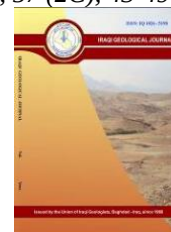




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Comparative Analysis for Bejerman Versus Kinematic Methods for Slope Stability Assessment

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Abstract

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In a previous study, the stability of eleven Haibat Sultan Road Crossing stations was assessed using Bejerman's Method. Amongst these 11 studied stations with the highest potential for slope failures, four stations (4, 5, 6, and 9) could be evaluated using kinematic analyses in another previous paper. This study focused on comparing the analysis results of these four stations using the Kinematic Method with those assessed by Bejerman's Method. The outcome showed negative relations, whereby an inverse correlation between the Landslide Possibility Index and the Factor of Safety has been found. Such a comparison enables us to use extrapolations to analyze the missing data. Both sets of data from the two methods of analysis, which were obtained by the two methods, were collected, compared, and discussed.

Keywords: Bejerman's Method; Correlation; Landslide Possibility Index (LPI); Kinematic analysis; Slope failure; Slope stability

1. Introduction

Several examples of slope instability appear on the roadside across Haibat Sultan Mountain near Koya town. This is attributed to shortcomings in the stability design of the bed slopes at the two sides of the road and the existence and orientation of planes of bedding, joints and faults, which all impact the rock strength, rock structure and stability of the slopes. Two of this road's most famous slope failures occurred on 14.12.2013 and 8.5.2016 (Jassim et al., 2019) (Fig. 1).



Fig. 1. Slope failures at Haibat Sultan Road: **a)** on 14.12.2013, **b)** on 8.5. 2016

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Several studies were performed dealing with the issue of road instability. In addition to the primary two works of Sissakian et al. (2021 and 2022), other instructions, guidelines, and published publications were reviewed. Among those studies, the remarkable ones are Markland (1972), Hocking (1976), Hoek and Bray (1981), Goodman (1989), Canadian Geotechnical Society (1992), Hertzberg (1996), Watts et al. (2003), Hack et al. (2003), Wyllie and Mah (2005).

The study area is located along the road that climbs Haibat Sultan Mountain, near Koya town (Fig. 2). This road is one-lane with a steep inclination. Different types of slope failures occurred. The road shoulder (along the whole road) consists mainly of limestone beds with a steep dip of the Pila Spi Formation (Fig. 1 b). All the studied stations using both methods of Bejerman and Kinematic in the previous two studies and the three parts of the road are clearly marked in Fig. 2. This study aims to compare the results of the assessment using the Kinematic Analysis Method, as conducted by the authors in a previous study (Sissakian et al., 2022), with the results obtained from another previous study by the same authors using a qualitative field method known as Bejerman's Method (Sissakian et al., 2021). Furthermore, the objective is to examine the appropriateness of Bejerman's Method, which is both simple and inexpensive, for evaluating slope failures as an alternative to the more intricate and expensive Kinematic Method.

While several studies have been conducted on slope instability issues along the road in Kurdistan Region-Iraq, there is still a lack of comprehensive research in this area. However, no previous research has utilized the Kinematic and Bejerman's approaches simultaneously, nor have any comparative studies have been conducted between these methodologies in Iraq or the Kurdistan Region-Iraq, as far as the authors know.

In this study, we attempted to cost-effectively use the data from two slope stability evaluation methods (Bejerman's and Kinematic methods). In this procedure, presenting the results graphically (cross-correlation) and determining a correlation between the two methods will allow us to find a way to reduce the time and cost required for slope stability assessment by reducing the number of stations that use the more expensive and time-consuming method.

2. Materials and Methodology

In this study, two previously published works were utilized. The first work involved a geotechnical assessment using the Qualitative Bejerman's Method, as described by Sissakian et al. (2021). The second work involved a geotechnical evaluation utilizing Kinematic analysis, also described by Sissakian et al. (2022). The obtained outcomes from both approaches were compared to demonstrate their correlation. The former refers to a rapid, uncomplicated, cost-effective technique, and the outcomes can be instantly acquired in the field. The latter refers to a process that is both time-consuming and costly. It requires specialized machinery for sample preparation and collection, as well as specialist labs and personnel to run the tests and analyze the results.

2.1. Comparison Method

The data acquired from Sissakian et al. (2021), which used Bejerman's (1994) Method, based on data acquired from 11 studied stations along the concerned road, were compared with those acquired by Sissakian et al. (2022) using kinematic analysis, using data of four stations among the 11 studied stations. The used data are presented in Table 1.

