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ASSESSMENT OF ROCK SLOPES STABILITY USING STEREOGRAPHIC PROJECTION ALONG WADI SHORSHIRIN IN ZURBATIYA REGION/ EAST OF IRAQ

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ABSTRACT

Wadi Shorsirin is located in the Wasit governorate east of Iraq, it is considered a promising tourist site for the people who live close to this area. The research aims to study the rocky slopes and assess their stability, along the two banks of Wadi Shorhirine, by choosing five stations distributed where the failure occurs and to determine the expected rock failure along this valley. In addition, determine the factors that affect stability, such as discontinuities, rock resistance, and weathering to take them into account when establishing engineering projects such as roads, andtourist complexes. The stereoscopic projection technique was used to analyze the stability of these rocky slopes and showed there are two types of slopes which are oblique lateral and orthogonal slopes. Toppling and rockfall werefound within the study area, in addition to the rolling. Differential eroded in the foot slope was the main reason for the failure, moreover, the existence of joint sets. The rocks of the slopes were evaluated based on the unconfined compressive strength deduced from the point load test into the moderately strong and strong.

1. INTRODUCTION

The most important problem facing researchers and specialists in engineering affairs is the instability of the slopes and the blocks they bear due to the force of gravity, and the instability is related to either the loading of the slopes or the removal of the supports supporting them or the reduction of the friction force on the surfaces separating the rock layers due to the penetration of water in them (Chigira, 1992). Landslides resulting from slope instability are considered one of the most dangerous environmental disasters that the inhabitants of mountainous areas are exposed to, and they usually occur whenever the causative factors are available (Hasan, 2019; Al-Bayati, 2021). The permanent discontinuities within rock mass play an important role in slope stability, especially their attitude (dip amount and dip direction) with respect to slope direction (Adeeb & Al-Jumaily, 2021), so the factors that affect the stability of these slopes must be studied and therefore the necessary treatments must be known to increase stability and stabilize these slopes (Bromhead, 1992). One of the most important factors affecting the stability of the rocky slopes is the natural factors that include geomorphological, petrographic, structural, and hydrological conditions of the region, erosion and weathering factors, as well as seismic activity. As for the factors that arise from human action, they include cutting and filling operations, especially in mining activities and quarries (Bayram et al., 2021; Hoek & Bray, 1981), the process of interpreting the occurrence of the failure is one of the important topics due to their influence on human life, (Qader and Syan, 2020). The study area is located in the eastern part of Iraq, within Wasit Governorate (Figure 1). The main cities that exist within the study area are Badrah, Jassan, and Zurbatiya, which are surrounded by several villages.

The research aims to study the rocky slopes and assess them along the banks of Wadi Shorhirine, which is considered a promising tourist site. In addition to determining the factors that affect stability, such as discontinuities, rock resistance, and weathering for the purpose of taking them into account when establishing engineering projects such as roads, tourist resorts, mining works, and quarries. Where Jasim et al. (2023) classified the landslide susceptibility of the research area as mostly high to very high in the Landslide susceptibility index map.

