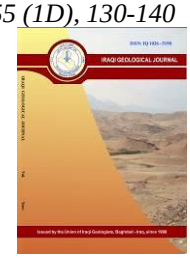
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Geotechnical Assessment of the Erbil-Hareer Highway in North Iraq, Kurdistan Region, Using a Field Method

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Abstract

A new highway is under construction since few years to join the capital; Erbil city with many main towns connecting; in the plan to the northern boarders of the Iraqi Kurdistan Region. It is a double lane road constructed according to modern standards. It crosses many mountains, and two tunnels are already completed, one is almost completed and another one is abandoned: hitherto. The completed part of the highway reaches the Hareer town with some parts being under construction before and after the Shaqlawa town. Because parts of the Highway are not completed yet; therefore, those parts suffer from slope stability problems; mainly due to the drainage problems. Other completed parts; however, suffer also from slope stability problems; mainly due to steep slope road cuts and/ or irrelevant treatments for the road cuts. Among those unstable slopes, we have chosen six stations, which experienced the most severe failures. At those six stations, we have applied field method to estimate the possibility of failure following Bejerman's method. We have found that the failure possibility is high in the station Nos. 1- 4, and is Low in the station Nos. 5 and 6.

Keywords: Bejerman Method; Slope failure; Landslide; Landslide possibility index; Tunnels

1. Introduction

The Iraqi Kurdistan Region is mainly mountainous area with high ascending and descending steep, mountain slopes where road cuts have created instability problems and/or potential areas for sliding, due to non-appropriate road cuts. Among those roads is the new Highway that joins the Erbil city with many main towns like Shaqlawa, Hareer, Aqra, etc. The new Highway is constructed following modern standards, where many tunnels were planned along the road. Two tunnels are already in use; those are the Pirmam and Mirawa East tunnels, one is under construction; it is the Mirawa West tunnel, and the abandoned Hareer tunnel (Fig. 1). Although the new Highway is constructed according to modern standards; however, many slope stability problems can be seen along the Highway. These are related to different reasons (Sissakian and Omer, 2018). Bejerman (1994) method was used in the current study to indicate the Landslide Possibility Index (LPI), which can be used to estimate the stability of any road cut and/ or any slope; natural or artificial (Bejerman, 1994 and 1998).

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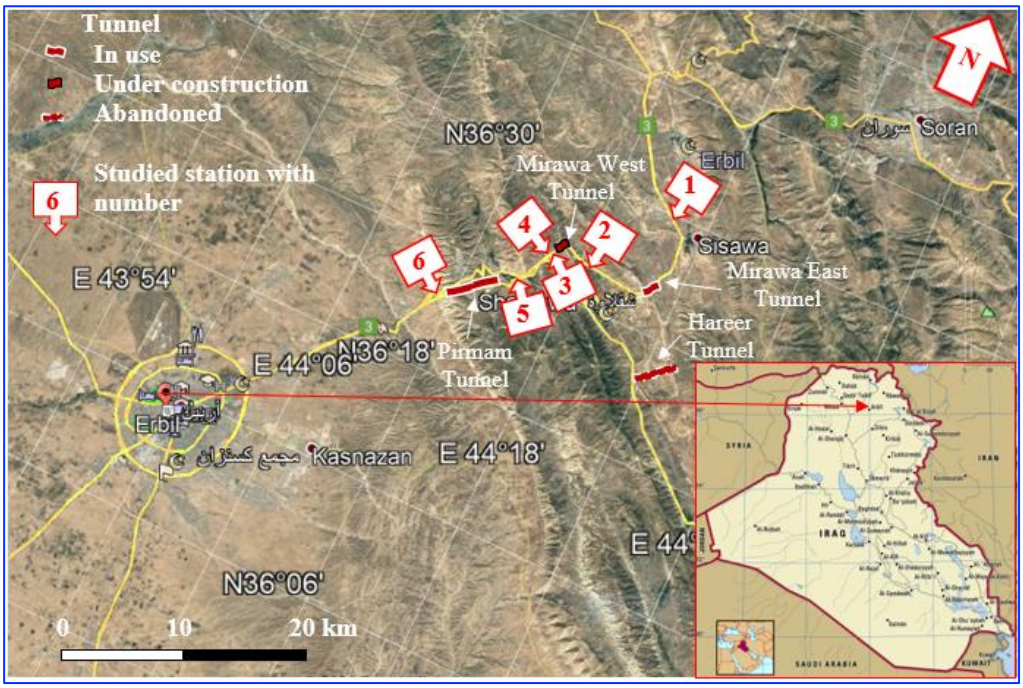


