DETERMINATION OF ROCK SLOPE STABILITY USING STEREOGRAPHIC PROJECTION BETWEEN SULAV AND AMADIYAH RESORTS – A STUDY FROM NORTHERN IRAQ

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ABSTRACT: Geological discontinuities play a significant role in the assessment of rock slope stability. Rock slope stability has been studied on the main road between Sulav and Amadiyah resorts in Duhok governorate on the southern limb of Mateen anticline, to determine the expected rockslides on this road. Five stations were chosen to study these rockslides that may occur on these steep slopes. All these stations were within the Pila Spi Formation that consists of hard dolomitic limestone and covering the areas from Sulav resort towards Amadiyah district with a length of up to 2.5 km. The stereographic analysis was used to study and classify the stability of these slopes. The analysis showed in all stations the possibility of plane sliding to happen on the bedding plane, and the wedge sliding between the bedding plane and planes of all joint sets, as well as the occurrence of rockfall on some stations.

Keywords: Rock slope stability; Stereographic analysis; Amadiyah; Sulav.

تحديد استقرارية المنحدرات الصخرية باستخدام الإسقاط الستيريوغرافي بين مصيفي سولاف والعمادية - دراسة من شمال العراق

هدير غازي محمد اديب* و ابراهيم سعد ابراهيم الجميلي

الملخص: تلعب الانقطاعات الجيولوجية دورًا مهمًا في تقييم استقرار المنحدرات الصخرية. تم دراسة استقرارية المنحدرات الصخرية على الطريق العام بين مصيفي سولاف والعمادية في محافظة دهوك وعلى الجناح الجنوبي لطية متين المحدبة، وذلك لتحديد الانزلاقات الصخرية المتوقعة على هذا الطريق. اختيرت خمسة محطات لدراسة الانزلاقات الصخرية التي قد تحدث على تلك المنحدرات؛ والمتكونة من تكوين بيلاسبي الجيري الدولومايتي الصلدة والشديدة الانحدار، وابتداءاً من مصيف سولاف باتجاه مصيف العمادية وبطول يصل الى حدود 2.5 كم. استخدم التحليل الستيريوغرافي في دراسة وتصنيف استقرارية تلك المنحدرات الصخرية. تبين من التحليل احتمالية حصول الانزلاقين المستوي، على اسطح التطبق والاسفيني بين مستويات التطبق ومستويات مجاميع الفواصل في كل محطات الدراسة، فضلاً عن حدوث الساقط الصخري في بعض المحطات.

الكلمات المفتاحية: استقرارية المنحدرات الصخرية؛ التحليل الستيريوغرافي؛ العمادية؛ سولاف.

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1. INTRODUCTION

Most road network, in the study area, is located in mountainous terrain. It is a very steep topography and slope failures are often caused when road construction is undertaken. Large-scale instability phenomena in cut slopes frequently occur in structurally and geologically complicated regions. Rockslides or so-called slope failure or landslides are considered natural phenomena with geological hazards that may occur suddenly or over time. A simple landslide definition according to Working Party on World Landslide Inventory (WP/WLI) (1990) and Cruden (1991) is "The movement of a mass of rock, earth or debris down a slope". Landslides refer to outstanding materials and environmental challenges to the societies living in areas exposed to various risks of landslides (UNISDR, 2015).

Geological discontinuities play an important role in assessing rock slope stability. Particularly, the orientation of geological discontinuities i.e. dip direction and dip angle with respect to the slope orientation represents a significant input parameter in the assessment of rock slope stability.

