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Slope Stability Assessment along Qalachwalan-Suraqalat Main Road, Sulaimani, NE-Iraq

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ABSTRACT

Rock failures are extremely frequent along the cut slopes of the road in the mountainous terrains of the Iraqi Kurdistan region. Qalachwalan – Suraqalat road which is to the north of Sulaimani city is one of the major transportation ways between Sulaimani city and many towns and villages of Sharbazher district. Sometimes, this road (especially in winter and spring seasons) shows many rock failures that causing hazards for locals and traffics. Therefore, the stability assessment of road-cut slopes along such road is very necessary.

For the present study ten (10) slope stations have been chosen from the road stretch of 10 Kilometers from Qalachwalan to Suraqalat, and this for stability assessment of the rock slopes with different techniques. The slope stations were chosen on the basis of difference in discontinuities pattern, variation in slope morphology and difference in the type of failure and the data were analyzed for their potential degree of stability by kinematic analysis, using DIPS v6.008 software and slope mass rating system [discrete-SMR and continuous-SMR (CSMR)], using SMR Tool - v205 software.

Kinematic analysis revealed that planar sliding may occur in slopes of station 5, 7 & 9, wedge sliding in slopes of station 2, 3, 4, 5, 6, 8 & 10, flexural toppling in slopes of station 1, 2, 3, 4, 6, 7, 8 & 10 and direct toppling in slopes of station 1, 2, 4, 5 & 7.

In the worst condition, the discrete-SMR and CSMR values for slopes in all stations range from 22-46 and 18-46 respectively, so It is observed that the values at slope station 1, 2 & 6 lie in partially-stable zone, with failure probability of 0.4, the values at slope station 4, 5, 7, 8, 9 & 10 lie in unstable zone, with failure probability of 0.6 and the value at slope station 3 lies in completely-unstable zone, with failure probability of 0.9.

1-Introduction

Assessment of rock slope stability along Qalachwalan – Suraqalat main road (north of Sulaimani city/ Iraq) is considered an important task due to the effect of slope instability on the human lives and traffic activities, so the stability problem of rock slopes along road-cut slopes in the study area is a major concern in the most places.

Rock slopes in most road cuts, especially in mountainous areas, are liable to instability problems due to changing in the rock mass conditions and external factors, such as seismic activities and water in the slope [1]. The material characteristics of a rock slope, the height, the face angle, and the discontinuity orientations play a great role in the instability problem of road cuts and slopes [2].

Many researchers (such as [3], [4], [5], [6], [7] and [8]) studied the stability of rock slopes along road cuts that are connecting remote areas in the valleys or on the hill and mountain slopes.

The present study comprises the assessment of road cut slopes in Shahrbazar district, Sulaimani/ NE-Iraq. Field investigations have been carried out to study the lithological and structural variations in rock slopes between Qalachwalan and Suraqalat, about 10 km road length. Ten stations (slope locations) were selected on the basis of rock exposures and the slope conditions. Slopes at these stations have been excavated by smooth blasting and mechanical methods for road construction, were studied and analyzed for their potential degree of stability using kinematic analysis and slope mass rating (SMR) system.

Kinematic analysis is commonly used to predict potential structural failure mechanisms (planar, wedge, and toppling) and the possible direction of failures movement along the potentially unfavorable joint planes using stereonet projection technique. This technique is used to project the orientation of discontinuities by pole, containing information about the dip and dip direction of a joint on a two-dimensional stereonet [2, 9].

Slope mass rating (SMR) includes rock mass rating (RMR) along with some adjustment factors based on the relation of discontinuity (bedding plane, joint, fault,...etc) orientation with slope and method of slope excavations. The adjustment factors in SMR technique, proposed by Romana [10], are discrete and are more decision based. The continuous slope mass rating (CSMR) proposed by Tomas [11], provides continuous determination and are no decision based.

2-Location and geology of the study area

The study area is located about 30km to the north of Sulaimani city or about 12 km to the southeast of Mawat town and along the Qalachwalan-Suraqalat main road, between latitudes 35° 41′ 30″ N - 35° 48′ 50″ N and longitudes 45° 24′ 13″ E - 45° 32′ 44″ E, as in Figure (1).

Tectonically the area is located in the northeastern part of the Arabian plate in the Zagros Fold - Thrust belt, exactly in the Imbricated Zone [12], which is close to the boundary between Imbricated and thrust Zones.

Structurally the rock strata represent a homoclinal structure of intermediate dip (24 – 40 degrees) which forming striking ridges, due to alternating resistant and nonresistant rocks [13], wherein the resistant rocks are sandstone, pebbly sandstone, and conglomerate, and the nonresistant rocks are claystone and siltstone.

The main lithology of the study area is conglomerate, pebbly sandstone, fine sandstone, siltstone, and red claystone, these rocks are belonging to the Red bed-Series that were deposited under continental conditions from proximal alluvial fan to delta environment [14].

3-Material and Methodology

Geological surveys were carried out in February and March 2019 with a rainfall period for ten (10) rock-cut slope stations, where all stations are locating in Red Bed-Series. All field attitude measurements of discontinuities (bedding planes, joints, faults,….etc) and slope are in the dip direction/dip angle manner.

The data measured in the field included slope angle and direction, dip & dip direction of discontinuities, spacing, and condition (persistence, roughness, weathering, aperture, filling materials) of discontinuities, also included determining groundwater condition. Laboratory analysis was also done to evaluate the strength index from the point load test as per ISRM [15] suggested method.

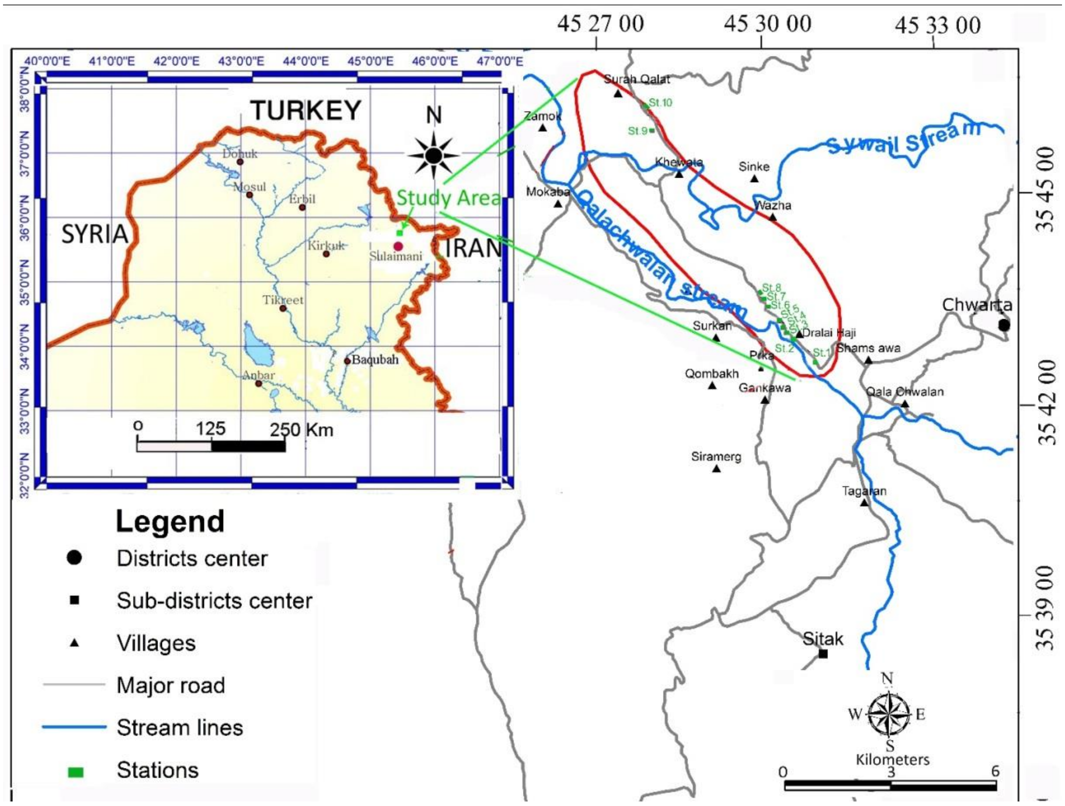

Fig. 1: Topographic map showing the locations of the 10 slope sites in Red bed series in the study area

This study concentrates on the assessment of the stability of the rock-cut slopes by kinematic analysis, slope mass rating (SMR) and continuous slope mass rating (CSMR) systems.
Kinematic analysis is the simplest failure analysis in terms of joint sets, bedding plane, cut slope, and sliding friction angle but it is only suitable for preliminary design [2]. The kinematic analysis is an easy method for determining the potential failure types (plane, wedge & toppling) and failure direction in jointed rock mass from angular relation between discontinuities and slope surface [2]. Markland test [16] is a kinematic method that is designated to assess the probability of wedge sliding, wherein the wedge-shaped mass slides along the intersection line of two planes. The collected data were represented stereographically using DIPS v6.008 software [17]. For a planar discontinuity, the cohesion will be zero and the shear strength will be defined only by the discontinuity friction angle. Friction angles were calculated by the tilting method [18].
Slope mass rating (SMR) which was proposed by Romana [10] is a system to determine the stability of rock slopes. This method is based on a rock mass rating (RMR) system given by Bieniawski [19].
RMR system is based on field and laboratory study, which includes uniaxial compressive strength (UCS) of the intact rock, rock quality designation (RQD), discontinuity spacing, discontinuity condition and groundwater condition, Table (1). The rating of these five parameters can be obtained from Table (1) and Figures (2, 3 & 4), then the ratings are added to give a value of RMRb (basic RMR).

Table 1: Basic Parameters of Rock Mass Rating (RMR). After [19]

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS									
	Parameter		Range of values						
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core Quality RQD		90% - -100%	75% - -90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation -> 5 mm Continuous		
	Rating		30	25	20	10	0		
-5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125		
		(Joint water press)/ (Major principal σ)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		
E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions									
	Discontinuity length (persistence) Rating		< 1 m 6	1 - 3 m 4	3 - 10 m 2	10 - 20 m 1	> 20 m 0		
	Separation (aperture) Rating		None 6	< 0.1 mm 5	0.1 - 1.0 mm 4	1 - 5 mm 1	> 5 mm 0		
	Roughness Rating		Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0		
	Infilling (gouge) Rating		None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0		
	Weathering Ratings		Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0		

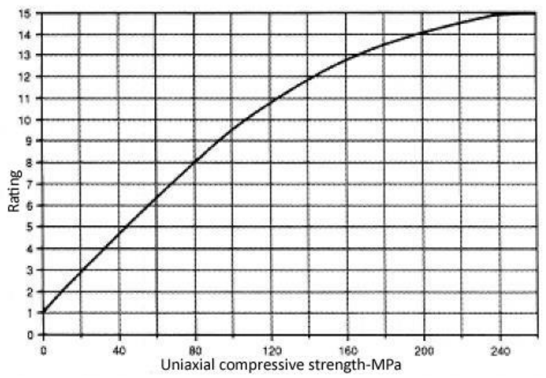

Fig. 2: Variation of rating for the uniaxial compressive strength [19]

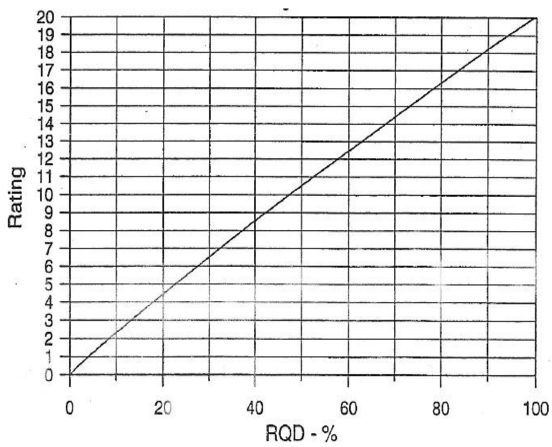

Fig. 3: Variation for the RQD rating [19]

