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SLOPE STABILITY ANALYSIS OF AL-QADHI CLIFF IN AL-QADISSIYA, IRAQ

Jaffar H.A. Al-Zubaydi[1]

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Key words: Rock slope stability, types of failures, Rock stabilization, Al-Qadhi Cliff, Iraq

ABSTRACT

Field studies of the (Subhorizontal-layer) slopes of Al-Qadhi area, central Iraq, revealed the abundance of rock slope failures, the dominant types are rock fall, secondary toppling, and rolling. Slope stability assessment was carried out by stereographic projection. Secondary toppling mechanisms (generally due to the effects of differential weathering and or erosion, and undercutting) include multidirectional toppling, tension crack toppling and toppling and slumping mechanism. Some measures are proposed to stabilize the slopes including removal of blocks liable to toppling in the critical cases, and filling the undercut slope toe by convenient soil with binding materials in the less critical slopes.

تحليل ثبات المنحدرات في جرف القاضي، القادسية وسط العراق

جعفر حسين الزبيدي

المستخلص

بينت الدراسات الحقلية لانحدار طبقة شبه افقية لمنطقة القاضي في محافظة القادسية في وسط العراق وجود العديد من انهيارات المنحدرات الصخرية، تمثل اغلبها بالسقوط الصخري والانقلاب الثنائي والتدحرج، حيث تم تقييم استقرارية المنحدرات في تلك المنطقة باستخدام طريقة الاسقاط الفراغي. وتبين ان ميكانيكية الانقلاب الثنائي (كانت نتيجة لتأثير التعرية التفاضلية و/ أو التجوية وقطع اسفل الصخور) والتي تشمل الانقلاب متعدد الاتجاهات وانقلاب التكسر الشدي والانقلاب والانزلاق. ان قسما من القياسات التي أجريت كانت قد أقترحت طرقا لتثبيت المنحدرات والتي شملت: إزالة الكتل الصخرية المنزلقة من اسفل المنزلقات في الحالات الحرجة وملء القطوعات الموجودة في أسفل المنحدرات بواسطة الترب المثبتة بمواد مثبتة في المنحدرات الأقل حرجا.

INTRODUCTION

Slope failure is a geologic process that involves down slope movement of rock masses under the influence of gravity. The inherent strength of rock mass keeps the slope stable. Occasionally, something occurs to disturb the rock mass causing it to fail and move down slope (Hoek and Bray, 1981; Ramamaurthy, 2008 and Maerz *et al*., 2005).

[1] Applied Geology Department, College of Science, Babylon University, Iraq,
e-mail: jafar_hussain68@yahoo.com

The study area lies about (85 Km) southwest of Al-Qadissiya Governorate, central Iraq. It lies along the rock slopes, locally known as Al-Qadhi cliff (Fig.1). The study aims at engineering geological evaluation of rock slope stability in the area by locating sites of occurred failures and those which are likely to occur in the future, in particular toppling failure which is the dominant mode of failure in the area, its mechanisms and all factors influencing slope instability. The area is a proposed location for engineering constructions such as roads. After surveying all the slopes, five station sites have been chosen for this paper and their rock masses have been described in engineering geological terms according to Anon (1972, 1977) and Hawkins (1986).