The risk of the rockslides occurs when parts of the rocks move, slide, and then collapse due to the overpowering of the catalytic forces against resistant forces for sliding. The catalytic forces are attributed either to natural or to human activity factors. The natural factors include tectonic and gravity activities, exposition of the region to differential weathering, intense rainfalls, rapid snow melting, and ground vibration by earthquakes. The human activities involve vegetation removal, excavation operations, manmade activities represented by the removal of rock masses under the roads during road cut operations, construction of buildings, and residential houses in the mountainous area. All of these factors lead to unbalancing the rock masses and soils and consequently become weak, and their strength represented by the coherence and friction forces are reduced against the movement. The daylighting slope refers to a slope where the discontinuities dip at an angle less than the exposure slope angle and in the same direction of slope inclination. The areas below the southern limb of Mateen anticline on the main road linking between Sulav and Amadiyah resorts are considered one of the most vulnerable areas where the daylighting rock layers are highlighted (Markland, 1972). This is due to the cutting road construction in the region, which is considered an important tourist place. The main failure mechanisms shown in this study can be summarized as planar failure which is governed by the main discontinuity dipping in the direction of the slope. The wedge failure mechanism is governed by two intersection discontinuities with their intersection lines dipping towards the slope. Finally, the rockfall consists of loose blocks or slabs due to slipping, rolling, or toppling on the slope.

The study area is considered one of the areas exposed to the risk of landslides where the occurrence of rock cuts prevails (daylighting). This is due to human activities represented by the road cutting operations in these areas that lead to landslides. One of the reasons that help to slide is the street design line, which in some parts is at a high angle with the direction of the bedding strike. In this case, the layers form a weak zone, which allows the catalytic forces for sliding to overcome the anti-sliding forces and triggered the landslides. This is due to weak cohesion and friction forces with increasing the weight coefficient of the materials. The higher the layers dip, the greater their instability and the failure start to move downward or remain in an unstable situation. For this reason, this area was considered one of the areas where a high risk of landslides is expected, as well as the rockfall, in which the rock masses generally fall free from the highest slopes, particularly in the areas where rocks are daylighted.

2. LOCATION OF THE STUDY AREA

The study area is located on the main road between Sulav and Amadiyah resorts in Duhok governorate – The Kurdistan Region of Iraq. The road is estimated for about 2-3 km Long, and the area is about 65 km NE of Duhok City, between the longitudes (43° 28' 25") and (43° 29' 55") E, and latitudes (37° 06' 13") and (37° 06' 18.72") N. (Fig. 1).

3. GEOLOGY OF THE STUDY AREA

The study area is situated geologically on the southern limb of the Mateen anticline within the High Folded Zone of Iraq, (Fig. 2). The exposed rocks are of the Pila Spi Formation of the Middle-Upper Eocene. It consists of well-bedded, medium to thick layers, the pale white of hard dolomitic limestone. The formation is exposed, with a steep slope ranged from 40° to 70°, as a continuous belt surrounding the anticline in the form of continuous anticlinal ridges. These outcrops have a high density of joint sets are exposed on the northern edge of the main road between Sulav and Amadiyah resorts.

4. SEISMIC HAZARDS IN THE REGION OF THE STUDY AREA

Strong earth trembling triggers landslides in many different topographic and geologic settings. Rockfall, soil slides, and rockslides from steep slopes, with relatively thin disaggregated soil or rock, or both have been the most abundant type of landslide triggered by historical earthquakes (Wieczorek, 1996). The seismic hazards map of the investigated area indicates its occurrence in a zone classified as a minor damage zone, with seismic intensity between 4-5, (Al-Sinawi and Al-Qasrani, 2003), (Fig. 3). This means that the region is under the influence of seismic activity.

