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Relationship between Horizontal Bedding and Joints Affecting Rocks Slopes Parallel to Al-Rujban Mountain Road, Libya

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ABSTRACT

The bedding planes and rock joints contribute to the weakening of the rock masses forming the slopes, increasing the likelihood of rockfalls and collapses. This study aims to analyze the relationship between horizontal bedding planes and rock joints and their effect on the stability of rock slopes parallel to the Rajban mountain road. The horizontal bedding planes represent the primary sedimentary structures of the rocks. To achieve the study objectives, the physical characteristics of joint surfaces and bedding planes were examined. Field observations of the Sidi Saad Formation (Ain Tobi Member) showed that horizontal bedding planes are the main structural weakness surfaces, with variations in thickness and lateral continuity. The joint spacing was about 0.20 m, and the values of Jv = 9.8 and RQD = 85.1% indicate relatively good rock quality. The results also reveal that the convergence of bedding planes increases weak points and promotes the development of vertical joints, reducing layer cohesion and increasing the likelihood of failure on steep slopes.

Keywords: Rock Joints, Slope Stability, Bedding Planes, Road cut.

العلاقة بين التطبّق الأفقي والفواصل المؤثرة في المنحدرات الصخرية الموازية للطريق الجبلي الرجبان، ليبيا

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ملخص البحث

تُسهم الفواصل ومستويات التطبق في إحداث حالة ضعف للصخور المكونة للمنحدرات فتزيد من احتمالية الصخور للسقوط والانهيارات، تهدف الدراسة إلى تحليل العلاقة بين مستويات التطبّق الأفقية والفواصل الصخرية وتأثيرها على استقرار المنحدرات الصخرية الموازية للطريق الجبلي الرجبان. إذ تمثل مستويات التطبّق الأفقية البنية الرسوبية الأولية، ولتحقيق الأهداف تم دراسة الخصائص الفيزيائية لأسطح الفواصل ومستويات التطبق، وأظهرت نتائج الدراسة الميدانية لتكوين سيدي الصيد – عضو عين طبي أن مستويات التطبّق الأفقية تُعد أسطح الضعف الرئيسة، مع تباين في السمك والامتداد الجانبي لها، حيث بلغ تباعد الفواصل 0.20 متر، وقيمة متانة الصخر 85.1% دالّة على متانة صخرية جيدة نسبيًا. كما بينت النتائج أن تقارب مستويات التطبّق يسهم في زيادة نقاط الضعف وتطور الفواصل الرأسية، مما يقلل تماسك الطبقات ويزيد احتمالية الانهيار من نوع السقوط الصخري.

الكلمات الدالة: مستويات التطبّق، استقرار المنحدرات، الفواصل الصخرية، شق الطريق الجبلي.

1. INTRODUCTION

The bedding planes in sedimentary rocks are among the most significant geological structures influencing the mechanical behavior of rocks and the stability of rock slopes, These planes exert both direct and indirect effects on failure mechanisms and deformation patterns [1]. Slope stability largely depends on the dip direction and dip angle of the bedding relative to the slope face [2], as these planes may act as potential sliding surfaces that facilitate landslides and mass movements [3]. When the bedding plane dip is parallel to or inclined toward the slope face, the likelihood of failure increases due to reduced shear resistance along these discontinuities [4]. Conversely, bedding planes that dip perpendicular or opposite to the slope direction tend to enhance slope stability [5]. Understanding the influence of bedding orientation on rock mass behavior is therefore essential in geotechnical and engineering geology investigations [6].

Bedding planes that are horizontal or nearly horizontal generally do not intersect the slope face at critical slip angles [7] and are thus not considered major potential failure surfaces, as occurs with parallel dips. However, such planes can indirectly reduce stability by separating rock layers and diminishing cohesion between strata [8]. Moreover, the accumulation of water along horizontal bedding planes increases pore pressure and decreases shear strength, further predisposing the slope to instability [9]. Weathering and differential erosion processes contribute to the mechanical disintegration of the upper layers of the rock mass, exposing them to progressive small-scale failures such as rockfalls and overturning [10].

