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STUDY OF ROCK FALL HAZARDS FOR UMM-ELSEED PLATEAU IN SHARM ELSHEIKH

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ملخص البحث
تقع هضبة أم السيد فى جنوب سيناء بمدينة شرم الشيخ فى مصر. وهى تعد واحدة من أكثر مناطق السياحة الموجودة فى مصر. يتميز موقع الهضبة بأطلالته الخلابة على البحر الاحمر. ظهرت فى العقود الاخيرة منحدرات صخرية بهضبة أم السيد و صاحبها أكثر من إنهيار صخرى. فى هذا البحث تم دراسة الطبيعة الجيولوجية والطبوغرافية بهضبة أم السيد كما تم الأخذ فى الاعتبار الخواص الجيولوجية للهضبة مثل أماكن الفواصل الصخرية والصدوع. وتم عمل دراسة معملية محدودة لتحديد الخواص الجيوتقنية للكتلة الصخرية لهضبة أم السيد.كما تم عمل دراسة كينماتيكية للتحقق من مصادر الانهيارات الصخرية التى وجدت بالمناطق المختلفة بهضبة أم السيد.

ABSTRACT
At south of Sinai in Sharm El-Sheikh city in Egypt, one of the most attractive touristy location exists, named “Umm El-Seed” plateau. This location has the advantageous of its glamorous view on the Red Sea. However, in the last few decades the cliffs of Umm El-Seed plateau have become associated with extensive rock fall hazards. In this study, the geology and the topography features of Umm El-Seed plateau are investigated. Considerable information is compiled regarding the characteristics of the plateau’s geological structures (e.g. joints and faults). A limited experimental work is presented to ascertain the basic geotechnical characteristics of Umm El-Seed rock units. The kinematic analysis is exploited to profoundly investigate the possible sources of rock falls throughout several zones of the plateau.

Keywords: kinematic analysis, rock falls, Umm El-Seed plateau

1. INTRODUCTION
One of the major hazards of rock cuts or natural rock cliffs is the potential of rock falls, which may lead to catastrophic disasters and losses in human lives. In most cases, rock falls occur due to the potential instability of upper rock blocks and that may be initiated by either climatic or biological sources. These sources may include increase of pore water pressure due to rainfall infiltration, erosion of surrounding material during heavy rain storms, freeze-thaw processes in cold climates, chemical degradation or weathering of the rock. Consequently, significant changes may arise in the forces acting on a definite capping rock layer resulting in an unstable rock block that tends to fall. Many factors may govern the potential of rock falls, such as the geological conditions and formations, the orientation of discontinuities, the rock cliff geometry, dip angle and surface morphology.

The assessment of causes and measures to prevent the rock fall hazards have became one of the urgent research topics in the geotechnical engineering, due to the increase in urban development close to rock slopes. Several rock fall remedial and protection measures have been proposed in the literature and those are in practices such as: berms,

avalanche shelters, catchment ditches, toe fill, wire mesh, fences and barriers. Determination of the most efficient remedial measure relies on a number of factors and may be case-specific. A number of studies have been presented in the literature to evaluate the different techniques of rock fall protection, e.g. Ritchie (1963); Bunce et al. (1997); and Abdel-Tawab (2012). Moreover, numerous techniques have been applied in the literature to analyze the problem of instability of rock blocks. Finite element analysis technique, e.g. Helmy (2007). Limit equilibrium kinematic analysis technique, e.g. Fahmy (2010).
Umm El-Seed plateau is one of the most attractive touristy location, which exists at south of Sinai in Sharm El-Sheikh city in Egypt, overlooking the Aqaba Gulf in the Red Sea. However, the cliffs of this plateau represent crucial examples of hazardous rock falls, especially in the last few decades. That may be relevant to the increases in urban developments, i.e. resorts, attached to several zones of the plateau's cliffs. Therefore, this paper focuses on investigating the geology and the topography of Umm El-Seed plateau, and to compile considerable information on the characteristics of the plateau's geological structures, e.g. joints and faults. The basic geotechnical characteristics of Umm El-Seed rock units have been ascertained in this paper based on a quite limited experimental work. Furthermore, the kinematic analysis has been exploited to profoundly investigate the possible sources of rock falls throughout several zones of the plateau. The numerical analysis has been employed to assess the performance of rock anchors as a rock fall protection measure.