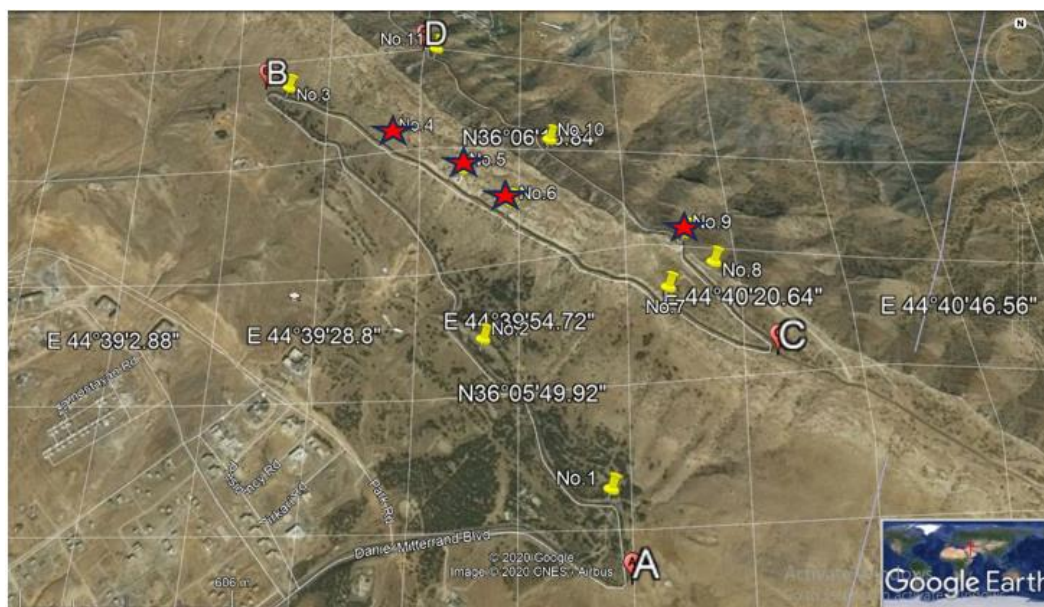


Fig. 2. Google earth image of the studied part of Haibat Sultan crossing road. The studied stations by the Kinematic Method are in red, in yellow are the locations of studied stations by Bejerman's Method, and in white are the three parts of the road (A-B, B-C and C-D)

A simple comparison between the two mentioned methods, including different aspects, was also presented (Table 2). Among those aspects are the details of the requirements to perform each method. From this simple comparison, the advantages and disadvantages of each method can be seen.

Table 1. Data acquired by Bejerman's Method and the Kinematic Method

Station No.	Data of Sissakian et al. (2021)					Data of Sissakian et al. (2022)	
	Scored Mark L.P.I.	Landslide		Hazard Zone	Failure Possibility	Kinematic Method	
		Possibility Index Grade	Category			Safety Factor	Sliding possibility
1	24	V	High	High	High	0.78	Plane sliding is low Medium sliding High potential
2	28	VI	Very High	High	Very High	0.66	
3	25	V	High	High	High	0.74	
4	19	IV	Moderate	Moderate	Moderate	0.91	
5	19	IV	Moderate	Moderate	Moderate	0.90	
6	28	VI	Very High	High	Very High	0.66	Sliding may occur
7	27	VI	Very High	High	Very High	0.68	
8	12	III	Low	Low	Low	1.10	
9	17	IV	Moderate	Moderate	Moderate	0.85	
10	17	IV	Moderate	Moderate	Moderate	0.98	
11	15	III	Low	Low	Low	1.02	

* Values of the Factor of Safety in red are indicated in Fig. 4

Table 2. A comparison between Bejerman's and the Kinematic methods for slope stability assessment.

No.	Subject	Methods	
		Bejerman (1994)	Kinematic
1	Work type	Field	Field and laboratory
2	Work requirements	Geological compass	Rock coring machine, geotechnical laboratory
3	Work personnel	One geologist or	Geologist or engineer, geotechnical laboratory
4	Required data	Measuring and	Dip and strike of bedding planes and joints,
5	The time needed to	One working day	10 – 12 working days
6	Accuracy of results	Acceptable	Very accurate
7	Recommended	Natural and artificial	Natural and artificial slopes within rocks and
8	Cost	Very low	Very high

