Assessment of Rock Slope Stability along Bazian-Basara Main Road, Sulaimani, NE Iraq

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Abstract
In Iraq, the majority of rock slope instability issues along highways result in road deterioration or collapse. Among these is located along Bazian-Basara main road on the southwestern limb of the Bazian anticline fold. For the study of this problem, stations along the road within Sinjar and Pila Spi formations 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 the slope’s stability. The stability analysis results demonstrate the possibility of wedge sliding and direct toppling occurrence in the stations 4, 8, and 10, thus, described as unstable slopes and need important intervention. Whereas the dominant failure modes in stations 3, 4, 6, 7, 9, and 10 and stations 1 and 5 in the slope with a dip of 90° are direct toppling, flexure toppling, and wedge sliding, therefore, described as normal and partially stable slopes and need to systematic monitoring. As well as, direct toppling is the dominant failure mode in stations 1 with a slope of dip 20° and stations 2, 5, and 7 which are classified as good and stable slopes but need to be monitored occasionally.

Keywords: Slope stability; Basin stability; SMR tool software; High folded zone

1. Introduction
The landslides are one of the most dangerous environmental disasters that the inhabitants of mountainous areas are exposed to it, and it usually occurs whenever the causative factors are available (Hasan, 2019; Al-Bayati, 2021). The failure may occur suddenly or it may be in several stages, or it may occur at long distances, and the occurrence of failures may be due to other factors, either natural, such as the increase in the forces that cause failures, moisture, freezing and thawing of snow, the force of Earth's gravity, as well as rock structures that assist with failures such as discontinuities. In general, there are three major reasons of slope instability especially in the mountainous areas which they are: I) Geological and environmental causes; II) Morphological and dynamic causes; and III) Human activities causes, such as slope excavation, blasting, land use (Bayram et al., 2021). However, the subject of evaluating the stability of slopes in their current reality or when exploiting them, as well as 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). Hereby, this study comes to investigate the rock slope instability problems along the Bazian – Basara main road. It provides a better connection to the residential area and allows agricultural centers and key residential areas to be connected. It is located within the southwest limb of

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Bazian anticline northeastern Iraq about 25 km to the southwest of Sulaimani city, between latitudes (35° 29' 0" - 35° 31' 30") and longitudes (45° 10' 0" - 45° 14' 0") (Fig. 1).

![Location map showing the investigated sites](image)

**Fig.1.** Location map showing the investigated sites

### 2. Materials and Methods

#### 2.1. Field Work and Sample Collection

For present study, a detailed scan-line has been conducted for three days (22-25 September 2020). According to study 10 stations were chosen within the study area, their locations were determined using a GPS device, and an extensive field survey has been performed over each slope, including the attitude of the slope and beds, discontinuities and their conditions, the width and height of the slope and also the lithological description. Determining the occurrence and potential failure is performed according to Hoek and Bray’s (1985), and also taking photograph and collecting of a representative sample.

#### 2.2. Laboratory Testing and Office Work

The laboratory work included conducting some geotechnical tests. Unconfined Compressive Strength Test, which was carried out according to the American Standard, ASTM, D-2938-95 (2004), (Table 1) and determining of the internal friction angle in the field according to the tilt method of Bruce et al. (1989) which consider important factor to study the condition of failures, (Zarraq, 2021). Office work included data and test results representation, Table 2. such as using kinematic analysis to evaluate Stability of rock slopes using Dips v6.008 software, classification of rock masses using rock mass rating basic (RMRb) and its use in classifying Slope mass rating (SMR) by SMRTool software (Riquelme et al., 2016).
Table 1. The results of Unconfined Compressive Strength Test

