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ROCK SLOPE STABILITY ASSESSMENT FOR SELECTED SITES AT IMAM MOHAMMED ROAD\ SULAIMANIYAH GOVERNORATE\ NORTHERN IRAQ

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ABSTRACT

A detailed engineering geological study was performed for rock slope stability for several selected sites at Imam Mohammed Road that connects Sulaimaniyah city and Darbandikhan town, the study included four sites in which a comprehensive survey was made for the rock slopes, the rocks forming them, and discontinuities affecting in them. The assessment of rock slope stability of the sites was executed through the stereographic projection, to determine the status of the slopes and discontinuities, field measurements revealed many occurred and probable failure types represented by the rock fall and sliding. The rock slopes were also classified based on three factors; divergence angle (parallel, oblique lateral, and orthogonal), Laterality (right and left emergent), and concordance (concordant and discordant). The rocks forming the slopes are described geometrically based on their color, grain size, texture, discontinuities, weathering, rock strength, lithology, and permeability. On the other hand, the risk of each site was also assessed depending on the Landslide Possibility Index (LPI), which showed that the first site lies within the (moderate hazard) category whereas the others lie within the (High hazard) category. Finally, some treatment strategies were proposed in order to stabilize the slopes and decrease the danger of their collapse on the road.

1. INTRODUCTION

Rock mass movements are classified into many different forms according to their nature, such as; wedge failure, plane failure, circular failure, and toppling (Hoek & Bray, 1981).

Different failure types are mentioned by various authors such as Falls; detachment from steep slopes or cliffs, which then free-falls, bounces, or rolls down the slope (Varnes, 1978), Toppling; when a block of rock pivots or rotates forward around a pivot point below or within the mass (Hutchinson, 1988), Slide; when a rock mass moves down a slope along a well-defined surface, such as a bedding plane or a fault (Cruden, D.M., and Varnes, 1996), Spreads; lateral extension of a coherent mass (Terzaghi, 1950), Flows; fluid-like movement of material, where the internal structure of the moving mass is disrupted (Iverson, 1997).

It is worth mentioning that any outer effects that influence the equilibrium state of the slope lead to distribution in the stability of rock mass forming it. This eventually leads to failure in

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the rock masses in any form, which, in turn, causes serious problems that affect general life such as the destruction of roads (near the slopes), destruction and damage of buildings and establishments, and endangering people's lives (Azeez, 2019).

The slope stability is thus an important branch that should be taken into consideration when man-made projects are planned, such as those for mining prospecting, a road cutting, a large establishment building … etc. (Blyth, F.G.H and De Freitas, 1984).

This study aims to evaluate the stability of rock slopes in the study area by choosing four sites in which rock failure occurred or is probable to occur in the future, the slopes are classified according to (Al-Saadi, 1981), and analyzed by stereographic projection. Rock masses were described in engineering geological terms (Anon, 1972), and the degree of danger of each site was assessed based on (Bejerman, 1998).

2. LOCATION OF THE STUDY AREA

The studied area lies at Imam Mohammed road (for about 1.20 Km length) covering area of about (2.46 Km^2), between latitudes (35°08'24" – 35°08'46") and longitudes (45°40'43" – 45°41'04"), and is located at about (2.5 Km) to the North of Darbandikhan town and about (2.8 Km) to the west of Darbandikhan lake (Figure 1).