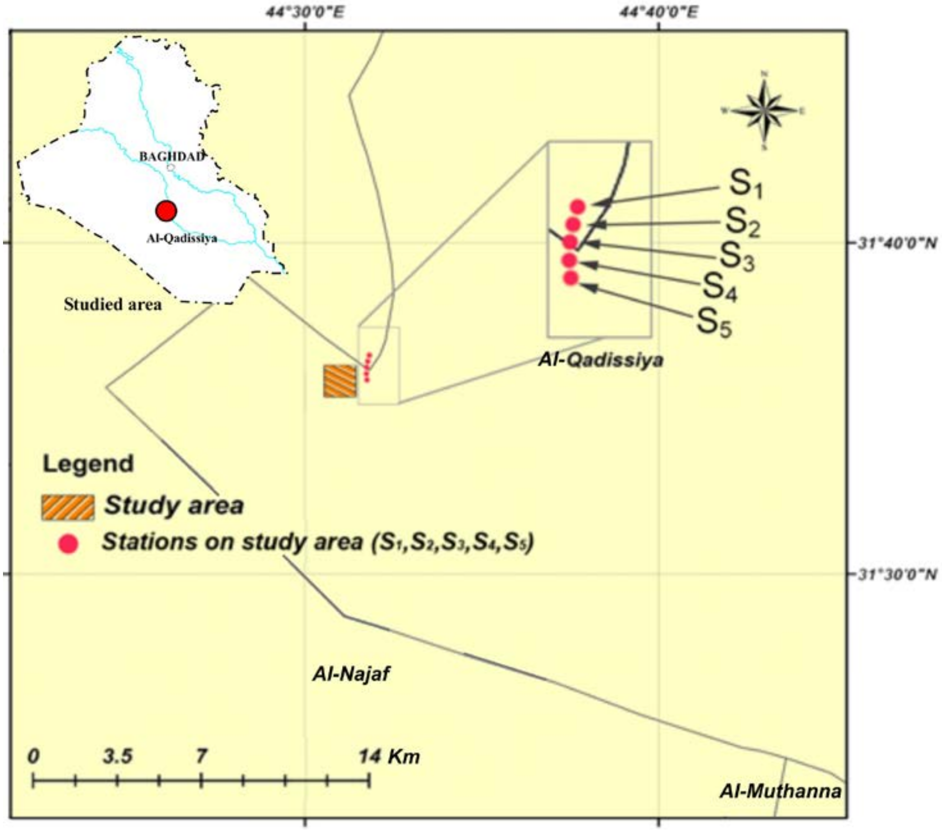


Fig. 1: Location map of the study area

- **Geology of Study Area**

The following rock units (from oldest to youngest) are exposed in the area:

— **Nfayil Formation (Middle Miocene):** This formation is divided into two members (Sissakian, 1999 and Ahamad, 2004).

- **Lower member;** consists of three cycles, each cycle consists of marl and limestone. The marl is olive green, soft, papery or massive, concoidally fractured; the fractures are filled with secondary gypsum. The thickness of marl beds ranges from (0.5 – 5.0) meters. The limestone is yellowish white to greenish grey, fractured, jointed, locally undulated and deformed, slightly oolitic, partly recrystallized and shelly. The shells are mainly pelecypods, gastropods, and oysters the oysters are found only in the second cycle it is a good marker over the whole exposed area of the Nfayil Formation.

- **Upper member;** consists of claystone and limestone. The claystone is reddish, bedded, and calcareous, whereas the limestone is pinkish with quartz grains, bedded and hared. The top of the upper member is always capped by splintery limestone and very hard. The thickness in the type locality ranges from (10 – 50) meters (Sissakian, 1999, Ahamad, 2004).

- **Injana Formation (L. Miocene):** It consists mainly of grey, green and brown sandstone, interbeded with red claystone, siltstone and green marl (Hassan, 2007).

- **Quaternary Deposits:** These deposits cover most of the study area, and can be described as follows:
  - **Aeolian Deposits:** Mainly sand sheet and sand dunes are developed in the study area. They are composed of sand deposited downwind from a natural sources.

  - **Wadi Fill Sediments:** This type of sediments is composed of poorly sorted admixture of silt, sand and gravel (pebble).

  - **Colluvial Sediments:** These sediment occur along restricted zone at the lower part of Al-Qadhi cliff area.

Structurally, the area is characterized by subhorizontal layers with average dip between (3 – 5°); therefore all slopes can be classified as subhorizontal layer slope according to Al-Saadi slope classification (Al-Saadi, 1981). There are two main sets of vertical orthogonal joints normal to the bedding planes, trending (NW – SE and NE – SW).

The main geomorphological features in the area are:
- Rock Slopes of Al-Qadhi cliff are underlain by Nfayil Formation (in the lower parts) and Injana Formation (in the upper parts).
- Scattered Hills, including mesas and butes (which are flat topped, and cut on their sides by steep escarpments). They generally occur in the low land. The main exposed layers of mesas, butes and hills are marl and limestone of the Nfayil Formation, and alternation of claystone, siltstone and sandstone of the Injana Formation.

- **Climate of the Study Area**

The climate of the study area is characterized by arid, hot and comparatively high summer temperature with low humidity and high evaporation. The rainfall increases in winter and becomes nill in the summer (June-September). Moreover, all seasons are dusty mainly in the summer when wind speed increases.

ROCK SLOPE STABILITY ANALYSIS

Five sites (stations) are chosen in this study where different types of slope failure exist, in order to analysis slope stability in the area. The unconfined compressive strength of the rock layers in the failure sites was found indirectly by point load test. In this paper, the slope inclination (or dip of strata) is indicated by two numbers representing the direction (to the left) and the amount of angle (to the right). Field observation showed that Al-Qadhi cliff slopes have many failures particularly rock fall, toppling, and local disintegration followed almost by rolling. All failures have been classified according to the common classifications of failures (Goodman and Bray 1976; Evans, 1981; Hoek and Bray, 1981; Al-Saadi, 1991; Wyllie and Mah, 2004; Cheng and Lau, 2008, and Ramamaurthy, 2008).

The symbols used to represent the data on the stereographic projection are based on/ or modified from (Al-Saadi, 1981), (Table 1 and 2).

