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# Field Evaluation of the Stability of a Mountainous Road in the Kurdistan Region of Iraq

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**Abstract**

The majority of the roads in the Kurdistan Region of Iraq (KRI) are mountainous, with steep ascending and descending slopes and acute curves. Therefore, the road cuts on both sides of the roads usually suffer from slope stability problems exhibiting different types of slope failures. One of the easiest methods to assess the stability of road cuts is the Bejerman Method. It is a field method based on 10 different attributes, which can be measured and/ or estimated directly in the field. The studied area is located in the High Folded Zone, which is a part of the Unstable Shelf and occupies the northeastern part of the Arabian Plate, and is characterized by different types of mass movements; like landslides and toppling, as well as active weathering and erosion, and highly weathered rocks**.** The Bejerman Method was applied on a selected segment of the road that crosses Haibat Sultan Mountain near Galka Smaq village in KRI. The studied part of the road was covered by 13 stations, and at each station, we measured and/ or estimated the 10 attributes at each station. The results showed that among the 13 studied stations, the Landslide Possibility Index (L.P.I.**)** ranking showed 4 scored Very High, 5 scored High, 3 scored Medium, and 1 scored Low. It's recommended to construct side and top ditches to reduce the water infiltration, decrease the slope gradients at the road cuts, and increase the vegetation cover on slopes.

**Keywords:** Bejerman Method; Filed assessment, Slope failure; L.P.I.; Failure possibility.; Hazard Zone.

# التقييم الميداني لاستقرارية طريق جبلي في منطقة إقليم كردستان العراق

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**الخلاصة**

غالبية الطرق في إقليم كردستان العراق جبلية، مع منحدرات صاعدة وهابطة وشديدة الانحدار ومنحنيات حادة. لذلك، عادة ما تعاني المنحدرات على جانبي الطرق من مشاكل استقرارية المنحدرات التي تظهر أنواعًا مختلفة من مشاكل المنحدرات. واحدة من أسهل الطرق لتقييم استقرارية الطرق هي طريقة بيجرمان. وهي طريقة ميدانية تستند إلى 10 سمات مختلفة، والتي يمكن قياسها و/أو تقديرها مباشرة في الميدان.

تقع منطقة الدراسة في منطقة الطيات العالية، وهي جزء من الرصيف غير المستقر وتحتل الجزء الشمالي الشرقي من الصفيحة العربية، وتتميز بأنواع مختلفة من الحركات الارضية ؛ مثل الانهيارات الأرضية والانقلاب، بالاضافة الى التجوية والتعرية، وصخور شديدة التجوية. تم تطبيق طريقة بيجرمان على جزء من الطريق الذي يعبر جبل هيبة سلطان بالقرب من قرية كالكا سماق في اقليم كردستان. تم تغطية الجزء المدروس من الطريق ب 13 محطة ، وفي كل محطة، تم قياس و/أو تقدير السمات العشرة. أظهرت النتائج ان من بين 13 محطة مدروسة أن ترتيب مؤشر احتمالية الانهيارات (L.P.I) كان 4 محطات سجلت درجات عالية جدًا، و 5 درجات عالية، و 3 درجات متوسطة، ودرجة واحدة منخفضة. نوصى ببناء خنادق جانبية وعلى لتقليل تسرب المياه الى المنحدرات على جانبي الطريق، وتقليل تدرجات المنحدرات عند قطع الطريق وزيادة الغطاء النباتي على المنحدرات.

## 1. Introduction

Most of the roads in the Iraqi Kurdistan Region (IKR) suffer from different slope stability problems [1]. The possibility of failure ranges from small-size events (Figure 1a) to large events that have caused serious damage to infrastructures (Figure 1b). Unfortunately, the majority of the roads in the KRI are constructed without a careful study of the road cuts on both sides of the roads; accordingly, the majority of the roads, especially steeply sloped roads suffer from different slope failures.