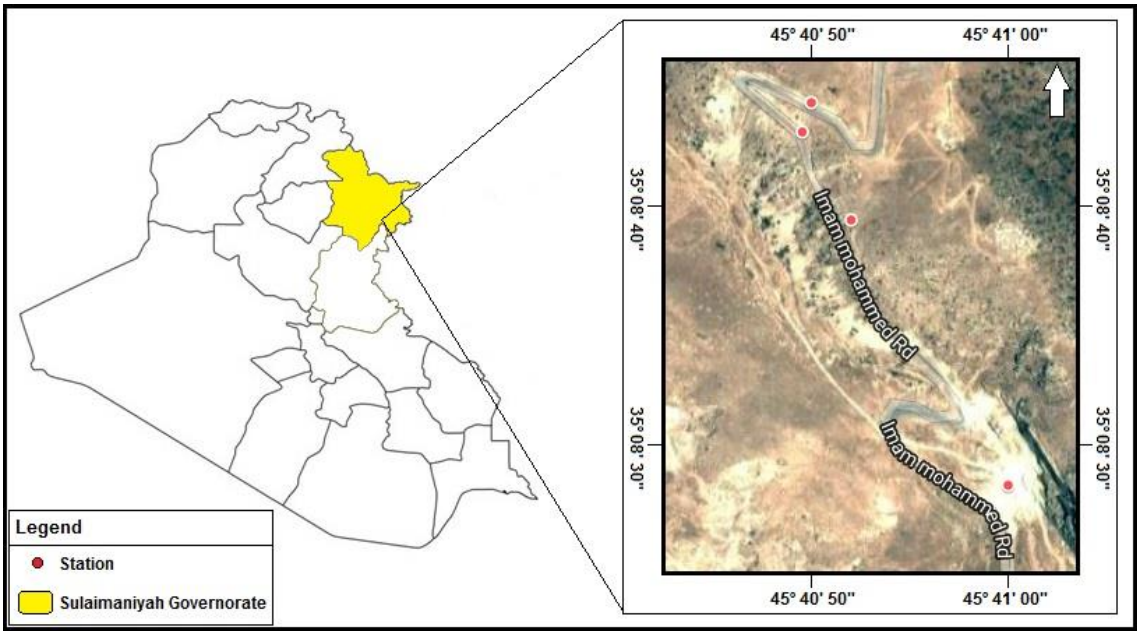


Figure 1: Location map of the study area.

3. GEOLOGY OF THE STUDY AREA

The geology of the study area includes stratigraphy, tectonic, structure, and geomorphology.

Stratigraphically, all the studied sites consist of the limestone rocks of Pila Spi formation (Middle – Late Eocene), in which the upper part comprises well-bedded, crystalline, limestone beds with Chert nodules and chalky marl bands towards the top, whereas well-bedded, porous, hard, limestone beds found in the lower part (Bellen et al., 1959) and (Buday, 1980).

Tectonically, the studied area is located within the High-Folded Zones near the boundary between the Low-Folded and High-Folded zones (Jassim & Goff, 2006).

Structurally, the area represents the northeastern part of the elongate double plunging, high ridge Baranan anticline is characterized by inclined layers with an average dip amount between (46° – 78°), with many sets of joints (orthogonal and conjugate) of various directions.

Geomorphology in the area is represented by many features such as breached anticlines (which resemble erodible soft sedimentary rocks of Kolosh and Gercus formations that eroded, forming valleys surrounded by hard limestone of the Pila Spi formation). Homoclinal (Strike) ridges also occurred in the study area, due to the folding and downcutting of rocks of less resistance (Salar, 2017).

The climate of the study area is characterized by heavy rainfall during the winter, especially in January, February, and March months, while it is very rare in summer, especially in July and August. The lowest average monthly temperature of the area was (4.8 ºC) recorded in January, and the highest temperature was (32.6 ºC) as the monthly average recorded during July (Iraqi General Air Conditioning Authority, 1989).

4. METHODOLOGY AND MATERIALS

The methodology of this work is represented by three stages (1) data collecting (to gather any maps, reports, research, and theses available that have relation to this work). (2) Fieldwork (to determine site location using Garmin 72 GPS, measuring dips and strikes of slopes and discontinuities using Silva compass, rock sampling, and failure type determination). (3) Office work (to analyze field data using stereonet software, point load test for rock samples).

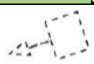
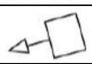
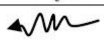
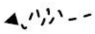
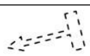
5. METHODOLOGY AND MATERIALS

In this study, four sites were selected in order to assess the discontinuities affecting the slope stability in the area. The strength of the rocks was assessed in the field by using a hammer test and sites 1, 2, and 3 were strong (rocks needed one strong hit by the hammer to be broken) except the rocks in site 4 were very strong (tested by Point Load Test and the σ_c was 168 MPa).

The inclination of slopes and the dip of beds and joints are defined by two numbers; representing the direction (to the left) and the amount (to the right). Field observation showed that the slopes in the study area have many failures, especially the rock fall, and toppling. All failures are classified according to the classifications of Hoek & Bray (1981).