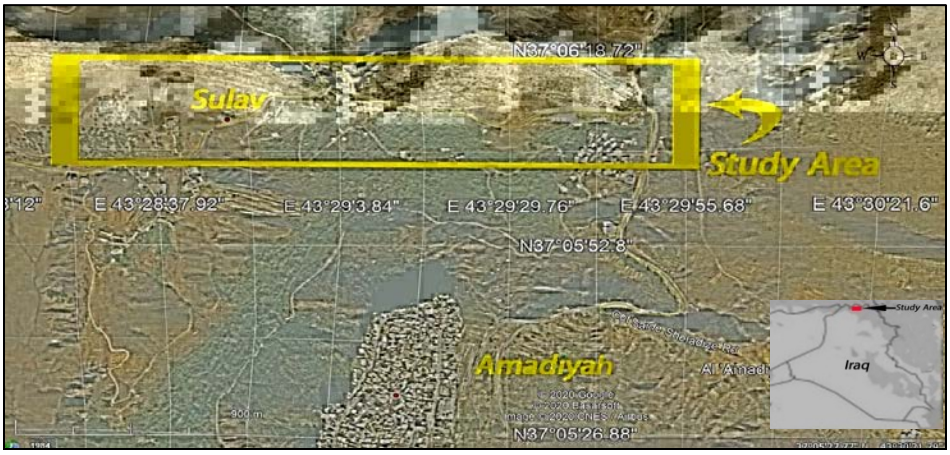


Figure 1. Google Earth image shows the location of the studied area.

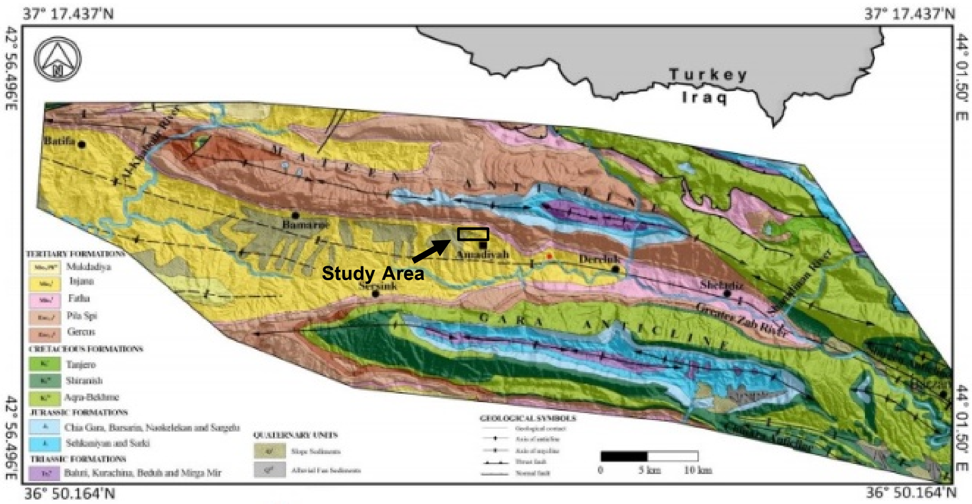


Figure 2. Geological map of the studied area (Sissakian and Fouad, 2012), imposed over the DTM (Sissakian *et al.*, 2020).

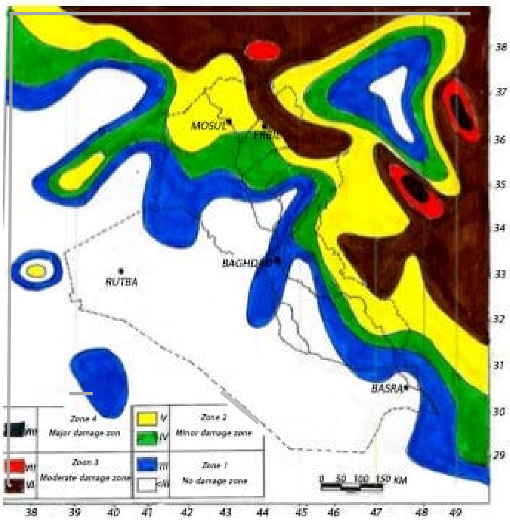


Figure 3. Seismic isointensity map of Iraq 1900-1988 (Al-Sinawi and Al-Qasrani, 2003).

5. OBJECTIVE

The main objective of this study is to assess the stability of these rock slopes by conducting geological analyses, to help the authorities establish appropriate engineering solutions to mitigate these landslides and to reduce their risks and severity on road users and buildings. Some of these analyses are to determine the type of landslide that occurs and is likely to occur on the side of the road, as well as the factors that affect the landslide.