Fig. 1. Satellite image of the studied parts of the new highway with the studied stations and existing tunnels

The studied area is located along the new highway (Fig. 1) which joins the capital Erbil with many other towns. The length of the studied part of the highway is about 30 km. Although hundreds of slope failures occur almost everywhere in IKR (Sissakian and Omer, 2018); studies however that dealt with slope instability problems are very rare. Many studies, and maps are presented by different authors but most of them are regional and don't identify neither the cause nor types of failures. Some of these maps and studies include: Hamasour (1991) studied the unstable parts of the Haibat Sultan Mountain Road and evaluated the types of mass movements using Bejerman's Method. Al-Saadi and Yousif (2013) studied road cut slopes near the Shaqlawa town using Bejerman's Method and evaluated the road cut slopes. Jassim et al. (2013 and 2014) studied the instability of the Haibat Sultan Mountain's Road through selected 14 studied stations and found high possibility of sliding. Sidiq et al. (2015) studied a large landslide that had occurred on 11 November 2015 along the Haibat Sultan Mountain's Road, and mentioned the reasons for the sliding, and gave recommendations for stabilizing the road cuts. Yousif and Shakir (2015) also have used Bejerman's Method to evaluate rock falls along the main old road of Mirawa. Sissakian et al. (2018), evaluated unstable road cut west of the current study area using Bejerman's method. Sissakian et al. (2021) evaluated the road cut slopes along the Haibat Sultan Mountain using Bejerman's Method and concluded that majority of the road cuts are unstable and are prone areas for future sliding. The aim of this research is to perform geotechnical assessment of the unstable slopes along the studied parts of the new Highway using qualitative field method which was developed by Bejerman (1994). Moreover, to give recommendations how to stabilize the unstable slopes.

2. Geological Setting

The geological setting concerning the studied parts of the new Highway is briefly mentioned hereinafter with emphasize on the rock types and topography. The exposed rocks within different geological formations along the studied parts of the Highway are briefly mentioned. The exposed rocks along the Highway are: 1) mainly clastic; including claystone and sandstone, and 2) carbonates;

including limestone and dolostone. The clastic are usually soft; therefore, cannot resist weathering and erosion processes, which are naturally occurring phenomena being very active during rainy seasons. The carbonates are hard; therefore, they resist weathering and erosion processes; however, they are exposed and inclined due to tectonic disturbances, then are prone areas for landslides, rock fall, and toppling. The exposed rocks along the studied part of the Highway are fractured and destroyed due to the tectonic forces exerted from the collision of the Arabian and Eurasian plates (Fouad, 2015); the studied area is located in the northeastern part of the former plate.

3. Materials and Methods

We have studied satellite images, geological and topographical maps of different scales, and relevant published articles and reports, beside field visit to perform this research. However, the Bejerman's Method was used following LPI form to evaluate the studied six stations (Fig. 2). Bejerman's Method is used in the current research work because: 1) It is a field method, 2) No need for specialists to conduct the analysis of the unstable slopes, 3) No need for special equipment and laboratories, and 4) It is very quick and cheap method, as compared to other methods.