2. UMM EL-SEED PLATEAU

2.1 Location

The location of Umm EL-Seed plateau is at the southern part of Sinai, certainly in Sharm El-Sheikh city, Egypt as shown in Figure (1). The Total area of the Plateau is about 3.5 km^2. It is bounded from the west by Sharm El-Maya bay and from the east by the Gulf of Aqaba. A broad number of hotels and villas are constructed near the top edge of the plateau, which is directly overlooking the gulf in the Red Sea. Relatively narrow beaches exist around the lower edge of the plateau, which is very close to the sea.

2.2 Topography

The round borders of the plateau comprise rock cliffs with variable height. All the rock cliffs are facing the sea in the Gulf of Aqaba. The top level of each cliff represents the elevation of the plateau surface, whereas the bottom level corresponds to a beach level. Most of the cliffs stand for almost semi-vertical rock slopes. The total height of the rock slopes range between 10 and 30 m, with a dipping angle of approximately 90^0 and a generic top surface slope of about 5° toward the south-west. In the present study, it has been proposed to divide the most crucial border of the plateau into seven zones, according to the topography of the rock slope and the existing human activity near the slope in each zone. The proposed seven zones are demonstrated in Figure (2). Details on the geometry and the topography of these zones are given in Table (1).

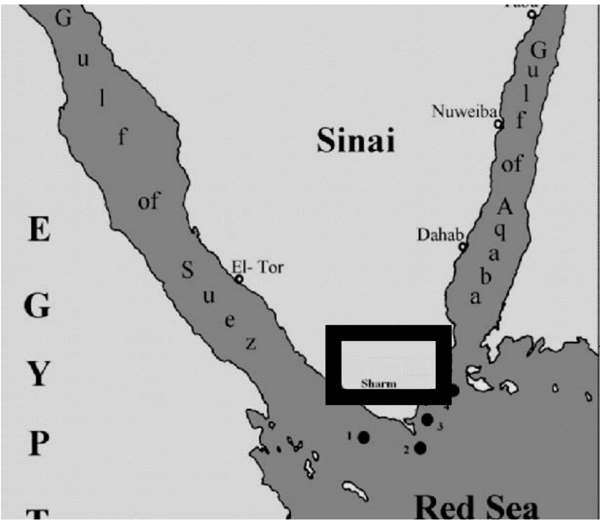


Figure 4: Location of Umm EL-Seed Plateau

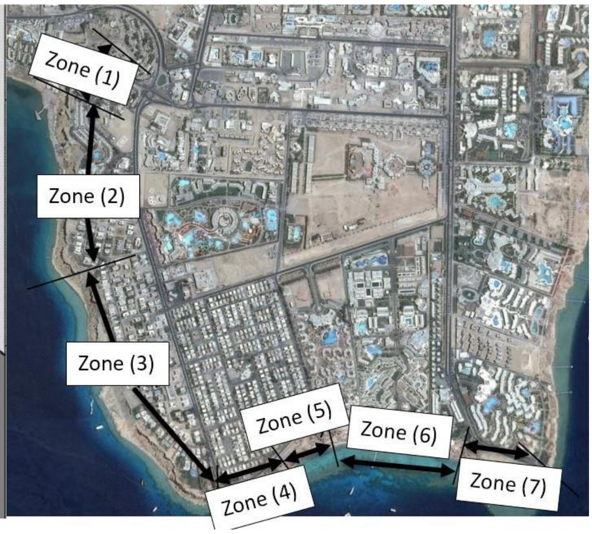


Figure 3: The critical zones of rock cliffs from a satellite view for Umm EL-Seed plateau

Table (1): Details of critical zones of Umm El-Seed plateau

Zone No.	Identification Nearby Location	Average Height of Rock Slopes (m)	Rock Slope Angle (deg.)	Slope Direction (deg.)	Joint Dip (deg.)	Joint dip Direction (deg.)
1	City Council Headquarter	30	90	270	88	195 – 352
2	Batros Hotel	30	90	270	88	243 – 298
3	Private Villas (Mazadat**)**	27	90	270	88	175 – 322
4	Pharaoh Hotel	27	90	120	86 – 88	50 – 245
5	Reef Oasis	27	90	120	86 – 88	50 – 245
6	Nine Hotels Open Beach	25	90	120	86 – 88	50 – 245
7	Fanar	20	90	180	75 – 88	190 – 275