Table 1: Types of great circles and poles used to represent the collected field data on stereogram, modified from (Al-Saadi, 1981)

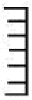
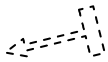
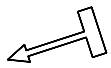
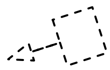
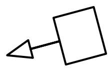
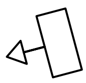
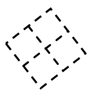
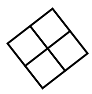
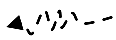
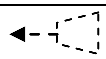
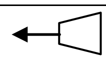
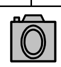
Symbol	Description	Symbol	Description
GS 	Cyclographic trace (great circle) of a general slope	R.m	Rock mass
SS 	Cyclographic trace of a side slope	L.S	Left side slope
OH or VS 	Cyclographic trace of vertical slope (VS) or overhanging slope (OH)	R.S	Right side slope
		L.S	Lower slope
S_0 	Cyclographic trace of mean orientation of bedding plane (S_0)	U.S	Upper slope
		L.p	Lower part
S_1, S_2 ●	Pole to joint plane, join sets	U.p	Upper part

Table 2: Symbols of types of failure and photo direction used and represented on stereogram, modified from (Al-Saadi, 1981)

Types of failure	Symbol	
	Possible	Present
Toppling		
Rock fall		
Plane sliding		
Granular disintegration		
Rolling		
Slumping		
Photo direction		

– **Station No.1:** This station lies (790 m) NW of Dewania street, at latitude (31° 35' 9.04" N) and longitude (44° 30' 7.9" E), within Injana Formation (Plate 1). The slope is (12 m) high, (30 m) long along its trend and its inclination is (280/82°). The average dip of strata is (210/05°); therefore it is subhorizontal – layer slope.

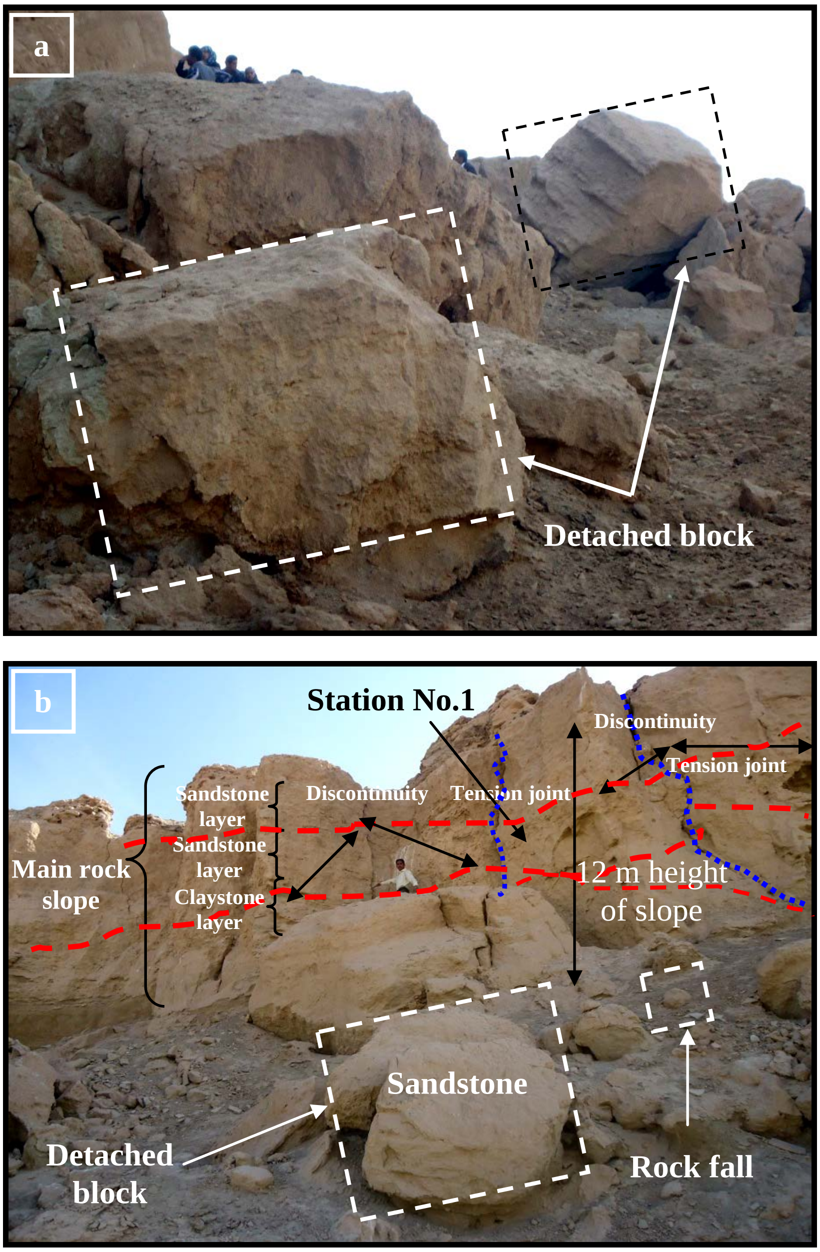


Plate 1: The slope of station No.1. **a)** side view showing detached rock block, photo direction NE, **b)** front view showing discontinuities, photo direction SW

In the upper part of the slope a (5 m) thick layers are exposed. They are pale green, fine grained, massive bedded, widely jointed, moderately weathered, calcareous SANDSTONE, moderately strong (σc = 22.7 MPa).