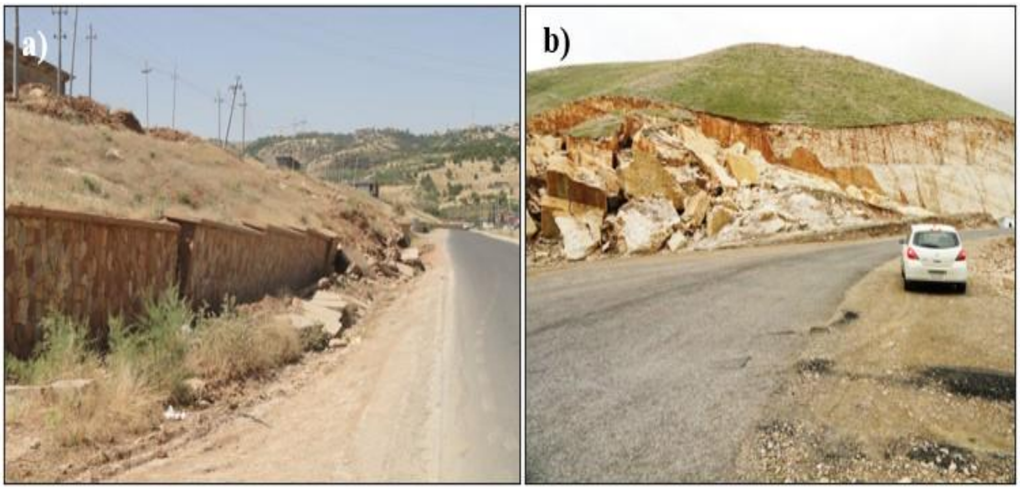


**Figure 1** : a) Small-sized failure near Kori village caused the failure of the protection wall, b) Large-sized failure east of Dokan Lake, caused changing the road route (the original route is under the blocks).

There are different methods to perform slope stability of road cuts. Some of them are very complicated methods and need a lot of laboratory work and field equipment with well-experienced engineers, geologists, and laboratory assistants, among these methods are methods described by[2],[3],[4],[5],[6],[7],[8],[9],[10],[11],[12],[13] and [14]. However, a very simple field method also exists to assess the slope stability of road cuts and any other slopes, such as Bejerman's Method. The Bejerman Method is based on measuring and/or estimating ten

attributes, which can be performed directly in the field without requiring special equipment and skills. Only a geological compass, measuring tape, and a geological hammer are needed to perform Bejerman's Method in the field [15]
Many researchers in the IKR used Bejerman's Method to evaluate slope stability problems along different types of slopes; mainly road cuts, among them, are [16],[1],[17], [18],[19],[20] and [21] evaluated unstable road cuts west of the current study area using Bejerman's Method.

The studied part of the road, which joins Erbil city with Koya and Dokan towns, is presented in Figure (2). It is a mountainous road with steep ascending and descending slopes. Moreover, there are many tourist sites along the road, and Aram tourist village (Figure 1) is near station No.13, besides spectacular scenes along the studied the road segment, which attract tourists and are used for holidays and camping.

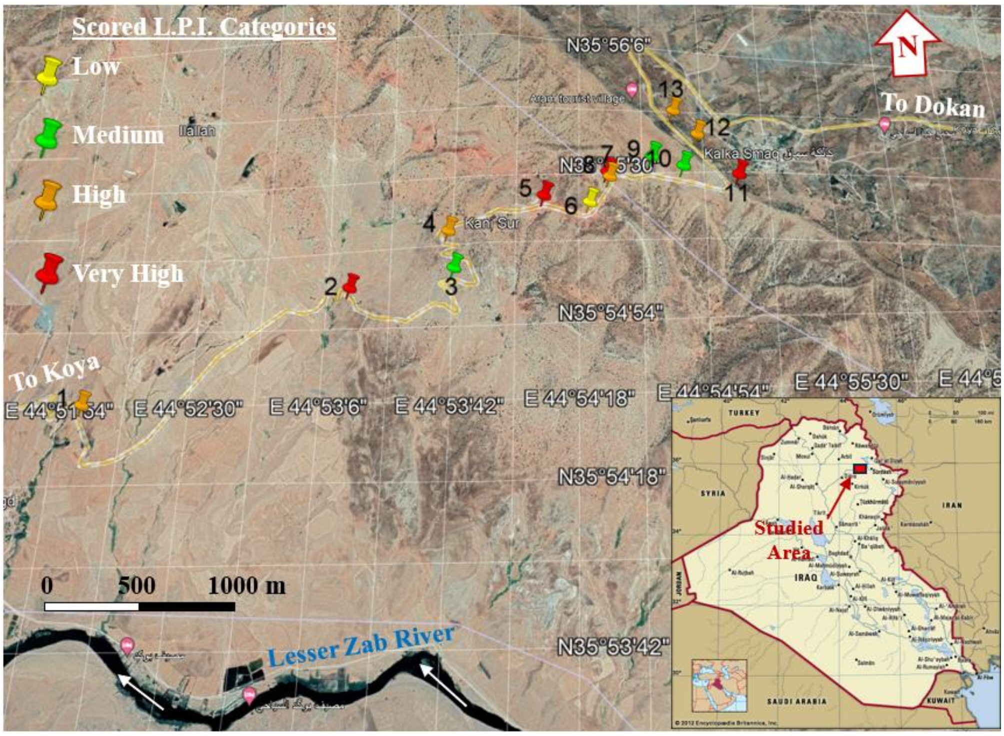


**Figure 2:** Satellite image of the studied part of the road. The studied stations are shown in Yellow pins with serial numbers.