2.3 Geological Conditions

Umm EL-Seed plateau is formed of an upper crust. i.e. capping layer, of white reefal limestone that overlies a deposit of sandstone. The upper limestone is rich of corals and cephalopods fossils, bounded together by carbonate cement, which had been formed as reefal fringes during the Pliocene age. Miocene conglomerate bedding layers occasionally exist within the reefal limestone. The underlying deposit is formed of an Oligocene clastic sandstone layer of reddish to greenish yellow fine to coarse-grained, sometimes gravelly, cemented sand. The bedding of the reefal limestone layer has an inclination of about 5° in a southeastern direction. Such an inclination results in an increase in the thickness of the upper limestone layer with respect to the underlying deposit of sandstone in some locations. The vital geological feature of the capping limestone layer is the remarkable presence of fractures, joints and cavities. Unstable rock units (blocks) are formed due to intersections of the fractures and joints. Figure (3) illustrates a typical lithological profile, which represents the approximated geological stratification of Umm El-Seed plateau.

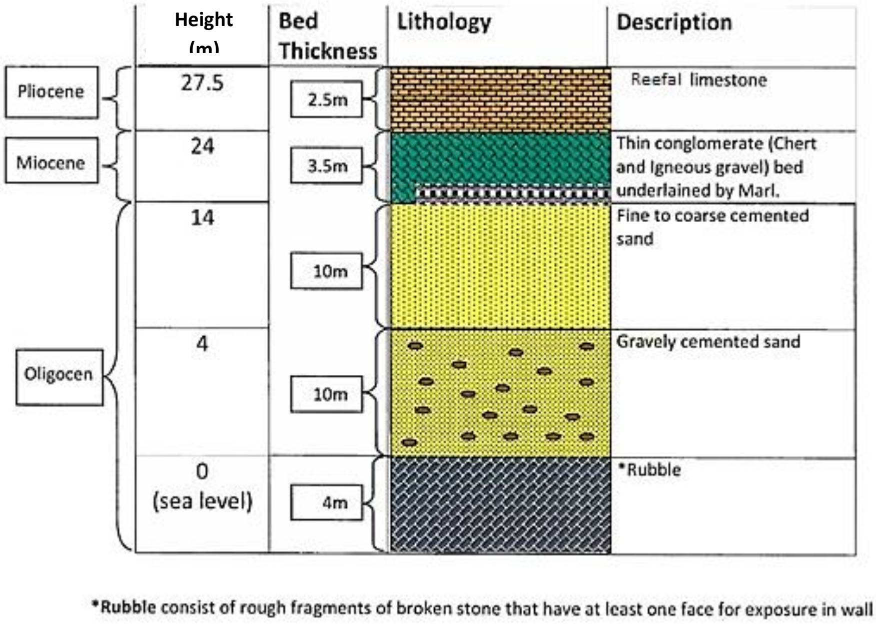


Figure 5: Approximated geological stratification in Zone (2) Umm El-Seed plateau

The plateau has been affected by many faults related to the Pliocene age. Most of these faults are in the form of cutting through the upper reefal limestone layer, as shown in Figure (4). The common regime of these faults has been detected in the NE-SW direction, parallel to Gulf of Aqaba. This trend of faults propagation is attributed to the lateral spreading of the Red Sea, which is spreading by 2.0 cm per year. The relative movement of these faults range between 0.50 m and 2.0 m. Other older faults had been created in the western zones of the plateau, however, through only the underlying sandstone deposit and that are related to the post Oligocene.
A detailed joints survey for Umm El-Seed plateau was carried out by Abdeltawab (2012). Structural joints were detected parallel to the common regime of faults in all over the area of the reefal limestone. Two major sets of joints were recorded and trended as NNW-SSE and ENE-WSW. Furthermore, some subordinate joint sets were found following the trends of NW-SE and NE-SW, as exhibited in the rosette diagram shown in Figure (5)