The underlying rock layers in the lower part of the slope are (6 m) thick. They are light grayish, medium grained, thickly bedded, widely jointed, moderately weathered, SANDSTONE. These sandstone layers are separated from the underlying claystone layers by (1.0 m) thick layer of highly weathered claystone which is removed by erosion.

The sandstone layers are cut by two sets of discontinuity (S1 and S2), (Fig.2). The spacing of discontinuity in (S1) range between (2 – 2.5 m), their persistence reaches (4 m) on the bedding plane and they are almost open up to (0.1 m). The spacing of discontinuity in (S2) ranges between (1 – 1.56 m); their persistence reaches (4 m) and they are almost open up to (0.1 m).

Rock block failure has occurred by rock fall or toppling including, multidirectional toppling mode. Discontinuity in (S1) set acted as back release surfaces (BRS) of the toppled block while (S2) joint set acted as lateral release surfaces (LRS).

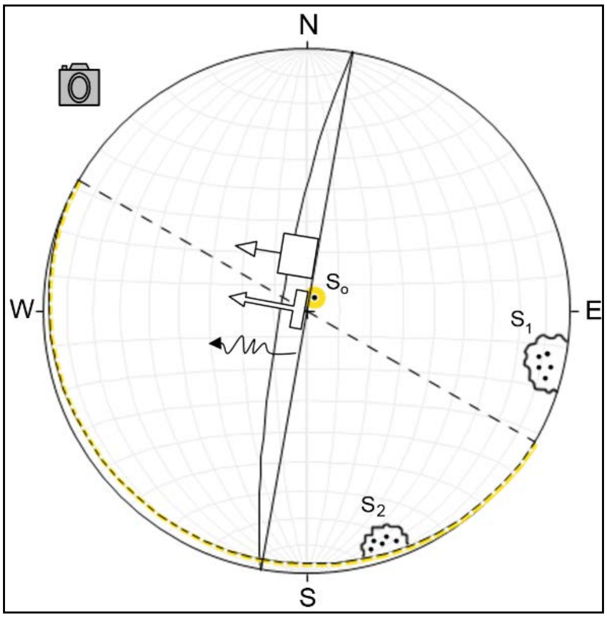


Fig.2: Stereogram of discontinuities, slope and types of failure for station No.1

─ **Station No.2:** This station lies (1030 m) SW of Dewania street, at latitude (31° 35' 8.43" N) and longitude (44° 30' 8.10" E), within Injana – Nfayil Formations, (Plate 2). The slope is (4.5 m) high, (10 m) long along its trend and its inclination is (190/83°). The average dip of strata is (230/03°), therefore it is subhorizontal – layer slope. In the upper part of the slope a (2 m) thick layers are exposed. They are pale green, medium grained, thick bedded, moderate weathered, calcareous SANDSTONE moderately strong (σc = 20.3 MPa).

The underlying rock layers in the lower part of the slope are (2 m) thick. They are light grayish, very fine grained, thickly bedded, highly weathered, CLAYSTONE, with (0.5 m) thick, pale grayish, very thin bedded, moderate weathered, LIMESTONE.

The sandstone layers are cut by two sets of discontinuity in (S1 and S2), (Fig.3). The spacing of discontinuity in (S1) range between (0.5 – 1.1 m), their persistence reaches (3 m) on the bedding plane and they are almost open up to (0.1 m). The spacing of discontinuity in (S2) ranges between (1 – 1.8 m), their persistence reaches (2 m) on the bedding plane and they are almost open up to (0.1 m).

Rock block failure has occurred by rock fall or toppling. Discontinuity in (S1) set acted as back release surfaces (BRS) of the toppled block while (S2) joint set acted as lateral release surfaces (LRS).