3.1. Field Investigation

Field investigation was performed to the six stations along the new highway; although tens of unstable slopes were observed along the Highway; but we have selected the severely unstable slopes. At each of the six stations, we have used the LPI form Fig. 2 and recorded the 10 aspects, which are present in the LPI form to identify the potentially unstable parts of the slopes and to collect the necessary field data to perform the geotechnical assessment. The acquired data at each station are presented in Table 1. The required data for the 10 characteristics mentioned in the Bejerman's Method (Fig. 2) at each station were measured and/ or estimated and recorded as follows: The slope height (No. 1) by measuring tape, slope angle (No. 2) by Brinton compass, grade of fracture (No. 3) and of weathering (No. 4) by direct inspection of the outcrops based on Hack and Price (1997), gradient of discontinuity (No. 5) by Brinton compass, spacing of discontinuity (No. 6) by measuring tape; both last 2 aspects were documented based on Hoek and Bray (1981) and Bieniawski (1989), orientation of discontinuity (No. 7) by comparing the direction of the discontinuity with the road cut direction; vegetation cover (No. 8), water infiltration (No. 9), and previous landslides (No. 10) by direct inspection of the concerned areas based on Hangr et al. (2003).

Table 1. Brief field description of the six studied stations

Studied station	Mass movement	Field observations
1	Active rockfall	Rockfall in limestone beds within the Pila Spi Formation and clastics of the Gercus Formation (Fig. 3).
2	Recent landslide	Recent landslide in clastic rocks of the Fatha Formation that has disturbed about 50 m of the Highway, mainly due to the inadequate drainage system (Fig. 4).
3	Recent landslide	Landslide that has cracked and disturbed the shotcrete south of the Mirawa West Tunnel for about 25 m within the black clastics of the Kolosh Formation (Fig. 5).
4	Recent landslide	Landslide that has cracked and disturbed the shotcrete near the south of the Mirawa West Tunnel for about 15 m within the black clastics of the Kolosh Formation (Fig. 6).
5	Unstable slope	Small landslides and creep phenomena along a high slope (about 125 m) within the clastics and gypsum beds of the Fatha Formation (Fig. 7).
6	Rockfall	A high (about 75 m) and steep (about 75º) road cut within the limestone beds of the Pila Spi Formation (Fig. 8).

Station No. ☐ Coordinates N: E: Elevation (m) Date ☐ ☐ ☐

1. Slope Height (m)	Estimate	**2. Slope Angle**	Estimate	**3. Grade of Fracture**	Estimate
1 -- 8	**1**	< 15°	**0**	Sound	**0**
9 --- 15	**2**	15° -- 30°	**1**	Moderately fractured	**1**
16 – 25	**3**	30° -- 45°	**2**	Highly fractured	**2**
26 – 35	**4**	45° -- 60°	**3**	Completely fractured	**3**
> 35	**5**	> 60°	**4**		

4. Grade of Weathering	Estimate	**5. Gradient of Discontinuities**	Estimate	**6. Spacing of Discontinuities**	Estimate
Fresh	**0**	< 15°	**0**	> 3 m	**0**
Slightly weathered	**1**	15°--- 30°	**1**	1 --- 3 m	**1**
Moderat. weathered	**2**	30°--- 45°	**2**	0.3 --1 m	**2**
Highly weathered	**3**	45°--- 60°	**3**	0.05 -- 0.3 m	**3**
Complet. weathered	**4**	> 60°	**4**	< 0.05 m	**4**
Residual Soil	**5**				

7. Orientation of the Discontinuities	Estimate	**8. Vegetation Cover**	Estimate
Favorable	**0**	Void (< 20%)	**0**
Unfavorable	**4**	Scarce (20 - 60%)	**1**
		Abundant (> 60%)	**2**

9. Water Infiltration	Estimate	**10. Previous Landslides**	Estimate
Inexistent	**0**	Not registered	**0**
Scarce	**1**	Registered (Small volume)	**1**
Abundant: Permanent	**2**	Registered (High volume)	**2**
Seasonal	**3**		

1 + 2 + 3 + 4 ± 5 + 6 + 7 + 8 + 9 + 10 = ☐

LPI Grades: I (Small) (0 – 5) III (Low) (11 – 15) V (High) (21 – 25)
II (Very low) (6 – 10) IV (Moderate) (16 – 20) VI (Very high) (> 25)

The LPI value is obtained by adding the estimations of attributes 1 to 10. If the orientation of the discontinuities is favorable, subtract the estimation of the gradient.