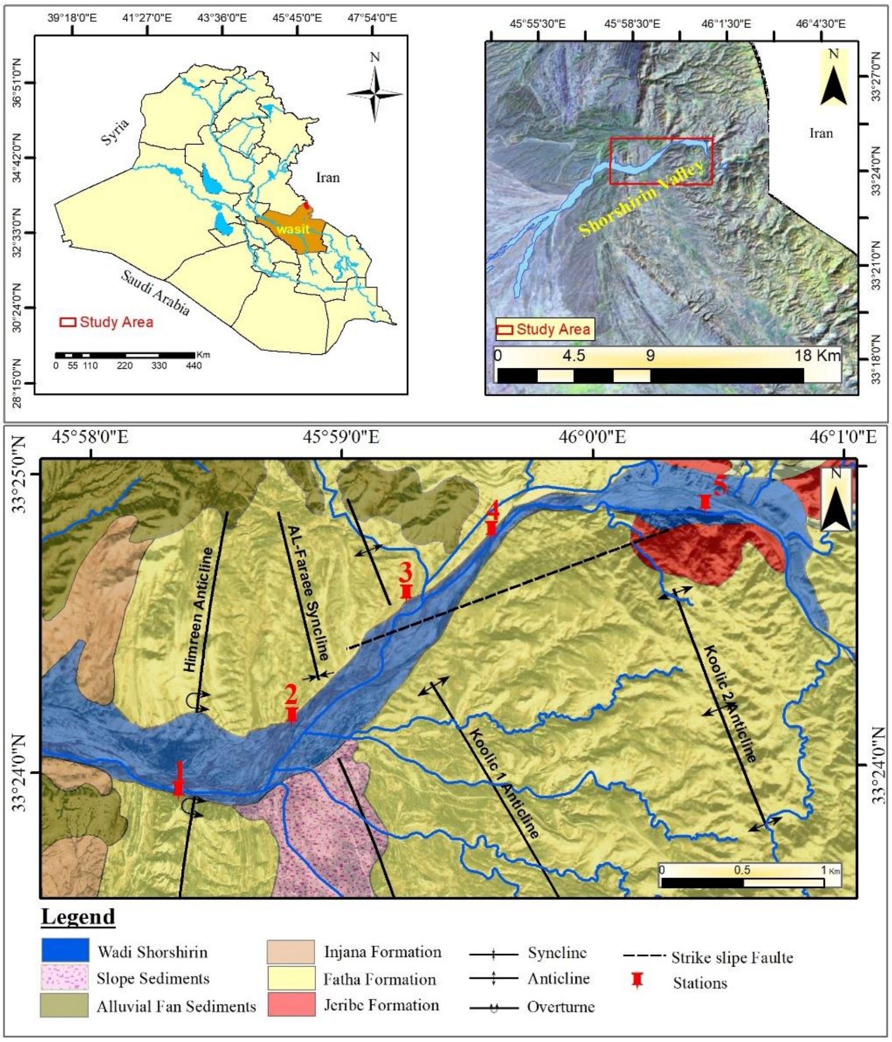

Figure 1: Location and geological map of the study area.

2. GEOLOGICAL SETTING

2.1. Topographically

Generally, the surface of the research area is characterized by flat and hilly terrains surface, and it can be divided into two parts: The first part includes the highlands in the eastern part of the area, while the second part represents the flat and less undulated features within the Mesopotamian fore land (Hamza, 1997). The highest point in the study area is (350) m a.s.l. and the lowest point in the study area is 88 m a.s.l. It is characterized by the presence of ephemeral and perennial valleys, one of the main valleys that drain within the study area is Wadi Shorsharin, which is characterized by its shallow and braided channels, which become narrow and deep after leaving the alluvial fans. All of them lead into a regional shallow depression called Hore Al-Shuwaicha out of the study area, forming small inland deltas (Figure 1) (Hamza, 1997).

2.2. Tectonically

According to (Fouad, 2015), the study area is a part of the Outer Platform within the Low-Folded Zone, it has been affected by the late regional intensive tectonic deformation that caused the uplifting of Himreen Structure. It lies within both, the central-eastern parts of the Mesopotamian Zone and the southeastern part of the Low-Folded Zone. These two zones represent the outer and central units of the Unstable Shelf of the Nubio-Arabian Platform, only the southern part of the south Himreen structure represents the Low-Folded Zone within The study area, which is characterized by long and narrow anticlines and synclines of NW – SE trend, change to the N – S trend northwards. Their axial length varies from 20 – 33 Km, and their width is from (1 – 6) Km, accordingly, they exhibit a high aspect (length/width) ratio and fall within linear folds' categories such as Himreen, Koolic1, Koolic2 Anticlines, and Al-Faraee Syncline (Mahmoud, A. A. et al., 2018), Wadi Shorshirin cut all of this folds. It coincides with Shorshirin strike-slip Fault which has an E–W trend, right-lateral strike-slip. The displacement is (0.5) Km. and approximately extends more of (2) Km within the study area (Mahmoud, A. A. et al., 2018).

2.3. Stratigraphically

2.3.1. Pre-quaternary sediments

In the study area, the exposed rock formations are; the Jeribe Formation (Early Miocene), which was first described by Van Bellen in 1959 (Bellen et al., 1959). which consists of 70 m of massive dolomitic limestone (Jassim & Goff, 2006; Mahmoud, A. A. et al., 2018). It is exposed in the northeastern limb of the Koolic 2 anticline in the eastern part of the study area. Fatha Formation (Middle Miocene), the main lithological difference between the two members of the formation is the red-colored claystone which is absent in the Lower Member, but well developed in the upper one (Al-Mubarak and Youkhanna, 1976), the upper member was exposed only and contains layers of Gypsum, red claystone, limestone, and marl in a cyclic manner. The maximum exposed thickness is (257 m). Injana Formation (Late Miocene), was first described by (Bellen et al.,1959) as the Upper Fars Formation, and renamed the Injana Formation by Jassim *et al.,* (1984). It consists of an alternation of claystone and sandstone, the thick sandstone predominates over the claystone and becomes frequent. The upper part is characterized by very thick claystone (up to 30 m) and thin sandstone beds. The total thickness is (350 m).

2.3.2. Quaternary sediments

Quaternary sediments of the Pleistocene-Holocene age, such as the Alluvial fans (Figure 1), are generally massive or lenticular and randomly bedded commonly consisting of poorly sorted clastic deposits. Usually gravels, cobbles, and boulders are imbricated with irregular arrangement predominate with a subordinate amount of sand, silts, and clays which are layers or lenses that show horizontal or cross-bedding. The individual alluvial fan body has generally a con shape or is composed of several segments (smaller cons) with the apex at the point where a watercourse leaves the mountains (Hamza, 1983). In addition, sediments of the infilled valley are well-developed in the Wadi Shorshirin and its tributaries. The distribution of the grain size along the channel is controlled by the river gradient and by the energy of flow, depending mainly on the topographic relief (Mahmoud, A. A. et al., 2018). In low relief within the alluvial fans and plains, valleys filled with finer materials; such as sand, silt, and clayey silt sediments. In high relief within alluvial fans and mountain areas, the valleys are filled with gravels of carbonate origin, and variable shapes, ranging in size up to 15 cm in diameter.