The rock masses are also described by engineering terms, and some symbols are used to represent the data on the stereogram; these symbols are based on Al-Saadi (1981).

Table 1: used symbols to describe rock failure types.

Failure Type	Symbol
	Possible Rockfall
	Present Rockfall
	Possible Plane Slide
	Present Rolling
	Possible Rolling
	Possible Toppling

6. SLOPE STABILITY ASSESSMENT IN THE SELECTED SITES

6.1. Site 1

This site is located at latitude (35°08'44" N) and longitude (45°40'50" E) as in Figure 2. The elevation (930.5 m) above sea level, within PilaSpi Fn., the slope at this station is about (22 m) high, its length with its trend is (72.7 m), and its inclination is (234/54°), as in Figure 2, the average bedding plane attitude is (230/54°) so that, the slope is a parallel (divergence angle = 4°), right lateral, and concordant.

The exposed rocks are composed of grey to yellowish grey, fine to very fine-grained, medium to thickly bedded (20 cm – 70 cm), moderately widely to very widely spaced joints (30 cm – 4 m), moderately to highly weathered, moderately to highly permeable, and strong (tested by hammer in the field and the rock sample can be brake by one hit of the hammer), composed of limestone of PilaSpi Fn.

The rocks are cut with (S_1, S_2, and S_3) joints, which are (bc, ac, and hkl), the first one has an average dip (044/29°), spacing range of joints in the first one is (50 cm – 3 m), with persistence range (1 m – 5 m), the second set of joints has an average dip (141/81°), spacing range (30 cm – 4 m), and persistence range (0.5 cm – 3 m), the latter one has an average dip (119/38°), spacing between joints ranging between (30 cm – 1.5 m), with a persistence range (3 cm – 6 cm).

Rolling occurred in the station due to the slope amount (54°) and the behavior of (bc) set as back release surfaces, and (ac) set as lateral release surfaces, rolling is also expected to happen for the same reason, and plane slide is probable too due to fact that the slope is daylight slope.

6.2. Site 2

This site is located at latitude (35°08'41" N) and longitude (45°40'51" E) as in Figure 3, at an elevation (919.3 m) above sea level, about (40 m) to the south of the previous site, within PilaSpi Fn., the slope at this station is about (25 m) high, its length with its trend is (63.5 m), and its inclination is (252/68°) as in Figure 3, The average bedding plane attitude is (084/46°), so that, the slope is a parallel (divergence angle = 12°), left lateral, and discordant.

The exposed rocks are composed of light grey to brown, very fine-grained, thinly to thickly bedded (10 cm – 90 cm), very closely to moderately widely spaced joints (2 cm – 50 m), slightly to moderately weathered, moderately to highly permeable, and strong (tested by a hammer in the field and the rock sample can be brake by one hit of the hammer), represented by limestone of PilaSpi Fn.

The rocks at this site are cut with two sets of joints; (hko > b) set with an average dip (284/53°), the spacing range (2 cm – 10 cm), and persistence range (10 cm – 90 cm), the second set is (hkl) which has an average dip (187/50°), spacing is ranging between (5 cm – 50 cm), with persistence range (10 cm – 40 cm).

The joints in the (hko > b) set act as basal surfaces, whereas (hkl) set joints represent back release surfaces, this caused rock failure in the form of rock fall in the site and led to expected rock fall and toppling (as the bedding dip opposite to the slope) to occur in the future.