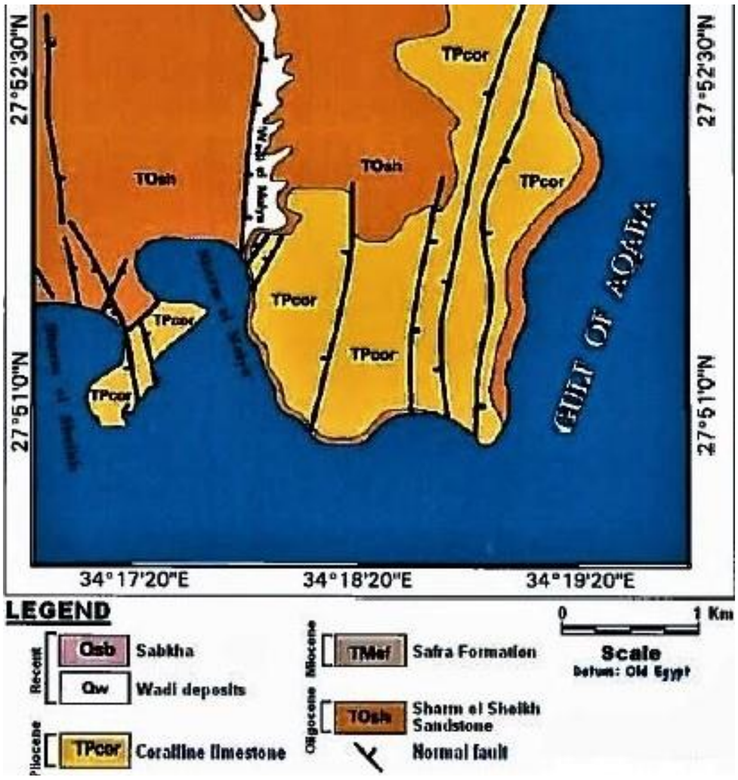


Figure 6: Geological sedimentations and structural faults of the southern part of Sinai (Geoscience, 2010)

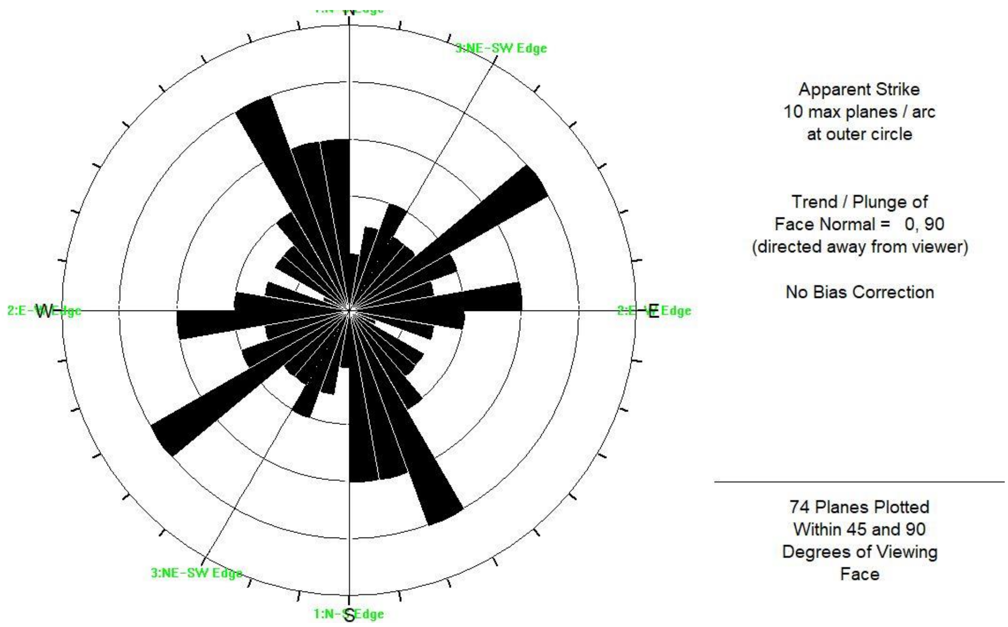


Figure 5: Rosette diagram for recorded sets of structural joints in Umm El Seed Plateau (Abdeltawab, 2012)

2.4 Geotechnical Engineering Parameters of Rock Units

In the present study, a limited experimental program has been conducted to determine the basic geotechnical characteristics of Umm El-Seed rock units. In accordance, bulk samples have been extracted in-situ from the vital two rock units of the plateau, i.e. the upper reefal limestone unit and the underlying sandstone unit. Laboratory tests have been carried out to ascertain some physical and mechanical properties of the intact rock units, including the unit weight, the unconfined compressive strength and the elastic secant modulus. Furthermore, the free swelling test has been performed on a number of samples from the encountered thin layers of clay and marl within the sandstone. Table (2) depicts a summary of the laboratory results for the reefal limestone and the sandstone units. Based on the unconfined compression tests result, the strength and moduli of the intact rock units have been classified, according to both the ISRM-classification (1981) and Deere and Miller's classification (1966), as provided in Table (2). Moreover, X-ray Diffraction (XRD) tests have been carried out to determine the essential minerals decomposition of certainly the sandstone unit, as shown in Table (3).