3. Geological Setting

The studied road is constructed crossing the Haibat Sultan road, representing the southwestern limb of a large anticline named Khalikan. The dip slope of the southwest limb is mainly defined by well-bedded and hard carbonate rocks of the Pila Spi Formation (Sissakian and Jiburi, 2014), including the studied stations (1 -7) with daylighting slopes. The anti-dip slope of the limb is represented by the soft clastic rocks of the Gercus Formation (Sissakian and Jiburi, 2014), including the studied stations (8- 11) (Fig. 2) The rocks along the studied part of the road are well bedded and highly jointed; usually of two prominent sets (Fig. 3) with an attitude of $115^{\circ}/60^{\circ}$ SW, and $200^{\circ}/80^{\circ}$ SE, respectively. The bedding plane strikes $120^{\circ}/50^{\circ}$ S.W. (as average), whereas the slope faces along the road within the dip slope and anti-dip slope have average orientations of $120^{\circ}/65^{\circ}$ SW and $220^{\circ}/70^{\circ}$ SW, respectively.

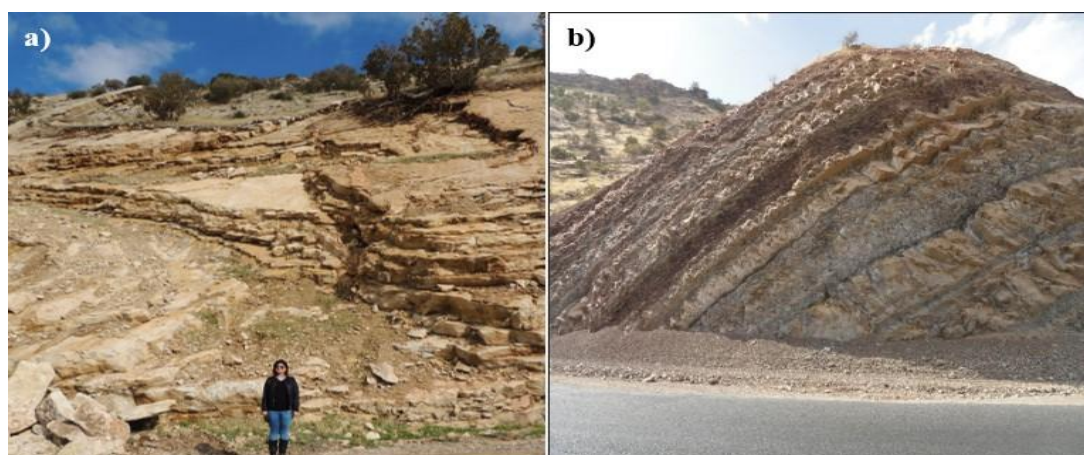


Fig. 3. Well-bedded and jointed rocks, a) Carbonates of the Pila Spi Formation along the dip slope part of the road exhibiting daylight slope, and b) Clastic rocks of the Gercus Formation along the anti-dip slope

4. Results and Discussion

4.1. Concept of the Comparison

Geotechnical evaluation can be conducted using many approaches, including Bejerman's (a procedure performed in the field) and the Kinematic (involving both field and laboratory work).

Nevertheless, every approach has its benefits and drawbacks (Table 2). An important component to consider in the geotechnical assessment of slopes is the safety factor, which cannot be determined using Bejerman's technique. Hence, to determine the safety factor, it is recommended that the kinematic technique be utilized. However, this procedure is quite costly and requires many prerequisites (Table 2), which are not readily accessible. To address this challenge, the Bejerman approach can be used for any slope being examined by doing a limited number of kinematic tests at several places within the same area of interest.

The acquired values of the safety factor can be correlated with the acquired LPI values (From Bejerman's method) to indicate the safety factor values in all stations where only Bejerman's method was applied. Because the kinematic method is more expensive than Bejerman's method, a geotechnical assessment for a slope can be performed by performing the latter method in more stations (along the concerned slope) than the former method. The correlation coefficient, however, will be more relevant as much as the number of the performed kinematic method is higher. We recommend a percentage of performing the former (Kinematic method) to the latter (Bejerman's method) of (25 – 35) % to speed up the work and decrease the cost. Accordingly, the assessment cost will be lower than using only the kinematic method for all stations.

4.2. Comparison Between Data of Kinematic and Bejerman's Methods

The data used in the current study (Table 1) were compared. The compared data of the factor of safety and the LPI values in the four stations No. 4, 5, 6, and 9 (Table 1) were plotted as a curve using Excel data, it showed a negative correlation (Fig. 4) with a correlation coefficient of -0.91352. As the factor of safety decreases, which means more failure possibilities, the LPI values increase, indicating a very high possibility of failure. Then, we manually extrapolated the remaining seven stations (1, 2, 3, 7, 8, 10, and 11) using their known LPI grades (Table 1). The intersections of the extrapolated values of LPI with the correlation curve indicate the values of the factor of safety of the seven stations (Fig. 4).