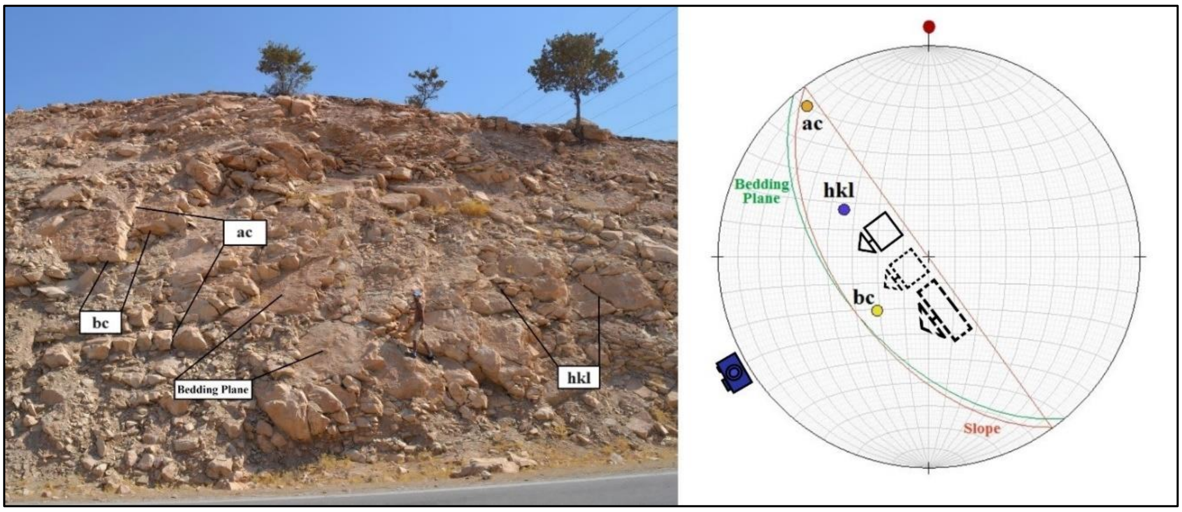


Figure 2: **a)** joints and bedding planes of site 1; **b)** Stereogram shows the relationship between discontinuities, slope, and types of occurred and probable failures for site 1.

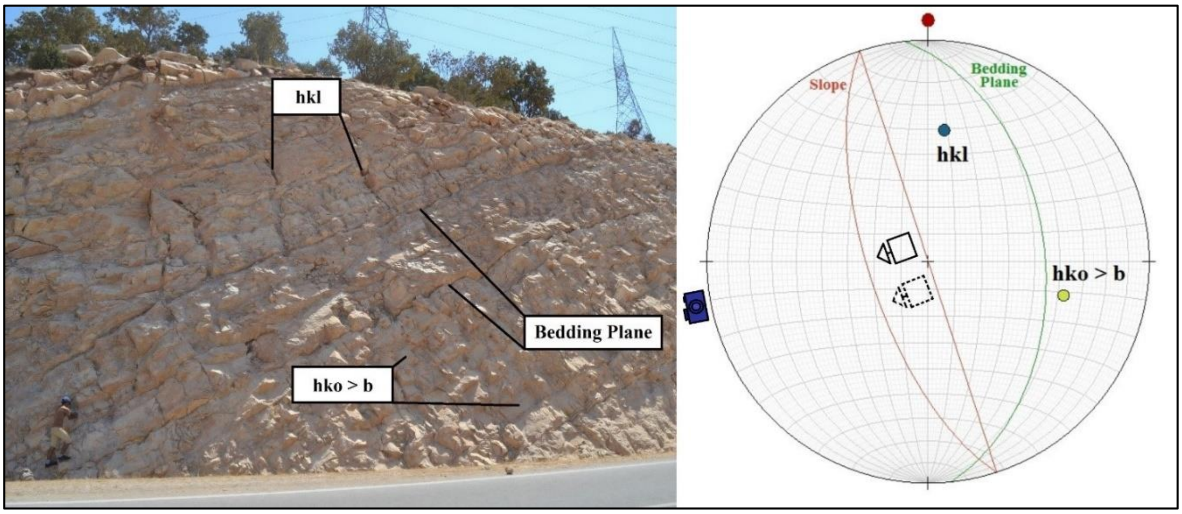


Figure 3: **a)** joints and bedding planes of site 2; **b)** Stereogram shows the relationship between discontinuities, slope, and types of occurred and probable failures for site 2.

6.3. Site 3

This site is located at latitude (35^{o}08'39" N) and longitude (45^{o}40'52" E) as in Figure 4, at an elevation (909 m) above sea level, about (130 m) to the southeast of the previous site, within PilaSpi Fn., the slope height at this site is about (22.5 m), its length with its trend is (31.5 m), and its inclination is (260/72^o), as in Figure 4, the average bedding plane attitude is (086/58^o), so that, the slope is a parallel (divergence angle = 6^o), left lateral, and discordant.