3. METHODOLOGY

The method of this study includes both field and office work, as the following:

1- Detailed fieldwork was carried out to:

- **a.** Selects the station in which the Failure has been taking place based on the recorded evidence. Within the laboratory work, all the obtained data (bedding planes and discontinuities) are plotted on Schmidt stereo net to analyze the stability of each station.
- **b.** Determining the location of the stations along the river banks in which it is located using the Global Positioning System (GPS) device and the units of Universal Transverse Mercator (UTM) for each of the units of Northern, Eastern, and height above sea level, as well as naming the geological formation that includes it.
- **c.** Measuring the slope direction and the slope angle, as well as measuring the length of the slope face in the direction of its strike, measuring the height of the slope and measuring the attitude of the layers and discontinuities, the value of the dip direction/dip amount of the slope, that is, the direction of the dip is written to the left, and the angle of inclination is written to the right.
- **d.** Collected rock samples from each station, depending on the variation in the lithology, to study them and conduct strength tests on them.
- **e.** Studying the type of failure that occurred and its potential.
- **f.** Description of the rocks, where the rocks were engineered described according to what was mentioned in the proposed report of the Geological Society of London (Anon, 1972 and 1977), as well as the rocky description proposed by (Hawkins, 1986).
- **g.** Conducting a comprehensive survey of the existing discontinuities, including their attitude, the distances between them (Spacing), their Frequency, their persistence, and their Aperture.

2- Determine the type of slope according to the divergence angle (d) between the strike of slope trend and the strike of layers, (Al-Saadi, 1981). Where

- **a.** Parallel Slope: (d) ranges between (0 – 20).
- **b.** Oblique Lateral Slope: (d) ranges between (21 – 70).
- **c.** Orthogonal Slope: (d) ranges between (90 – 71).

3- Using the symbols in Table 1 represent the collected field data on a stereogram, modified from (Al-Saadi, 1981).

4- Analysis of the data and assess the stability.

Table 1: The symbols used a stereogram, modified from (Al-Saadi, 1981).

Symbol	Description	Symbol		Description
		present	Possible	
	Cyclographic trace (great circle) of a general slope (GS)			The type of Failure is Toppling
	Cyclographic trace of vertical slope (VS) or overhanging slope (OH)			The type of Failure is Rockfall
	Cyclographic trace of the mean orientation of the bedding plane (S_0)			The type of Failure is Rolling
S_1, S_2 ●	Pole to the joint plane, joint sets			The type of Failure is Slumping
R.m	Rock mass			Photo direction
d	Divergence Angle			

4. RESULTS AND DISCUSSION

The strength of the rocks was estimated in the field by hammering with the field geological hammer, then selecting rock samples that are representative of some rock units to conduct a point load testing and obtain the unconfined compressive strength values indirectly. This test was conducted on samples with lump shapes using the apparatus: Portable Point-Load tester which was borrowed from the Central laboratories of the Iraqi Geological Survey (Figure 2). From the following equation, we can derive the values of the point loading coefficient (*Is)*:

$$Is = P/D^2 \text{ .... (1)}$$

where *D*e is the equivalent core diameter, and P is the load kn.

Figure 2: Point load testing for the selected rock samples in the field.

The size-corrected point load strength index $I_{s(50)}$ of a rock specimen is defined as the value of I_s that would have been measured by a diametric test with *D* = 50 mm. For tests conducted on samples with dimensions different from 50 mm, the results can be standardized to a size-corrected point load strength index by applying a correction factor ***k*** as follows:

$$Is(50) \ = \ Is\ k \text{................ (2)}$$

The value of the size-correction factor ***k*** is given by

$$K = \left(\frac{D_e}{50}\right)^{0.45} \quad \text{............... (3)}$$

Classification of rocks according to resistance values was executed based on (Anon, 1977) shown in Table 2.

Table 2: Description of the strength of rocks, (Anon, 1977).

Term	**Compressive strength Mpa**
Extremely strong	>200
Very strong	100 – 200
Strong	50 – 100
Moderately strong	12.5 – 50
Moderately weak	5 – 12.5
Weak	1.25 – 5
Very weak (soil)	<1.25

4.1. Station No.1

This station is located at the left bank of Wadi Shorshirin, with latitude (33°23'53") and longitude (45°58'19") within the upper member of the Fatha Formation. The station consists of a vertical slope which is represented by the sequence of massive Gypsum with thickness reaches up to (2 m), white color, banded texture, moderately weathered, and moderately strong (σc = 43.3 Mpa). Marl with (0.5 m) thick, light green to green color, moderately weathered, very weak. The attitude of this vertical slope (355/90°) with a height of (18 m) from top to bottom and (22 m) long its face, the type slope is Orthogonal Slope, (d = 85°) (Al-Saadi, 1981). The attitude of strata is (260/37°); (Figure 3).