The Joints, as structural discontinuities, influence the geomechanical behavior of rocks and govern their response to both natural and anthropogenic factors. The orientation and spacing of joint systems play a critical role in determining the mode and direction of rockfall development [11],

The evaluation of slope stability represents a fundamental aspect of geomechanical analysis. It is often expressed by the angle of repose, which defines the maximum inclination at which rock or unconsolidated materials can remain stable without undergoing failure or collapse [12]. Field observations at the slope site revealed that the rock masses are extensively affected by fractures and cracks exhibiting variations in orientation and dip angle. Distinct stratigraphic planes were identified, differing in their thickness, lateral continuity, and the nature of the materials filling the discontinuities. Evidence of a rockfall-type failure was observed, involving blocks of various sizes and shapes that had detached and accumulated approximately two meters from the roadside Fig 1.

Fig 1. Rockfall at the study site.

It is important to note that the Rujban Mountain road is occasionally affected by Rockfall, particularly during periods of intense rainfall or after prolonged weathering processes Fig 2. Reference [13] pointed out that a rock debris collapse occurred in December 2023, indicating the ongoing instability of the slope in that area.

Fig 2. Rockfall at the Rujban Mountain Road.

On the other hand, rock outcrops without any Bedding plane and joints were observed. The main objective of the study was to analyze the relationship between Bedding plane and the joints, as well as to evaluate slope stability based on detailed field measurements. The study area is situated on the northern edge of Mountain Rujban, with the road extending northward to connect to the Tripoli–Nalut road Fig 3.

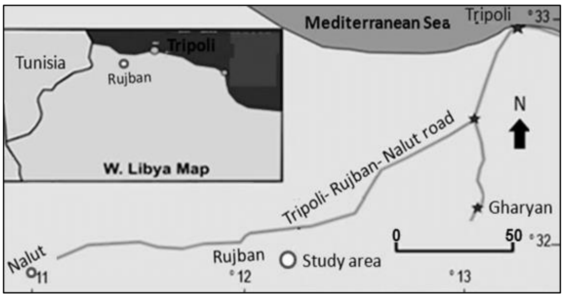

Fig 3. Location of the study area [13].

The Jebel Rujban Uplift and its mountainous road are part of the Nafusa Uplift, which extends from southeastern Tunisia to northwestern Libya, spanning approximately 400 km [13]. The main formations along the adjacent slopes include, from bottom to top, the Kiklah Formation, the Sidi As Sid Formation, and the Nalut Formation Fig 4, capped by the Upper Cretaceous Tigrinah Formation

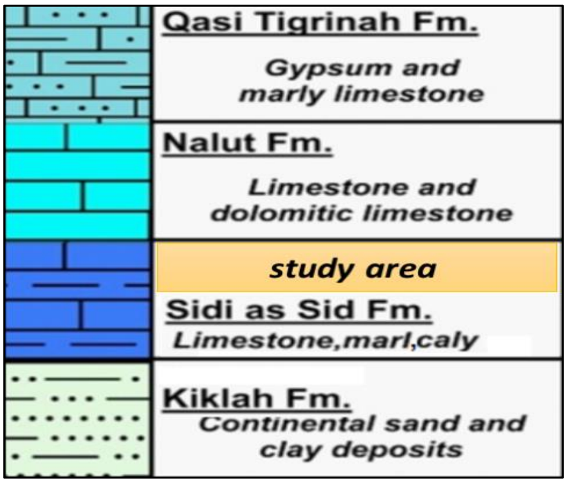

Fig 4. Stratigraphic columnar section.

The Sidi As Sid Fm was first described by El Hinnawy & Cheshited (1975). It comprises a sequence of carbonate rocks deposited in a shallow marine environment and is subdivided into two members. The upper member mainly consists of mudstone and dolomite, with intercalations of claystone and gypsum, while the lower member, the Ain Tobi Member [14], is composed of dolomite with crystal sizes ranging from fine to coarse, thin marl intercalations, and abundant fossils indicating a Late Cretaceous (Cenomanian) age [15].