The exposed rocks are composed of light grey to brown, very fine-grained, thinly to medium bedded (15 cm – 1 m), very closely to very widely spaced joints (5 cm – 2.5 m), moderately to highly weathered, slightly to highly permeable, and strong (tested by a hammer in the field and the rock sample can be brake by one hit of the hammer), composed of limestone of PilaSpi Fn.

The rocks are cut with (S_1, S_2, and S_3) joints, these are (hkl, okl > c, and hko > b), the joints in the (hkl) set have an average dip (317/81°), spacing range (90 cm – 2.5 m), and persistence range (1 m – 6 m), whereas the joints in (okl > c) set have an average dip (142/86°), range of spacing (5 cm – 2.5 m), and persistence range (10 cm – 10 m), the average dip in the (hko > b) set is (241/44°), the spacing range (5 cm – 30 cm) and persistence range (5 cm – 32 cm).

As the joints in (hkl) set and (okl > c) set act as lateral release surfaces, (hko > b) set joints represent basal surfaces, and the bedding planes serve as upper release surfaces, this triggered rock fall in the station, and led to the probability that rock fall will also occur in the future.

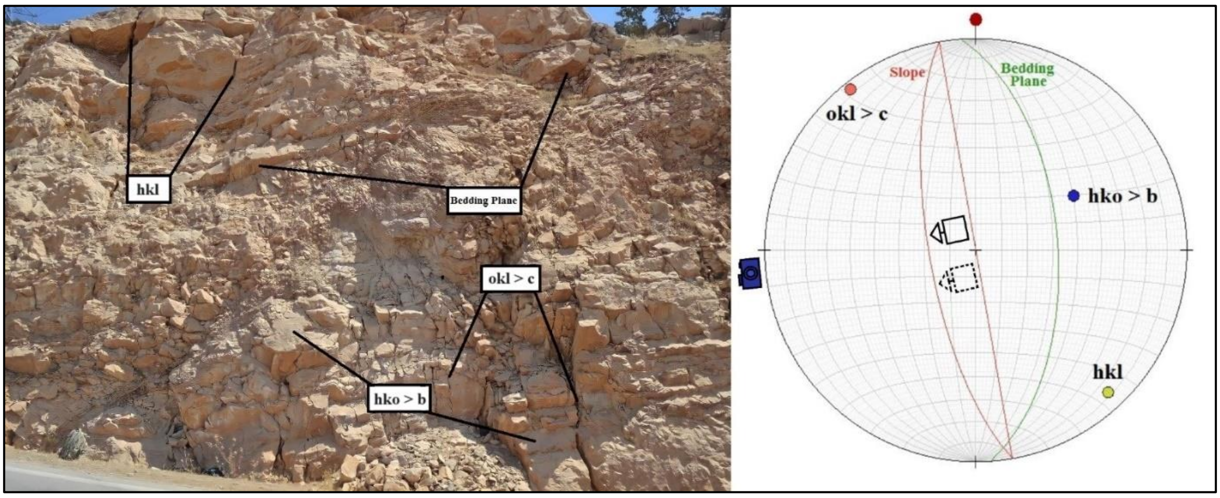


Figure 4: **a)** joints and bedding planes of site 3; **b)** Stereogram shows the relationship between discontinuities, slope, and types of occurred and probable failures for site 3.

6.4. Site 4

This site is located at latitude (35°08'28" N) and longitude (45°41'00" E) as in Figure 5, at an elevation (895.4 m) above sea level, about (395 m) to the southeast of the previous site, within PilaSpi Fn., the slope height at this station is about (80 m), its length with its trend is about (325 m), and its inclination is (236/82°), as in Figure 5, The average bedding plane attitude is (224/78°), so that, the slope is a parallel (divergence angle = 12°), right lateral, and concordant.

The exposed rocks are composed of light to dark grey and yellow, fine to very fine-grained, thinly to thickly bedded (10 cm – 1.5 m), very closely to very widely spaced joints (5 cm – 20 m), moderately to highly weathered, slightly to highly permeable, and very strong (σc = 168 MPa), represented by limestone of PilaSpi Fn.