This study aims to perform a geotechnical assessment of the road cuts along a part of the road that ascends and descends at the Haibat Sultan Mountain using Bejerman's Method. Moreover, it gives recommendations to keep the stability of the road to provide safe driving along the road, especially, during rainy seasons when different slope failures occur along the road during the rainy seasons.

## 2. Materials and Methods

One of the easiest methods to assess the stability of road cuts is the Bejerman Method. It is a field method based on ten different attributes, which can be measured and/ or estimated directly in the field. The main used method is Bejerman's Method, which is based on 10 attributes (Figure 3). The ten attributes can be measured (Attributes No. 1, 2, 5, 6, and 7) or estimated (Attributes No. 3, 4, 8, 9, and 10) directly in the field.

| ttribute No. | Attributes | Limits and Weights | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Slope height (m) | *a)* 1 – 8 | *1* | *b)* 9 – 15 | *2* | *c)* 16 – 25 | *3* | *d)* 25 – 35 | *4* | *e)* > 35 | *5* | | |
| 2 | Slope angel (°) | *a)* < 15 | *0* | *b)* 15 – 30 | *1* | *c)* 30 – 45 | *2* | *d)* 45 – 60 | *3* | *e)* > 60 | *4* | | |
| 3 | Grade of Fracture | *a)* Sound | *0* | *b)* Moderately Fractured | *1* | *c)* Highly Fractured | *2* | *d)* Completely Fractured | *3* | | | | |
| 4 | Grade of Weather. | *a)* Fresh | *0* | *b)* Slight. W. | *1* | *c)* Moderate. W. | *2* | *d)* Highly W. | *3* | *e)* Complete . W. | *4* | f) Residual Soil | *5* |
| 5 | Grade of Discontinuities (°) | *a)* < 15 | *0* | *b)* 15 – 30 | *2* | *c)* 30 – 45 | *3* | *d)* 45 – 60 | *4* | *e)* > 60 | *5* | | |
| 6 | Space of Discontinuities (m) | *a)* > 3 | *0* | *b)* 1 – 3 | *1* | *c)* 0.3 – 1 | *2* | *d)* 0.05 – 0.3 | *3* | *e)* < 0.05 | *4* | | |
| 7 | Orientation of Discontinuities | *a)* Favorable | *0* | *b)* Unfavorable | *4* | | | | | | | | |
| 8 | Vegetation Cover (%) | *a)* < 20 | *0* | *b)* 20 – 60 | *1* | *c)* > 60 | *2* | | | | | | |
| 9 | Water Infiltration | *a)* Inexistence | *0* | *b)* Scarce | *1* | *c)* Abundant: Permanent | *2* | *d)* Abundant: Seasonal | *3* | | | | |
| 10 | Previous Landslides | *a)* Not registered | *0* | *b)* Registered (Small volume) | *1* | *c)* Registered (High volume) | *2* | | | | | | |

| Attribute No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | *Total* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Weight* | | | | | | | | | | | |

The LPI value is obtained by adding the estimations of attributes 1 to 10. If the orientation of the discontinuities is favourable, subtract the estimation of the gradient (Attribute No.7)

| L.P.I. Class | I (Small) 0 – 5 | II (V. Low) 6 – 10 | III (Low) 11 – 15 | IV (Moderate) 16 – 20 | V (High) 21 – 25 | VI (V.High) > 25 |
|---|---|---|---|---|---|---|

**Figure 3:** The attributes of Bejerman's (1994) Method with the given weights.

Attributes Nos. 2 and 5 were measured by a geological compass, and attributes Nos.1 and 6 were measured by a measuring tape. Attributes Nos. 3 and 4 were estimated from the status of the rocks along exposures. Attribute No. 7 was calculated based on the dip direction as the road cut direction is concerned. Attributes Nos. 8 and 9 were estimated directly in the field from careful checking of the vegetation cover and the presence of springs. Attribute No.10 was estimated from the existing previous landslides.