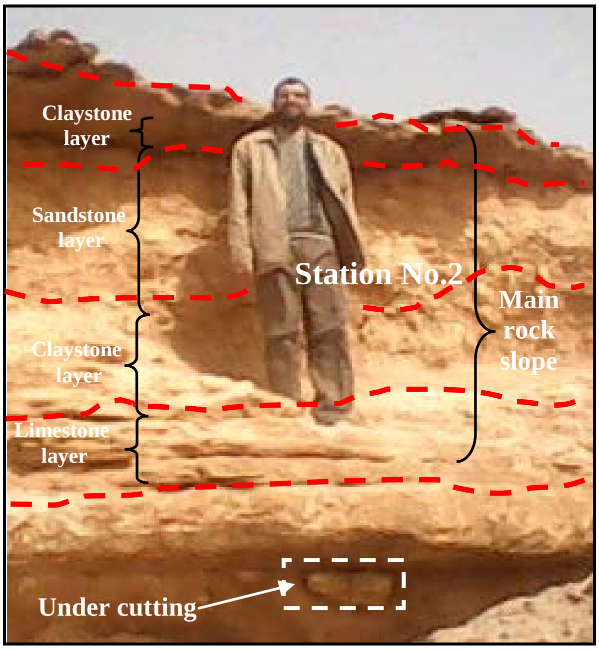


Plate 2: The slope of station No.2. Front view showing rock fall, photo direction SE

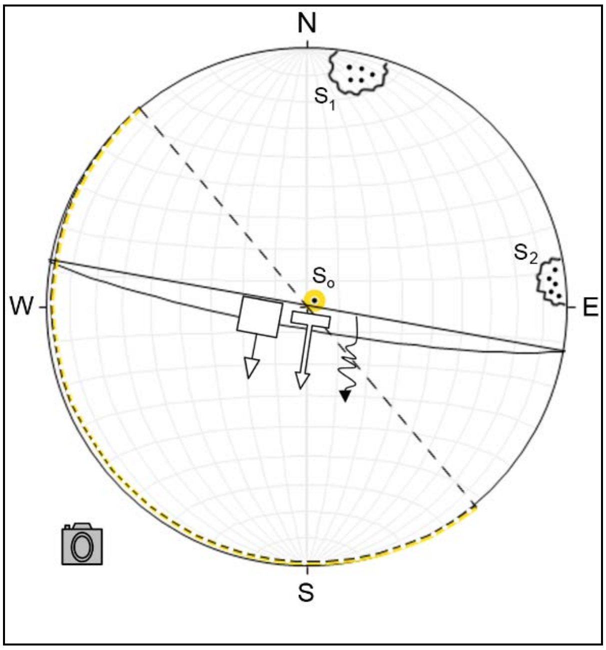


Fig.3: Stereogram of slope and types of failure for station No.2

– **Station No.3:** This station lies (1250 m) NE of Dewania street, at latitude (31° 35' 8.41" N) and longitude (44° 30' 8.12" E), within Injana – Nfayil (Plate 3). The slope is (5.5 m) high, (10 m) long along its trend and its inclination is (170/84°). The average dip of strata is (260/03°); therefore it is subhorizontal – layer slope. In the upper part of the slope a (4 m) thick layers are exposed. They are pale green, medium grained, thickly bedded, slightly weathered, calcareous SANDSTONE moderately strong (σc = 26.3 MPa). These sandstone layers are separated from the underlying layer in the lower part of the slope by (1 m) thick layer of light reddish brown, very fine grained, thickly bedded, moderately weathered, CLAYSTONE, strong (σc = 60 MPa) effectively impermeable.

The lower part of the slope is (0.5 m) thick. It is light grayish, very fine grained, very thinly bedded, highly weathered, LIMESTONE. The sandstone layers are cut by two sets of subvertical discontinuity (S1 and S2); the spacing of discontinuity in (S1) ranges between (1.7 – 2.0 m); their persistence reaches (1 m) on the bedding plane and they are open up almost to (0.2 m). The spacing of discontinuity in (S2) ranges between (0.8 – 1.2 m), their persistence reaches (1.6 m) on the bedding plane and they are open up almost to (0.01 m). With differential erosion at the toe of the slope, in some parts, the slope is overhanging, contributing to rock fall failure; the inclined soil slope helps rolling of detached rock block.