Observations:

Fig. 2. LPI estimation form of the Bejerman (1994)'s Method

We have calculated the LPI values as proposed by Bejerman's Method (1994) at the selected six stations where we have identified unstable slopes. The LPI assesses landslide possibility for rock slopes along mountainous roads as well as in natural slopes (Bejerman, 1994).

3.1. Field Description of the Studied Stations

The six stations along the new Highway represent those areas where slope failures have occurred. At each station, a detailed description is given including the type of recent slope failures that have occurred and other relevant observations (Table 1).

4. Results

The following results from field investigation and application of Bejerman's (1994) Method were acquired.



Fig. 3. Station No. 1, Active rockfall in station No.1, note the fallen rocks and the absence of side ditch



Fig. 4. Station No. 2, Damaged road due to unstable slope and inadequate drainage system



Fig. 5. Station No. 3, Slope failure south of the Mirawa West Tunnel, note the damaged shotcrete and the fallen materials



Fig. 6. Station No.4, Failure in the shotcrete, note the absence of drainage ditches



Fig. 7. Station No.5, note the unstable slope with a lot of waste dumped materials



Fig. 8. Station No. 6, note the bare road cut, the side ditch is full of fallen materials and the accumulated fallen materials between the slope and the side ditch

4.1. Landslide Possibility Index (L.P.I.)

The method of Bejerman (1994) was applied in the six selected studied stations (Fig. 1) using the special form (Fig. 2) to indicate the status of the stability of the studied road cut slopes, based on the L.P.I. classification given by Bejerman (1994 and 1998) (Table 2). The results of the scored marks from the special form (Fig. 2) are presented in Table 3. The scored L.P.I. values at each station (Table 3) were compared with the failure possibility classification established by Bejerman (1994 and 1998), which consists of six classes (Table 3). The grade, category, hazard zone and failure possibility were accordingly indicated at each of the six studied stations and presented in Table 4.

Table 2. Landslides hazard classification (After Bejerman, 1994 and 1998)

Landslide Possibility Index (L.P.I.)			Failure Possibility	L. P. I. Value	Hazard Zone
Grade	**Category**	**Estimation**			
VI	Very High	> 25	High	> 25	High Hazard
V	High	21 – 25	Moderate		
IV	Moderate	16 – 20	Low	11 – 24	Moderate Hazard
III	Low	11 – 15	Very Low		
II	Very Low	6 – 10	Small	< 10	Low Hazard
I		0 – 5			

Table 3. Raw field data and ratings of L.P.I. (After Bejerman, 1994) of the six studied stations

Studied station No.	Numbers of the used characters in L.P.I. Form										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
	Slope		**Grade of**		**Discontinuities**						
	Height (m)	**Angle (^{O})**	**Fracture**	**Weathering**	**Gradient (^{O})**	**Spacing (m)**	**Orientation**	**Vegetation Cover (%)**	**WateInfiltration (%)**	**Previous land Slide volume**	**Rating L.P.I.**
1	38	78	C. Fractu.	H. We.	65	0.5-1	Unfa.	Void	Season.	Small	
	5	4	3	3	4	2	4	0	3	1	**29**
2	26	65	H. Fractu.	H. We.	46	1-3	Unfa.	Void	Season.	High	
	4	4	2	3	3	1	4	0	3	2	**26**
3	28	81	H. Fractu.	H. We.	82	0.5-0.3	Unfa.	Void	Season.	Small	
	4	4	2	3	4	3	4	0	3	1	**28**
4	30	68	H. Fractu.	H. We.	63	0.5-0.3	Unfa.	Void	Season.	Small	
	4	4	2	3	4	3	4	0	3	1	**28**
5	68	48	H. Fractu.	H. We.	22	1-3	Favo.	Abun.	Season.	Small	
	5	3	2	3	-1	1	0	2	3	1	**19**
6	88	63	M. Fractu.	M.We.	13	0.3-1	Favo.	Scarce	Season.	Small	
	5	4	1	2	0	2	0	1	3	1	**19**