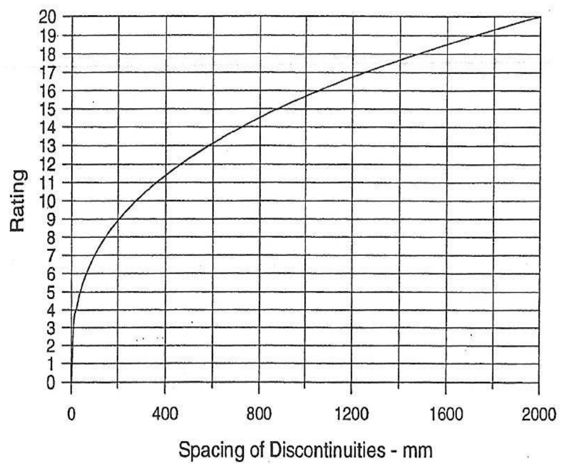

Fig. 4): Variation of rating for the discontinuity spacing [19]

RMR plays a basic role in the calculation of the SMR and CSMR. RMR includes the collection of field data; i.e. attitudes (dip direction / dip angle) of different discontinuities, UCS for ten stations (road-cut slopes) have been derived from point load test on the prism specimens according to ISRM [10] suggested method, spacing, slope direction and dip, conditions of discontinuities and groundwater conditions. The average spacing of all discontinuities was calculated from the inverse relationship with the average frequency of all discontinuities [20]. Rock quality designation (RQD) has been calculated according to Palmstrom [21] using volumetric joint count (Jv) (number of discontinuities per unit volume) and thus the RQD is equal to 110 - 2.5 Jv.

A slight modification was made for SMR by Anbalagan [22] to include wedge failure along with plane and topple failures, as in Table (2). Table (3) shows the different stability classes and the empirically found limit values of SMR associated with the different failure modes that are proposed by Romana [10]. Also, Tomas [11] developed a continuous-SMR (CSMR), which is a modification of the discrete SMR technique of Romana. The CSMR offers a unique value of each adjustment factor unlike a range as in discrete SMR.

SMR is calculated by using RMRb along with some adjustment factors proposed by Romana [10] as shown in equation no.1.

SMR = RMRb + (F1 . F2 . F3) + F4 ……..(1)

The CSMR results in a more precise value of SMR by providing unique value to each adjustment factor of slope unlike a range as in SMR. For CSMR, the adjustment factors F1, F2, and F3 are calculated by using the following equations proposed by Tomas [11]:

F1 = (16/25) – (3/500) Arctan [(1/10) (‖A‖ - 17)] ……(2)

Where: |A| = |αj-αs| for planar failure, |αi - αs| for wedge failure, ||αj - αs|-180| for toppling failure, and αj, αs, and αi are dip direction of joint, slope and plunge direction of intersection line of two joint planes.

F2 = (9/16) + (1/195) Arctan [(17/100) B - 5]…...(3) (for planar and wedge failure)

F2 = 1 ……………(4) (for toppling failure)

Where: B equals to dip (βj) of joint for planar failure and toppling failure and dip of the plunge of intersection line for wedge failure.

F3 = -30 + (1/3) Arctan (C) ………(5) (for planar and wedge failure)

F3 = -13 – (1/7) Arctan (C -120)…...(6) (for toppling failure)

Where: C is an angular difference of dip of joint and slope (βj, βs) for planar failure. C is the difference of dip of the plunge of intersection line and dip of slope (βi-βs) for a wedge. For toppling, C is defined as a sum of dip of joint and slope (βj+βs).

F4 refers to the adjustment factor for the excavation method of the rock slope, which has been fixed empirically as shown in Table (1). The stability classes, SMR-values, rock mass description, stability condition, type and probability of failure given by Romana [10] are also applicable for CSMR classification is given in Table (3).

Slope mass rating (SMR) of Romana [10] and continuous slope mass rating (CSMR) of Tomas [11] have been employed using SMRTool-v205 [23] that use RMRb values, discontinuities and slope attitude, also method of excavation of the slope for all rock-cut slope stations.

Table 2: Adjustment factors for SMR (Modified from Romana [10] by Anbalagan et al. [22])

TYPE OF FAILURE			VERY FAVORABLE	FAVORABLE	NORMAL	UNFAVORABLE	VERY UNFAVORABLE
P	A	$\lvert \alpha_j-\alpha_s \rvert$	>30°	30-20°	20-10°	10-5°	<5°
T		$\lvert \lvert \alpha_j-\alpha_s \rvert -180 \rvert$					
W		$\lvert \alpha_i-\alpha_s \rvert$					
P/T/W	**F_1**		**0.15**	**0.40**	**0.70**	**0.85**	**1.00**
P/W	B	$\lvert \beta_j \rvert$ or $\lvert \beta_i \rvert$	<20°	20-30°	30-35°	35-45°	>45°
P/W	**F_2**		**0.15**	**0.40**	**0.70**	**0.85**	**1.00**
T			**1.00**				
P	C	$\beta_j-\beta_s$	>10°	10-0°	0°	0-(-10°)	<(-10°)
W		$\beta_i-\beta_s$					
T		$\beta_j+\beta_s$	<110°	110-120°	>120°	-	-
P/T/W	**F_3**		**0**	**-6**	**-25**	**-50**	**-60**
EXCAVATION METHOD (F_4)							
Natural slope				+15	Blasting or mechanical		0
Presplitting				+10	Deficient blasting		-8
Smooth blasting				+8			

Where:- P: planar failure; T: toppling failure; W: wedge failure; α_j: joint dip direction; α_s: slope direction α_i: intersection line direction; β_j: joint dip angle; β_i: intersection plunge angle; β_s: slope angle

Table 3: Description of slope mass rating (SMR) classes [10]

Classes →	V	IV	III	II	I
SMR	0-20	21-40	41-60	61-80	81-100
Description	Very bad	Bad	Normal	Good	Very good
Stability	Completely unstable	Unstable	Partially stable	Stable	Completely stable
Failures	Big planar or soil-like	Planar or big wedges	Some joints or many wedges	Some blocks	None
Failure probability	0.9	0.6	0.4	0.2	0

4- Results and Discussion:

This study includes surveying of slopes at ten (10) stations (rock-cut slopes) in the Red Bed-Series, which have different geomorphological and structural characteristics. The rock-cut slopes composed of a succession of sandstone, siltstone and claystone beds, in which resistant sandstone beds form unstable conditions, as in slope stations 2, 3, 4, 5, 6, 7, 8 & 9. In some stations, the slopes composed of a succession of conglomerate, pebbly sandstone and claystone beds in which relatively resistant conglomerate and pebbly sandstone beds form unstable conditions, as in slope stations 1and 10. The rock-cut slopes have gentle to very steep dip angle. Slope and discontinuities (bedding planes, joints and faults) attitude was measured using the Silva compass to determine the dip direction and dip angle that is given in Table (4). The friction angle of discontinuities failure surfaces was determined from performing the tilting method of Bruce [18] which is equal to 31° for sandstone and 32° for pebbly sandstone and conglomerate.

Table 4: Dip direction /Dip angle of slope face, bedding planes and joints in the stations of road-cut slopes

Station no. (Slope site)	Slope Dip direction / Dip angle (Average)	Bedding plane Dip direction / Dip angle (Average)	Join set (J1) Dip direction / Dip angle (Average)	Joint set (J2) Dip direction / Dip angle (Average)	Joint set (J3) Dip direction / Dip angle (Average)	Joint friction Angle (ϕ)
1	215/90°	045/40°	302/61°	094/40°	——	32°
2	220/90 °	050/34°	308/70°	193/63°	——	31°
3	220/90°	050/38°	289/74°	196/67°	——	31°
4	230/90°	045/40°	305/72°	202/70°	——	31°
5	225/80°	050/30°	286/74°	110/75°	212/65°	31°
6	240/90°	045/40°	284/82°	192/70°	——	31°
7	207/90°	020/40°	097/88°	188/56°	——	31°
8	226/90°	058/38°	288/70°	184/72°	——	31°
9	065/40°	060/34°	132/89°	062/78°	——	31°
10	230/90°	064/34°	252/50°	154/48°	——	32°

4.1-Results and discussion from the kinematic analysis:

The kinematic analysis which is based on Markland's test was conducted using internal friction angle of rock discontinuities, the average attitude of slopes and discontinuities to identify any potential structurally controlled failure by application DIPS v6.008 software. The potential failure zone has been shown in pink color in stereographic projection for all the ten (10) stations (road-cut slopes) and the discontinuities (bedding plane and joints) were represented as poles (perpendicular to the plane). Kinematic analysis of slopes reveals that there is:

1) Potential for planar sliding at stations 5, 7 & 9 on J3, J2 & So (bedding plane) respectively, as shown in Figures 13a, 14, 17a, 18, 21a & 22.

2) Potential for wedge sliding at stations 2, 3, 4, 5, 6, 8 & 10, in which the wedge sliding occurs on the J1 & J2 joint sets in all slope stations except that of slope station no.5 that is on the J1 & J3 joint sets, as shown in Figures 7b, 8, 9b, 10, 11b, 12, 13b, 14, 15b, 16, 19b, 20, 23b & 24.

3) Potential for flexural toppling about (So) at stations 1, 2, 3, 4, 6, 7, 8 & 10 as shown in Figures 5c, 6, 7c, 8, 9c, 10, 11c, 12, 15c, 16, 17c, 18, 19c, 20, 23c &24.

4) Potential for direct toppling at stations 1, 2, 4, 5 & 7 about intersection planes [(So&J1, J1&J2), (So&J1), (So&J1), (So&J2) and (So&J1)] respectively, as shown in Figures 5d, 6, 7d, 8, 11d, 12, 13d, 14, 17d & 18.

The direction of failure is in the southwest direction, ranges among 188^0 to 251^0 except for slope station no.9 in which the direction of failure is in the northeast direction (60^0) where they are shown on the stereonet as an arrow (Figures: 5, 7, 9, 11, 13, 15, 17, 19, 21 & 23) and Table (5), wherein these slope sites (stations) were already failed. All results of the kinematic analysis are listed in Table (5).