6. METHODOLOGY

The method of the study includes both field and laboratory work. In the fieldwork, a detailed field survey of these landslides was carried out across five (5) stations on the main road linking Sulav and Amadiyah resorts, as evidence exists in these stations that indicate that landslides have occurred. It is therefore considered study stations. At each station, Layer and joint attitudes were measured in terms of the dip angle and dip direction, as well as taking photographs of each station. The laboratory work included analysing the obtained measurements using the Schmidt Net for Stereographic Projection, by representing the attitude of the layers and joints by great circles using software concerning stereographic projection. Both discontinuities and slope faces were represented as planes using the above-mentioned net (Wyllie and Mah, 2004). The stability or instability of the rock mass depends on its weight and on the external forces that affect it, such as the dynamic loads, the shear forces, and the pore water pressure on the sliding surface. This leads to define the safety factor, which is the ratio of the actual shear strength to the shear resistance required for equilibrium. It is accounted for by the angle of internal friction, (Department of the Army, US Army Corps of Engineer, 2003). The internal friction angle of the dolomitic limestone layers of the Pila Spi Formation was represented by a circle of 25º (Al-Jawadi, 2013).

The following symbols and colours are used below in the stereographic figures:

Ø: Circle of cohesion angle for discontinuities surfaces.

S0=Gs: General slope face and bedding attitude as great circles.

S1: First discontinuity attitude as a great circle.

S2: Second discontinuity attitude as a great circle.

S3: Third discontinuity attitude as a great circle.

S4: Fourth discontinuity attitude as a great circle.

S5: Fifth discontinuity attitude as a great circle.

Plane sliding

Wedge sliding

Rockfall

7. ANALYSIS OF THE ROCK SLOPE STABILITY

The rock slopes were analysed to examine their stability through selected stations in the Pila Spi Formation that is exposed in the study area as given in Table 1. The following is an analytical description of the landslide and rockfall of such rock slopes at these stations according to the Hunt classification (Hunt, 2006):

Table 1. Geological and engineering data of the study stations in the investigated area.

Stations	Formation	Bedding Attitude (S0) = General Slope Face (Gs)	First Discontinuity Attitude (S1)	Second Discontinuity Attitude (S2)	Third Discontinuity Attitude (S3)	Fourth Discontinuity Attitude (S4)	Fifth Discontinuity Attitude (S5)	Cohesion (Φ) Angle
1	Pila Spi Formation	80/180	88/250	56/293	60/066	77/089	---	25 °
2		62/178	80/074	51/300	58/044	84/096	---	
3		66/179	51/279	54/308	50/067	80/082	---	
4		61/179	80/260	44/291	30/058	83/075	79/289	
5		63/178	---	58/297	64/036	81/080	48/352	

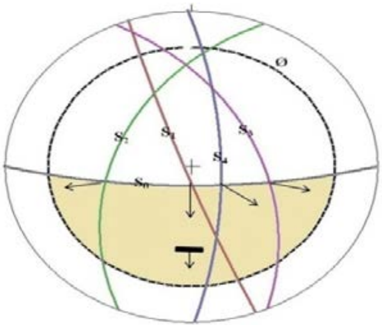


Figure 4. The stereographic diagram of the station (1) shows the relationship between the slope face (bedding plane) and the joints, and plane and wedge sliding on the limestone beds of the Pila Spi Formation.