C. Fractur. = Completely Fractured, M. Fractur. = Moderately Fractured, Favo. = Favorable, Unfa. = Unfavorable, Season. = Seasonal, H. We. = Highly Weathered, M. We. = Moderately Weathered

Table 4. L.P.I. scored marks and grade, category, hazard zones, and failure possibility (After Bejerman, 1994) at the six studied stations

Stations	L.P.I.	LPI		Hazard Zone	Failure Possibility
		Grade	**Category**		
1	29	VI	Very High	High	High
2	26	VI	Very High	High	High
3	28	VI	Very High	High	High
4	28	VI	Very High	High	High
5	19	IV	Moderate	Moderate	Low
6	19	IV	Moderate	Moderate	Low

5. Discussion

The results from the current study, which was based on field investigation and applying the Bejerman Method indicate that unstable slopes exist along the studied parts of the Highway representing already failure slopes and other potential areas for slope failures. To facilitate the discussion, the studied six stations are discussed. Recommendations are given for each station to keep as safe as possible.

5.1. Station No.1

This station is along a steep road cut (Fig. 3 and Table 1), it shows active rock fall of different sizes (Fig. 9). The fallen rock and other weathered material occasionally cover part of the road and fill the side drainage ditch along the active failure area. These are the reasons the station scored L.P.I. value of 29, which means High Failure possibility (Table 3). To keep the road cut as stable as possible, the following actions have to be considered: 1) Decreasing the slope angle of the rod cut, 2) Construction of a relevant drainage ditch on the top of the road cut-slope; in order to minimize rainwater infiltration in the bare rocks of the slope-cut, 3) Covering the road cut-slope by relevant metallic mesh; in order to prevent falling of small rock fragments, and 4) Maintaining the drainage side ditch by cleaning; in order to facilitate flowing of the rainwater.



Fig.9. Station No. 1, note the size of the fallen rocks and weathered materials

5.2. Station No.2

This station is north of Mirawa West tunnel (Fig. 1), it is a highly damaged road (Fig. 4). The main reason is the construction phases were not completed, including the side drainage ditches. Therefore, the rainwater has severely weathered and eroded, and enlarged the ditch, and accordingly the water has penetrated in the sub-base below the paved part, causing extreme damage to the road. Cracks up to 1.5 m in depth and 1 m in width can be observed in the pavement and the sub-base. Moreover, the road faces very steep slope towards a very deep valley, part of it was filled to keep the gradient of the road. The used materials; however, seem to be inadequate, not well graded and compacted. These are the reasons that the station scored L.P.I. value of 26, which means High Failure possibility (Table 3).

To keep the road as stable as possible, the following actions have to be considered: 1) Scrubbing the whole damaged part of the road, 2) Filling the depression by adequate materials with continuous dumping, 3) Lining the side drainage ditch by impervious material, so that the rain water cannot penetrate the sub-base, and 4) To keep the slope that faces the valley in gentle gradient and constructing relevant draining ditches; above and below the slope.

5.3. Stations Nos. 3 and 4

These two stations are nearby to each other (Fig. 1) and has the same failure mechanism; therefore, they were discussed together. Both stations suffer from damaged shotcrete (Figs. 5 and 6). The main reasons for the failure are: 1) Absence of top and side drainage ditches, 2) Steep road cut (Table 3), and

3) Absence of outlets along the shotcrete to drain the excess water that have increased the internal pore water pressure, such case is mentioned by Terzaghi (1934) and Terzaghi et al. (1996). These are the reasons that the two stations scored L.P.I. value of 28, which means High Failure possibility (Table 3). The damaged parts of the shotcrete range from less than 1 square meter up to 80 m^2 (Figs. 5, 6 and 10).