| St. | Fn. | 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   |     | 4.9                  | 5.3                    | 1.081 | 28.690              | 13.040                                    | 12.822                                  | Moderately strong        |
| 2   |     | 4.9                  | 5.3                    | 1.081 | 28.690              | 13.040                                    | 12.822                                  | Moderately strong        |
| 3   |     | 4.9                  | 5.3                    | 1.081 | 28.690              | 13.040                                    | 12.822                                  | Moderately strong        |
| 4   | Sinjar | 5.9                  | 5.3                    | 0.898 | 52.183              | 23.719                                    | 24.277                                  | Moderately strong        |
| 5   |     | 6                    | 5.3                    | 0.883 | 59.816              | 27.189                                    | 27.914                                  | Moderately strong        |
| 6   |     | 6                    | 5.3                    | 0.883 | 59.816              | 27.189                                    | 27.914                                  | Moderately strong        |
| 7   |     | 6                    | 5.3                    | 0.883 | 59.816              | 27.189                                    | 27.914                                  | Moderately strong        |
| 8   | Pila Spi | 6.9                  | 5.3                    | 0.768 | 52.15               | 23.704                                    | 25.004                                  | Moderately strong        |
| 9   |     | 5.6                  | 5.3                    | 0.946 | 55.345              | 25.156                                    | 25.461                                  | Moderately strong        |
| 10  |     | 5.6                  | 5.3                    | 0.946 | 55.345              | 25.156                                    | 25.461                                  | Moderately strong        |

Table 2. The attitude of slopes, beds and sets

| St. | Fn. name | Slope dip direction/ dip angle | Bed dip direction/ dip angle | Set1 dip direction/ dip angle | Set2 dip direction/ dip angle |
|-----|----------|--------------------------------|-----------------------------|------------------------------|-------------------------------|
| (1) |          | 240°90'-20'                   | 237/33'                     | 305/83'                      | 050/75'                       |
| (2) |          | 240°90'                       | 240/30'                     | 320/70'                      | 105/52'                       |
| (3) |          | 240°90-40'                    | 224/32'                     | 320/70'                      | 105/52'                       |
| (4) | Sinjar   | 240°90-40'                    | 224/32'                     | 110/85                       | 210/90'                       |
| (5) |          | 050°90'                       | 230/35'                     | 150/79                       | 078/76                        |
| (6) |          | 207°90'-33'                   | 235/36'                     | 180/83                       | 100/70'                       |
| (7) |          | 235°90'                       | 210/25'                     | 006/82                       | 080/77                        |
| (8) | Pila Spi | 290°90'                       | 220/30'                     | 270/90                       | 360/85                        |
| (9) |          | 240°90-44'                    | 220/32'                     | 095/72                       | 016/70                        |
| (10)|          | 240°90-44'                    | 220/35'                     | 97/78                        | 360/72                        |

3. Geological Setting

Geologically, in addition to the Quaternary deposits, Sinjar and Pila Spi formations are exposed within the study area. The Sinjar Formation consists of thick layers of yellowish-gray limestone, Pebby limestone, argillaceous limestone, and sandy limestone, and its age is Paleocene – Lower Eocene, and the Pila Spi Formation consisting of, dolomitic limestone, well-bedded highly fractured limestone, chalky limestone and dolomite, and its age is Middle-Upper Eocene (Sissakian et al., 2021), and Quaternary deposits which consist of a mixture of coarse-grained soils (gravel and sand) along with fine-grained soils (clay and silt) (Bellen et al., 1959; Hamasur, 2009). From tectonic point of view, the study area is part of the High folded zone at its southwestern borders (Fig. 2), which formed by Alpine movements. The region forms a wide depression (valley) located between two mountain ranges: a mountain chain extending along the southwest called Hanjira - Darband Basara - Sagra and a mountain chain extending along the northeast called Bakhshi - kalawe, the first chain representing the boundary between the low and high folds (Jassim and Goff, 2006; Hamasur, 2009).
4. Results and Discussion

The stability of rocky slopes was investigated and assessed at all stations. The SMR classification system which assigned by Romana (1985) and the continuous slope mass classification by Tomas et al. (2007) are adopted using SMRTool-v205 software of Riquelme et al. (2016) which includes discrete – SMR (D – SMR), (Table 3), and continuous SMR (C – SMR), Table 4. The RMRs, three adjustment factors and methods of slope excavation used in calculating the SMR for all stations. Three of the adjustment factors (F1, F2 and F3) were calculated by SMRTool-v205 software based on the relative orientation of the joints relative to the slope, dip angle of joint and the difference between slope inclination and joint. For the fourth one F4, it was zero in all stations, where the excavation method was mechanical means to pave the road.