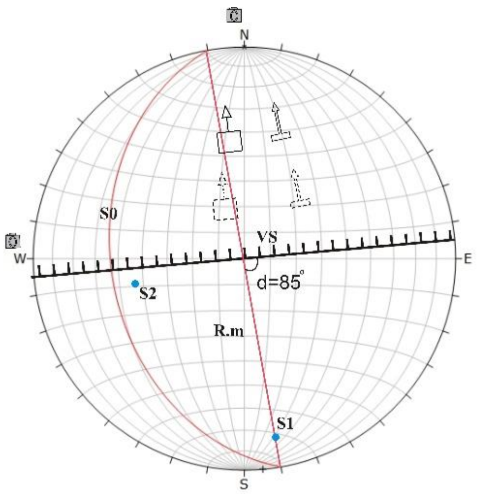

Figure 3: Stereogram of discontinuities, slope, and types of failure for station No. (1).

The layers of the vertical slope are cut by two sets of joints (S1 and S2), the attitude of (S1) is (350/75°), joint spacing ranges to (0.35 m), and the aperture (0.1 m). The Attitude of (S2) is (077/44°), joint spacing ranges up to (0.45 m), and aperture (0.12 m) (Figure 4a). Failure in this station is Secondary Toppling and Rockfall, the rock mass of gypsum detaching because of differential weathering of marl under gypsum layers and the existence of joints (S1 and S2).

The size of the gypsum rock mass that failures reaches up to (1.5 m^3) (Figure 4b). more toppling and rock falls are likely to occur in the future so the slope is unstable.

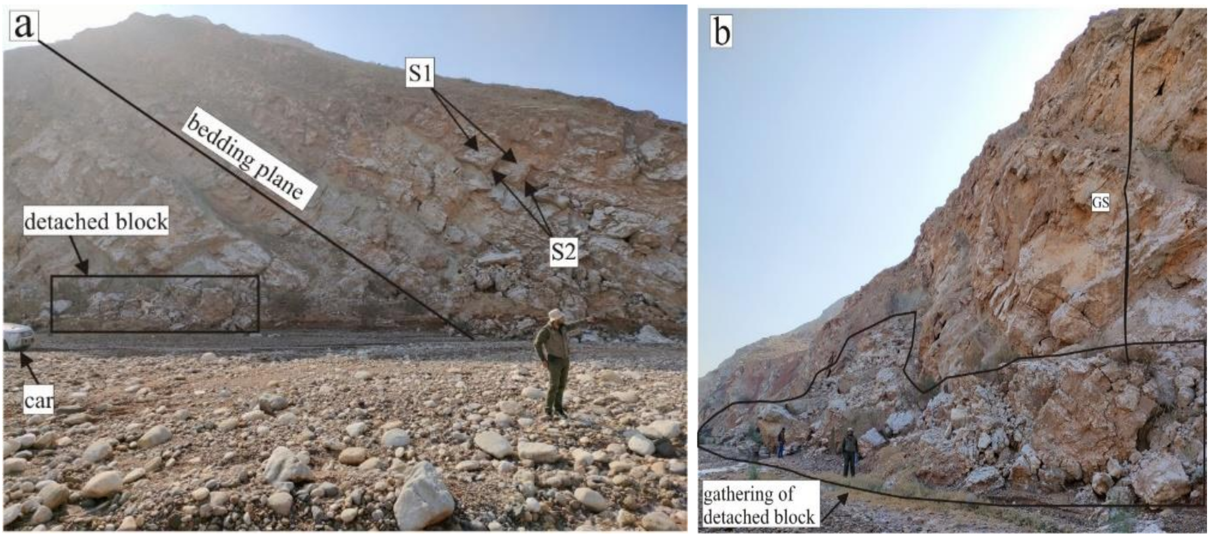

Figure 4: **a)** Front view showing the tow set of joints, **b)** Side view showing slope and size of the detached block.

4.2. Station No.2:

This station is located at the right bank of Wadi Shorshirin, with latitude (33°24'11.827") and longitude (45°58'46.778") within the upper member of the Fatha Formation. The station consists of a vertical slope which is represented by the sequence of massive Gypsum with thickness reaches up to (1.5 m), white color, nodular texture, moderate to highly weathered, and moderately strong (σc = 22.9Mpa). Marl with (0.4 m) thick, light green color, highly weathered, very weak. Mudstone with (0.35 m) thick, light brown color, highly weathered, weak (σc = 4.1Mpa). The attitude of this vertical slope (120/90º-OH) with a height of (7.5 m) from top to bottom and (8 m) long its face, the type of slope is an Orthogonal Slope (d = 78º); (Al-Saadi, 1981), where the attitude of strata is (042/28º); (Figure 5).

