Volume 12| September 2022 ISSN: 2795-7365

Assessment of Rock slope Stability of the Northwestern Plunging Area of Hamrin Anticline in the Sallahaddin Governorate / Northern Iraq

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ABSTRACT

In Iraq, the majority of rock slope instability issues along highways result in road deterioration or collapse. One of these is located on the northwestern plunge of the Hamrin anticline fold. For the study of this problem, stations along the road within the Fatha Formation are selected. The study included an investigation of the slope's stability and the occurrence and potential failures. The stability of the slopes was evaluated using the SMRTool-v205 software, which is used to classify the condition and degree of slope stability. The stability analysis results demonstrate the possibility of wedge sliding occurrence in the stations (2,3, and 6), thus describing them as unstable slopes and needing important intervention. Whereas the dominant failure modes in stations (1,4,5,7, and 8 in the slope with a dip 90°) are direct toppling and wedge sliding. Therefore, they have been described as normal and partially stable slopes and need systematic monitoring. As well, direct toppling is the dominant failure mode in the stations (2, 4, and 8), which are classified as good and stable slopes but need to be monitored occasionally.

Keywords: Slope stability, RMR, SMR, Low folded zone, Hamrin fold

1. Introduction

Landslides are one of the most dangerous natural disasters to which people living in mountainous areas are susceptible, and they typically happen whenever the necessary conditions are present,[2] ;[1] . The failure could happen gradually, suddenly, over a long period of time, or even at a long distance, and the occurrence of failures may be caused by additional factors, either natural, such as an increase in the forces that cause failures, moisture, the freezing and thawing of snow, the force of Earth's gravity, as well as rock structures, such as discontinuities, that assist in failures. Slope instability often has three main causes, particularly in mountainous areas, and they are as follows: I) Causes related to geology and the environment, II) Causes related to morphology and dynamics, and III) Causes related to human activities, such as slope excavation, blasting, land use, etc.,[3] However, because of the influence, they have on human life, evaluating the stability of slopes in their current state or when exploiting them, as well as the process of interpreting the occurrence of failure, is one important topic, [4]. However, the purpose of this study is to look at the issues with unstable Rocky slopes near main roads in the study area. Agricultural centers and key residential areas can be connected, improving the connectivity to the residential area. The study area is located within the northwestern Hamrin anticline in northeastern Iraq and is about 50 km northeast of the city of Sallahaddin, and it is located between longitudes (43° 33' 36", 43° 34' 12") and latitudes (35° 02' 48", 35° 03' 20"), (Figure.1).