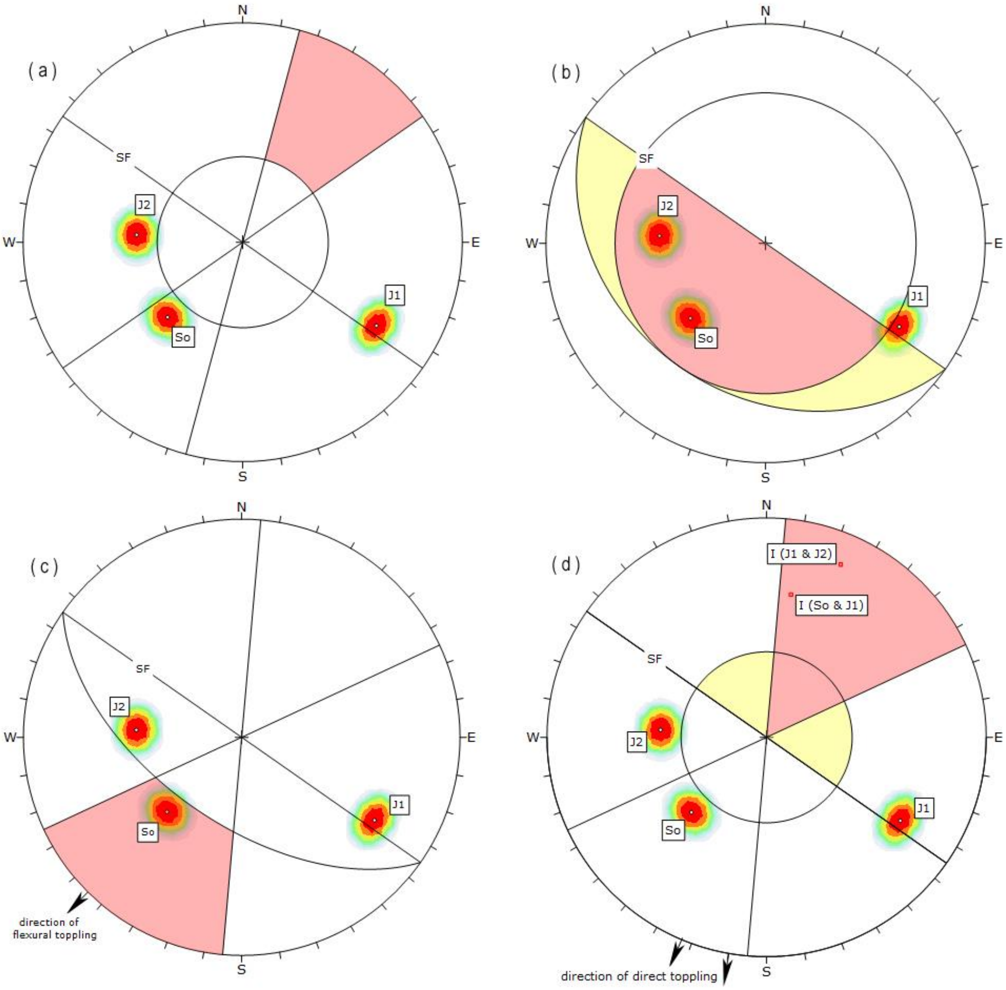

Fig. 5: Kinematic analysis of station no.1: (a)No plane sliding ; (b)No wedge sliding; (c) Flexural toppling about So; (d)Direct toppling via two release intersected planes. Where: SF=slope face; So=bedding plane; J1 & J2 are joint sets

Fig. 6: General view for slope at station no.1 with marked discontinuity sets

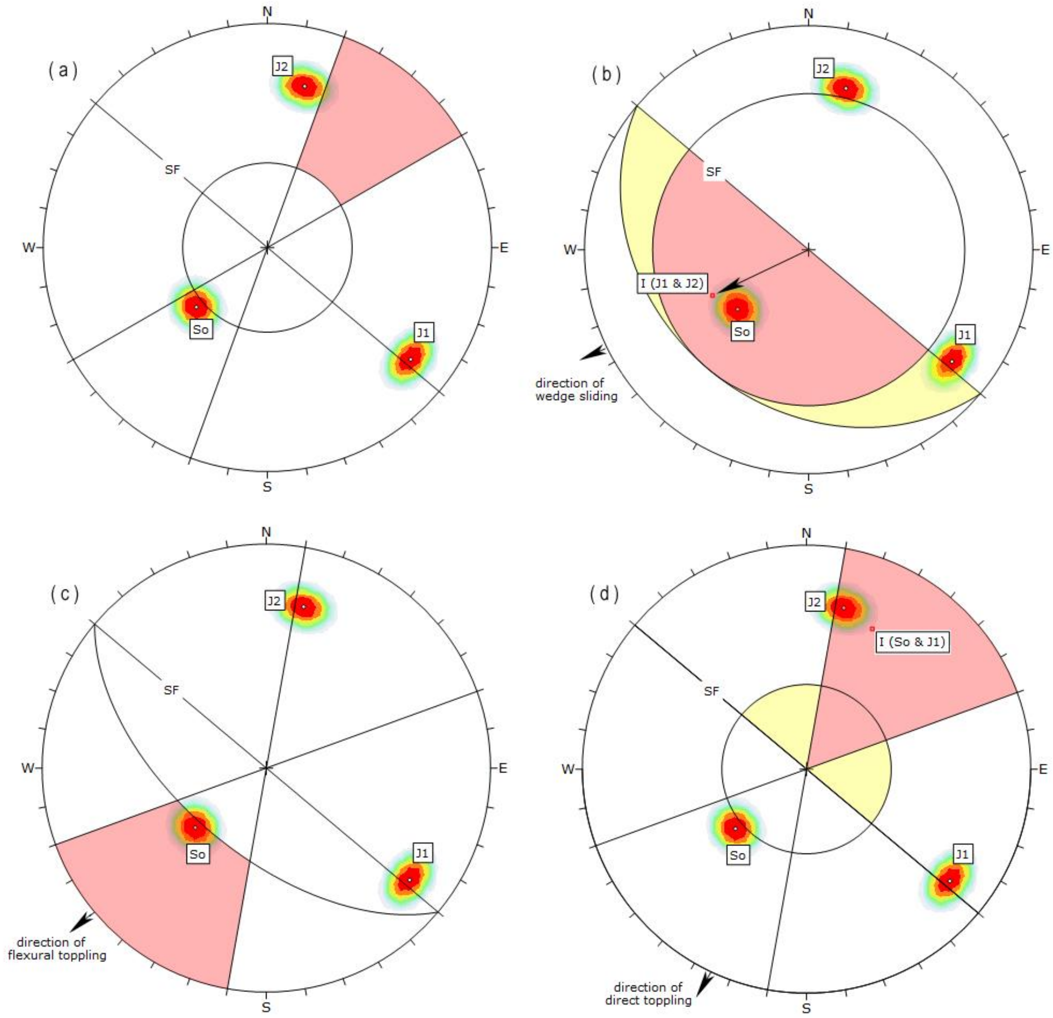

Fig. 7: Kinematic analysis of station no.2: (a)No plane sliding ; (b)Wedge sliding on J1 & J2; (c) Flexural toppling about So; (d)Direct toppling via release intersected planes (So & J1). Where: SF=slope face; So=bedding plane; J1 & J2 are joint sets

Fig. 8: General view for slope at station no.2 with marked discontinuity sets

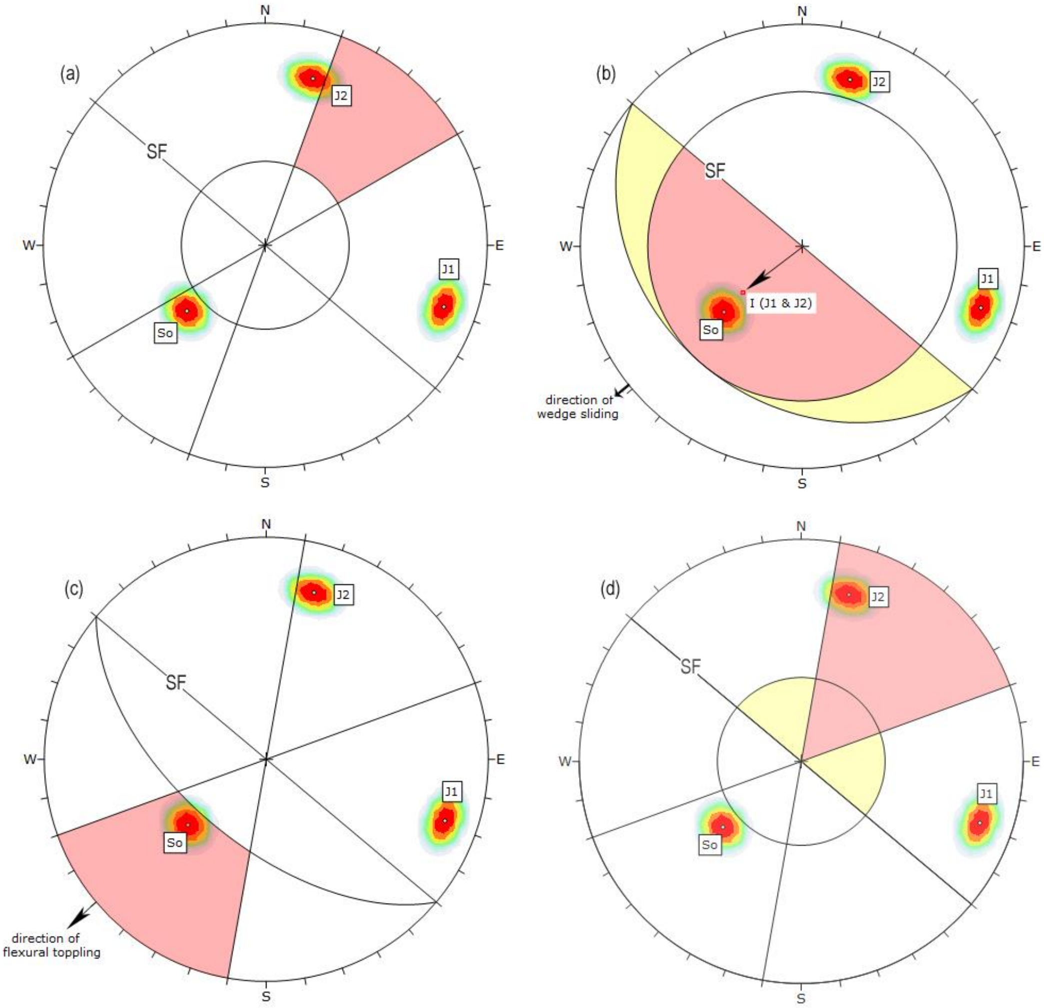

Fig. 9: Kinematic analysis of station no.3: (a)No plane sliding ; (b)Wedge sliding on J1 & J2; (c) Flexural toppling about So; (d)No direct toppling. Where: SF=slope face; So=bedding plane; J1 & J2 are joint sets

Fig. 10: General view for slope at station no.3 with marked discontinuity sets

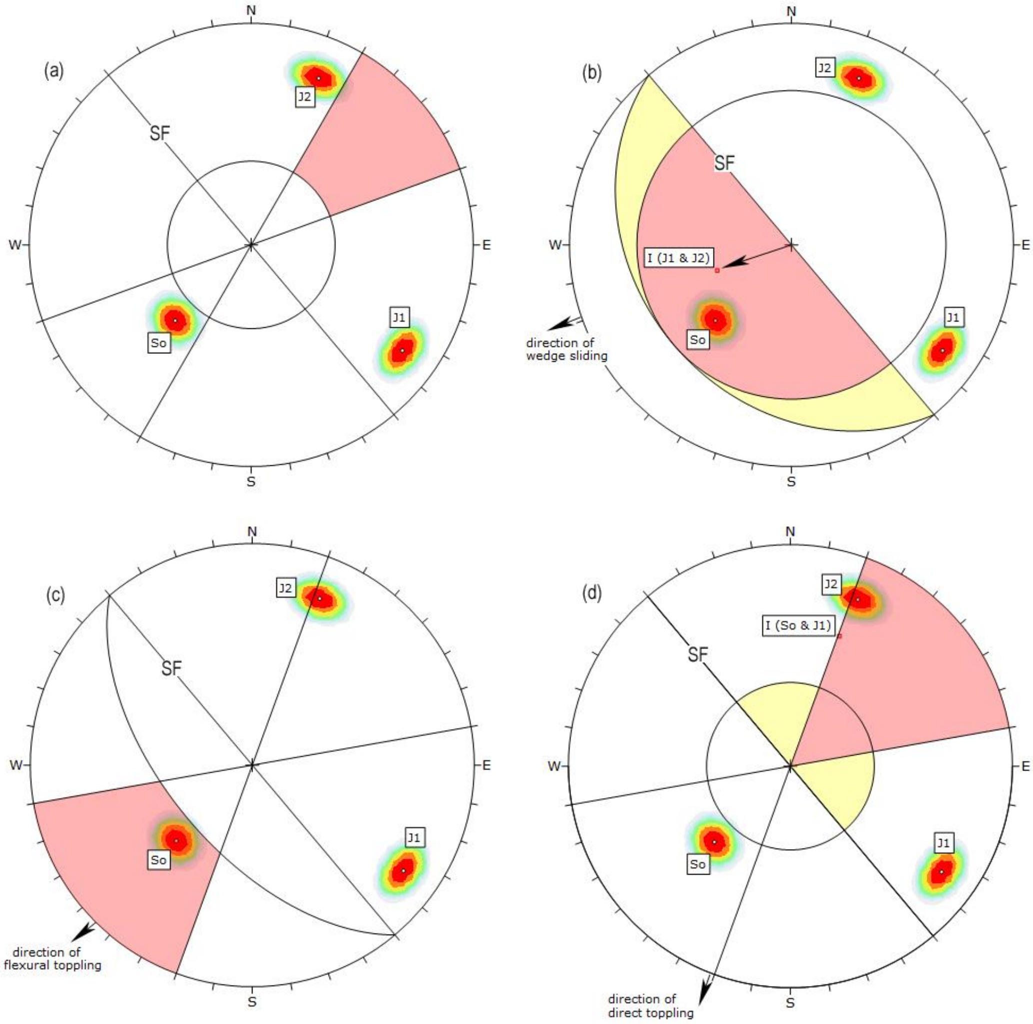

Fig. 11: Kinematic analysis of station no.4: (a)No plane sliding ; (b)Wedge sliding on J1 & J2; (c) Flexural toppling about So; (d)Direct toppling via release intersected planes (So & J1). Where: SF=slope face; So=bedding plane; J1 & J2 are joint sets