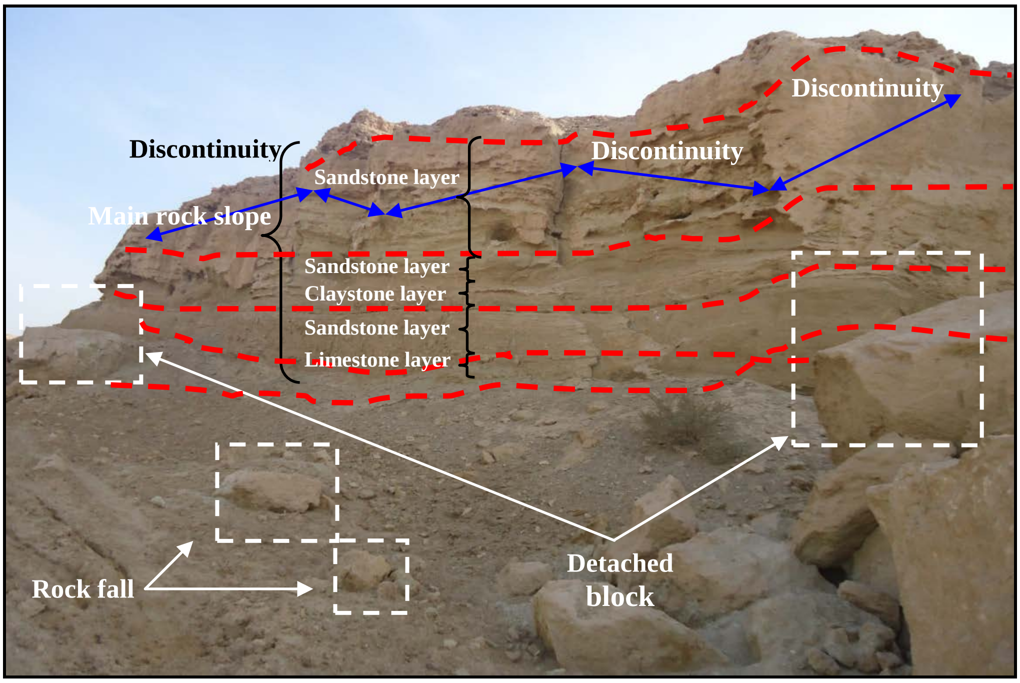


Plate 3: The slope of station No.3. Front view showing detached rock block, rock fall, photo direction NW

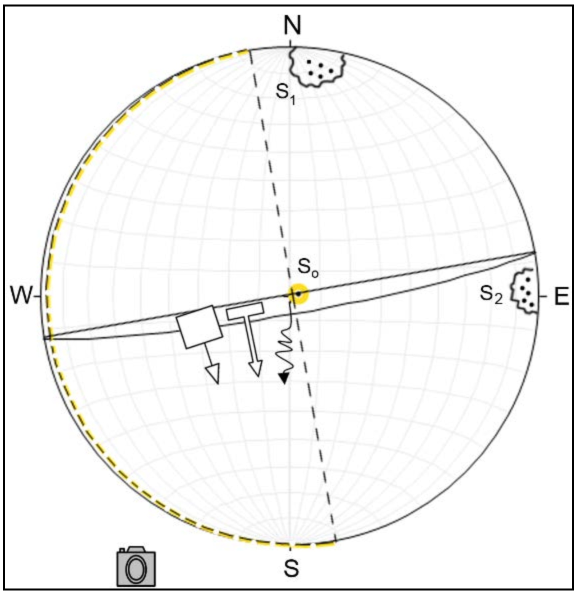


Fig.4: Stereogram of slope and types of failure for station No.3

— **Station No.4:** This station lies (1800 m) SE of Dewania street, at latitude (31° 35' 8.99" N) and longitude (44° 30' 9.37" E), within Injana Formation, (Plate 4). The slope is (4 m) high, (40 m) long along its trend and its inclination is (350/88°). The average dip of strata is (340/04°); therefore it is a subhorizontal – layer slope. In the upper part of the slope a (1.5 m) thick layers are exposed. They are pale green, coarse grained, thickly bedded, highly weathered, calcareous SANDSTONE moderately weak (σc = 12.4 MPa). The underlying rock layers in the lower part of the slope are (0.5 m) thick. They are light grayish, fine grained, thickly bedded, highly weathered, SANDSTONE; with (2 m) thick, pale grayish, very fine grained, thickly bedded, highly weathered CLAYSTONE.

The sandstone layers are cut by two sets of subvertical joints in (S1 and S2), the spacing of discontinuity in (S1) ranges between (1 – 2.0 m); their persistence reaches (1 m) on the bedding plane and they are open up almost to (0.1 m). The spacing of discontinuity in (S2) ranges between (0.6 – 1 m); their persistence reaches (1.0 m) on the bedding plane and they are almost open up to (0.02 m), with differential erosion at the toe of the slope, in some parts,the slope is overhanging, helping in rock fall failure; the inclined soil slope helps rolling of detached rock block.