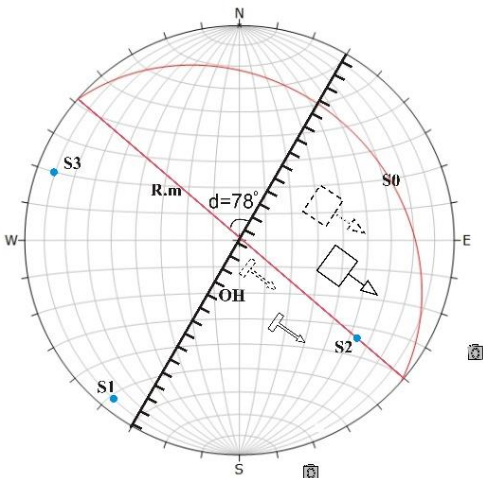

Figure 5: Stereogram of discontinuities, slope, and types of failure for station No. (2).

The layers are cut by three sets of joints (S1, S2, and S3), the attitude of (S1) is (037/84º), joint spacing ranges to (1.0 m), and aperture (0.1 m). The attitude of (S2) is (310/63º), joint spacing ranges up to (0.55 m), and aperture (0.11 m). The attitude of (S3) is (110/81º), and joint spacing ranges to (0.5 m). Rockfall and secondary toppling were occurring in this station, the rock mass of gypsum detaching because of differential weathering of marl mudstone under gypsum layers and the existence of joints. The size of the failed blocks of gypsum rock mass reaches up to (1.8 m^3), (Figure 6a). More falling is likely to occur in the future due to the continuous growth of the releasing fractures at the top of the slope of this station, so the slope is unstable because of the existing joints shown in (Figure 6b).

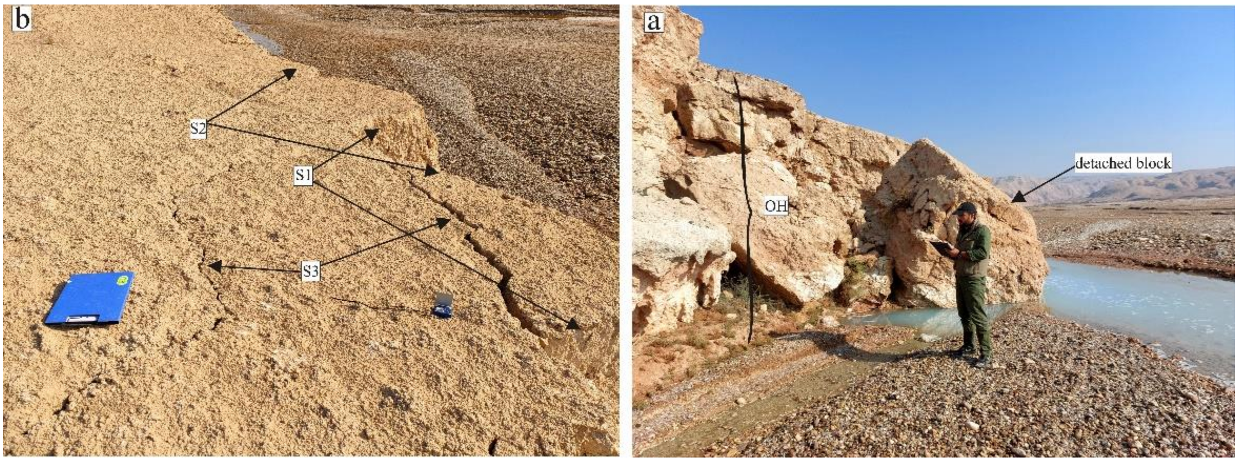

Figure 6: **a)** Side view showing slope and size of the detached block, **b)** view showing the three sets of joints.

4.3. Station No.3:

This station is located at the right bank of Wadi Shorshirin, with latitude (33°24'34.127") and longitude (45°59'15.239") within the upper member of the Fatha Formation. The station consists of a vertical slope which is represented by the sequence of Limestone with (3 m) thickness, light grey color, thickly bedded, moderately weathered, and strong (σc = 81.0MPa). Gypsum with thickness reaches up to (1.25 m), white color, highly weathered, and moderately strong (σc = 33.1MPa). Marl with thickness (0.70 m), green color, highly weathered, very weak. Mudstone with thickness reaches up to (2.0 m), brown color, highly weathered, moderately weak (σc = 6.3Mpa). The attitude of the slope (145/90°) with a height of (16 m) from top to bottom equal long its face, the type of slope is an Oblique Lateral Slope (d = 67°) ; (Al-Saadi, 1981), where the attitude of strata is (033/38°); (Figure 7).

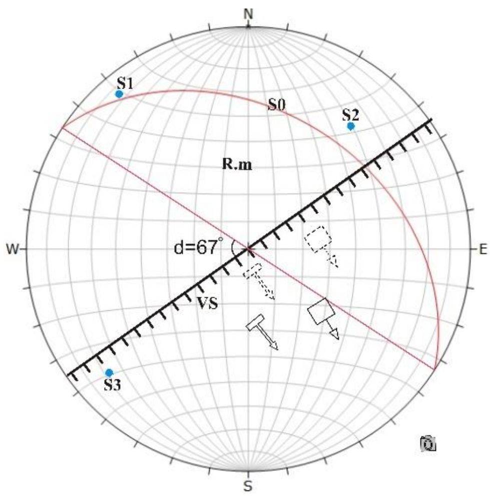

Figure 7: Stereogram of discontinuities, slope, and types of failure for station No. (3).