Fig. 12: General view for slope at station no.4 with marked discontinuity sets

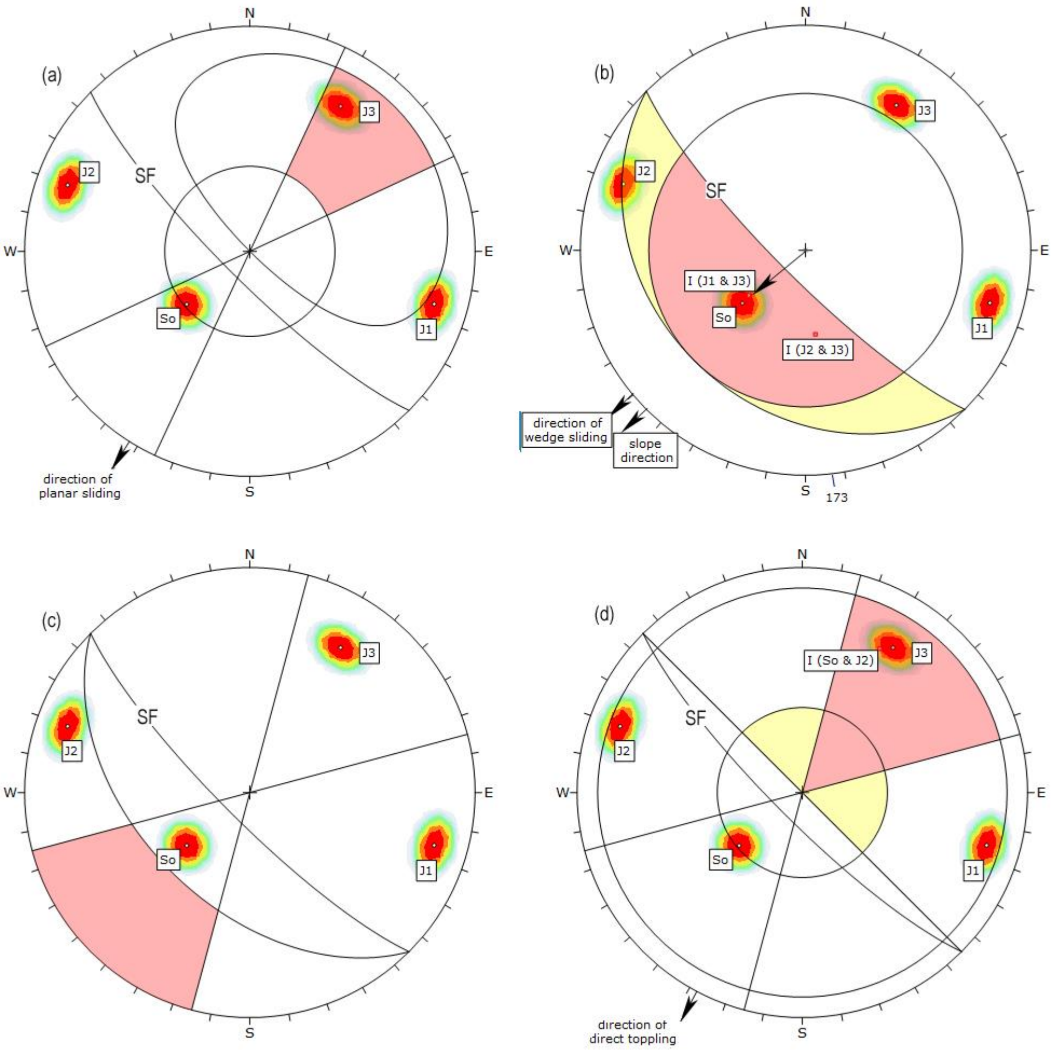

Fig. 13: Kinematic analysis of station no.5: (a)Plane sliding on J3 ; (b)Wedge sliding on J1 & J3; (c)No flexural toppling; (d)Direct toppling via release intersected planes (So & J2). Where: SF=slope face; So=bedding plane; J1, J2 & J3 are joint sets

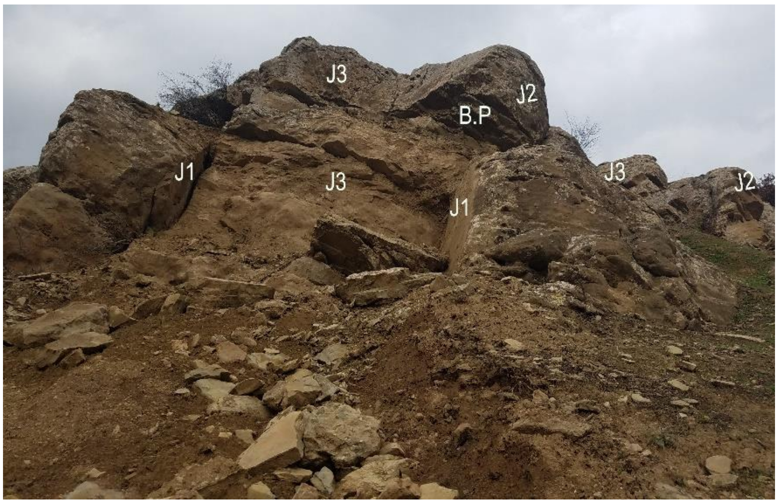

Fig. 14: General view for slope at station no.5 with marked discontinuity sets

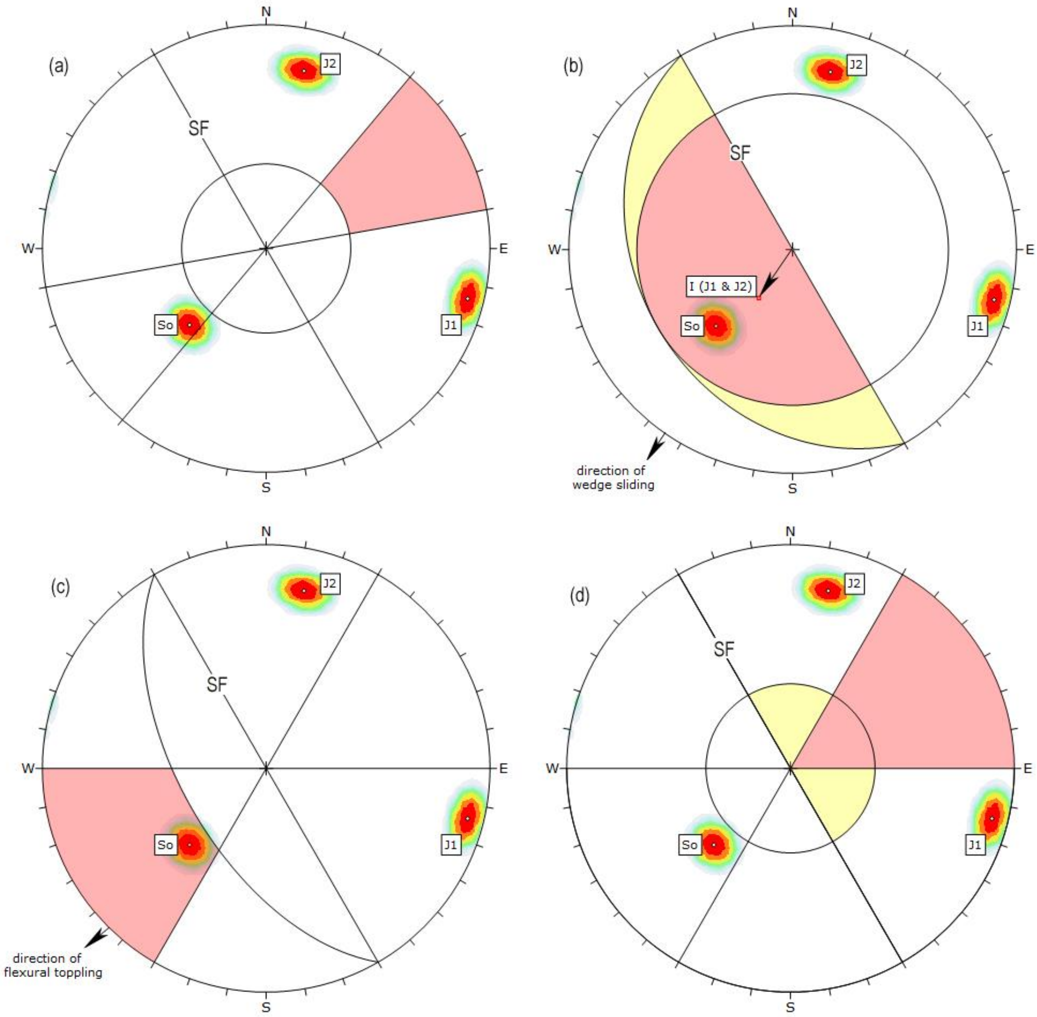

Fig. 15: Kinematic analysis of station no.6: (a)No plane sliding ; (b)Wedge sliding on J1 & J2; (c) Flexural toppling about So; (d)No direct toppling. Where: SF=slope face; So=bedding plane; J1 & J2 are joint sets