The rocks are cut with (S_1, S_2, and S_3) joints which are (hko > a, ac, and hkl), the (hko > a) set has an average dip (320/71°), spacing range (20 cm – 1.4 m), and persistence range (3 cm – 7 cm), the (ac) set has an average dip (316/89°), has a range of spacing (5 cm – 20 m), and range of persistence (5 m – 30 m), the average dip of (hkl) set is (149/32°), with spacing range (30 cm – 10 m), and persistence range (1 m – 30 m).

The joints in the (ac) set act as lateral release surface that triggered rock fall in this site, this set in addition to the (hko > a) set which behaves at lateral release surface for sliding, and the (hkl) set which serves as basal surfaces make the rock fall as probable failure types in the future.

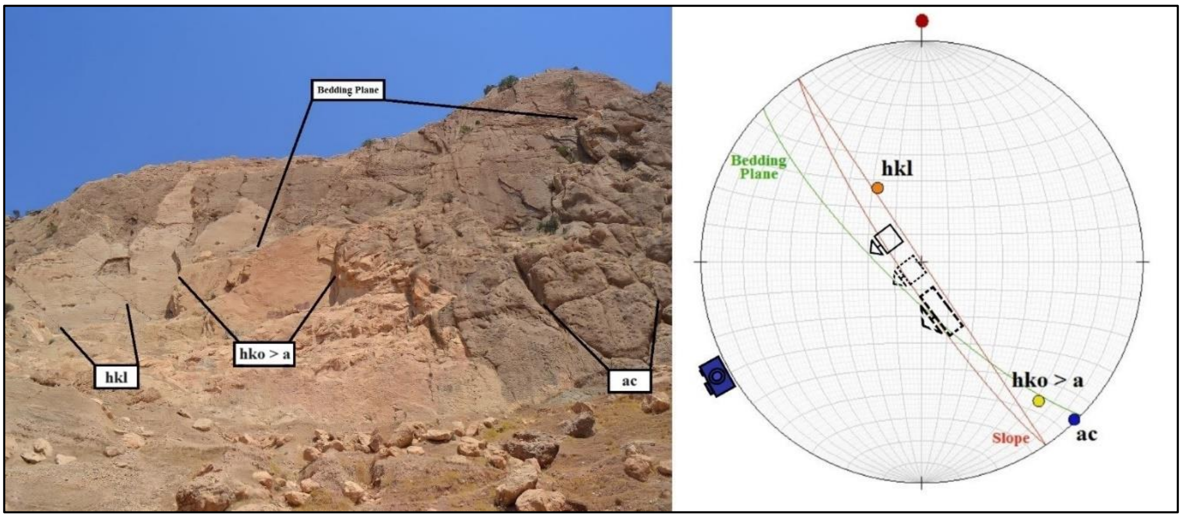


Figure 5: **a)** joints and bedding planes of site 4; **b)** Stereogram shows the relationship between discontinuities, slope, and types of occurred and probable failures for site 4.

7. Hazard Zonation according to (LPI)

This classification is used to evaluate the probability and to indicate the need for a detailed study, regarding the stability of certain slopes with respect to others that present fewer tendencies to the slide (Bejerman, 1998).

The zonation of hazards depends on the values of the Landslide Possibility Index (LPI), which in turn relies on ten variables, shown in Table (2), and then the total (LPI) values indicate the hazard category of each site as in Table (3) (Bejerman, 1998).

Table 2: LPI values for the four sites in the study area according to (Bejerman, 1998).

St. No.	Slope Height	Slope Angle	Grade of Fracture	Grade of Weathering	Gradient of Discontinuities	Spacing of Discontinuities	Orientation of Discontinuities	Vegetation Cover	Water Infiltration	Previous Landslides	Total (LPI)
	1	2	3	4	5	6	7	8	9	10	
1	3	3	2	3	3	1	4	0	0	1	20
2	3	4	2	2	3	3	4	0	0	1	22
3	3	4	2	3	4	1	4	0	0	1	22
4	5	4	2	3	4	0	4	0	0	2	24

Table 3: Hazard categories for the measured sites, according to the Hazard Category chart (Bejerman, 1998).

