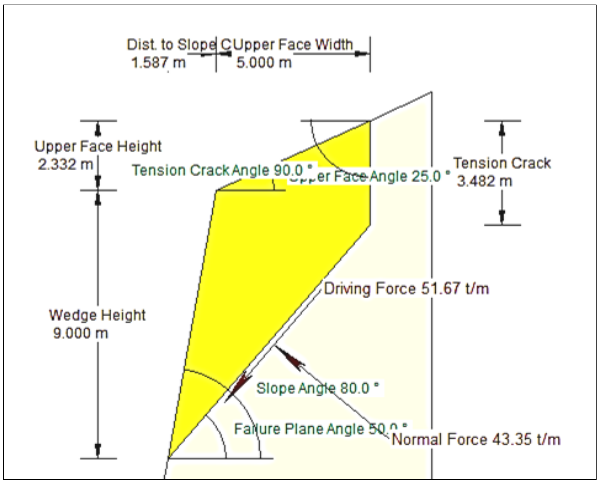

Figure 9: slope simulated at 16.5% saturation

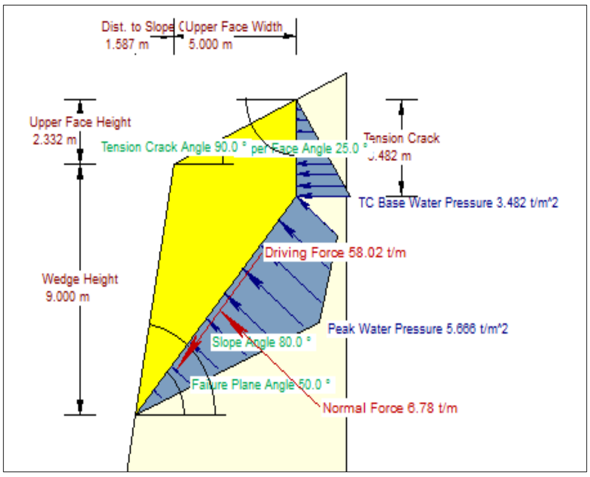

Figure 10: slope simulated at 19.5% saturation

Conclusions

This study showed that slope stability depends not only on surface geology but primarily on internal hydrological conditions and soil mechanics. Field evidence, such as the inclination of tree trunks, revealed active soil creep. Laboratory results confirmed that internal saturation ratio not water quantity is the key factor reducing cohesion and friction angle. RocPlane simulations supported this, showing a decline in the Factor of Safety and progression toward the "Choking Phase" of instability. These findings highlight the need for integrated monitoring that combines field observations with simulation models to assess and mitigate slope failure risks in rainfall-prone areas.

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