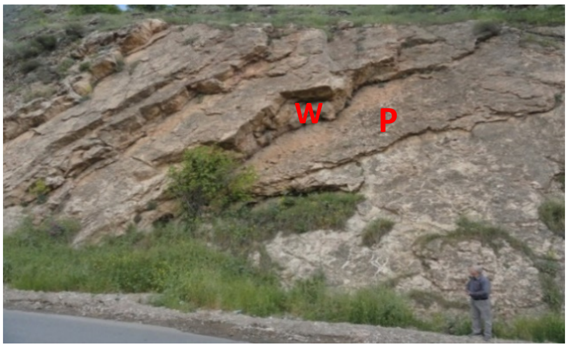
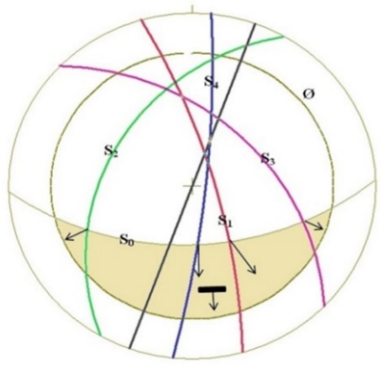
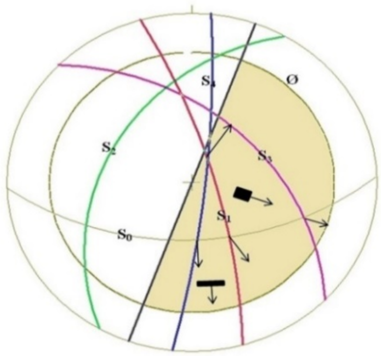


Figure 5. Showing the plane sliding (P), and the wedge sliding (W) at station 1.



(a)



(b)

Figure 6. The stereographic diagrams of the station 2 ((a) and (b)) show the relationship between the slope face (bedding plane) and the joints, and the different types of sliding on the dolomitic limestone of the Pila Spi Formation.

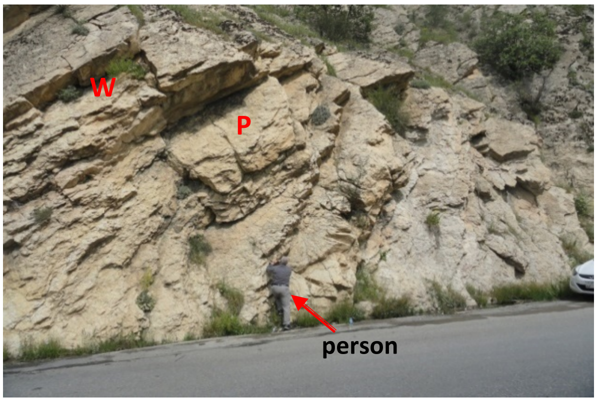


Figure 7. Showing the plane sliding (P), and the wedge sliding (W) at station 2a.

Station No. 1

The slopes of the dolomitic limestone of Pila Spi Formation were exposed on the left side of the main road overlooking the entrance of Sulav resort. This station is characterized by the possibility of the plane sliding on the bedding planes, which also represents the slope face, and the wedge sliding between the bedding planes and the discontinuities represented by the joint sets (S1, S2, S3, and S4) because the friction angle of the sliding surfaces is less than their dip angle (Fig. 4 and Table 1). Such joints also act as lateral release surfaces for sliding (Fig. 5).

Station No. 2

The first part of this station is the extension of the first station. The landslides are of two types: the plane sliding on the bedding plane, and the wedge sliding between the bedding plane and the same joint sets referred to in station 1, (Figs., 6(a), and 7). Whereas rockfall, plane, and wedge sliding occur in the second part of the station, because of changes in the direction of the main road and its intersection with the bedding strike (Figs., 6(b), and (8)). The presence of the joints helps to cause rockfall in this part of the station. Rockfall occurs on steep slopes; therefore the unstable rocks are difficult to stay in their position due to the effect of the joints so that they fall to the bottom of the slope. Some of the rockfalls are gathered in very narrow longitudinal ditches that have been prepared for this purpose. It is noted that most of these blocks settle down on the main road due to the narrow area of the shoulder of the road. Such blocks are nearly a few meters away from the buildings in Sulav resort, which threatens to destroy them and cause endanger to their inhabitants, as well as to cause significant environmental hazards (Fig. 8).

Station No. 3

This station is characterized by the occurrence of the rockfall as well as both plane and wedge sliding due to the high slope of the outcrops overlooking the side of the main road. The plane sliding occurs on the bedding plane, while the wedge sliding occurs between the bedding plane and the joint sets mentioned in the previous two stations, (Figs. 9, 10, and 11).