Table (2): Summary of the laboratory determined geotechnical properties of the intact rock units of Umm El-Seed plateau

Laboratory Determined Property	Symbol	Unit	Intact Rock Unit	
			Upper Reefal Limestone	Underlying Sandstone
Unit weight *	γ	kN/m^3	14.30 – 16.20	19.60 – 20.0
Uniaxial unconfined compressive strength *	q_{un}	MPa	1.80 – 7.70	0.30 – 10.90
Angle of failure plane on horizontal direction (from the uniaxial unconfined compression test)	θ	degrees	45 – 73	--------
Elastic Secant Modulus (from the uniaxial unconfined compression test)	E_{50}	MPa	2157 – 3042	--------
Percentage of Free Swelling *	FS	%	--------	0.0 – 20
Classification of intact rock unit according to ISRM-classification (1981)	-----	------	Very weak (R1)	Very weak (R1)
Classification of intact rock unit according to Deere and Miller's classification (1966)	-----	------	Very Low strength with medium modulus ratio (EM)	--------

* All Tests were executed according ECP 202 - 2001

Table (3): Summary of the XRD tests for Umm El-Seed sandstone

Mineral	Range	Mineral	Range
SiO_3	28.06 – 88.02 %	Na_2O	0.45 – 1.71 %
Al_2O_3	4.68 – 8.11 %	K_2O	0.64 – 2.59 %
Fe_2O_3	0.95 – 2.91 %	SO_3	0.01 – 0.03 %
CaO	0.01 – 39.41 %	TiO_2	0.01 – 0.3 %
MgO	0.0 – 0.75%	P_2O_2	0.02 – 0.13 %

2.5 Geomechanical Parameters of the Rock Mass

The geomechanical parameters of the rock mass have approximately been estimated for both the upper reefal limestone layer and the underlying layer of sandstone, utilizing the empirical geomechanical common classification schemes. The laboratory tests results and the field observations and measurements have been employed. The modified Rock Mass Rating (RMR) proposed by Bieniawski (1989) has been applied in conjunction with the adjustment of the joint orientation rating proposed by Romana (1985). Table (4) provides a summary of the estimated rock mass parameters.

Table (4): Summary of the estimated rock mass parameters of Umm El-Seed plateau

Rock Mass Parameter	Rock Layer	
	Upper Reefal Limestone	Underlying Sandstone
RMR	52.50	58.50
Class No.	III	III
Rock Mass Description	Normal – Fair rock	Normal – Fair rock
Expected Stability Class According to Romana (1985)	Partially stable	Partially stable
Expected Failures Surfaces According to Romana (1985)	Planer along some joints and many wedges	Planer along some joints and many wedges
Probability of failure (%)	40	40
Cohesion Strength of Rock Mass Range (kPa)	200 – 300	200 – 300
Friction angle of Rock Mass Range (degrees)	25 – 35	25 – 35

3. PROPOSED FAILURE MECHANISMS

Among of the several factors that govern the instability of the rock cliffs and the rock falls hazards in Umm El-Seed plateau, the following four factors may be considered as the most predominant:

- The geological stratification of the rock cliff as the presence of an upper limestone layer followed by a weak clastic sandstone deposit has a considerable tendency of deterioration.
- The significant influence of waves and wind causing scouring, erosion and undercutting of the lower parts of the cliff.
- The potential intersections of joints and faults with regard to the free edge of the cliff.
- The possible seeping of surface water from the exiting buildings and human activities through the rock joints, causing deterioration of rock units.

Accordingly, three rock fall failure mechanisms have been proposed and examined in the present study for the cliffs of Umm El-Seed plateau. The proposed failure mechanisms have been relied on postulated modes of failure and corresponding potential causes. Figures (6.a, b and c) demonstrate schematically the proposed three failure mechanisms, respectively.

The first failure mechanism (Figure 6.a), the rock fall is suggested to be associated with an outward sliding of the rock blocks as a result of the potential intersection of joints (or faults) with the free edge of the cliff. Typically, the second failure mechanism (Figure 6.b), is referred to the outward sliding of the rock blocks due to complete deterioration of the rock cliff material. The rock fall in the third failure mechanism (Figure 6.c) is suggested to be attributed to toppling of the rock blocks due to erosion and undercutting of the lower parts of the cliff. Erosion and undercutting may be predominantly caused by wave scouring, wind deterioration and/or seeping of surface water from the exiting buildings and human activities through the rock joints. The aforementioned sources of undercutting mainly affect the underlying sandstone deposit leading to a potential instability of the upper reefal limestone blocks. The probability of the suggested first failure mechanisms has been examined in the present study only, as presented in the next section.