Along the studied part of the road (Figure 2), we selected 13 stations where slope failures were observed to evaluate the slope stability of the concerned part of the studied road using Bejerman's Method (Figure 3). At each station, the ten attributes were measured and/ or estimated, the results of which are shown in Table (1). At each station, the given weights of the ten attributes were summed, and the total summed weights represented the L.P.I. scored mark. The total scored mark at each station was compared with the L.P.I. ranking of Bejerman, which shows the grade and category of each station (Table 1). Accordingly, the slope stability of each station can be evaluated.

**3. Geological Setting**

The exposed formations along the studied part of the road are presented and briefly described in Figure (4), whereas the geological map is presented in Figure (5). The presence of hard rocks of the Pila Spi and Khurmala formations underlain by soft rocks of the Gercus and Kolosh formations, respectively, have developed favourable conditions for unstable slopes (Figure 6) [3], [4].

Tectonically, the studied area is located in the High Folded Zone, which is a part of the Outer (Unstable) Platform and occupies the northeastern part of the Arabian Plate. The Arabian Plate has collided with the Eurasian Plate since the Late Cretaceous. The collision has developed tens of anticlines and faults Figure 5 of different types and sizes [3], [4].

The studied area is characterized by different types of mass movements; such as landslides, and flow (Figure 5), active weathering and erosion (Figure 6), toppling (Figure 7a), and highly weathered rocks (Figure 7 b) [3],[4].

| Formation | Age | Thick. (m) | General Description |
|---|---|---|---|
| Fatha | M. Miocene | 100 | Thick reddish-brown claystone with thin limestone and rare gypsum, weathered and slope-forming |
| Pila Spi | U. Eocene | 55 | Well bedded and hard dolostone and limestone with rare marl beds, steep cliff-forming |
| Gercus | Eocene | 100 | Reddish brown fine clastics, fairly hard and weathered, slope-forming |
| Khurmala | Paleocene | 30 | Well bedded, hard and dark grey limestone, cliff-forming |
| Kolosh | | 75 | Black fine clastics fairly hard and weathered, slope-forming |

**Figure 4:** The stratigraphic section of the studied part of the road (Not to scale)

**Table 1**: Field data of the studied stations (H= Highly, M = Moderate, Unf.= Unfavorable, Fav.= Fvaorable; Inex.= inexistent, Seas.= Seasonal, Sca= Scarce; N.R.= Not Registered)