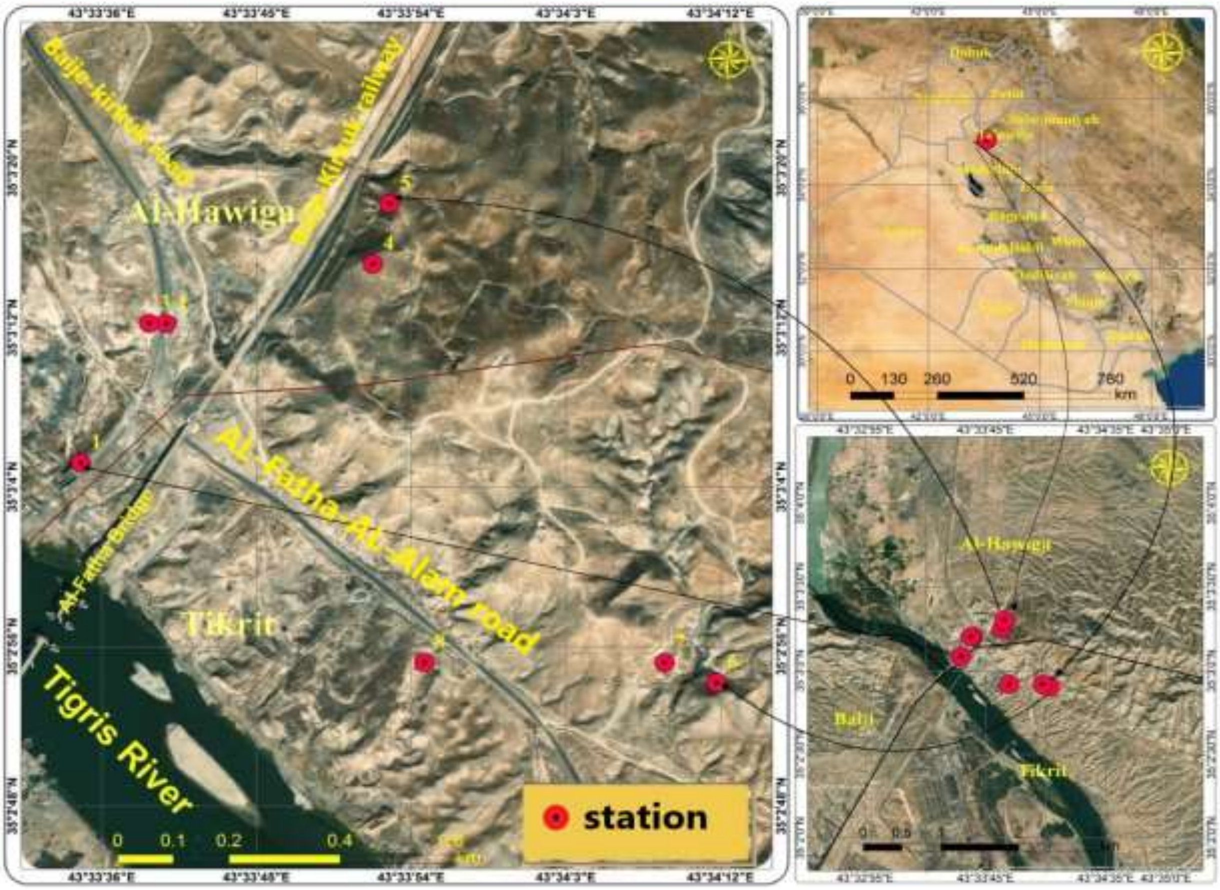


Figure (1) Location map of the study area

2. Materials and Methods

2.1 Field Work and Sample Collection

For the current study, a three-day, in-detailed scan-line has been carried out (18-21 October 2021). The study found that eight stations were selected within the study area. Their locations were determined using a GPS device, and a thorough field survey was carried out over each slope, including (the attitude of the slope and beds,the width and height of the slope, discontinuities and their conditions, as well as the lithological description. determining the occurrence and possible failure, according to [5], and also taking photographs and collecting a representative sample).

2.2 Laboratory Testing and Office Work

Some geotechnical tests were carried out as part of the laboratory work. The Unconfined Compressive Strength Test was carried out in accordance with [6], Table 1, for the determination of internal friction angle in the field according to the tilt method of [7] which consider important factor to study the condition of failures, [8].Office work included data and test results representation, Table 2. such as using kinematic analysis to assess rock slope stability with the software Dips v6.008, classifying rock masses with Rock Mass Rating Basic (RMRb), and classifying Slope Mass Rating (SMR) with the software SMRTool [9].