Station No. 4

This station consists of two parts, in each of which there is the plane sliding on the bedding planes, and wedge sliding between the bedding planes and the same joint sets described in the previous stations, as well as the rockfall in the other parts of this station, (Figs., 12 (a and b), 13, and 14).

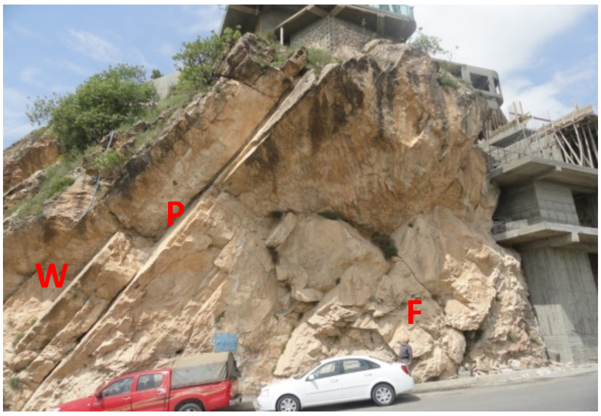


Figure 8. Showing the rockfall (F), and the plane sliding (P), and the wedge sliding (W) at station 2b.

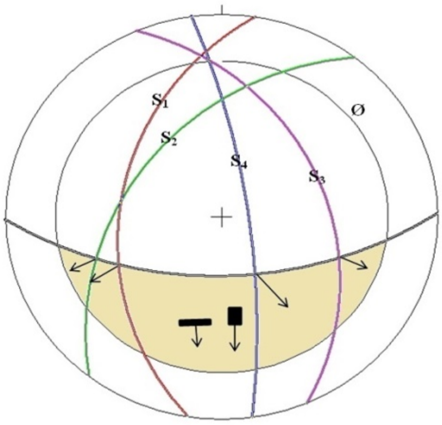


Figure 9. Stereographic projection of the station (3) shows the relationship between the slope face (bedding plane) and the joints, and the different types of sliding on the dolomitic limestone of the Pila Spi Formation.

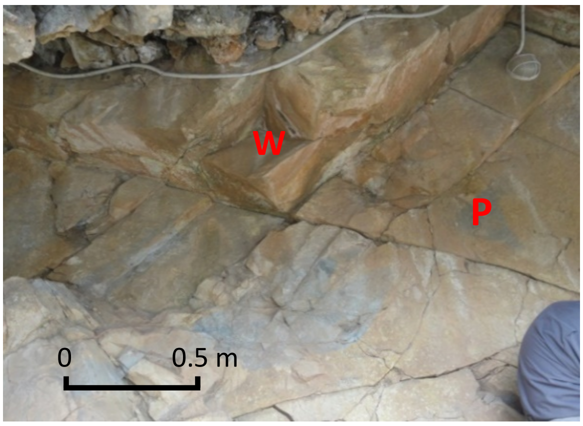


Figure 10. Showing the plane sliding (P), and the wedge sliding (W) at station 3.

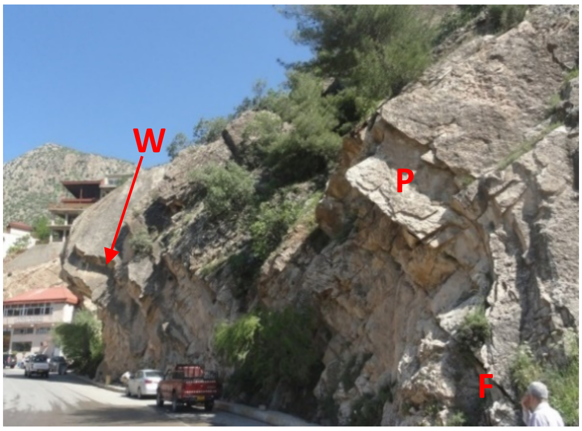


Figure 11. Showing the rockfall (F), and the plane sliding (P), and the wedge sliding (W) at station 3.