| Station No. | Numbers of the attributes used in L.P.I. Form (Bejerman, 1994) | | | | | | | | | | L.P.I. Mark | Ranking | Coordinates | | Elevation (m, a.s.l.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | | | | |
| | Slope | | Grade of | | Discontinuities | | | Vegetation Cover | Water Infiltration (%) | Previous Land Slide Volume | | | | | |
| | Height (m) | Angle (°) | Fracture | Weathering | Gradient (°) | Spacing (m) | Orientation | | | | | | Latitude (N) | Longitude (E) | |
| 1 | 70 | 52 | H | H | 16 | 1 – 3 | Unf | Void | Sea | Small | 24 | V | 35° 55.620' | 44° 53.969' | 490 |
| | *5* | *3* | *2* | *3* | *1* | *2* | *4* | *0* | *3* | *1* | | H | | | |
| 2 | 60 | 55 | H | H | 35 | 0.05 – 0.3 | Unf | Void | Seas. | Small | 26 | VI | 35° 55.055' | 44° 53.096' | 551 |
| | *5* | *3* | *2* | *3* | *2* | *3* | *4* | *0* | *3* | *1* | | VH | | | |
| 3 | 19 | 20 | H | H | 25 | 0.3 – 1.0 | Unf | Void | Seas. | N.R. | 19 | IV | 35° 55.005' | 44° 53.579' | 628 |
| | 3 | 1 | 2 | 3 | 1 | 2 | 4 | 0 | 3 | 0 | | M | | | |
| 4 | 72 | 80 | M | M | 55 | 1 – 3 | Unf | Sca. | Seas. | Small | 25 | V | 35° 55.157' | 44° 53.777' | 764 |
| | *5* | *4* | *1* | *2* | *3* | *1* | *4* | *1* | *3* | *1* | | H | | | |
| 5 | 65 | 55 | H | H. | 33 | 0.05 – 0.3 | Unf | Void | Seas. | Small | 26 | VI | 35° 55.364' | 44° 54.105' | 854 |
| | *5* | *3* | *2* | *3* | *2* | *3* | *4* | *0* | *3* | *1* | | VH | | | |
| 6 | 58 | 52 | H | H | 47 | 1 – 3 | Fav. | Void | Seas. | Small | 15 | III | 35° 55.065' | 44° 53.755' | 874 |
| | *5* | *3* | *2* | *3* | *- 3* | *1* | *0* | *0* | *3* | *1* | | L | | | |
| 7 | 66 | 49 | M | R.S. | 13 | > 3 | Unf | Void | Seas. | High | 22 | V | 35° 55.306' | 44° 53.796' | 891 |
| | *5* | *2* | *1* | *5* | *0* | *0* | *4* | *0* | *3* | *2* | | H | | | |
| 8 | 76 | 55 | H | H | 25 | < 0.05 | Unf | Void | Seas. | Small | 27 | VI | 35° 55.396' | 44° 54.423' | 901 |
| | *5* | *3* | *2* | *3* | *- 1* | *4* | *4* | *0* | *3* | *2* | | VH | | | |
| 9 | 78 | 52 | M | H | 35 | 0.3 – 1.0 | Fav. | Void | Seas. | High | 17 | IV | 35° 55.458' | 44° 54.613' | 913 |
| | *5* | *3* | *1* | *3* | *2* | *2* | *0* | *0* | *3* | *2* | | M | | | |
| 10 | 75 | 51 | H | H | 21 | 1 – 3 | Fav. | Void | Seas. | High | 18 | IV | 35° 55.389' | 44° 54.948' | 906 |
| | *5* | *3* | *2* | *3* | *1* | *1* | *0* | *0* | *3* | *2* | | M | | | |
| 11 | 88 | 63 | H | H | 19 | 0.3 – 1.0 | Unf | Void | Seas. | High | 26 | VI | 35° 55.446' | 44° 54.710' | 893 |
| | *5* | *4* | *2* | *3* | *1* | *2* | *4* | *0* | *3* | *2* | | VH | | | |
| 12 | 89 | 62 | M | M | 22 | 0.3 – 1.0 | Unf | Void | Seas. | High | 24 | V | 35° 55.447' | 44° 53.096' | 891 |
| | *5* | *3* | *1* | *2* | *1* | *2* | *4* | *0* | *3* | *2* | | H | | | |
| 13 | 92 | 61 | M | M | 24 | 0.3 – 1.0 | Unf | Sca. | Seas. | Small | 24 | V | 35° 55.901' | 44° 53.592' | 862 |
| | *5* | *4* | *1* | *2* | *1* | *2* | *4* | *1* | *3* | *1* | | H | | | |