Fig. 16: General view for slope at station no.6 with marked discontinuity sets

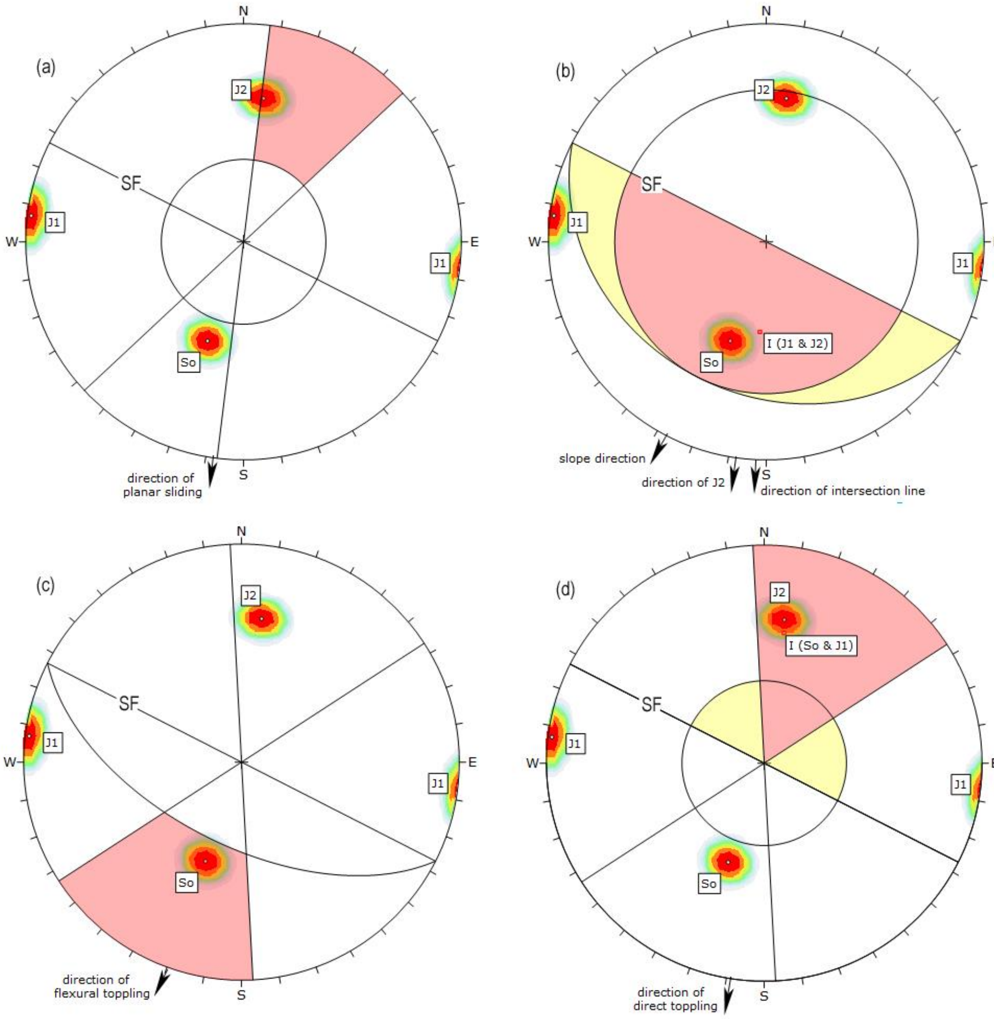

Figure 17: Kinematic analysis of station no.7: (a)Plane sliding on J2 ; (b)Wedge sliding on J1 & J2; (c)Flexural toppling about So; (d)Direct toppling via release intersected planes (So & J1). Where: SF=slope face; So=bedding plane; J1 & J2 are joint sets

Fig. 18: General view for slope at station no.7 with marked discontinuity sets

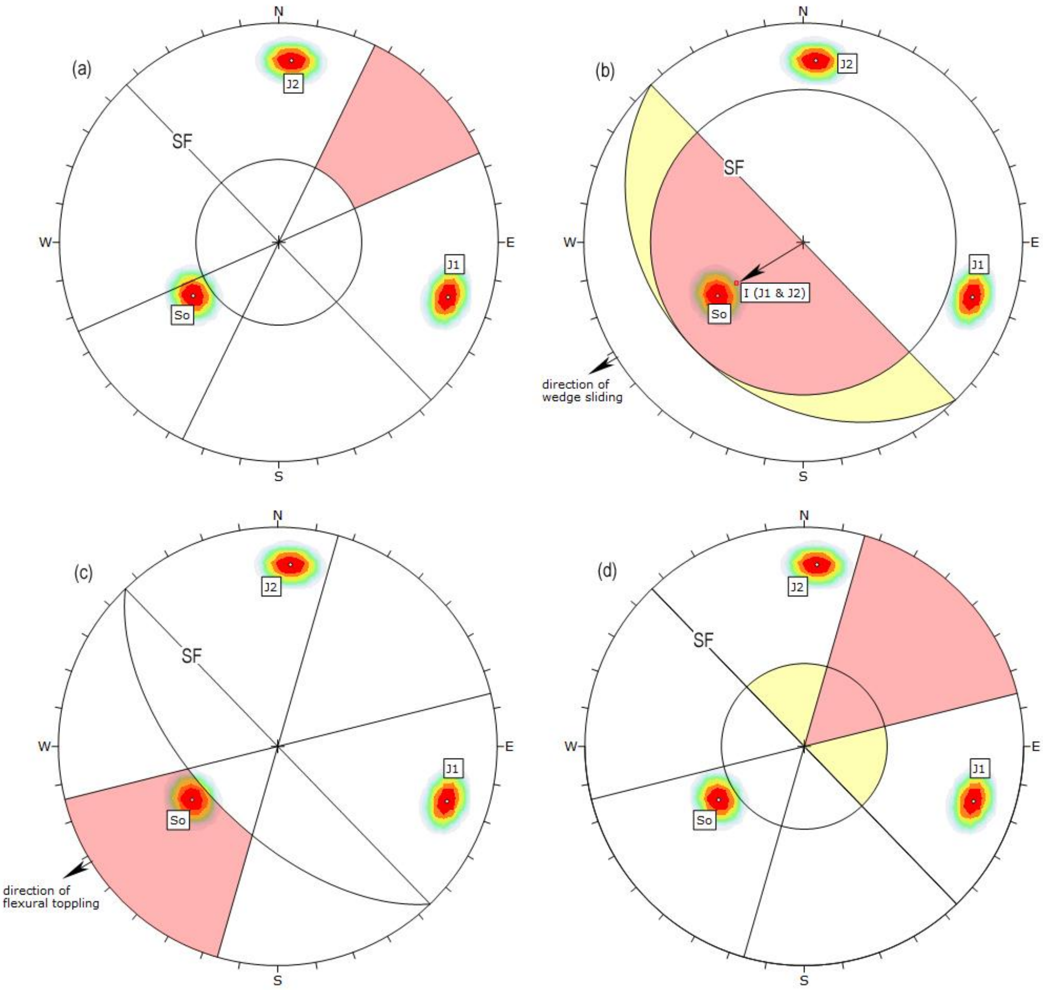

Fig. 19: Kinematic analysis of station no.8: (a)No plane sliding; (b)Wedge sliding on J1 & J2; (c)Flexural toppling about So; (d)No direct toppling. Where: SF=slope face; So=bedding plane; J1 & J2 are joint sets

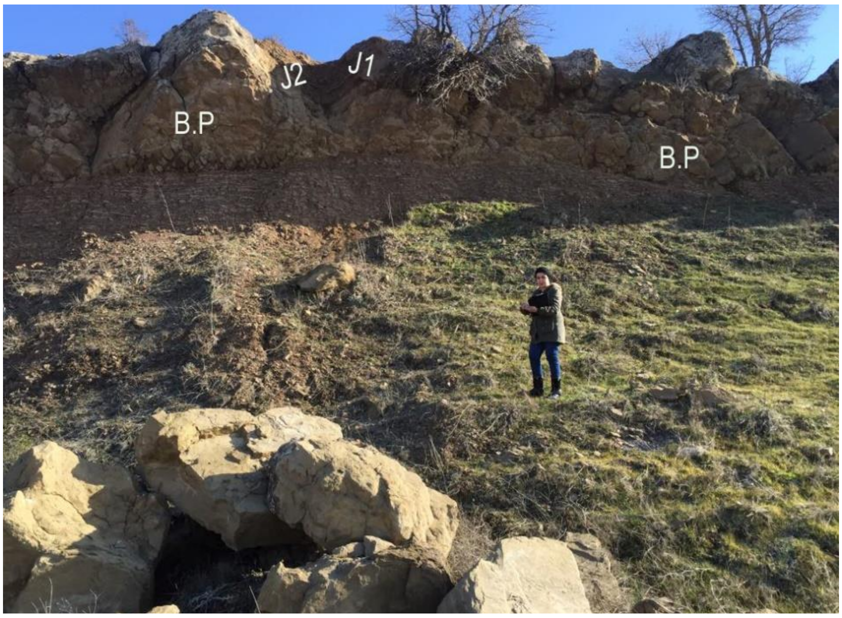

Fig. 20: General view for slope at station no.8 with marked discontinuity sets

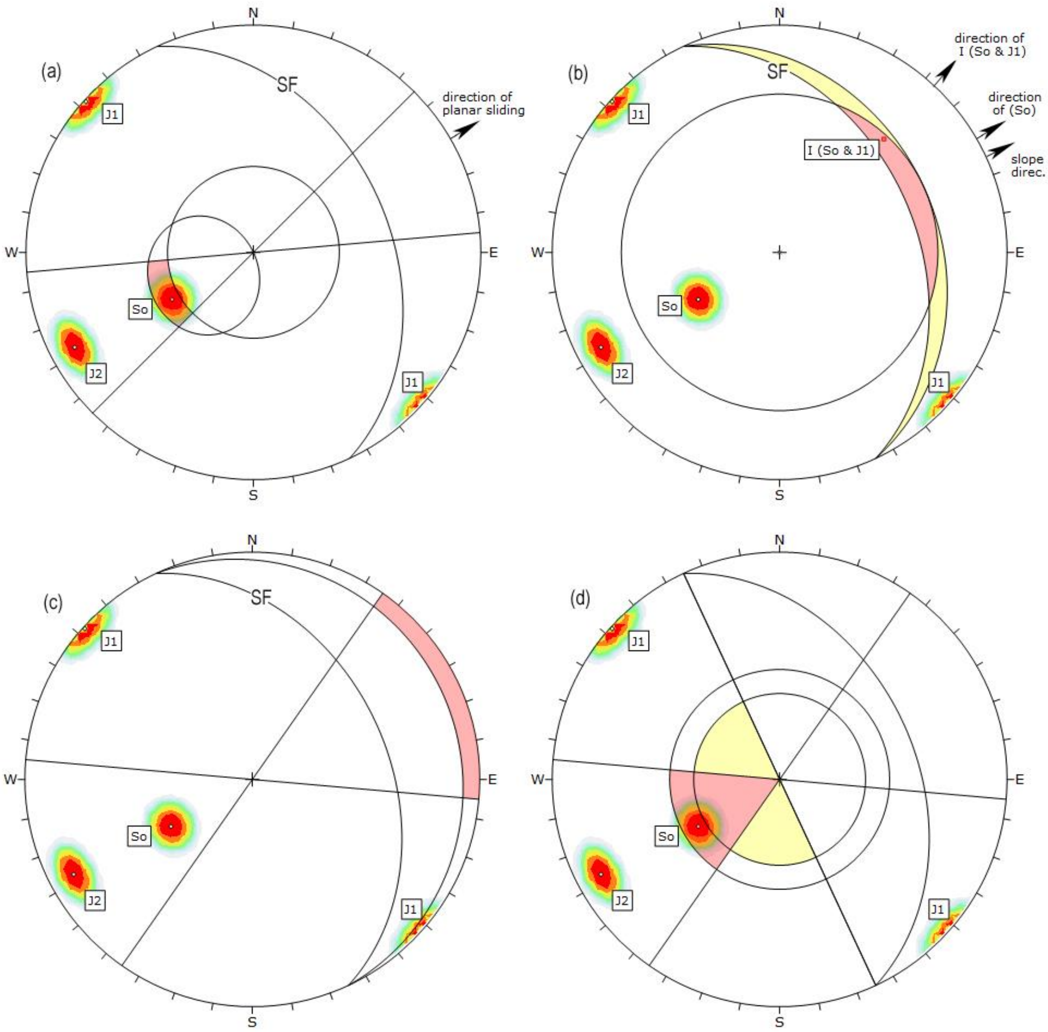

Fig. 21: Kinematic analysis of station no.9: (a)Plane sliding on So; (b)No wedge sliding; (c)No flexural toppling; (d)No direct toppling. Where: SF=slope face; So=bedding plane; J1 & J2 are joint sets