The layers are cut by three sets of joints (S1, S2, and S3), the attitude of (S1) is (140/80º), joint spacing ranges to (1.5 m), and the aperture (0.1 m). The Attitude of (S2) is (220/61º), joint spacing ranges up to (1.1 m), and aperture (0.15 m). The Attitude of (S3) is (048/73º), joint spacing ranges up to (1.25 m), and aperture (0.18 m); (Figure 8). Secondary Toppling and Rockfall were occurring in this station, the rock detaching because of the existence of joints (S1, S2, and S3). The size of the rock mass that failures reaches up to (0.8 m^3). More toppling is likely to occur in the future so the slope is unstable.

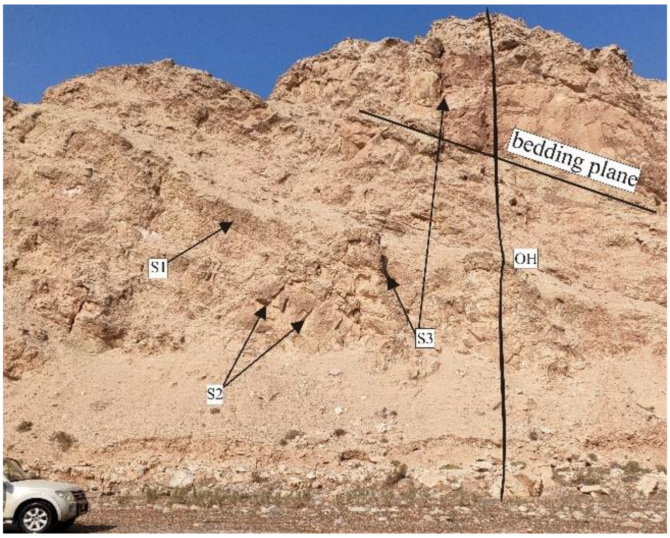

Figure 8: Front view showing the slope S1, S2, and S3.

4.4. Station No.4

This station is located at the right bank of Wadi Shorshirin, with latitude (33º24'46") and longitude (45º59'34") within the upper member of the Fatha Formation. The station consists of a vertical slope which is represented by the sequence of massive Gypsum with thickness reaches up to (2 m), white color, nodular texture, highly weathered, and moderately strong (σc = 33.1Mpa). Marl with thickness (1.25 m), green color, highly weathered, very weak. Mudstone with thickness reaches up to (2.25 m), brown color, moderate to highly weathered, moderately weak (σc = 6.3MPa). The attitude of this vertical slope (155/90º-OH) with height (20 m) from top to bottom and (23 m) long face, the type of slope is an Oblique Lateral Slope (d = 57º) ; (Al-Saadi, 1981), where the attitude of strata is (213/51º) ; (Figure 9).

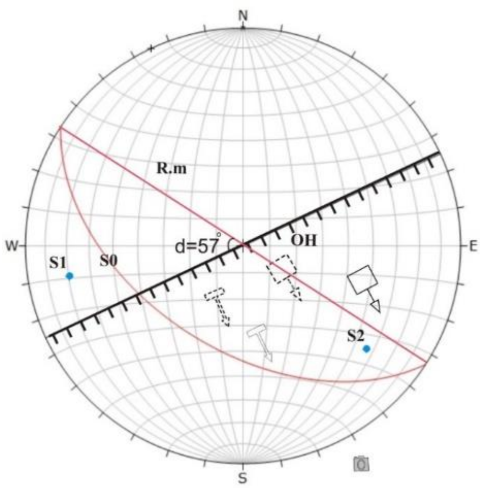

Figure 9: Stereogram of discontinuities, slope, and types of failure for station No. (4).

The layers of gypsum are cut by two sets of joints (S1 and S2), the attitude of (S1) is (080/70°), joint spacing ranges to (0.7 m), and aperture (0.05 m). The altitude of (S2) is (310/63°), joint spacing ranges up to (0.55 m), and aperture (0.07 m) (Figure 10b). Rockfall and Secondary Toppling were occurring in this station, the rock mass of gypsum detaching because of differential weathering of marl mudstone under gypsum layers and the existence of joints (S1 and S2). The size of the gypsum rock mass that failures reaches up to (2.0 m^3) ; (Figure 10a). More falling is likely to occur in the future so the slope is unstable.