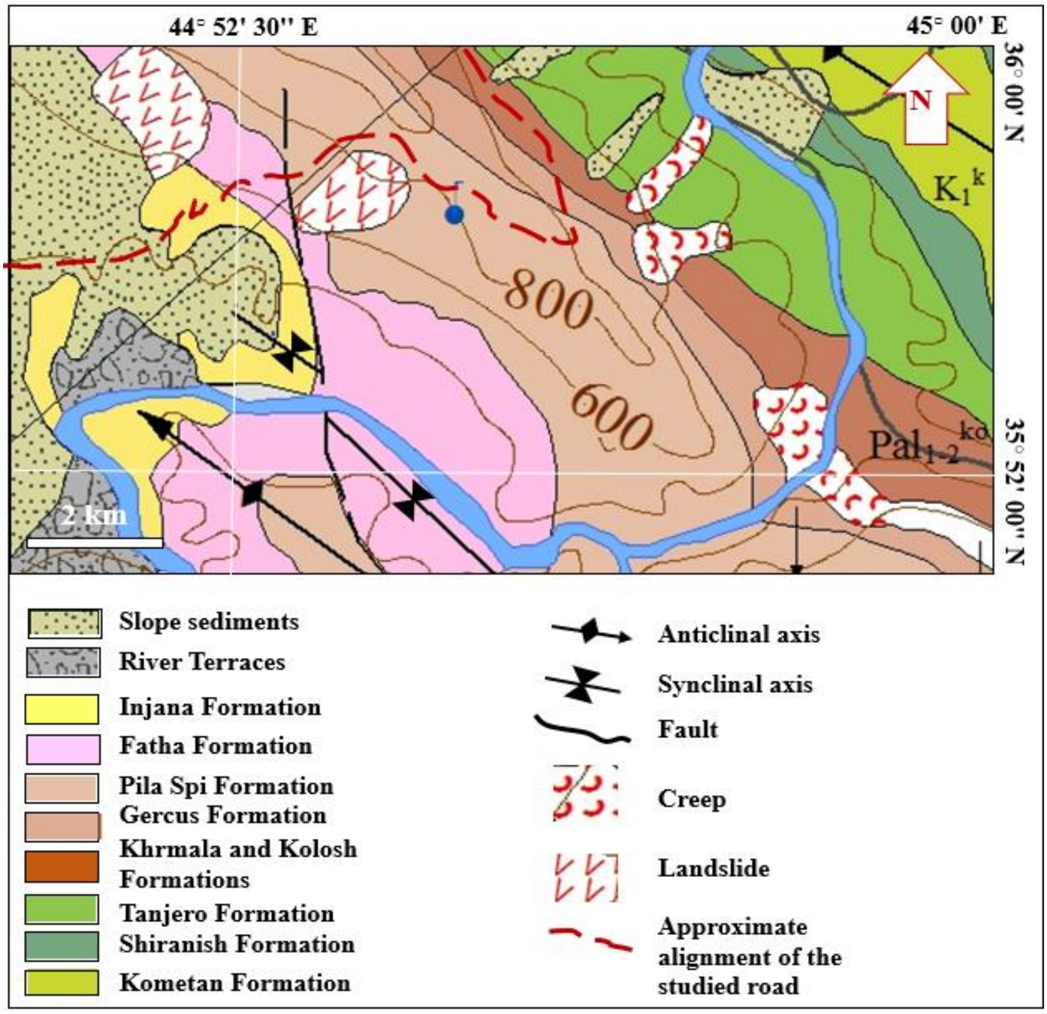


**Figure 5:** Geological map of the studied area (Modified from Sissakian and Fouad, 2014)

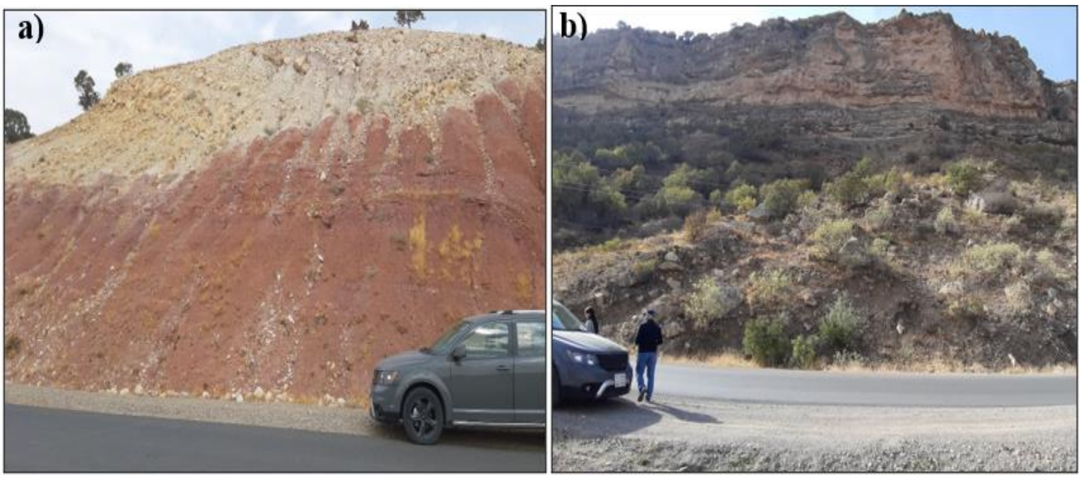


**Figure 6 :** Hard rocks underlain by soft rocks, a) Pila Spi and Gercus formations (Station 5), b) Khurmala and Kolosh formations (Station 13). Note the unstable slopes.


**Figure 7:** a- Toppled limestone blocks from the Pila Spi Formation over the red clastics of the Gercus Formation (Station No. 6), b- Highly jointed and weathered limestone beds of the Khurmala Formation underlain by the highly weathered clastics of the Kolosh Formation (Near Station No. 7).

## 4. Results

The recorded results of the 10 attributes in the 13 studied stations (Table 1) were processed following Bejerman's (1994) Method (Table 2) to indicate the L.P.I. Category and Grade, Hazard Zone, and Possibility of Failure (Table (3). To elucidate the L.P.I. for the categories along the studied segment of the road, we have differentiated the studied stations into four different colors (Figure 2). Accordingly, it can be seen which segments suffer more from landslide possibilities.