Total no. of sites	Sites numbers	Hazard category
1	1	Moderate hazard (LPI = 11 – 20)
3	2, 3, 4	High hazard (LPI = 21 – 25)

8. CONCLUSIONS AND RECOMMENDATIONS

- The discontinuities (joints and bedding planes) in the rock masses play various roles during different failure types according to their nature; back release surfaces (BRS), lateral release surfaces (LRS), or basal surfaces (BS).
- Rockfall is the main rock failure that occurred in all sites, except site 1 which shows the presence of rolling, whereas the probable failures in the area are rock fall (in sites 2, 3, and 4), plane sliding (in sites 1 and 4), rolling in site 1 and toppling in site 2.
- According to (LPI) values and Hazard zonation classification, we can see that site 1 represents a moderate hazard slope (LPI = 20), whereas the rest sites are of high hazards (LPI values of sites 2, 3, and 4 = 22, 22 and 24 respectively).
- Removal of the unstable blocks, which are liable to fail in the critical cases in all sites.
- Construction of retaining walls as well as digging protection trenches can be very useful, especially in sites 1, 2, and 3.
- Using gabions to encapsulate slope faces, especially in sites in which rock failure happened continuously such as sites 2 and 3.
- Sealing the slope face with covenant materials like concrete such as in site 4
- Use warning signs along hazardous locations that are prone to collapse to attract the attention of pedestrians to the gravity of the place.

REFERENCES

Al-Saadi, S. N. (1981). *A Method for Mapping Unstable Slopes with Reference to the Coast Line of SW Dyfed, Wales, Unpub PhD.* PhD. Thesis, University of Bristol.

Anon. (1972). The Preparation of Maps and Plans in Terms of Engineering Geology. *Quarterly Journal of Engineering Geology*, *5*, 293–381.

Azeez, O. G. (2019). *The Role of Structural Factors in Rock Slope Stability for Selected Sites of Southwestern Limb of Baranan Anticline \ Sulaimaniya Governorate \ North Iraq*. University of Baghdad.

Bejerman, N. J. (1998). Evaluation of landslide susceptibility along State Road 5, Cordoba, Argentina. Proceedings of the 8th Int. Congress of IAEG, Balkema, Rotterdam, Vol.2. *Engineering Geology: A Global View from the Pacific Rim*, 1175–1178.

Bellen, R. C. van, Dunnington, H. V, Wetzel, R., & Morton, D. M. (1959). Lexique stratigraphique international Asia, fascicule, 10a, Iraq. *Center National de La Recherché Scientifique, Paris*, *33*, 333.

Blyth, F.G.H and De Freitas, M. . (1984). *A Geology for Engineers* (E. A. London (ed.); 7th ed.).

Buday, R. T. (1980). *The Regional Geology of Iraq: Stratigraphy and Paleogeography* (S. Z. Kassab, I.I.M and Jassim (ed.); 1st ed.). D.G Geo. Surv. Min. Invest. (SOM), Baghdad.

Cruden, D.M., and Varnes, D. J. (1996). Landslide Types and Processes. In: Turner, A.K., and Schuster, R.L. (eds.), Landslides: Investigation and Mitigation. In *Transportation Research Board: Vol. Special Re*.

Hoek, E., & Bray, J. W. (1981). Rock Slope Engineering Inst. of Mining and Metallurgy. *London*, 358.

Hutchinson, J. H. (1988). Morphological and geotechnical parameters of landslides in relation to geology and hydrogeology. *Proceedings of the Fifth International Symposium on Landslides*, 3–35.

Iraqi General Air Conditioning Authority. (1989). *Climatological Atlas of Iraq*.

Iverson, R. M. (1997). The physics of debris flows. *Reviews of Geophysics*, *35*(3), 245–296.

Jassim, S. Z., & Goff, J. C. (2006). Geology of Iraq. In *Dolin, Prague and Moravian Museum, Brno* (1st editio).

Salar, S. G. (2017). Urban Geomorphology of Darbandikhan District Using GIS & RS Iraqi Kurdistan Region. *Journal of Garmian University*, *4*(Special Issue; ICBS Conference), 301–319.

Terzaghi, K. (1950). Mechanism of Landslides. In S. Paige (Ed.), *Application of Geology to Engineering Practice*. Geological Society of America. https://doi.org/10.1130/Berkey.1950.83

Varnes, D. J. (1978). Landslides-Analysis and Control. *National Academy of Sciences, Transportation Board Special Report*, 176, 11–33.

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