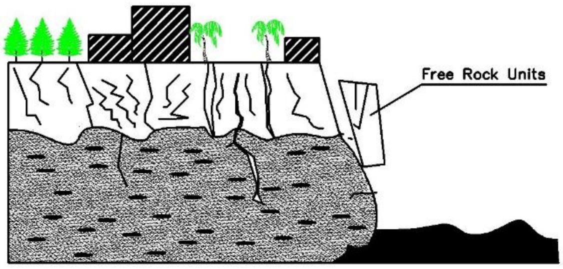


Figure 6.a: Proposed failure mechanism (I): outward sliding of the rock blocks due to the potential intersection of joints with the free edge of the cliff

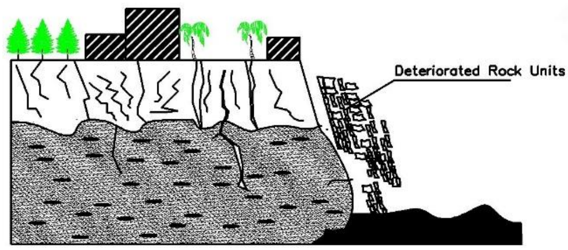


Figure 6.b: Proposed failure mechanism (II): outward sliding of the rock blocks due to complete deterioration of the rock cliff material

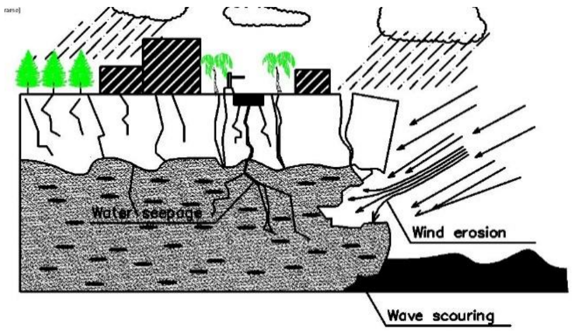
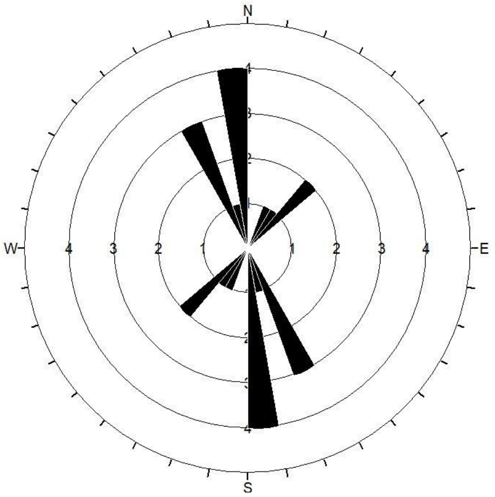


Figure 6.c: Proposed failure mechanism (II): rock blocks toppling due to erosion and undercutting of the lower parts of the cliff

4. KINEMATIC ANALYSIS AND RISK ASSESSMENT OF FIRST FAILURE MECHANISM

The kinematic analysis has been employed in the present study to examine the proposed first failure mechanism (I) that implies the rock falls as rock blocks sliding due to the intersection of joints with the free edge of the cliff. Rosette and contour plots have been developed using DIPS software for the previously highlighted seven critical zones of Umm El-Seed plateau (refer to Figure 2 and Table 1). Consequently, the direction and the pole concentration of the rock joints in each zone have been determined. Figure (7) shows the rosette and contour plots for zone no. (2) as samples of the analysis representative outcomes. Throughout the seven implicated zones of the plateau, it has been revealed that the fundamental joints trends are NNE-SSW and NW-SW. Consequently, the intersection of these trends with the free edges of cliffs usually create unstable rock blocks. Moreover, the probability of either planar, wedge or toppling failure of such unstable rock blocks has been examined utilizing the stereographic analysis, as shown in Figure (8). The results showed that the mechanism of failure of the unstable rock blocks has much likelihood of being planar or wedge failure rather than toppling failure. Furthermore, the corresponding factor of safety and degree of risk have been estimated. In this regard, RocPlane software and Swedge software have been utilized to assess the planer and wedge failure, respectively, as illustrated in Figure (9). Throughout the seven critical zones of Umm El-Seed plateau, the estimated factor of safety generally ranged between 0.02 and 0.036. The estimated degree of risk, on the other side, has been classed as “critical” according rockfall hazard System proposed by

Saroglou et.al (2012) Table (5) provides a summary of the analysis results for the seven critical zones.