Table 1. The results of the Unconfined Compressive Strength Test

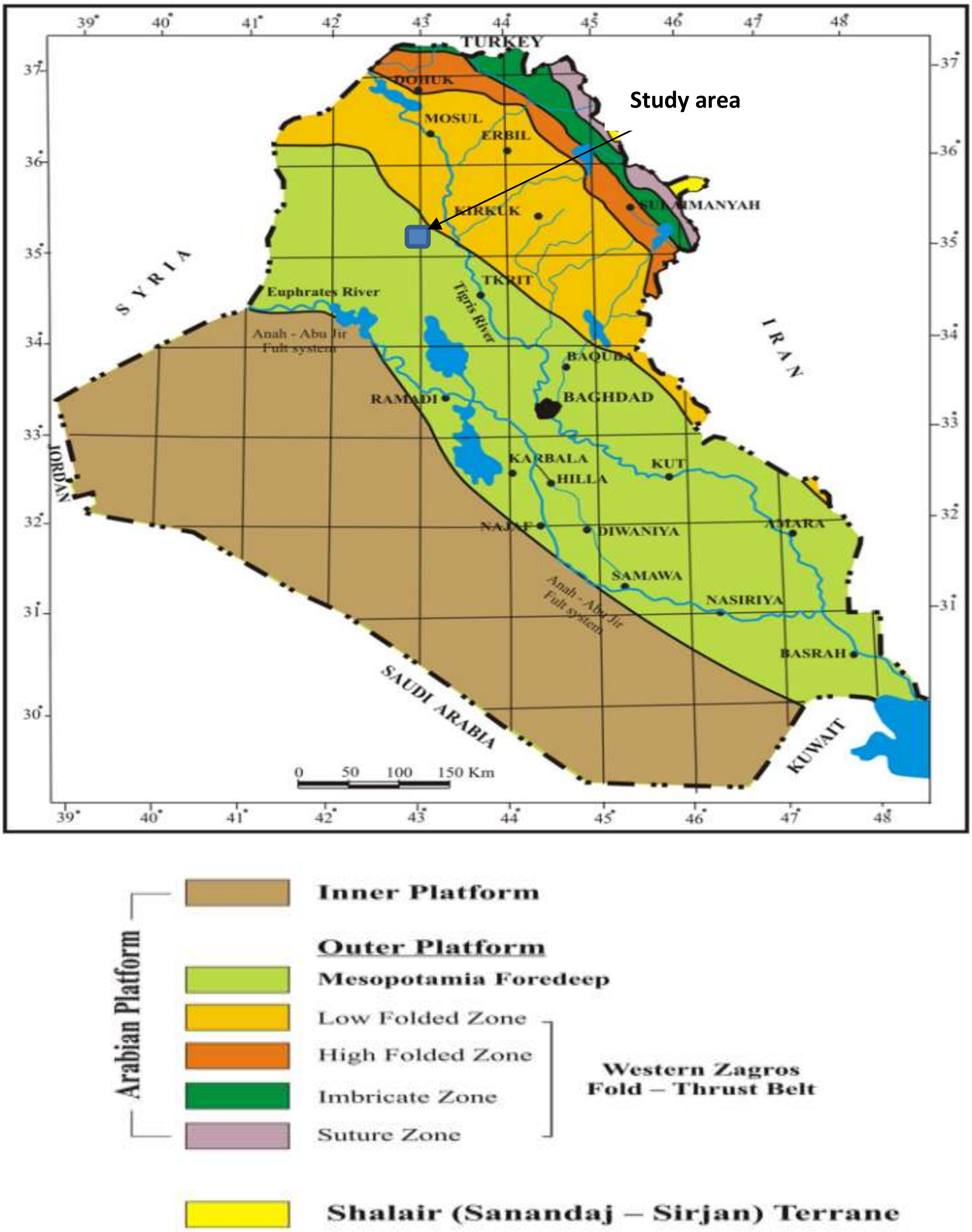
St. no.	Formation	Sample Length L (cm)	Sample Diameter D (cm)	D/L	Force at Failure F (KN)	Unconfined Compressive Strength σc (MPa)	Corrected Compressive Strength Cc (MPa)	Classify by (Anon, 1977)
(1)	Fatha Fn.	5.0	5.5	1.060	34.400	14.480	14.294	moderately strong
(2)		4.0	5.5	1.325	29.000	12.210	11.400	moderately weak
(3)		4.6	5.5	1.152	32.700	13.770	13.330	moderately strong
(4)		4.3	5.5	1.232	25.100	10.570	10.057	moderately weak
(5)		4.1	5.5	1.292	23.100	9.720	9.135	moderately weak
(6)		4.0	5.5	1.325	18.300	7.700	7.189	moderately weak
(7)		8.2	5.5	0.646	32.000	13.470	13.578	moderately strong
(8)		3.9	5.5	1.358	58.000	24.420	22.678	moderately strong

Table 2. The attitude of slopes, beds and Joints

St. no.	Formation	Slope dip direction/ dip angle	Bed dip direction/ dip angle	Set1 dip direction/ dip angle	Set2 dip direction/ dip angle
(1)	Fatha Fn.	240/90	250/05	212/80	264/89
(2)		222/90	017/10	284/88	185/78
(3)		064/90	240/07	014/80	104/83
(4)		300/90	040/10	330/90	210/68
(5)		261/64	030/10	185/82	135/65
(6)		290/90	220/12	218/85	330/75
(7)		265/90	215/12	315/85	130/62
(8)		230/90	040/12	300/90	012/75

3. **Geological Setting**

Geologically, in addition to the Fatha Formations, Quaternary deposits are exposed within the study area. The Fatha Formation consists of thick layers of yellowish-gray limestone, gypsum, marly limestone, marl, and the Quaternary deposits, which consist of a mix of coarse-grained soils gravel, and sand along with fine-grained soils clay and silt[10] ;[11] . From a tectonic point of view, the study area is part of the low-folded zone at its northeastern borders (Fig. 2), which was formed by Alpine movements[12].