**Table 2:** Landslides hazard categories, Hazard Zones, and Failure possibility ranges (Modified from Bejerman, 1994) (Scored values of the ten attributes)

| Landslide Possibility Index (L.P.I.) | | | Hazard Zone | | Failure | |
|---|---|---|---|---|---|---|
| Grade | Category | Scores | Scores | Name | Scores | Possibility |
| I | Small | 0 – 5 | < 10 | Low Hazard | 0 – 5 | Small |
| II | Very Low | 6 – 10 | | | 6 – 10 | Very Low |
| III | Low | 11 – 15 | 11 – 25 | Moderate Hazard | 11 – 15 | Low |
| IV | Moderate | 16 – 20 | | | 16 – 20 | Moderate |
| V | High | 21 – 25 | < 25 | High Hazard | 20 – 25 | High |
| VI | Very High | < 25 | | | > 25 | Very High |

**Table 3 :** L.P.I. Scored values, L.P.I. Grade and Category, Hazard Zones, and Failure possibility at the 13 studied stations

| Station No. | L.P.I. Value | LPI | | Hazard Zone | Failure Possibility |
|---|---|---|---|---|---|
| | | Grade | Category | | |
| 1 | 24 | V | High | Moderate | High |
| 2 | 26 | VI | Very High | High | Very High |
| 3 | 19 | IV | Moderate | Moderate | Moderate |
| 4 | 25 | V | High | Moderate | High |
| 5 | 26 | VI | Very High | High | Very High |
| 6 | 15 | III | Low | Moderate | Low |
| 7 | 22 | IV | High | Moderate | High |
| 8 | 27 | VI | Very High | High | Very High |
| 9 | 17 | IV | Moderate | Moderate | Moderate |
| 10 | 18 | IV | Moderate | Moderate | Moderate |
| 11 | 26 | VI | Very High | High | Very High |
| 12 | 24 | V | High | Moderate | High |
| 13 | 24 | V | High | Moderate | High |

## 5. Discussion

From the acquired L.P.I. results, which are based on Bejerman (1994) (Table 3), it is clear that large parts of the studied road are suffering from failure possibility (Table 3) and have scored a Vey High and High L.P.I. values (Table 3 and Figure 2). In contrast, small parts have low failure possibility and have scored medium and low L.P.I. values (Table 3 and Figure 2). The length of the studied part of the road is 8.4 km; of this length, 6.9 km suffers from Very High to High L.P.I. Categories, which means Very High to High Failure possibilities. At the same time, the remaining part, which is only 1.5 km, suffers from Moderate and Low L.P.I. Categories, which means Medium and Low failure possibilities. This means that 78.26% of the studied segment of the road suffers from Very High to High failure possibilities.

Table (4) is prepared to elucidate the most effective attributes of the stability of the studied part of the road. Table (4) shows the distribution of the 10 attributes of Bejerman (1994) and their subdivisions on the studied 13 stations. Each attribute is divided into the number of limits given by Bejerman (1994), and each subdivision is given a letter that indicates its serial number within the attribute. For example, Attribute No.1 (Slope height) includes 5 limits; therefore, the assigned letters are *a, b, c, d, e,* and *f* (Figure 3 and Table 4)

The data shown in Table (3) can elucidate which of Bejerman's (1994) 10 attributes are most effective in stabilising the slopes of the road cuts along the studied part of the road. To make it clearer, we have presented the distribution of all subdivisions of the ten attributes in Figure (8) statistically.

In Figure (8) and Table (3), it is clear that the most effective attribute of Bejerman (1994) is Water Infiltration (Attribute No. 9, subdivision ***d***), which has scored in all the 13 studied stations. This is attributed to the highly jointed and fractured rocks Figures (6b and 7b) and can be overcome by constructing side and top ditches lined by concrete to decrease water infiltration.