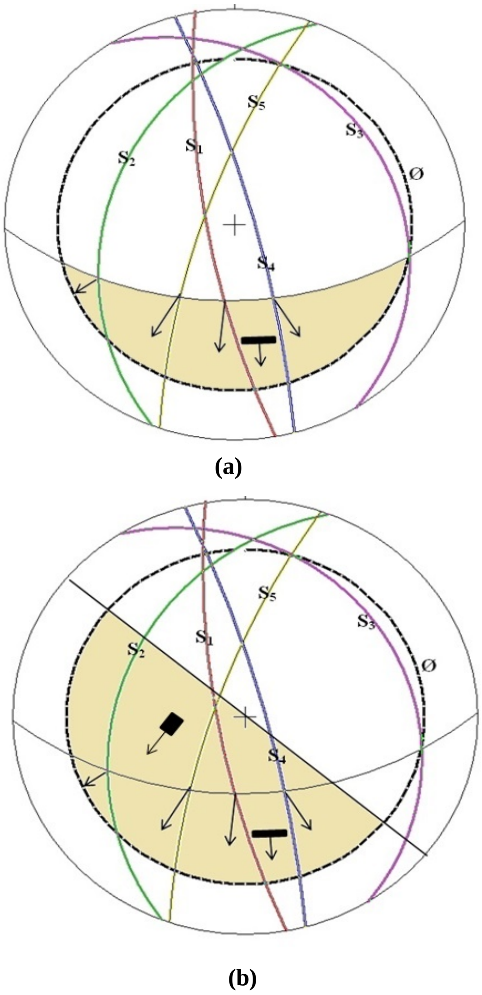


Figure 12. The stereographic diagrams of station (4a, b) show the relationship between the slope face (bedding plane) and the joints, and the different types of sliding on the dolomitic limestone of the Pila Spi Formation.

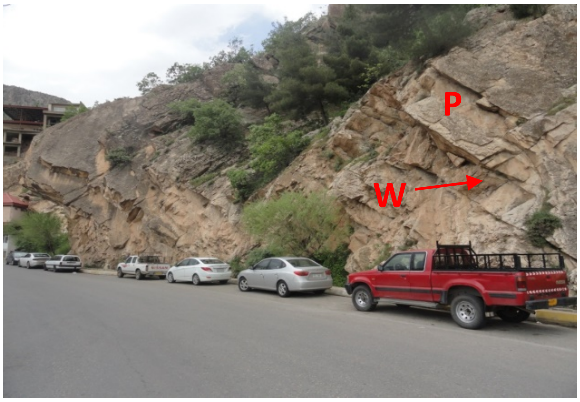


Figure 13. Showing the two types of the plane sliding (P), and the wedge sliding (W) at station 4a.

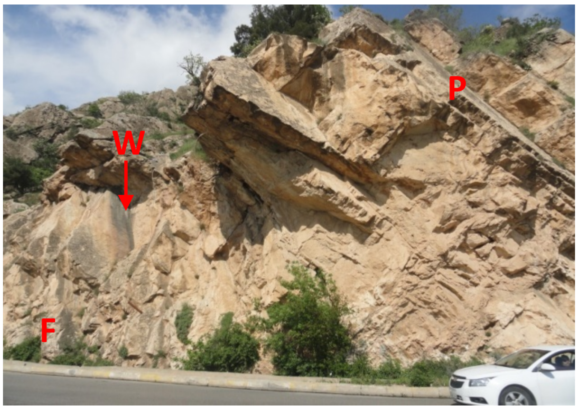


Figure 14. Showing the rockfall (F), and the plane sliding (P), and the wedge sliding (W) at station 4b.