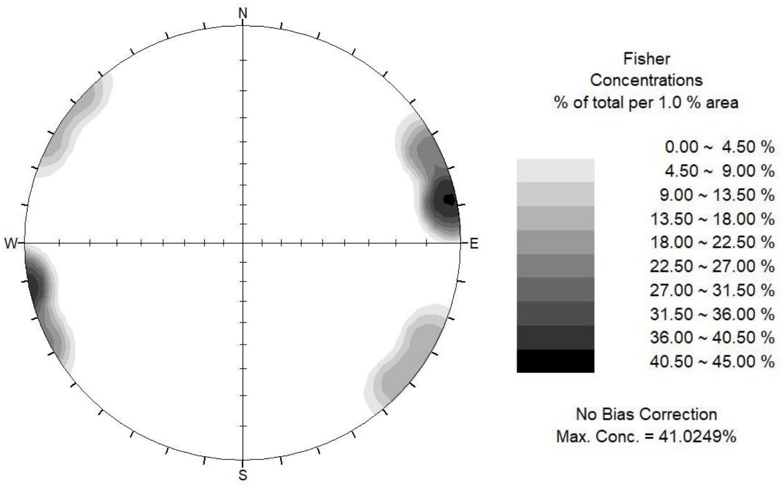


Table (5): Summary of the kinematic analysis and risk assessment results for rock joints

Zone number	F.O.S Planar	F.O.S Wedge	Degree of Risk
1	0.02	0.024 – 0.600	Critical
2	0.02	0.024 – 0.031	Critical
3	0.02	0.020 – 0.300	Critical
4 – 5 - 6	0.02 – 0.05	0.036 – 0.260	Critical
7	0.02	0.024	Critical