(Fig. 2). Tectonic map of the study area (Fouad,2012)

4. Results and Discussion

At all stations, the stability of rocky slopes was assessed and evaluated. The SMR classification system assigned by [13]and the continuous slope mass classification by [14] are adopted using the SMRTool-v205 software of [15] which includes discrete – SMR (D – SMR), Table 3., and continuous SMR (C – SMR), Table 4. The SMR for each station was calculated using the RMRb, three adjustment factors, and various slope excavation methods. The SMRTool-v205 program calculated three of the adjustment factors (F1, F2, and F3) based on the relative orientation of the joints with respect to the slope, joint dip angle, and the difference between slope inclination and the joint. For the fourth F4, it was zero (0) at every station when the road was being paved using mechanical means for excavation.

The SMRTool-v205 software showed that the discrete - SMR and continuous – SMR values in the worst case (the lowest value of the SMR) for wedge sliding in stations (3 and 6) range from (0) to (16), implies that the rock mass classified as V Category, and can be described a bad slope and completely unstable. for wedge sliding in stations (2) range from (30) to (38), implies that the rock mass classified as IV Category, and can be described a bad slope and unstable. The wedge sliding has an SMR value range from (46) to (59) in stations (1, 4, 5, and 8), meaning that the rock masses are within III Class, and can be described as a normal and partially stable slope. As well as, the direct toppling has SMR values ranging from (61) to (72) in the station (2, 4, and 8) meaning that the rock masses are within the second category (II), so it can be described as a good slope and are in a stable condition.

The study showed that the vertical slopes and the slopes formed due to the cracking of the road greatly affected the stability of the slope and it is possible to occur more failures in the unstable parts in the future, so some slopes need important corrective as in stations (2,3,6), and some of them to systematic monitoring as in the stations (1,4,5,8) and others that need to be monitored occasional for direct toppling, as in the stations (2,4,8)

Table 3. The results of discrete – SMR system using SMRTool-v205

station no.	The attitude of the slopes	RMRb	failure type	failure direction	F1	F2	F3	F4	F1.F2.F3*	SMR value	SMR class / Stability
1	240/90	57	a) WS	a)177	a) 0.15	a) 1	a) -60	a) 0	a)-9	a) 48	a)III/ Pa.Sta.
2	222/90	72	a) WS b)DT	a)202 b)194	a) 0.7 b) 0.4	a) 1 b) 1	a) -60 b) 0	a) 0 b) 0	a)-42 b)0	a) 30 b) 72	a)IV/ Unsta. b)II/ Sta.
3	064/90	57	a) WS	a)227	a) 0.7	a) 1	a) -60	a) 0	a)-42	a) 15	a)V/ CUnsta
4	300/90	64	a) WS b)DT	a)241 b)301	a) 0.15 b) 1	a) 1 b) 1	a) -60 b) 0	a) 0 b) 0	a)-9 b)0	a) 55 b) 64	a)III/ Pa.Sta. b)II/ Sta.

5	261/64	67	a) WS	a)202	a) 0.15	a) 0.85	a) -60	a) 0	a)-7.65	a) 59	a)III/Pa.Sta.
6	290/90	59	a) WS	a)293	a) 1	a) 1	a) -60	a) 0	a)-60	a) 0	a)V/CUnsta
7	265/90	64	—	—	—	—	—	—	—	—	—
8	230/90	62	b)DT b)DT	b)209 b)210	b) 0.4 b) 0.4	b) 1 b) 1	b) -25 b) 0	b) 0 b) 0	b)-10 b)0	b) 52 b) 62	b) III/Pa.Sta. b)II/Sta.

Where: WS is Wedge sliding, DT is Direct toppling, F1, F2, F3 &F4 are SMR adjustment factors, Sta: Stable, Pa.sta: Partially stable, Unsta: Unstable, CUnsta: completely unstable. Letters: a, b are belonging to wedge sliding and direct toppling respectively,[16] ; [17].