Fig. 22: General view for slope at station no.9 with marked discontinuity sets

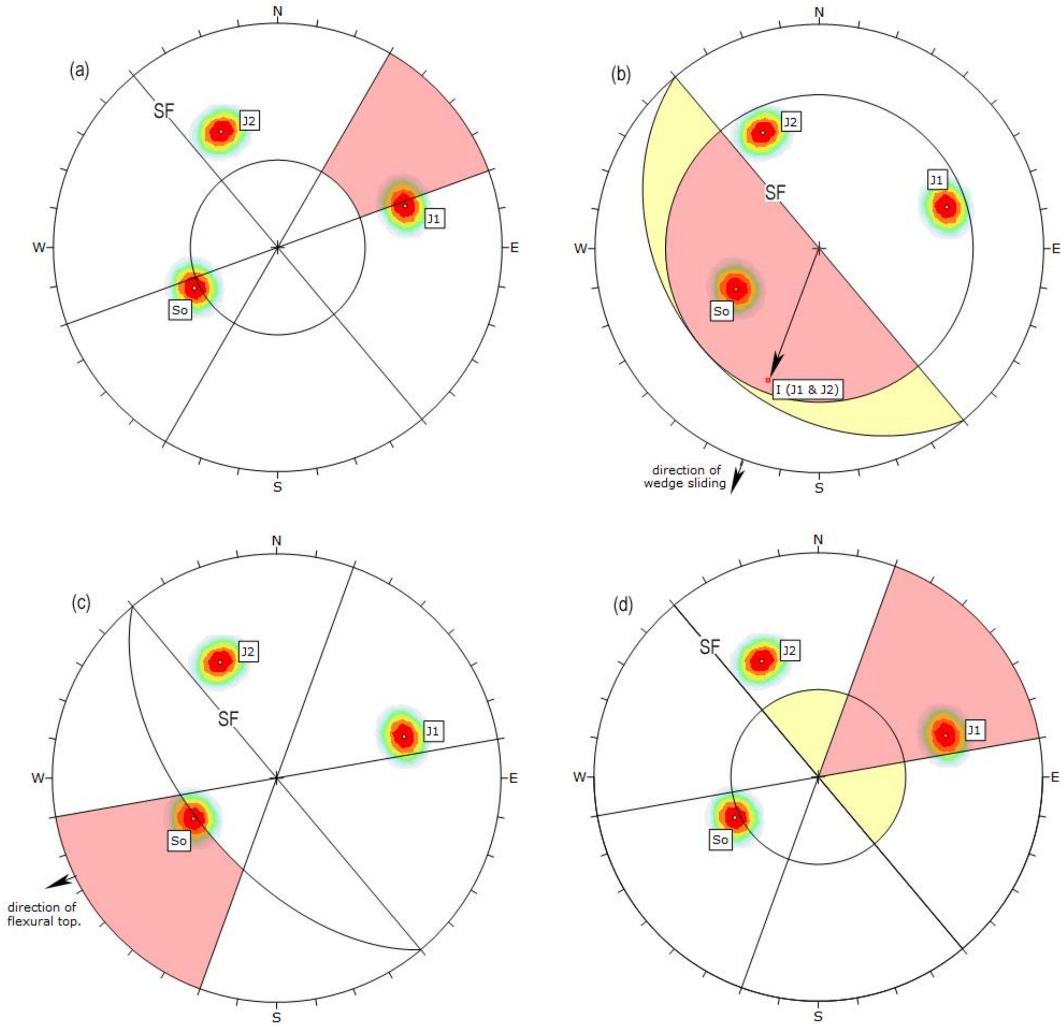

Fig. 23: Kinematic analysis of station no.10: (a)No plane sliding; (b)Wedge sliding on J1 & J2; (c)Flexural toppling about So; (d)No direct toppling. Where: SF=slope face; So=bedding plane; J1 & J2 are joint sets

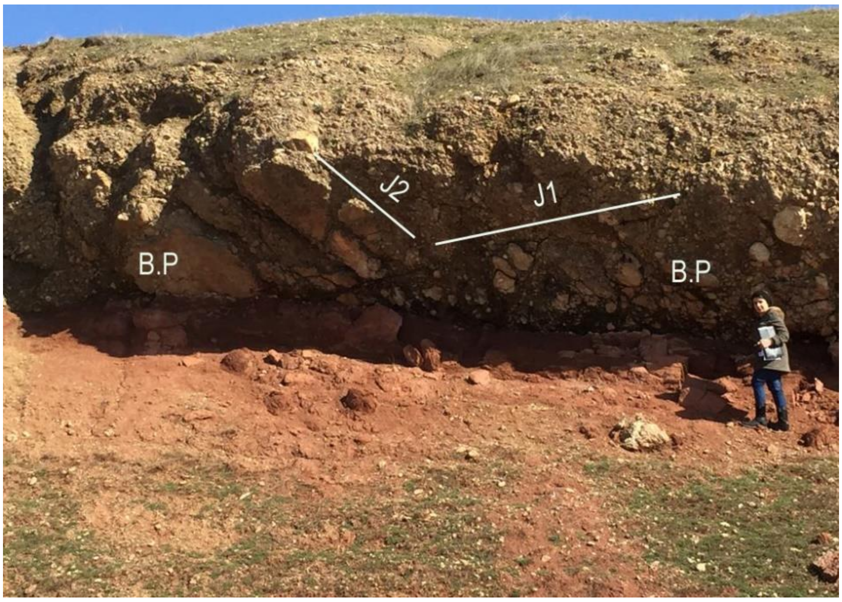

Fig. 24: General view for slope at station no.10 with marked discontinuity sets

Table 5: Results of kinematic analysis of rock slopes using DIPS-Software

Station No. (Slope site)	Planar sliding & its direction	Wedge sliding & its direction	Flexural toppling & its direction	Direct toppling & its direction
1	——	——	√ (225°)	√ (190°, 203°)
2	——	√ (245°)	√ (230°)	√ (206°)
3	——	√ (232°)	√ (230°)	——
4	——	√ (251°)	√ (225°)	√ (200°)
5	√ (212°)	√ (230°)	——	√ (208°)
6	——	√ (215°)	√ (225°)	——
7	√ (188°)	——	√ (200°)	√ (188°)
8	——	√ (238°)	√ (238°)	——
9	√ (60°)	——	——	——
10	——	√ (200°)	√ (244°)	——

4.2-Results and discussion from Slope Mass Rating (SMR) system:

Three main failure mechanisms were defined using kinematic analysis for the structurally controlled rock cuts [planar, wedge and toppling (flexural and direct toppling)], and their results have been used in the Slope Mass Rating classification system.

RMR_b was calculated according to the guidelines of Bieniawski [19]. UCS obtained indirectly from point load tests, which was done according to the procedure of ISRM [15], with using the index-to-strength conversion factor equal to 21 (k=21), in which this value is suitable for a variety of rock types [24], UCS value ranges from 22 MPa to 71 MPa as shown in Table (6). RQD obtained from the relation between RQD and volumetric joint count (Jv) of Palmstrom [21] (RQD=110-2.5 Jv) which it ranges from 94 to 100, and the average spacing of all discontinuities obtained from the inverse of average frequency of all discontinuities [20] which it ranges from 493mm to 1226mm, as shown in Tables (7 & 8).

The rock mass characterization for the RMR_b-parameters in all stations of the rock-cut slopes are shown in Table (9).

The required parameters of RMRb (1989) were rated from comparison the rock mass characterization with general RMR-table of Bieniawski [19] (Table 1) and other three tables proposed also by Bieniawski [19] for determining the fine rating of UCS, RQD and discontinuity spacing (Figures 2, 3 & 4), finally, the values of RMRb (1989) for the rock mass were determined in each slope stations, as shown in Table (10).

Table 6: Results of Point load test (PLT) and Value of Uniaxial compressive strength (UCS) for intact rock in the rock slopes of stations 1, 2, 3, 4, 5 & 6

Station. No	1	2	3	4	5	6
Rock Series	Red bed					
D (mm)	38	40	41	43	36	40
W (mm)	60	42	60	63	40	60
F (KN)	3.37	4.79	9.86	10.31	7.19	11.05
F (MN)	0.00337	0.00479	0.00986	0.01031	0.00719	0.01105
A (mm^2)	2280	1680	2460	2709	1440	2400
$D_e^2=(4A/\pi)$ m^2	0.002901	0.002138	0.003130	0.003447	0.001832	0.003054
$Is=F/D_e^2$ (MPa)	1.161668	2.240411	3.150159	2.991006	3.924672	3.618205
$F=(D/50)^{0.45}$	0.883824	0.904462	0.914568	0.934381	0.862580	0.904462
$Is_{(50)}=Is*f$	1.026710	2.026366	2.881034	2.794739	3.385343	3.272528
$UCS=21*Is_{(50)}$ (MPa)	21.56091	42.553	60.501	58.689	71.092	68.723
UCS (MPa)	22	43	61	59	71	69

Where: D=Diameter (distance between the two loaded points), W=Width of the specimen A=W*D((Area of idealized failure plane), F=Force at failure, Is=Point load strength index f =(size correction factor), UCS=uniaxial compressive strength.

Table (6 - Continuer): Results PLT and Value of USC for intact rock in the stations 7, 8, 9 & 10

Station no.	7	8	9	10
Rock Series	Red bed			
D (mm)	40	40	41	53
W (mm)	65	40	61	71
F (KN)	9.26	4.20	7.58	5.50
F (MN)	0.00926	0.0042	0.00758	0.0055
A (mm^2)	2600	1600	2501	3763
$D_e^2=(4A/\pi)$ m^2	0.003309	0.002036	0.003183	0.004789
$Is=F/D_e^2$ (MPa)	2.798428	2.062868	2.381401	1.148465
$F=(D/50)^{0.45}$	0.904462	0.904462	0.914568	1.026567
$Is_{(50)}=Is*f$	2.531071	1.865785	2.177953	1.178976
$UCS=21*Is_{(50)}$ (MPa)	53.152491	39.181485	45.737013	24.758496
UCS (MPa)	53	39	46	25

Table 7: Volumetric joint count (Jv), Rock Quality Designation (RQD), and average spacing of all discontinuities measurements from joint sets observed in the Pebbly Sandstone of the Redbed Series at station no.1

Discontinuities (Bedding plane and Joints)	Set spacing and frequency				Average spacing(m)	Average frequency*
	Spacing (m)		Max. frequency	Min. frequency		
	Min.	Max.				
Bedding plane (S_o)	0.10	0.50	10	2	0.30	3.333
Joint set 1 (J_1)	0.25	1	4	1	0.625	1.600
Joint set 2 (J_2)	0.25	1.5	4	0.666	0.875	1.142
Random joint **						
Volumetric joint count Jv=∑Frequencies (joints/m^3)						6.075
RQD = 110 – 2.5 Jv	94					
Average frequency of all discontinuities = Jv / 3						2.025
Average spacing of all discontinuities (m)=(1 / average frequency)= 3 / Jv					0.493 m = 493 mm	

*Average frequency=1/Average spacing…….[21]
**For random joints, a spacing of 5m for each random joint is used in the Jv calculation.
-RQD = 110 -2.5 Jv ………………………….[21]
-Average frequency of all discontinuities=Jv/3 …………………………..[20]
-Average spacing of all discontinuities (m)=1/average frequency………..[20]

Table 8: Volumetric joint count (Jv), Rock Quality Designation (RQD) and average spacing of all discontinuities measurements from joint sets observed in the stations