2. MATERIALS AND METHODS

This study investigates the Sidi As Sid Fm, particularly the Ain Tobi Member, informed by field observations that revealed rockfall occurrences in some areas but not in others, along with a high abundance of joints and multiple planes of foliation. A direct field-based approach was adopted to collect data, including measurements of joints and identification of joint sets. Detailed descriptions of the joints were recorded in terms of their length, spacing, and surface characteristics, with the objective of evaluating their influence on slope stability and clarifying their relationship to rockfall phenomena.Various geological field tools were employed, such as Vernier calipers for precise thickness measurements, geological hammers, measuring rods of different lengths for distance estimation, and Jacob's Staff for assessing elevation differences. All field observations were documented through photographs, maps, and illustrations, and the geographic coordinates of each site were recorded to facilitate subsequent structural and geomechanical analyses. To investigate the interaction between bedding planes and joint systems at the study site, the physical characteristics of horizontal bedding planes were examined in the first stage, considering them as significant joint sets. The second stage focused on analyzing random fractures affecting the area, as described below.

2.1 Roughness

Roughness refers to the morphological irregularities and textural characteristics of a joint surface, representing an important structural attribute that significantly influences the stability and mechanical behavior of rock masses [16], Based on the degree of roughness, joint surfaces are commonly categorized into three main types:

- Smooth surfaces, characterized by uniform texture and clear light reflection, which reduce mechanical interlocking and cohesion between adjacent rock blocks;
- Very rough, exhibiting pronounced protrusions and irregularities that enhance shear strength and interlocking; and
- Rough, representing an intermediate condition between the two extremes and typically occurring in sedimentary rocks.

2.2 Continuity (Joint Persistence)

Joints are classified according to their length, which may range from a few centimeters to several kilometers. This parameter serves as an important criterion for distinguishing between cracks and fractures and for evaluating their influence on the mechanical behavior and stability of rock masses. The length of joints can be precisely measured by tracing their continuity along the rock slope and comparing the obtained values with those presented in Table1. Field observations indicate two primary types of joints: continuous joints, which extend over considerable distances and terminate at other joint surfaces, and discontinuous joints, which end against large rock blocks or massive intact rock. The weakening effect of joint continuity and size on rock mass stability becomes more pronounced when accompanied by greater depth, as increasing joint penetration enhances the likelihood of separation and loss of cohesion between rock blocks [17].

Table1. Persistence Classification of Joints Sets.

Joints Sets Persistence	Classification
Less than 1 m	Very low persistence
1 to 3 m	Low persistence
3 to10 m	Medium persistence
10 to 20 m	High persistence
Greater than 20	Very high persistence

2.3 Joints Spacing:

Joint spacing refers to the horizontal or vertical distance, typically measured in centimeters, between adjacent joints. It serves as an important indicator of the size and degree of separation of individual rock blocks. Generally, wider joint spacing corresponds to larger, more stable rock masses, whereas closer spacing produces smaller blocks with reduced cohesion and greater susceptibility to instability. The distance between bedding surfaces also represents a complementary parameter to joint spacing. Bedding planes act as natural, continuous joints within sedimentary formations and are distinguished from other joint systems by their origin during sediment deposition, which may later be modified by sedimentary or diagenetic processes. The spacing values between joints are determined using Equation (1) in Reference [18], which allows for the calculation of spacing for each joint set individually and the correlation of these values with the structural and mechanical properties of the rocks within the study area. The classification and range of joint spacing values are presented in Table 2 [18].

$$Sa = S1+S2+S3+....SN. \qquad (1)$$

Sa -The average distance between joints
S1- The distance between the first &second Joint
S2- The distance between the second & thiard Joint
S3- The distance between the thiard & forth Joint
SN: Joint count per set.

Set (or Joint Set) refers to a group of joints that share a common or nearly common orientation in dip and strike, and exhibit similar geometric characteristics such as spacing, length, roughness, and aperture.