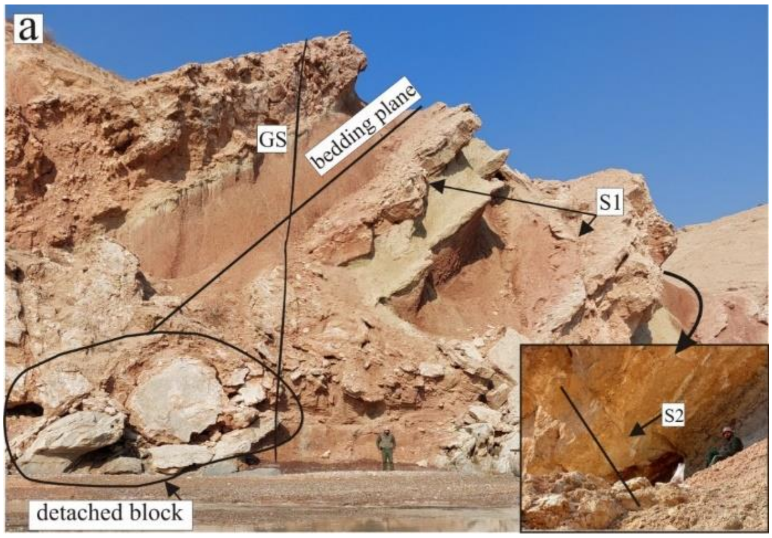

Figure 10: **a)** Front view showing the slope S1, and detached block,
b) Side view showing S2.

4.5. Station No.5

This station is located at the left bank of Wadi Shorshirin, at the axis of a minor anticline with latitude (33°24'52") and longitude (46°00'26") within the Jeribe Formation. The station consists of a slope represented by the sequence of massive dolomitic limestone with thickness reaches up to (2 m), light gray, strong (σc = 94.5Mpa), contains fossils, fine grain texture, contains rusty materials, and moderately weathered. The attitude of the upper part of the slope is (350/90°-OH) with a height (6 m) equal long of its face. The attitude of the lower part of the slope is (350/70°) with a height of (16 m) from top to bottom and of (20 m) long its face, the type of slope is Orthogonal Slope (d = 90°), (Al-Saadi, 1981), and there are two attitudes of strata (080/13°) and (260/23°) represent the NE and SW limbs of this minor anticline (Figure 11). The layers are cut by three sets of joints (S1, S2, and S3), the attitude of (S1) is (179/85°), and joint spacing (0.5 m). The attitude of (S2) is (100/70°), joint spacing ranges up to (1.0 m), aperture (0.1 m) their continuity reaches (0.35 m) on the bedding plane. The attitude of (S3) is (281/73°), the aperture (0.15 m) and their continuity reaches (0.20 m) on the bedding plane (Figure 12). Secondary toppling occurs in this station (toppling and slumping). Joints in (S1) acted as back release surfaces (BRS), while those in (S2 and S2) acted as lateral release surfaces (LRS) during toppling in the two modes of toppling. The rock mass is detaching because of the existence of joints. Dimensions of detached rock mass reach up to (0.2×0.6×0.4m).

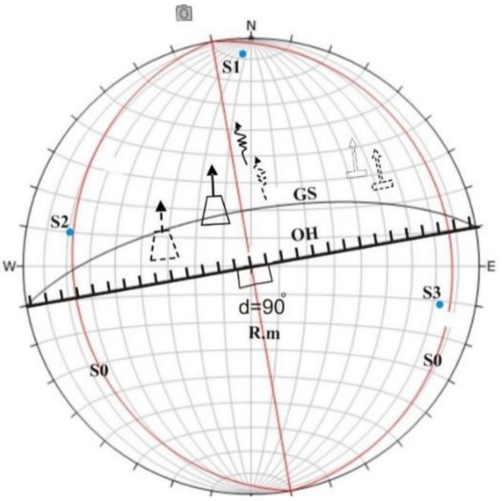

Figure 11: Stereogram of discontinuities, slope and types of failure for station No. (5).

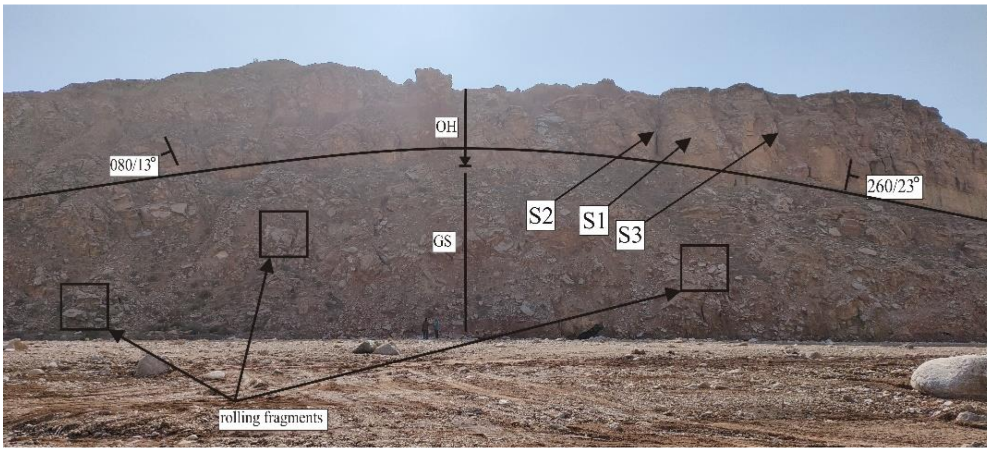

Figure 12: Front view showing slopes 1 and 2, three sets of joints, and detached block.