To keep the shotcrete as stable as possible, the following actions have to be considered:1) construction of drainage ditches and outlets, 2), decreasing the gradient of the covered road-cut slope, and 3) using better shotcrete materials.



Fig. 10. Station No. 3, a failure within the shotcrete. Note the high and steep slope, absence of drainage ditches and outlets, the fallen materials, and the cracked part above the tunnel

5.4. Station No.5

This station is facing steep slope of about 48º and height of 68 m. The exposed rocks are mainly soft clastics with thin interlayers of limestone and gypsum. These inhomogeneous materials beside the haphazard cuts along the slope by the local people have increased the slope stability problem. Although small failures have been seen along the slope; however, currently the slope is not dangerous, as the scored L.P.I. value is only 19, which means Low Failure possibility. However, if it is not well treated and not relevant protection measures are carried out, then the whole slope will fail, then the whole Highway will be blocked near this station. To keep the slope as stable as possible, the following actions have to be considered: 1) Stopping of haphazard cutting of the slope for different purposes by the local people, 2) Construction of drainage ditches on the top of the slope; as well as along the slope to avoid penetration of the rainwater in the exposed rocks and/or weather them, and 3) Preventing the local people from using large and heavy limestone blocks for levelling their farm lands and/or using them as fences, because the exerted forces by the weight of the blocks will increase the possibility of failure.

5.5. Station No.6

This station is within a high slope; 88 m, and a steep slope, 63º. The rocks are of hard limestone almost horizontal because it is the core of the Pirmam anticline; therefore, the station has scored zero for the character No.7; "Orientation of Discontinuities" (Table 3). The L.P.I. recorded value is 19, which means "Low failure possibility" (Table 4). Such a high and steep slope will be a potential area for mass movement if the beds are not horizontal; however, still there are some unstable parts in this station. Therefore, the slope suffers from fallen rock pieces and blocks, and weathered materials which filled the side drainage ditch (Fig. 8). To keep the slope as stable as possible, the following actions have to be considered: 1) Constructing drainage ditch on the top of the slope to prevent the rainwater from penetrating through the bedding planes of the limestone, and flowing down the steep slope, 2) Covering the slope with a relevant metallic mesh, and 3) Continuously leaning the side draining ditch (Fig. 8).

5.6. Miscellaneous

The studied part of the Highway suffers from tens of slope failures as those described in the six stations. Different types of failures can be seen along the highway (Fig. 11). Majority of the slope failures are due to: 1) absence of top and side drainage ditches, 2) Ignoring the maintenance of the ditches; when they exist (Fig. 11 a), 3) steep road cut-slopes, 4) high road cuts without using benches; even though, the used heights are not relevant (Fig. 11 d), 5) uncompleted parts of the highway, which will be severely weathered and eroded (Fig. 4), 6) The used materials in the shotcrete are inadequate, 7) The used materials in dumping of lowlands; for levelling are not suitable and/or not well compacted (Fig. 11 c). Moreover, some of the planned tunnels are abandoned (Fig. 12), for different reasons. It is highly recommended to complete those channels to maintain the standards of the constructed Highway.



Fig. 11. Slope failures along the studied part of the Highway, a) Small landslide; north of Station No.1, b) Rill erosion along a road cut, opposite to the Station No.1, c) Slope failure within dumped materials for leveling, 300 m north of the Mirawa East tunnel, and d) severe rill erosion, opposite to the site shown in "c"



Fig. 12. The abandoned Hareer tunnel, a) general view, b) the inlet of the tunnel with the inner lining form, note the quantity of outflowing water

5. Conclusions

From the studied parts of the Erbil- Hareer Highway through six stations using Bejerman's Method, we can conclude that the recognized slope failures are of different types and sizes. The main reasons for

those failures are: 1) Improper road-cuts as far as the height and slope are concerned, 2) Absence of drainage ditches, 3) Incomplete parts of the constructed Highway, 4) Improper treatments of the road embankments, used sub-base, shotcrete materials, 5) Ignoring the required continuous maintenance of the road and its facilities.

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