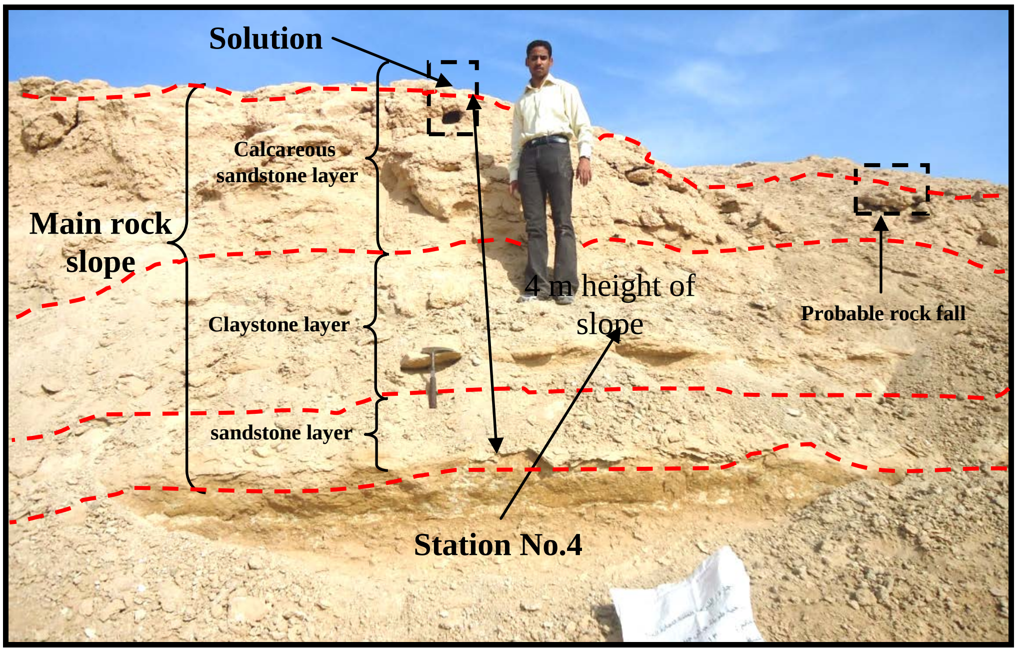


Plate 4: The slope of station No.4. Front view showing rock fall and toppling, photo direction SE

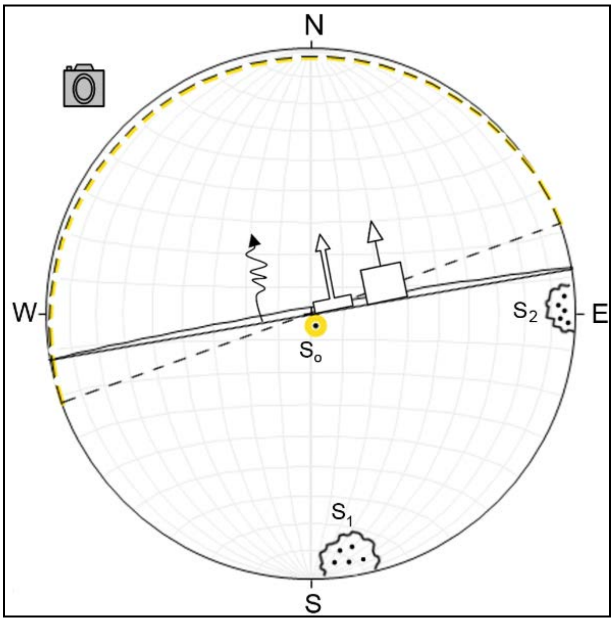


Fig.5: Stereogram of discontinuities, slope and types of failure for station No.4

- **Station No.5:** This station lies (2500 m) NE of Dewania street, at latitude (31° 35' 9.14" N) and longitude (044° 30' 13.4" E), within Injana Formation, (Plate 5). The slope is (8 m) high, (25 m) long along its trend and its inclination is (285/88°). The average dip of strata is (340/04°); therefore it is subhorizontal – layer slope.

In the upper part of the slope, (3 m) thick layers are exposed. They are pale green, medium grained, massive bedded, widely jointed, moderately weathered, CLAYSTONE moderately strong (σc = 28.2 MPa). These claystone layers are separated from the underlying sandstone layers by (3 m) thick layer of highly weathered sandstone which is removed by erosion.

The underlying rock layers in the lower part of the slope are (2 m) thick. They are light grayish, coarse grained, thickly bedded, widely jointed, moderately weathered, SANDSTONE. The sandstone layers are cut by two sets of discontinuities (S1 and S2); the spacing of the discontinuity in (S1) ranges between (1 – 2.5 m); their persistence reaches (4 m) on the bedding plane and they are open up almost to (0.1 m). The spacing of discontinuity in (0.5 – 1 m) ranges between (2 – 3 m); their persistence reaches (4 m) on the bedding plane and they are open up to almost (0.1 m). The sandstone layer in the lower part of the slope is highly weathered and eroded, leaving some parts of the slope overhanging; this has resulted in secondary toppling of sandstone blocks by differential settlement toppling mode. Also toppling in this station has occurred by tension cracks mechanism especially in the upper part of slope.