5. CONCLUSIONS

- Two types of slopes were identified based on the classification of Al-Saadi (1981), which are discordant oblique lateral and orthogonal slopes.
- The main reason for the instability of the slopes is the weathering of the foot of the slope of the studied stations which results from Shorshirin Valley water. In addition, discontinuities contributed to the occurrence of the failures.
- Toppling and Rockfall were found within the study area, in addition to the rolling that occurs later for the separated blocks by failure.
- Occurrence or possibility of rock fall and toppling due to the presence of slopes resulting from the erosion of the mudstone and marl layers under the gypsum layer of stations 1, 2, and 3, and the expansion of the discontinuities as a result of weathering, which made it incoherent.
- The main effect in the occurrence of failures is due to differential weathering and erosion, and this is what makes them structural-complex, while discontinuities determine the type of failures.
- The rocks of the study area were evaluated based on the unconfined compressive strength deduced from the point load test to strong, moderately strong, moderately weak, and weak rocks only based on the geometric description (Hawkins, 1986).

REFERENCES

Adeeb, H. G. M., & Al-Jumaily, I. S. I. (2021). Determination of rock slope stability using stereographic projection between Sulav and Amadiyah resorts: A study from northern Iraq. *Journal of Engineering Research, 18*(1), 36–43.

Al-Bayati, A. Q. (2021). Study of the stability of the rocky slopes of a part of the Bikhair convex fold on both sides of the road linking Dohuk and Zawita, northern Iraq (Master's thesis, Department of Applied Geology, College of Science, University of Tikrit, 80-105).

Al-Mubarak, M. A., & Youkhanna, R. Y. (1976). Report on the regional geological mapping of the Fatha – Mosul area. GEOSURV, Int. Rep. No. 753.

Al-Saadi, S. N. (1981). A method for mapping unstable slopes with reference to the coastline of SW Dyfed, Wales (Unpublished PhD thesis, University of Bristol, p. 252).

Anon. (1972). The preparation of maps and plans in terms of engineering geology. *Quarterly Journal of Engineering Geology, 5*, 293-382.

Anon, Q. (1977). The description of rock masses for engineering purposes. *QJ Engineering Geology, 10*, 355–399.

Bayram, A. F., Mohamed, A. I., & Othman, A. A. (2021). Stability and sustainability assessment for the surface failure of various rock slopes excavated along the Konya-Alanya Road segment, Turkey. *Kuwait Journal of Science, 48*(4), 1-15.

Bromhead, E. (1992). *The stability of slopes* (2nd ed.). CRC Press. https://doi.org/10.4324/9780203975350

Chigira, M. (1992). Long-term gravitational deformation of rocks by mass rock creep. *Engineering Geology, 32*, 157-184.

Fouad, S. F. A. (2015). Tectonic map of Iraq, scale 1:1000 000, 2012. *Iraqi Bulletin of Geology and Mining, 11*(1), 1–7.

Hamza, N. M. (1997). Geomorphological map of Iraq, scale 1:1000 000. GEOSURV, Baghdad, Iraq, 1st ed.

Hamza, & Yacoub. (1983). The Mesopotamian Plain project: The geology of Mandali area, scale 1:25000. GEOSURV, Int. Rep.

Hasan, A. E. (2019). Engineering geological study of selected sites for the southeastern plunge of Bekhair anticline, North Iraq. *The College of Science, University of Tikrit, Tikrit, Iraq*, 71-95.

Hawkins, A. B. (1986). Rock descriptions. *Geological Society, London, Engineering Geology Special Publications, 2*(1), 59–66.

Hoek, E., & Bray, J. D. (1981). *Rock slope engineering* (3rd ed.). Institution of Mining and Metallurgy, London.

Jassim, A. Dh., Hussain, A. I., & Al-Shwaily, A. K. H. (2023). Assessment of landslide susceptibility using the AHP and GIS techniques for the Zurbatiya region, east of Iraq. *Iraqi Geological Journal, 56*, 13-14.

Jassim, S. Z., Karim, S. A., Basi, M. A., Al-Mubarak, M. A., & Munir, J. (1984). Final report on the regional geological survey of Iraq. Vol. 3 "Stratigraphy." GEOSURV, Int. Rep. No. 1447.

Jassim, S. Z., & Goff, C. J. (2006). *Geology of Iraq*. Published by Dolin, Prague and Moravian Museum, Brno, 341.

Mahmoud, A. A., Ali, M. A., Mohammed, A. J., Al-Mikhtar, L. E., Al-Kubaysi, K. N., Hussien, M. S., Al-Obaidy, R. A., Mohammed Ali, S. M., Tawfeeq, G., & Jassim, M. K. (2018). Detailed geological mapping of Iraq, Zurbatiyah region, east Iraq, scale 1:250000.

Qader, R. M., & Syan, S. H. A. (2021). Rock slope stability assessment along Rawanduz main road, Kurdistan Region. *The Iraqi Geological Journal, 79-93*.

Van Bellen, R. C., Van Dunnington, H. V., Wetzel, R., & Morton, D. (1959). *Lexique Stratigraphique International. Asie, Face Loa. Iraq*. Paris.