* F.O.S. = Factor of Safety

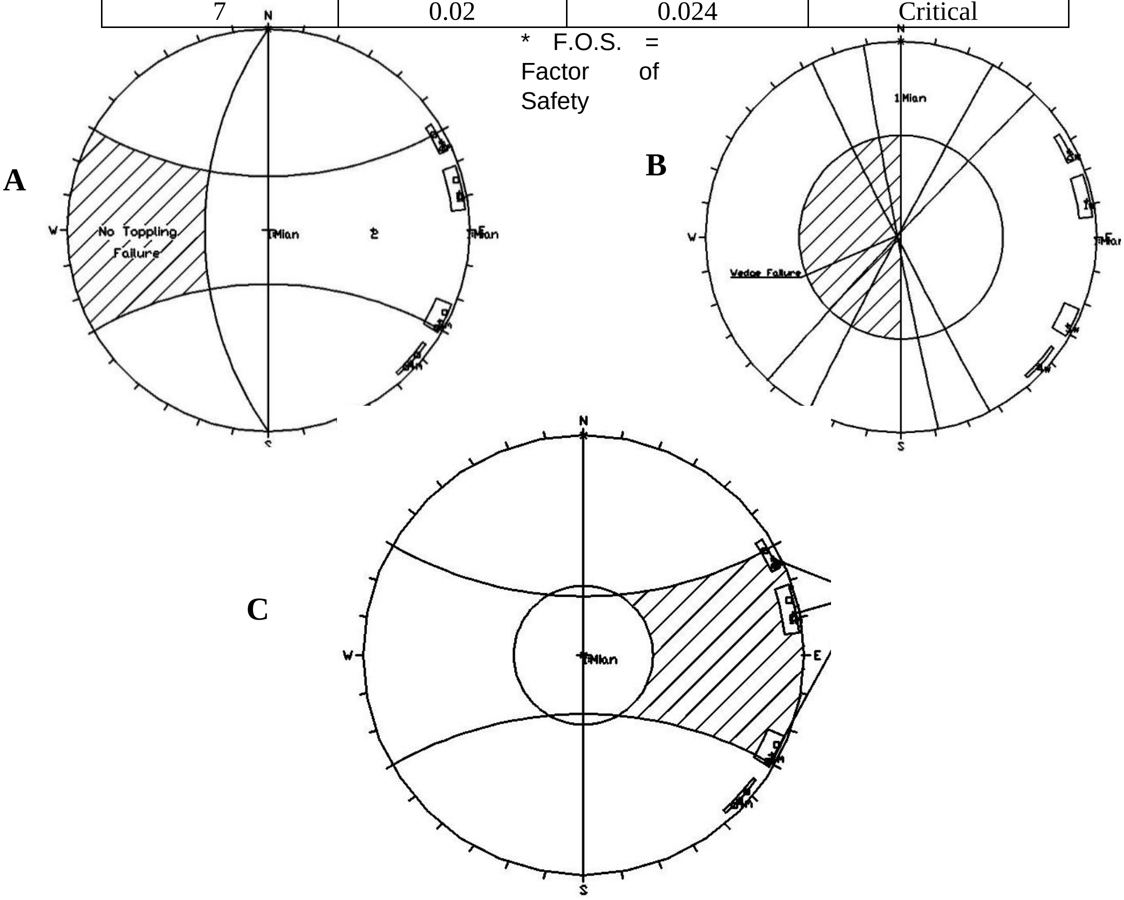


Figure 8: Stereographic analysis for zone no. (2): (a) toppling; (b) wedge and (c) planar

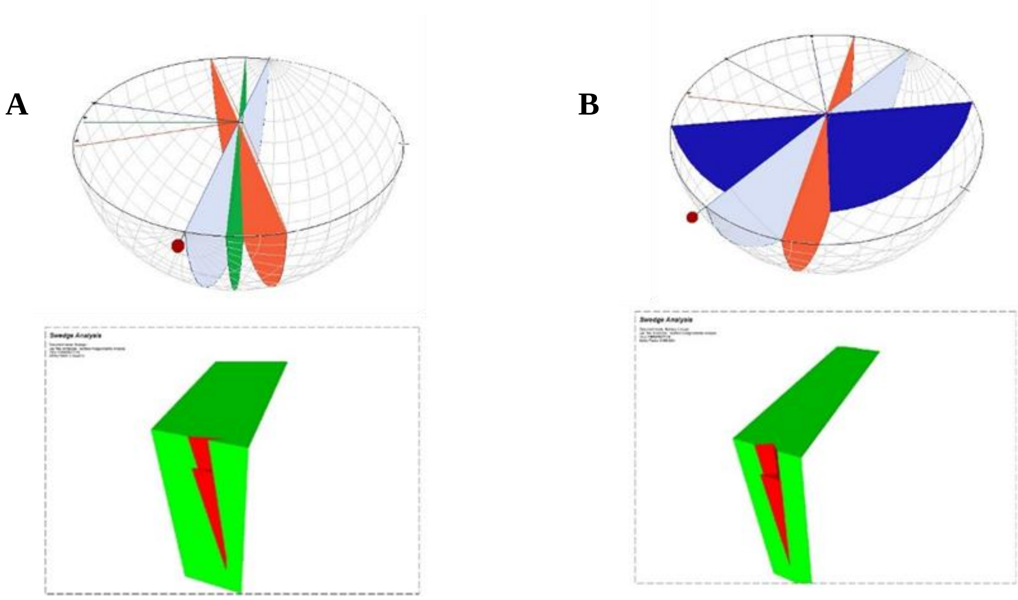


Figure 9: F.O.S determination for zone no. (2): (a)wedge failure with F.O.S = 0.024; (b) wedge failure with F.O.S = 0.036

5. CONCLUSIONS

The instability mechanisms of failure proposed in this study were divided into three categories. Failure mechanism (I) describes the sliding and wedge failure of rock blocks as a result of the potential intersection of joints (or faults). Failure mechanism (II) also describes the sliding and wedge failure of rock blocks as a result of complete deterioration of the rock cliff material. As for failure mechanism (III) the toppling failure was described to erosion and undercutting of the lower parts of the cliff.

The kinematic analysis was applied to evaluate the probability of failure mechanism (I), the results are summarized as follows:

- The joints intersection detected that most of the failure modes are planer or wedge, failure with extremely high-risk i.e. considerable probability of failure.
- Most of the joint dip angles range from 75 to 88 degrees considered to be shallower than the slope angle 90 degree which gives high probability of intersection creating a daylight crack on the outer face of the cliff leading to progressive failure.
- Toppling failure was not detected in the kinematic analysis. Toppling failure occurs in the undercutting failure mechanism due erosion of sandstone descried in instability failure mechanism (III)

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