From the correlation diagram (Fig. 4), we have estimated the values of the Factor of Safety in those stations where no Kinematic method was used, i.e., stations studied only by Bejerman's method. This means that the safety factor can be estimated using Bejerman's method, provided that the Kinematic method is used in certain stations.

5. Conclusions

According to the comparison analysis, the following findings can be derived: The safety factor values were plotted against the LPI values for the four stations where Bejerman's and Kinematic methods were employed for assessment. The result showed an inverse correlation (-0.91352) between the LPI and the Factor of Safety. As the factor of safety drops, suggesting a higher likelihood of failure, the LPI values grow, indicating a very high probability of failure. The safety factors in stations not analyzed using the Kinetic approach, namely those evaluated only using Bejerman's method, can be readily identified in the correlation diagram. A significant reduction in both time and cost can be achieved by conducting both the expensive Kinematic Method and the relatively cheaper Bejerman's

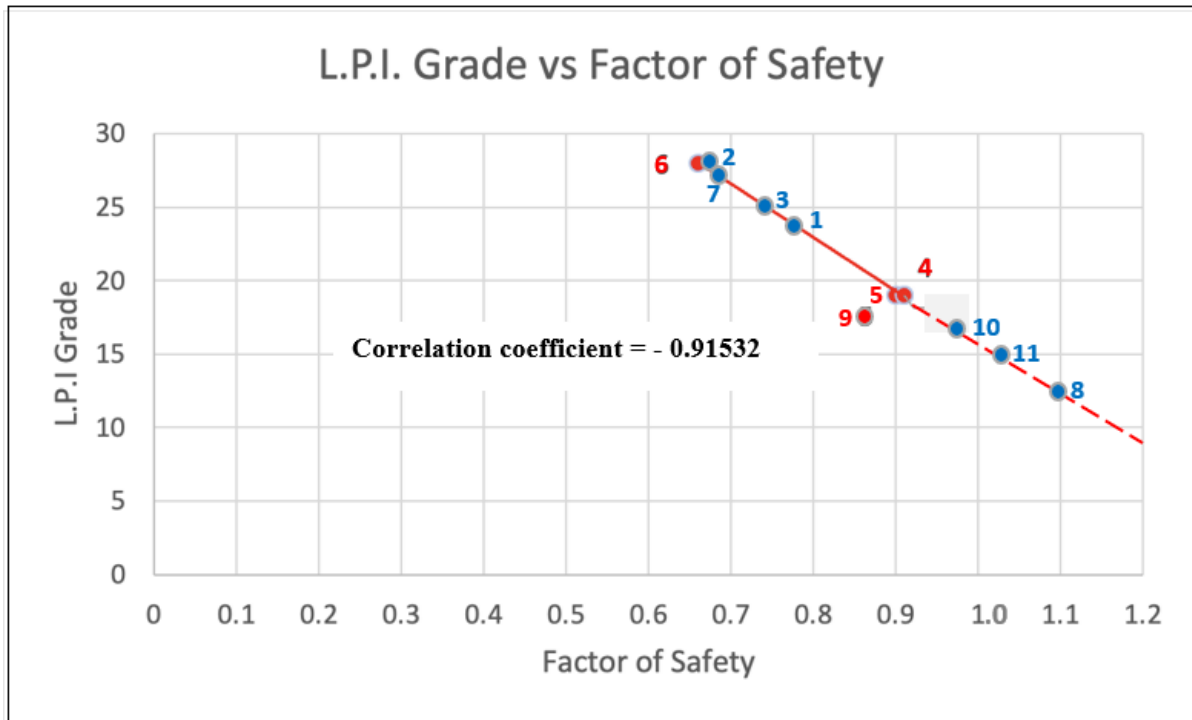


Fig. 4. Comparison of LPI Grade vs Factor of Safety. In red color are stations studied by the Kinematic Method

Method of assessment on a select number of stations, as shown in Table 2, for the remaining stations, which were assessed using only the cheaper Bejerman's Method, the factor of safety can be determined directly from the correlation graph.

6. Recommendations

1- After acquiring positive results from comparing the results of the Kinematic Method with Bejerman's Method in road stability assessment, the results of the current study were used to assess slope stability of roads, quarries, mines, etc.

2- It is also recommended to adopt both methods of stability assessment on a small number of stations, which is just enough to construct the correlation trend, whereby the rest of the stations can be done with the cheaper and faster method (Bejerman) to reduce the cost of stability assessment considerably.

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