Geologic Name	Station no.	Jv (joints /m^3)	RQD	Average spacing of all discontinuities (mm)
Red-bed Series	1	6.075	94	493
	2	5.86	95	511
	3	4.188	99	716
	4	5.301	96	565
	5	4.995	97	600
	6	4.021	99	746
	7	5.365	96	559
	8	3.278	100	915
	9	2.852	100	1051
	10	2.445	100	1226

Table 9: Rock mass characterization in the rock slopes of stations no. 1, 2 & 3

Geologic name	Red-bed Series			Remarks
Stability station	1	2	3	
Elevation(a.s.l) (m)	875	877	868	
Rock type	Conglomerate	Fine Sandstone	Sandstone	From Field
Strength of intact rock material UCS$_{(50)}$(MPa)	22	43	61	From table (6)
RQD (%)	94	95	99	From table (8)
Average spacing (mm)	493	511	716	
Surface condition of discontinuities	Rough, slightly-mode-rately weathered, fine filling < 5mm, no separation, persistence: 6-7m	Smooth- rough, slightly weathered, fine filling < 5mm, no separation, persistence: 2-10m	Rough, slightly weathered, fine filling > 5mm, several centimeters separation, persistence > 5m	From field description
Ground water condition	Dry – Dripping (Summer – Winter)	Dry – Dripping (Summer – Winter)	Dry – Dripping (Summer – Winter)	From field description

Table (9 - Continuer) : Rock mass characterization in the rock slopes of stations no. 4, 5 & 6

Geologic name	Red-bed Series			Remarks
Stability station	4	5	6	
Elevation(a.s.l) (m)	867	865	905	
Rock type	Sandstone	Sandstone	Sandstone	From Field
Strength of intact rock material UCS$_{(50)}$(MPa)	59	71	69	From table (6)
RQD (%)	96	97	99	From table (8)
Average spacing (mm)	565	600	746	
Surface condition of discontinuities	Slightly - very rough, slightly weathered, fine filling < 5mm, several centimeters separation, persistence > 5m	Rough-very rough, slightly weathered, fine filling ≈ 5mm, separation > 5mm, persistence > 5m	Slightly rough- very rough, slightly weathered, fine filling < 5mm, no separation, persistence about 4m	From field description
Ground water condition	Dry – Dripping (Summer – Winter)	Dry – Dripping (Summer – Winter)	Dry – Dripping (Summer – Winter)	From field description

Table (9 - Continuer): Rock mass characterization in the rock slopes of stations no. 7, 8, 9 & 10

Geologic name	Red-bed Series				Remarks
Stability station	7	8	9	10	
Elevation(a.s.l) (m)	922	929	881	913	
Rock type	Sandstone	Silty Sandstone	Sandstone	Conglomerate	From Field
Strength of intact rock material UCS$_{(50)}$(MPa)	53	39	46	25	From table (6)
RQD (%)	96	100	100	100	From table (8)
Average spacing (mm)	559	915	1051	1226	
Surface condition of discontinuities	Rough- very rough, slightly weathered, fine filling > 5mm, no separation, persistence: ≈7m	Rough- very rough, slightly weathered, fine filling > 5mm, no separation, persistence: ≈5m	Rough, slightly weathered, hard filling < 5mm, no separation, persistence: >5m	Very rough, slightly weathered, hard filling > 5mm, no separation, persistence: >3m	From field description
Ground water condition	Dry – Dripping (Summer-Winter)	Dry – Dripping (Summer–Winter)	Dry – Dripping (Summer–Winter)	Dry – Dripping (Summer–Winter)	From field description

Table 10: Rating of RMR-parameters and values of $RMR_{b(1989)}$ for the rock masses in the rock slopes of stations no. 1, 2, 3, 4 & 5

Geologic name		Red-bed Series				
Slope station		1	2	3	4	5
Elevation above sea level (m)		875	877	868	867	865
Rating of parameters	Strength of intact rock (UCS)	3	4.8	6.4	6.3	7.3
	RQD	19	19.1	19.9	19.2	19.4
	Average spacing of all discontinuities	12.2	12.4	13.9	12.7	13.2
	Condition of discontinuities	19	18	14	14	13.5
	Ground water condition	9.5	9.5	9.5	9.5	9.5
$RMR_{b\,(1989)}$		62.7	64.8	63.7	61.7	62.9
		≈ 63	≈ 65	≈ 64	≈ 62	≈ 63
Where: $RMR_{b\,(1989)}$= Basic Rock Mass Rating, with no adjusting factor for discontinuity orientation						

Table (10 -Continuer): Rating of RMR-parameters and values of $RMR_{b(1989)}$ for the rock masses in the rock slopes of stations no. 6, 7, 8, 9 &10

Geologic name		Red-bed Series				
Slope station		6	7	8	9	10
Elevation above sea level (m)		905	922	929	881	913
Rating of parameters	Strength of intact rock (UCS)	7.1	5.7	4.6	5.1	3.3
	RQD	19.9	19.2	20	20	20
	Average spacing of all discontinuities	14.2	12.6	15.2	16	16.8
	Condition of discontinuities	19.5	20	20	22	21
	Ground water condition	9.5	9.5	9.5	9.5	9.5
$RMR_{b\,(1989)}$		70.2	67	69.3	72.6	70.6
		≈ 70		≈ 69	≈ 73	≈ 71
Where: $RMR_{b\,(1989)}$= Basic Rock Mass Rating, with no adjusting factor for discontinuity orientation						

For quantitative assessing of the stability of rock slopes in all station, slope mass rating (SMR) of Romana [10] and continuous slope mass rating (CSMR) of Tomas [11] were applied using SMRTool-v205 [23], where in this software includes both SMR of Romana (discrete SMR) and continuous-SMR (CSMR) of Tomas [11].

RMR_b which was calculated on the basis of various rock mass parameters rating was further used in the calculation of SMR for all the ten slope stations. F1, F2, and F3 were calculated by SMRTool-Software on the basis of the relative orientation of joints with respect to the slope. The value of F4 is equal to zero (0) for most slope stations (nine stations) as the excavation method was blasting and mechanical means, but the value of F4 for slope station no.5 is equal to +15 as the rock mass under study is in natural slopes.

SMRTool-Software had calculated for flexural toppling in slope station no.1, as in Figure (25), and for planar sliding, wedge sliding and toppling (flexural, direct and oblique toppling) failure for all the ten (10) slope stations, are shown in Tables (11 & 12).

SMRTool–Software results for discrete–SMR and continuous-SMR values in the worst condition for flexural toppling at station no.1 and for wedge sliding at stations no.2 and 6 ranges from 41 to 46, so the rock mass under study falls in class lll (three) of normal slope type, which they are in partially stable condition with failure probability of 0.4. Also in the worst condition for wedge sliding at stations no.3 is equal 18, so the rock mass falls in class V (five) of very-bad slope type, which is in completely-unstable condition with failure probability of 0.9, and for wedge sliding at stations no. 4, 8 & 10, planar sliding at stations no.5, 7 & 9 ranges from 23 to 34, as shown in Tables 11 and 12, so the rock mass falls in class lV (four) of bad slope type, which they are in unstable condition with failure probability of 0.6.

Finally, this study compares the results of discrete-SMR and continuous-SMR (CSMR). In the stability classification for slopes at station no.3 and 9 results of discrete-SMR and CSMR are varying. In discrete-SMR, the slopes of stations 3 and 9 are unstable and partially-stable respectively, whereas CSMR classifies these slopes as completely-unstable and unstable respectively, as shown in Tables 11 and 12.

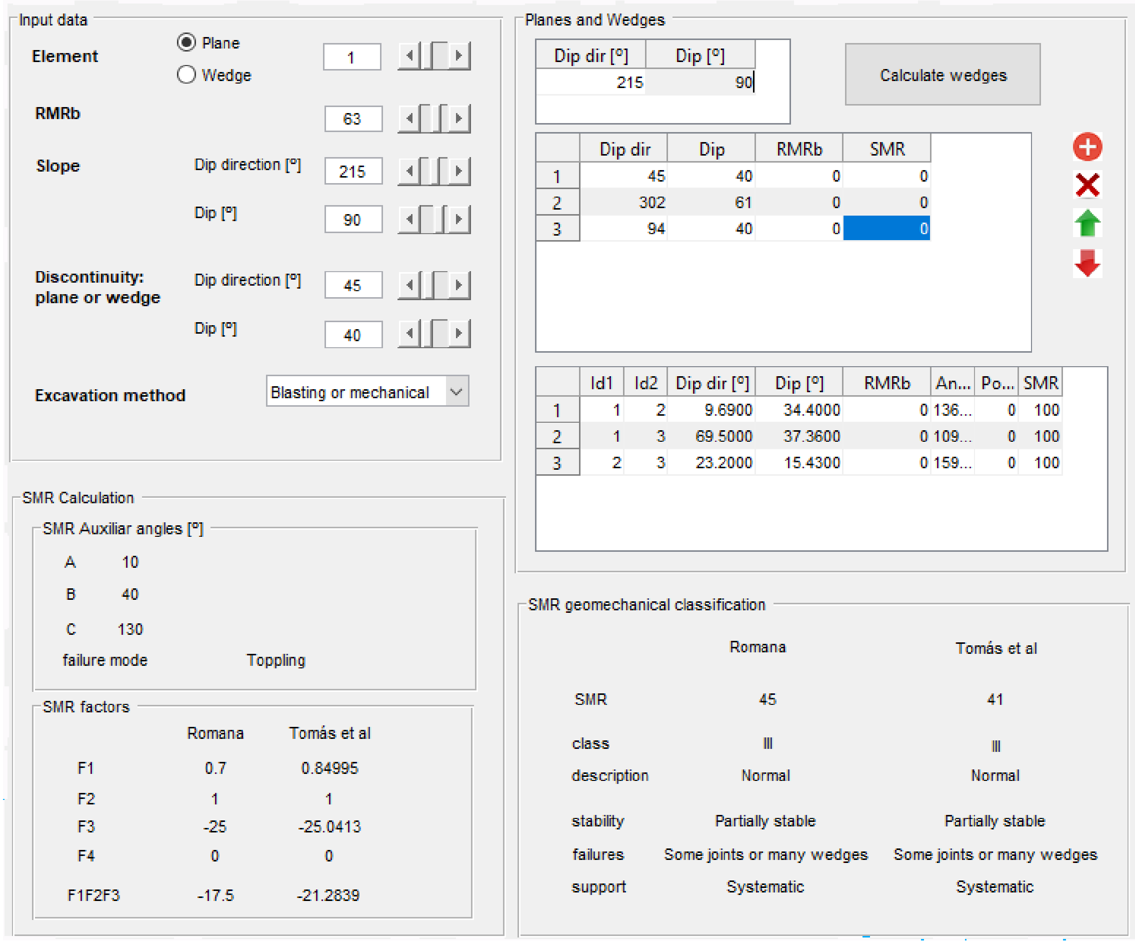

Fig. 25: Assessment of rock slope stability at station no1, showing Flexural toppling about bedding plane (So) for both discrete-SMR and continuous-SMR (CSMR), using SMRTool-software