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 and direct toppling in stations 4, 8, and 10 range from 30 to 39 implies that the rock mass classified as IV Category, and can be described a bad slope and unstable. The direct toppling, flexure toppling, and wedge sliding, having SMR value range from 41 to 60 in stations (1&5 in the slope with a dip 90°) and the stations 3, 4, 6, 7, 9, and 10 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 62 to 67 in station 1 with a slope of dip 20° and

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Fig.2. Tectonic map of the study area (Jassim and Goff, 2006)
stations 2, 5, and 7 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 4, 8, 10 and some of them to systematic monitoring as in the stations 1, 5 with a slope of dip 90° and the stations 3, 6, 9, 10 and others that need to be monitored occasional, as in the stations 1 with a slope of dip 20° and stations 2, 5, 7.

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

| Station no. | Attitude | RMRe | Failure type | Failure direction | F1 | F2 | F3 | F4 | F1/F2/F3* | SMR value | SMR class / Stability |
|-------------|----------|------|--------------|------------------|----|----|----|----|------------|------------|----------------------|
| 1          |          | 24090 | d)DT         | d)194             | d)0.7 | d)1 | d)0 | d)0 | d)67       | d) II/ Sta. |                      |
| 2          |          | 24090 | d)DT         | d)189             | d)0.7 | d)1 | d)25 | d)0  | d)3.75     | d)56        | d) III/ Pa.Sta.        |
| 3L         |          | 24090 | d)DT         | d)218             | d)0.15 | d)1  | d)25 | d)0  | d)3.75     | d)56        | d) III/ Pa.Sta.        |
| 3R         |          | 24090 | b)WS         | b)108             | b)0.4 | b)1 | b)60 | b)0  | b)24       | b)38        | d) IV/ Unsta.         |
| 4          |          | 05090 | d)DT         | d)52              | d)1   | d)25 | d)0  | d)25 | d)37       | d)37       | d) IV/ Unsta.         |
| 5          |          | 20790 | b)WS         | b)266             | b)0.15 | b)0.7 | b)60 | b)0  | b)6.3      | b)60       | b) III/ Pa.Sta.        |
| 6          |          | 23590 | c)FT         | c)257             | c)0.4 | c)1  | c)25 | c)0  | c)10       | c)49       | c) III/ Pa.Sta.        |
| 7          |          | 29090 | b)WS         | b)355             | b)0.4 | b)1 | b)25 | b)0  | b)10       | b)62       | b) II/ Sta.           |
| 8          |          | 24090 | d)DT         | d)230             | d)0.15 | d)1  | d)25 | d)0  | d)3.75     | d)36       | d) IV/ Unsta.         |
| 9          |          | 24090 | d)DT         | d)220             | d)0.15 | d)1  | d)6  | d)0  | d)0.9      | d)49       | d) III/ Pa.Sta.        |
| 10         |          | 24090 | b)WS         | b)204             | b)0.4 | b)0.7 | b)60 | b)0  | b)16.8     | b)38       | b) IV/ Unsta.         |

Where: PS is Planar sliding, WS is Wedge sliding, FT is Flexural toppling, DT is Direct toppling, F1, F2 & F3 are adjustment factors of SMR, Sta: Stable, Pa.sta: Partially stable, Unsta: Unstable, Letters: a, b, c & d are belonging to plane sliding, wedge sliding, flexural toppling and direct toppling respectively, (Hamasur and Qadir, 2020; Hamasur et al., 2020).
Table 4. The results of continuous – SMR system using SMRTool-v205