Plate 5-a: The slope of station No.5. Front view showing tension crack in station No.5

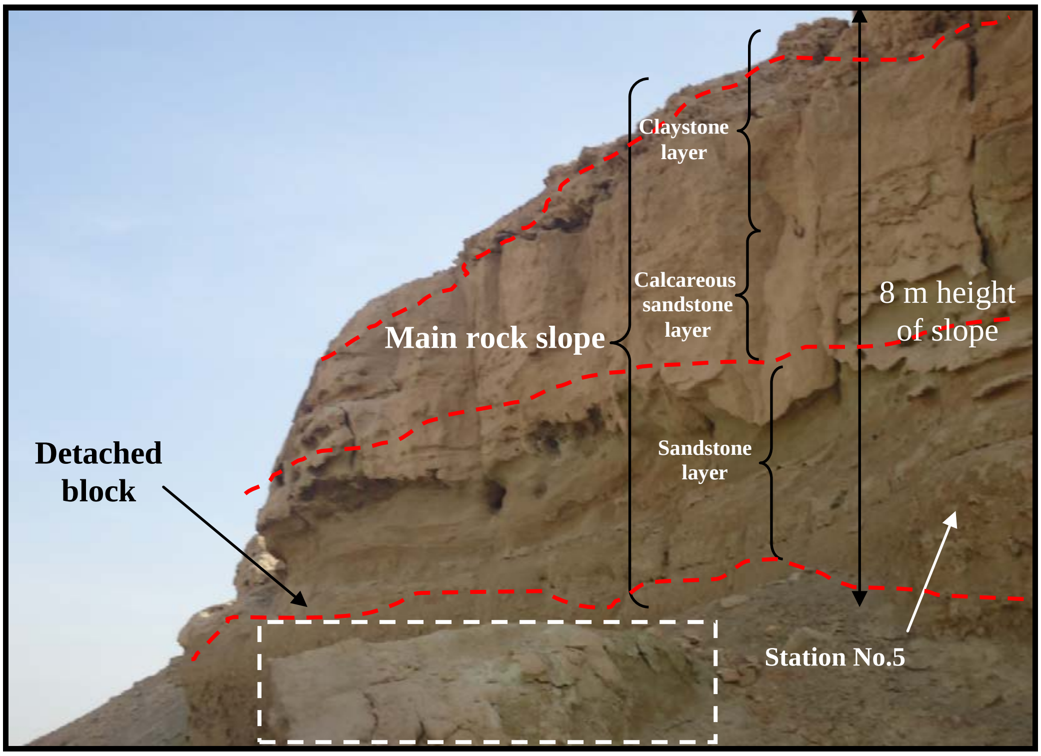


Plate 5-b: The slope of station No.5. Front view showing detached rock block and rock fall

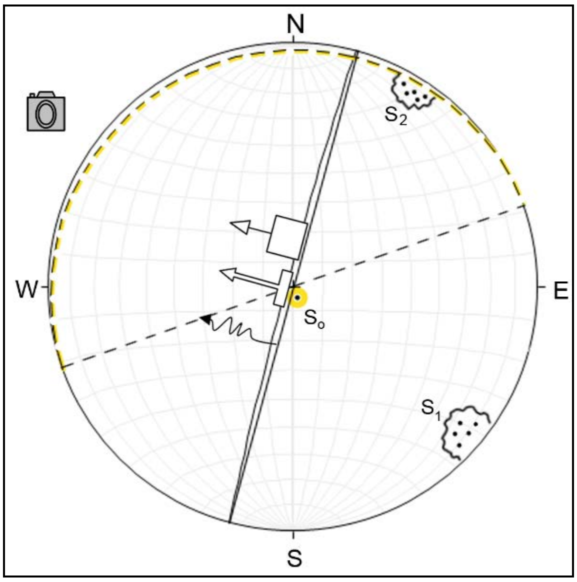


Fig.6: Stereogram of discontinuities, slope and types of failure for station No.5

CONCLUSIONS

- The cliff of Al-Qadhi is located in an arid area where wind is considered to be a principal factor influencing rock slope geomorphology. Wind help in the differential erosion of weak strata forming overhanging unstable slopes.
- Weak claystone and sandstone layers fail mostly by physical weathering, helping in forming overhanging unstable slopes, while hard claystone and sandstone layers have failed by toppling and rock fall as rock blocks.

- The vertical discontinuities in the rock mass played different roles during toppling failure; they acted as back release surface (BRS) or lateral release surface (LRS) layers or bedding planes acted as basal zones of under cutting.

RECOMMENDATIONS

The following measures are proposed to stabilize slopes:

1. Removel of the unstable blocks which are liable to toppling in the critical cases.
2. Filling slope toes which is subjected to undercutting by convenient filling materials that contain binding materials like cement or sodium silicate.
3. All slopes undergo different types of failure (toppling and rock fall); the failing blocks move down slope along cliff toes and may hit persons; therefore, it is recommended to construct retaining walls to protect the slopes and reduce the hazard.
4. Diverting the surface water from the top of the cut especially along the weathering sections.

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