Table 2. Description joint spacing.

Joints Spacing-cm	Description
200<	Extremely widely spaced
200 - 60	Widely spaced
60 - 20	Moderately widely spaced
20 - 6	Closely spaced
6 – 2	Very closely spaced
2<	Extremely closely spaced

2.4 Separation:

Separation refers to the degree to which a rock mass, or parts thereof, is displaced from the original mass due to the presence of joints, and it is measured in millimeters. The Vernier caliper is the primary field instrument used to obtain these measurements. The separation index serves as an important indicator of rock disintegration and the influence of joints on rock mass stability [19]. Following field measurements, the recorded separation values are summarized in Table 3.

Table 3. Classification Of Separation [19].

Separation	Classification
>200 mm	Wide
60 – 200 mm	Moderately wide
20 – 60 mm	Moderately narrow
6 – 20 mm	Narrow
2 – 6 mm	Very narrow
0 – 2 mm	Extremely narrow
Zero	**Tight**

2.5 Rock Quality Designation (RQD):

The (RQD) index is one of the most important indicators for assessing the strength of rock masses. It can be measured using various methods, including core sampling with a coring device where applicable. In the slopes of the study area, however, the transport and operation of such equipment proved difficult. Therefore, the RQD was determined directly using Equation (2) [20].

RQD=115-3.3 (JV)………….. (2)

This approach was adopted for several reasons, the most important being that the measurements and results provide a comprehensive description of the strength of the exposed rock masses. The results also take into account the depth of the joints within the rock blocks and highlight the influence of both visible and hidden fractures, based on the joint size, referred to as Joints Volumetric (JV). The obtained results are presented in Table 4, and the JV values were calculated using Equation (3).

JV=1/S1+1/S2+1/S3+.1/SN…….. (3)

When random cracks (Nr) are present, the joint volumetric count (JV) is calculated according to equation (3)

$$JV = 1/S1 + 1/S2 + 1/S3 + ..1/SN + NR/5\sqrt{A} \text{ .... (4)}$$

Where, S1, 2S and S3, are values obtained from Equation (1), A denotes the area of the studied sector, and Nr - random number fractures [20]

Table 4. Description Of RQD %.

RQD %	Description
90–100	Very Good
75–90	Good
50–75	Fair
25–50	Poor
<25	Very Poor

3. RESULTS AND DISCUSSION

Fig (4) of the Road Cut rock (Set 2) shows a distinct sequence of beddingPlanes with horizontal to sub-horizontal orientations. These levels represent natural bedding planes that separate the sedimentary layers. According to Table (6), approximately twenty bedding levels were identified, indicating a clear repetition of horizontal discontinuities within the rock section. The bedding layers vary in thickness and lateral continuity, reflecting differences in depositional conditions and the succession of sedimentary environments.

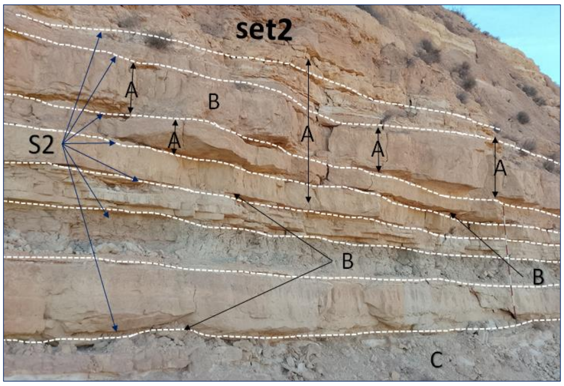

Fig 4. Road Cut rock- Ain Tobi Member.

Table 5. Data of Ain Toby Member Road Cut.

Data	Values and Description
Sectional area	200 m^2
Classification Of Surface Shapes	Rough
Bedding plane frequency	20
Joint Spacing = Sa	20**cm-0.20m**
Descriptive (Bedding)	Moderately widely spaced
Random Fractures	10
Joint Volumetric -Jv	9.8
R Q D	85.1%
Description of R Q D	Good
High persistence	10 to 20 m
Slope Angle	˚85-˚90
Type of Movement	Rock fall
separation	10-20mm
Classification of separation	Narrow

It is worth noting that some bedding planes are extremely close, with separations of up to 10 mm, forming thin lamina units that are not clearly visible in the Fig 6.