| Station no. | Attitude | RMb | Failure type | Failure direction | F1 | F2 | F3 | F4 | F1/F2/F3 | SMR value | SMR class/ Stability |
|-------------|----------|-----|--------------|------------------|----|----|----|----|----------|-----------|----------------------|
| 1 240/20°  | d) DT    | d)194 | (0.84995)    | d)0.47009        | d)0 | d)0.39955 | d)66 | d)II/ Sta. |
| 2 240/90°  | c) FT    | c)230 | (0.84995)    | c)25.6753        | c)0 | c)21.8228 | c)45 | c)III/ Pa.Sta. |
| 3 240/90°  | d) DT    | d)189 | (0.84995)    | d)25.6753        | d)0 | d)21.8228 | d)45 | d)III/ Pa.Sta. |
| 4 240/90°  | d) DT    | d)228 | (0.21792)    | d)25.4853        | d)0 | d)5.5538 | d)64 | d)II/ Sta. |
| 5 240/90°  | d) DT    | d)218 | (0.21792)    | d)25.4853        | d)0 | d)5.5538 | d)54 | d)III/ Pa.Sta. |
| 6 240/90°  | d) DT    | d)204 | (0.21792)    | d)25.4853        | d)0 | d)5.5538 | d)64 | d)II/ Sta. |
| 7 240/90°  | d) FT    | d)189 | (0.21792)    | d)25.4853        | d)0 | d)5.5538 | d)54 | d)III/ Pa.Sta. |
| 8 240/90°  | d) DT    | d)204 | (0.21792)    | d)25.4853        | d)0 | d)5.5538 | d)64 | d)II/ Sta. |
| 9 240/90°  | d) DT    | d)228 | (0.21792)    | d)25.4853        | d)0 | d)5.5538 | d)64 | d)II/ Sta. |
| 10 240/90° | d) DT    | d)218 | (0.21792)    | d)25.4853        | d)0 | d)5.5538 | d)54 | d)III/ Pa.Sta. |
| 11 240/90° | d) DT    | d)204 | (0.21792)    | d)25.4853        | d)0 | d)5.5538 | d)64 | d)II/ Sta. |
| 12 240/90° | d) DT    | d)228 | (0.21792)    | d)25.4853        | d)0 | d)5.5538 | d)64 | d)II/ Sta. |

5. Conclusions

By comparing the results of the discrete – SMR and continuous – SMR values, it was found that there is a discrepancy in their results. Station 4 is assessed as unstable according to the Discrete – SMR and falls within the fourth category (IV), whereas it is classified as partially stable according to the Continuous – SMR and falls within the third category (III). Meanwhile, station 7 is classified as a stable slope and within the second (II) category according to the discrete-SMR, as well as it is classified as being partially stable and falling within the third category (III) according to the continuous – SMR. 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. (8), where the values of [D-SMR=39, C-SMR=39] are within the fourth category (IV), and the most Stable are the slopes of the two stations (1 in the slope with a dip of 20°) and (5 with a dip of slope 33°) and their values [D-SMR=67, C-SMR=66] and they fall within the second category (II). 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, the station 2 is unstable due to the intersection of the joint groups in the direct toppling probability region, but it was stable according to the SMR system. Based on the obtained results, the most common types of failure in the study area are rock fall, accompanied by planar sliding, and the likely dominant failure that may occur according to the field study are plane sliding, rock fall, toppling and wedge sliding. As for the likely failure, according to the office study (according to the software), they are direct toppling, wedge sliding and flexural toppling.
6. Recommendations

This study proposes the following recommendations:

- Due to the difficulty of seeing the road (the presence of sharp turns) and the proximity of the slopes to the street, stations (5 and 6) require weekly monitoring in addition to the placement of warning signs.
- Because the stations 4, 8, and 10 are unstable, they require significant treatment (major corrective), as well as the placement of warning signs to guide pedestrians to the danger of slope failure.
- Stations 1 and 5 with slope inclination 90° and the stations 3, 6, 9, and 10 need regular (systematic) monitoring, as they are partially unstable and need some treatments.
- The station 1 in the slope with a dip of 20° and the stations 7, 5, and 2 need to be monitored regularly (occasional) and they are stable and do not need support or may need minor intervention such as digging old channels (trenches).

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