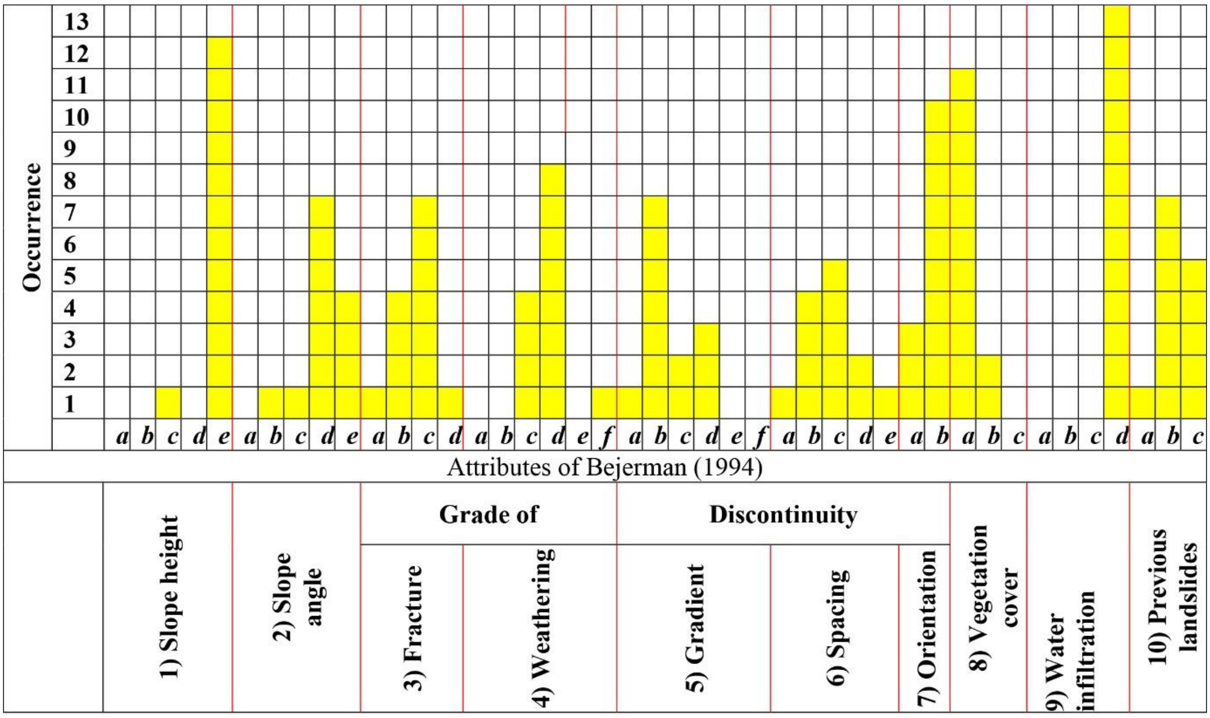


**Figure 8:** Statistical presentation of the occurrences of the 10 attributes and their subdivisions in the studied part of the road

The second effective attribute of slope stability along the studied part of the road is Attribute No.1 (Slope height, subdivision ***e***). In 12 stations, the slope is more than 35 m high (Figures 6 and 7a). Based on the slope height and the type of rocks and soils, the slope height should be decreased by benching to reduce the shear stress [5].

Attributes No. 7 (Discontinuity orientation, subdivision ***b***) and No. 8 (Vegetation cover, subdivision ***a***) have significant effects on the slope stability of the road cuts along the studied part of the road [18]. These two attributes cannot be treated easily. The first one needs to change the route, which is very costly, whereas the second one requires a lot of water to plant trees on the road cuts to increase stability.

Another attribute that significantly affects slope stability is No. 2 (Slope angle, subdivision ***d***), where the slope angle ranges between (30 – 45)°. The steepness of the slope angles can be reduced by cutting the slope at lower angles; however, this needs to remove more quantities of rock and soil from the road cut.

Attributes No. 3 (Gradient of Fracture), No.4 (Gradient of Weathering), No. 5 (Gradient of Discontinuities), No.6 (Spacing of Discontinuities), and No. 10 (Previous Landslides) are naturally occurring characteristics; therefore, cannot be treated easily. However, using retaining walls, metallic mesh, and cement shotcrete; as applicable is the possible solution to stabilize the road cuts when such road cut slope characteristics exist.

## 6. Conclusions

The current study; based on the applied Bejerman (1994) Method at 13 stations along the studied part of the road that crosses Haibat Sultan Mountain near Galka Smaq village has the following conclusions: Among the 13 stations, 5 stations are suffering from High L.P.I values, 4 stations from Very High L.P.I. values, 3 stations from Medium L.P.I. values and 1 station from Low L.P.I. Values. This means that 78.26% of the studied part of the road suffers from Very High to High failure possibilities. The most effective attributes of Bejerman's Method are Water Infiltration, High slopes, Discontinuity orientation, Vegetation cover, and Slope angle.

## 7. Recommendations

To increase the stability of the road cuts along the studied part of the road under consideration, the following actions should be taken:

- Construction of side and top ditches to reduce the water infiltration,
- Application of benching at high slope cuts,
- Decreasing the slope gradients at the road cuts,
- Increasing the vegetation cover on slopes, and
- Adding metallic mesh, retaining walls, and cement shotcrete as needed at different parts of the studied road.

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