The data indicate that the joint spacing averages around 0.20 m, classifying it as moderately to widely spaced Table 2, suggesting that the rock mass retains its structural cohesion despite the presence of these joints. The calculated value of JV = 9.8 corresponds to a medium joint density, consistent with an RQD value of 85.1% good Table 4, which characterizes the rock as of good quality in terms of homogeneity and stability.

However, the presence of horizontal joints (bedding planes) forms potential weak surfaces, particularly on steep slopes (85°–90°), increasing the likelihood of rockfalls under vibrations or basal erosion Fig 4 The occurrence of clay seams between bedding planes further facilitates collapse and slope weakening. These planes exhibit rough textures and narrow separations (10–20 mm), which reduce water permeability and enhance shear resistance. Nevertheless, prolonged weathering and erosion processes may gradually widen these openings and increase the potential for surface failure.

Overall, the bedding planes in this exposure act as major horizontal structural discontinuities that control rock disintegration and block distribution. They represent the most influential structural element governing the geomechanical behavior of the rock slope.

Fig 5 shows a series of discontinuous and irregular vertical joints (A–B–C) that penetrate the horizontal bedding planes shown in the previous Fig. These fractures do not follow a specific structural trend but are randomly and irregularly distributed within the rock masses, indicating that they developed after the formation of the bedding planes, most likely as a result of tensile stresses or blasting activities associated with the construction of the Rayayna mountain road. The horizontal bedding planes represent the original sedimentary structure within the outcrop, formed through successive depositional stages. Over time, due to mechanical stress or surface erosion, vertical fractures developed that penetrated these horizontal planes without disturbing their arrangement, confirming their nature as secondary structural features. These vertical joints intersect the bedding surfaces at nearly right angles, forming a network of intersecting fractures. However, they do not constitute a well-defined

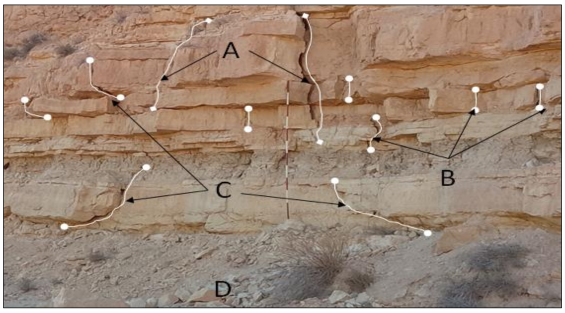

Fig 5. Ain Tobi Member Random fractures.

Fig 6 shows that Road Cut rock- Ain Tobi Member without bedding planes do not exhibit random fractures or joints. It can also be observed that the presence of a plane parallel to the slope face (Set 1) is responsible for the detachment of rock blocks along the slope, indicating that this structural feature controls the separation of blocks parallel to the slope face.

Fig 6. Road Cut - without bedding planes.

4. CONCLUSIONS

Structural analysis and field observations indicate that horizontal bedding planes represent the main sedimentary structure in the rock outcrop. Their close spacing and low cohesion have created internal weaknesses that facilitated the development of perpendicular vertical fractures due to subsequent tensile stresses. This structural relationship appears sequential, as the bedding planes preceded the formation of vertical fractures, which later evolved under ongoing uplift and weathering processes.

This interaction led to the fragmentation of the rock mass into irregular blocks, reducing rock homogeneity and increasing susceptibility to collapse, particularly on steep slopes. Accordingly, bedding planes are identified as the primary structural factor controlling outcrop stability, while vertical fractures act as secondary elements that facilitate block detachment and failure. Understanding this relationship is fundamental for geological risk assessment and for designing slope stabilization and protection strategies, such as slope reinforcement and fracture monitoring.

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