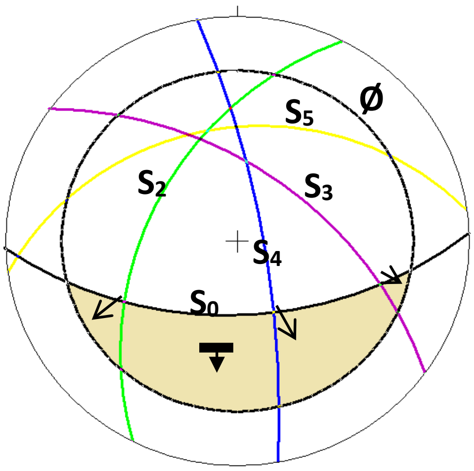


Figure 15. The stereographic diagram of station (5) shows the relationship between the slope face (bedding plane) and the joints, and plane and wedge sliding occurred on dolomitic limestone of Pila Spi Formation.

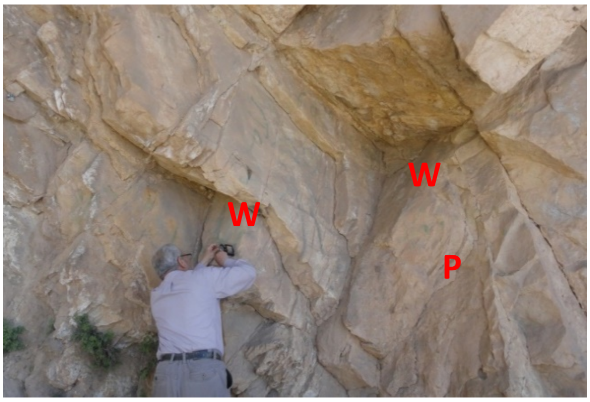


Figure 16. Showing the plane sliding (P), and the wedge sliding (W) at station 5.

Station No. 5

The rock slopes of this station are also exposed on the left side of the main road leading to Amadiyah district centre. The two types of sliding are repeated; plane sliding on the bedding planes, and wedge sliding between the bedding planes and the same joint sets for the above-mentioned stations, (Figs, 15 and 16).

8. CONCLUSION

Investigation of rock slopes along the road joining Sulav and Amadiyah resorts has achieved the following conclusions:

1. The rock slopes consist of limestone beds of Pila Spi Formation (Middle-Upper Eocene) at the southern limb of Mateen anticline trending east-west. These beds are dipping southward, with their dip slope ranges (40°-70°).
2. There are five sets of discontinuities (joints) disrupting the limestone beds at high angles and with various angular relations with the bedding strike.
3. Stereographic representation of bedding and discontinuity planes, as well as the angle of internal friction for limestone beds, have characterized the following modes of rock failure in the investigated area:
   a. In all study stations where the road trend coincides with the bedding trend (or at low angles), the rock sliding has been categorized into plane and wedge sliding. The plane sliding occurs down-dip of bedding planes where the joint sets accommodate as back and lateral release for sliding of rock blocks. Wedge sliding occurs down-dip of intersection line between conjugated joint sets that are with low to moderate angles with bedding planes. Meanwhile, wedge sliding occurs between vertical joints transversal to bedding strike and bedding planes as well.
   b. The rockfall occurs at some stations where the road trend is at a high angle with the bedding

strike.

4. In all study stations, it has been found that the longitudinal ditches, designed to accommodate falling and sliding rock masses, appear to be very close to the slopes where potential landslides and rockfall are likely to happen. This contributes to the falling of the rock masses on the main road immediately away from these ditches.

9. RECOMMENDATION

Based on the findings obtained from the analysis of the information relating to the types of rock sliding in the study area, some recommendations were proposed as follows:

1- Establish good drainage networks for rainwater and springs whose routes intersect with roads and maintain good monitoring of them, particularly during the rainy season, and ensure that they are not blocked and diverted.

2- One of the significant recommendations, and as an aimed solution to preserve the tourist area from sliding and falling rock blocks, the researchers suggest that a wire mesh barrier can be placed between the longitudinal ditches and the main road. This barrier is placed at an appropriate height with the inclination of the slopes, to prevent the rolling rock blocks from reaching the main road.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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