Table 4. The results of continuous – SMR system using SMRTool-v205

station no.	The attitude of the slopes	RMRb	failure type	failure direction	F1	F2	F3	F4	F1.F2.F3*	SMR value	SMR class / Stability
1	240/90	57	a) WS	a)177	a) 0.17641	a)0.9887	a)-58.4002	a) 0	a)-10.1857	a) 46	a)III/Pa.Sta.
2	222/90	72	a) WS b)DT	a)202 b)194	a) 0.57181 b) 0.34829	a)0.9882 b)1	a)-58.4874 b)-0.55136	a) 0 b) 0	a)-33.0491 b)-0.19204	a) 38 b) 71	a)IV/Unsta. b)II/Sta.
3	064/90	57	a) WS	a)227	a) 0.70289	a)0.98854	a)-58.4291	a) 0	a)-40.5986	a) 16	a)V/CUnsta
4	300/90	64	a) WS b)DT	a)241 b)301	a) 0.17855	a)0.97589 b)1	a)-59.2368	a) 0 b) 0	a)-10.3218	a) 53 b) 63	a)III/Pa.Sta. b)II/Sta.

					b) 0.9912		b)0.43135		b)-0.42756		
5	261/64	67	a) WS	a)202	a) 0.18001	a)0.87702	a)-59.199	a) 0	a)-9.3457	a) 57	a)III/Pa.Sta.
6	290/90	59	a) WS	a)293	a) 0.96793	a)0.98317	a)-58.9725	a)0	a)-56.1206	a) 2	a)V/CUnsta
7	265/90	64	—	—	—	—	—	—	—	—	—
8	230/90	62	b)DT b)DT	b)209 b)210	b) 0.5398 b) 0.5398	b)1 b)1	b)-25.6723 b)-0.59263	b)0 b)0	b)-13.858 b)-.3199	b) 48 b) 61	b) III/Pa.Sta. b)II/Sta.

5. Conclusions

By the results of the discrete – SMR and continuous – SMR values, it was found:

1-Stations (2) and (4), for example, are classified as stable by the discrete - SMR and continuous - SMR and fall within the second category (II) for direct toppling, whereas station (2) is classified as unstable by the discrete - SMR and continuous - SMR and falls within the fourth category (IV) for wedge sliding, Stations (4) are classified as a partially stable slope and fall within the third category (III) for wedge sliding.

2-Direct toppling in a station (8) is classified as partially stable and falls within the third category (III) or stable and falls into the second category (II) according to discrete-SMR and continuous-SMR.

3-According to the SMRTool-v205 software, for each of the discrete – SMR and continuous – SMR values, the most unstable rocky slope within the study area is the slope of Station No. (6), where the values of [D-SMR=0, C-SMR=2] are within the fifth category (V), and the most stable are the slopes of the stations (2) and their values [D-SMR=72, C-SMR=71] for direct toppling, and they fall within the second category (II).

4-The SMRTool-v205 software is more accurate in determining the stability of the slope compared to the kinematic analysis software Dips-v6.008. For example, station No.(8) is unstable due to the intersection of the joints groups in the direct toppling probability region, but it was stable according to the SMR system.

5-Based on the obtained results, the most common types of failure in the study area are rockfall, accompanied by wedge sliding, and the likely dominant failures that may occur according to the field study are plane sliding, rockfall, toppling, and wedge sliding. As for the likely failure, according to the office study (according to the softwares), they are direct toppling, and wedge sliding.

6. Recommendations

The following suggestions are made as a result of this study:

1. Stations (2 and 3) require weekly monitoring in addition to the placement of warning signs due to the difficulty of seeing the road (The presence of steep curves) and slopes being close to the road.
2. The stations (2, 3, and 6) require extensive treatment (major corrective) as well as the placement of warning signs to warn pedestrians of the risk of slope failure. This is because they are completely unstable and unstable.
3. Because they are partially unstable and require some treatments, the Stations (1, 5, and 8), need routine (systamatic) monitoring.
4. The stations (2, 4, and 8) in the direct toppling require periodic monitoring and are stable; they do not require assistance or may only require minor intervention, such as digging up old channels (trenches).

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