Table 11: Results of discrete slope mass rating (SMR), using SMRTool software

Station no.	RMR_b	Type of failure	Failure direction	F1	F2	F3	F4	F1.F2.F3	SMR-Value	SMR Class / Stability
1	63	c) **FT** d) **DT** d) **DT**	c) 225^0 d) 190^0 d) 203^0	c) 0.70 d) 0.40 d) 0.70	c) 1 d) 1 d) 1	c) -25 d) -25 d) 0	0	c) -17.5 d) -10 d) 0	c) 45 d) 53 d) 63	c) lll / Pasta d) lll / Pasta d) ll / Sta
2	65	b) **WS** c) **FT** d) **DT**	b) 245^0 c) 230^0 d) 206^0	b) 0.40 c) 0.70 d) 0.712	b) 1 c) 1 d) 1	b) -60 c) -25 d) -25	0	b) -24 c) -17.5 d) -17.5	b) 41 c) 47 d) 47	b) lll / Pasta c) lll / Pasta d) lll / Pasta
3	64	b) **WS** c) **FT**	b) 232^0 c) 230^0	b) 0.70 c) 0.70	b) 1 c) 1	b) -60 c) -25	0	b) -42 c) -17.5	b) 22 c) 46	b) lV / Unsta c) lll / Pasta
4	62	b) **WS** c) **FT** d) **DT**	b) 251^0 c) 225^0 d) 200^0	b) 0.40 c) 0.85 d) 0.40	b) 1 c) 1 d) 1	b) -60 c) -25 d) -25	0	b) -24 c) -21.25 d) -10	b) 38 c) 40 d) 52	b) lV / Unsta c) lV / Unsta d) lll / Pasta
5	63	a) **PS** b) **WS** d) **DT**	a) 212^0 b) 230^0 d) 208^0	a) 0.70 b) 0.85 d) 0.70	a) 1 b) 1 d) 1	a) -60 b) -60 d) 0	+15	a) -42 b) -51 d) 0	a) 36 b) 27 d) 78	a) lV / Unsta b) lV / Unsta d) ll / Sta
6	70	b) **WS** c) **FT**	b) 215^0 c) 225^0	b) 0.40 c) 0.70	b) 1 c) 1	b) -60 c) -25	0	b) -24 c) -17.5	b) 46 c) 52	b) lll / Pasta c) lll / Pasta
7	67	a) **PS** c) **FT** d) **DT**	a) 188^0 c) 200^0 d) 188^0	a) 0.70 c) 0.85 d) 0.70	a) 1 c) 1 d) 1	a) -60 c) -25 d) -25	0	a) -42 c) -21.25 d) -17.5	a) 25 c) 45 d) 49	a) lV / Unsta c) lll / Pasta d) lll / Pasta
8	69	b) **WS** c) **DT**	b) 238^0 c) 238^0	b) 0.70 c) 0.70	b) 1 c) 1	b) -60 c) -25	0	b) -42 c) -17.5	b) 27 c) 51	b) lV / Unsta c) lll / Pasta
9	73	a)**PS**	a) 60^0	a) 0.85	a) 0.70	a) -50	0	a) -29.75	a) 43	a) lll / Pasta
10	71	b) **WS** c) **FT**	b) 200^0 c) 244^0	b) 0.70 c) 0.70	b) 1 c) 1	b) -60 c) -25	0	b) -42 c) -17.5	b) 29 c) 53	b) lV / Unsta c) lll / Pasta

Where: PS=Planar sliding, WS=Wedge sliding, FT=Flexural toppling, DT=Direct toppling, F1,F2&F3 are adjustment factors of SMR, Sta=Stable, Pasta=Partially stable, Unsta=Unstable, Letters: a, b, c & d are belonging to plane sliding, wedge sliding, flexural toppling and direct toppling respectively.

Table 12: Results of continuous slope mass rating (CSMR), using SMRTool software

Station no.	RMR_b	Type of failure	Failure direction	F1	F2	F3	F4	F1.F2.F3	CSMR-Value	SMR Class / Stability
1	63	c) **FT** d) **DT** d) **DT**	c) 225^0 d) 190^0 d) 203^0	c) 0.849 d) 0.40 d) 0.80	c) 1 d) 1 d) 1	c)-25.04 d)-24.03 d)-0.703	0	c)-21.28 d)-9.65 d)-0.566	c) 41 d) 53 d) 62	c) lll / Pasta d) lll / Pasta d) ll / Sta
2	65	b) **WS** c) **FT** d) **DT**	b) 245^0 c) 230^0 d) 206^0	b) 0.420 c) 0.849 d) 0.712	b) 0.944 c) 1 d) 1	b)-59.51 c)-23.85 d)-20.94	0	b)-23.62 c)-20.27 d)-14.91	b) 41 c) 44 d) 50	b) lll / Pasta c) lll / Pasta d) lll / Pasta
3	64	b) **WS** c) **FT**	b) 232^0 c) 230^0	b) 0.796 c) 0.849	b) 0.972 c) 1	b)-59.31 c)-24.84	0	b)-45.94 c)-21.11	b) 18 c) 42	b) V / Cunsta c) lll / Pasta
4	62	b) **WS** c) **FT** d) **DT**	b) 251^0 c) 225^0 d) 200^0	b) 0.511 c) 0.941 d) 0.333	b) 0.969 c) 1 d) 1	b)-59.34 c)-25.04 d)-24.75	0	b)-29.44 c)-23.56 d)-8.25	b) 32 c) 38 d) 53	b) IV / Unsta c) IV / Unsta d) lll / Pasta
5	63	a) **PS** b) **WS** d) **DT**	a) 212^0 b) 230^0 d) 208^0	a) 0.770 b) 0.919 d) 0.648	a) 0.975 b) 0.974 d) 1	a)-58.72 b)-58.83 d)-0.834	+15	a)-44.17 b)-52.68 d)-0.541	a) 33 b) 25 d) 77	a) IV / Unsta b) IV / Unsta d) ll / Sta
6	70	b) **WS** c) **FT**	b) 215^0 c) 225^0	b) 0.404 c) 0.707	b) 0.980 c) 1	b)-59.11 c)-25.04	0	b)-23.46 c)-17.72	b) 46 c) 52	b) lll / Pasta c) lll / Pasta
7	67	a) **PS** c) **FT** d) **DT**	a) 188^0 c) 200^0 d) 188^0	a) 0.572 c) 0.91 d) 0.593	a) 0.96 c) 1 d) 1	a)-59.43 c)-25.04 d)-24.99	0	a)-32.64 c)-22.04 d)-14.84	a) 34 c) 44 d) 52	a) IV / Unsta c) lll / Pasta d) lll / Pasta
8	69	b) **WS** c) **DT**	b) 238^0 c) 238^0	b) 0.784 c) 0.799	b) 0.969 c) 1	b)-59.34 c)-24.83	0	b)-45.12 c)-19.85	b) 23 c) 49	b) IV / Unsta c) lll / Pasta
9	73	a)**PS**	a) 60^0	a) 0.941	a) 0.757	a)-56.84	0	a)-40.50	a) 32	a) IV / Unsta
10	71	b) **WS** c) **FT**	b) 200^0 c) 244^0	b) 0.808 c) 0.740	b) 0.940 c) 1	b)-59.52 c)-23.85	0	b)-45.28 c)-17.65	b) 25 c) 53	b) IV / Unsta c) lll / Pasta

Where: PS=Planar sliding, WS=Wedge sliding, FT=Flexural toppling, DT=Direct toppling, F1,F2&F3 are adjustment factors of SMR, Sta=Stable, Pasta=Partially stable, Unsta=Unstable, Cunsta=Completely unstable, Letters: a, b, c & d are belonging to plane sliding, wedge sliding, flexural toppling and direct toppling respectively.

5- Conclusions

This study has led to the following conclusions:

1-Kinematic analysis is an easy method for the preliminary assessment of the failure type in the rock slopes having joint sets.

2-Kinematic analysis by DIPS-v6.008 software revealed that planar sliding may occur in slopes of station 5, 7 & 9, wedge sliding in slopes of station 2, 3, 4, 5, 6, 8 & 10, flexural toppling in slopes of station 1, 2, 3, 4, 6, 7, 8 & 10, direct toppling in slopes of station 1, 2, 4, 5 & 7.

3-The most prevailing type of failure is flexural toppling and wedge sliding.

4-Only one type of failure occurred and may occur in the slope of station 9, which is plane sliding.

5-In the worst condition, the discrete-SMR and CSMR values for slopes in all stations range from 22-46 and 18-46 respectively, so It is observed that these values at slope station 1, 2 & 6 lie in partially stable zone, with failure probability of 0.4, at slope station 4, 5, 7, 8, 9 & 10 lie in unstable zone, with failure probability of 0.6 and at slope station 3 lies in completely-unstable zone, with failure probability of 0.9.

6-From comparison of the results of discrete-SMR and continuous-SMR (CSMR), it is observed that in the stability classification for slopes at station no.3 and 9 results of discrete-SMR and CSMR are varying. In discrete-SMR the slopes of stations 3 and 9 are unstable and partially-stable respectively, whereas CSMR classifies these slopes as completely-unstable and unstable respectively, this means that the CSMR has given the more precise assessment of slope stability grades in terms of quantitative numbers.

7-According to the value of discrete-SMR and CSMR, the more unstable rock slope is of station no.3 [SMR=22 (unstable slope), CSMR=18 (completely-unstable slope)].

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تقييم استقرارية المنحدرات بمحاذاة الطريق الرئيس بين قلعه جوالان – سوره قلات، السليمانية، شمال شرق العراق

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الملخص

الانهيارات الصخرية من الظواهر المتكرره جدا في المنحدرات المقطوعه بمحاذاة الطرق في المناطق الجبليه. يعتبر طريق قلعه جوالان – سوره قلات الذي يقع شمال مدينة السليمانية أحد طرق النقل بين مدينة السليمانية وكثير من النواحي والقرى التابعه لمنطقة شهربازار، ان هذا الطريق أحيانا، وخصوصا في فصلي الشتاء والربيع تقع فيه عدد من الأنهيارات الصخرية التي تسبب صعوبة للناس وفي المواصلات. لذلك ان تقييم استقرارية المنحدرات المقطوعه في مثل هذا الطريق يكون ضروري جدا.

تم اختيار عشرة محطات انحدار على امتداد عشرة كيلومترات من الطريق الرابط بين قلعه جوالان – سوره قلات وذلك لتقيم استقرارية المنحدرات الصخرية بتقنيات مختلفه. ان اختيار لمحطات االأنحدار يكون على أسس الأختلاف في نمط الأنقطاعات والتغير في مورفولوجية المنحدر والأختلاف في نوع الأنهيار، وقد تم تحليل المعلومات لمعرفة درجة احتمالية الأستقراريه من خلال التحليل الهندسى (Kinematic analysis) باستخدام برنامج DIPS-v6.008 وكذلك من خلال نظام اعطاء القيم لكتلة الانحدار ((Slope Mass Rating(SMR) باستخدام برنامج SMRTool-V205.

اظهر التحليل الهندسي بأن الأنزلاق المستوي يمكن ان يحدث في المحطات 5 و 7 و 9 والأنزلاق الأسفينى في المحطات 2 و 3 و 4 و 5 و 6 و 8 و 10 أما الانقلاب الانزلاقي (Flexural toppling) من الممكن حدوثه في المحطات 1 و 2 و 3 و 4 و 6 و7 و 8 و 10 والانقلاب المباشر (Direct toppling) في المحطات 1 و 2 و 4 و 5 و 7.

أن قيم كتلة الانحدار لكلا Discrete-SMR و Continuous-SMR لمنحدرات كل المحطات تتراوح من 22 – 46 ومن 18 – 46 على التوالى. وقد لوحظ بأن القيم في المحطات 1 و 2 و 6 تقع ضمن نطاق مستقر جزئيا مع احتمالية الأنهيار بحدود 0.4 ، أما القيم في المحطات 4 و 5 و 7 و 8 و 9 و 10 تقع ضمن نطاق الغير مستقر مع احتمالية الأنهيار بحدود 0.6 والقيمة في المحطة 3 تقع ضمن نطاق الغير مستقر كليا مع احتمالية الانهيار بحدود 0.9.