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Kinematic Analysis of Landslides: A Case Study Along Jerash-Amman Highway, Jordan

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Abstract

One of the important environmental issues and structural and engineering phenomena in on the earth is the landslide that which are is considered also one of the biggest threats worldwide that hit mountainous and highland areas. Therefore, the current study was carried out in nine measurement stations along Jerash- Amman highway, to analyze the landslides by means ofthrough stereographic projection or kinematic analysis. Results show that the dominant type of the rock slope failure is the wedge failure which is observed in the first five stations of the study area. Stations 1, 2, 5, and 9 showed a toppling failure, while stations 2, 3, 4, and 5 showed planar failure. The circular failure is only found in station 9. Structural control of most of these landslides was inferred through this study.

Keywords: *Landslides, Kinematic analysis, Geological structures, Jerash- Amman highway, Jordan*

1. Introduction

The stability of rock slopes is often significantly influenced by the geological structures of the rock in which the slope is excavated. Geological structures refer to naturally occurring breaks in the rock such as joints and faults, in addition to bedding planes which are generally termed discontinuities. The significance of discontinuities is that they are planes of weakness in the much stronger intact rock, so failure tends to occur preferentially along these surfaces (Wyllie and Mah 2005).

In many research studies with some of the landslides which have been encountered through and after the construction of the Jerash-Amman highway (Fig.1), that occurred through during the very exceptional winter of 1991/1992 which was characterized by dense rain and snowfalls (Al-Homoud and Masanat 1998). However, where it was found that landslides occur when the forces of shear stress exceed the forces of strength in the soil and rock due to many reasons, including the obvious causes such as nature, topography, human intervention, and water flow (Masannat 2014). Many researchs have has been carried out along Irbed-Jerash and/ or Jerash- Amman highway using different methods and techniques (e.g., Dames and Moor ,1993; Al-Basha, 1996; Al-Homoud et al.,1996; Abederahman,1994; Mansour et al.,1997; Saleh,1997; Abederahman,1998; El-Naqa, and Abdelghafoor, 2006; Abederahman,2007; Al-Omari ,2006, 2014; El-Moghrabi, 2016; Al- Hawareen, 2020; Diabat and Abu Rumman 2021).

Cut slopes along the Amman-Jerash highway are composed of highly weathered rock masses and/or alternating sequences of sandy, silty and argillaceous sedimentary rocks. Therefore, several major landslides occurred at different parts along this highway such as rock slides, toppling, slumping, and earth flow (Dames and Moor 1993). Almost all rock slope stability studies should address the structural geology of the site, and such studies have to determine the influence of the discontinuities on stability, which involves studying the relationship between the orientation of the discontinuity and the slope face (Wyllie and Mah 2005). So this study is mainly concentrated on the kinematic analysis to identify possible modes of slope failure in the study area.

The study area is bounded by the coordinates:32°13 to 32° 28N and 35° 85 to 35° 91E and subdivided into nine measurement stations (Fig 1).

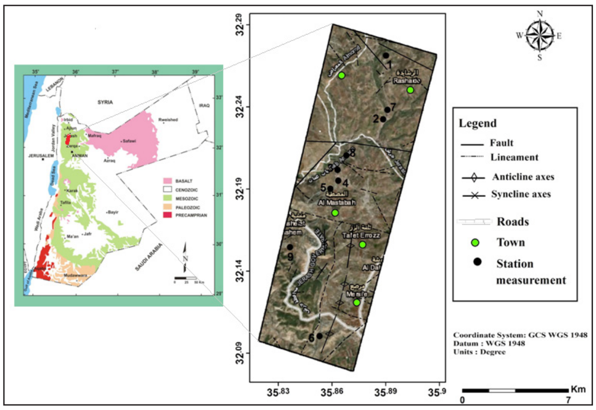

Figure 1. Location map of the study area and satellite image (Explorer 2018)

Most of the study area is mountainous and is a part of the northern highlands of Jordan. It varies in elevation from about 150 m above sea level (A.S.L.) near Zerqa river in the central part of the study area to about 900 m (A.S.L) near Marssa in the southern part (Fig. 2).

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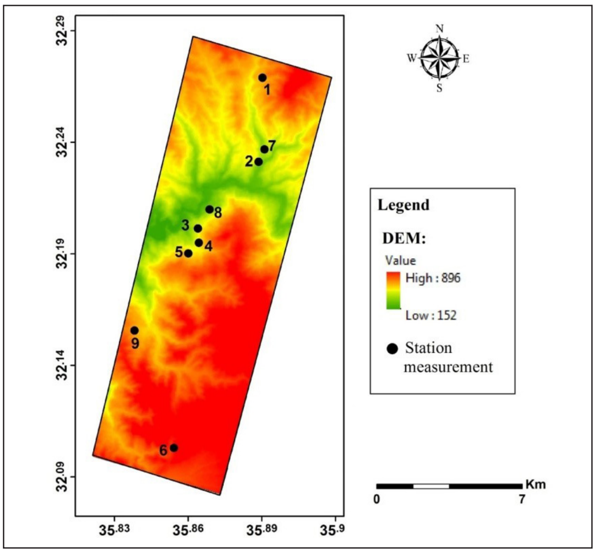

Figure 2. A digital elevation map (DEM) of the study area.

The objectives of this study can be summarized as follow: Determining the orientation and nature of the fracture systems and their relationships with the landslide, collecting relevant field data such as bedding, fractures, and slopes in selected sites to assess stability conditions using kinematic methods.

2. Geological Setting

The following lithostratigraphic units are exposed in the study area (Table1 and Fig. 3):

The study area is located about 20 km east of the Jordan valley fault: the northern segment of the Dead Sea transform fault and about 20-25 km to the north of Amman- Hallabat structure (Fig.4). The southern part of the study area is crossed by part of the NE-SW Wadi Shu'ayb structure. It consists of en echelon folds, monoclinal flexures and faults (Sawariah and Barjous 1993 , Abdelhamid 1993, Abdelhamid 1995). The Zarqa river fault crossed the study area in E-W direction. The fault systems in the study area are oriented E-W, NE- SW, and NW- SE (Fig. 3). The tectonic phases cause incentive drainage, where mass movement is motivated and takes place (Sawariah and Barjous 1993, Abdelhamid 1993).

Table 1. The outcropping lithostratigraphic units in the study area were modified after (Sawariah and Barjous 1993, Abdelhamid 1993, Abdelhamid 1995, Powell 1989)

Group	Formation	Age	Thickness (m)	Lithology
Belqa	Amman Silicified Limestone	Campanian to Maasterichtian	120	Limestone, Chert
	Umm Ghudran	Coniacian to Campanian	15 – 20	Chalk, Chalky marl, and Chalky limestone
Ajlun	Wadi As Sir	Turonian	100 – 125	Massive limestone
	Shu'eib	Turonian	60	Marly limestone
	Hummar	Cenomanian	40 – 60	Dolomitic limestone
	Fuheis	Cenomanian	80	Marl and Marly limestone
	Na'ur	Albian – Cenomanian	180 – 200	Limestone, Dolomitic limestone and marl
Kurnub		Aptian – Albian	250 – 300	Sandstone

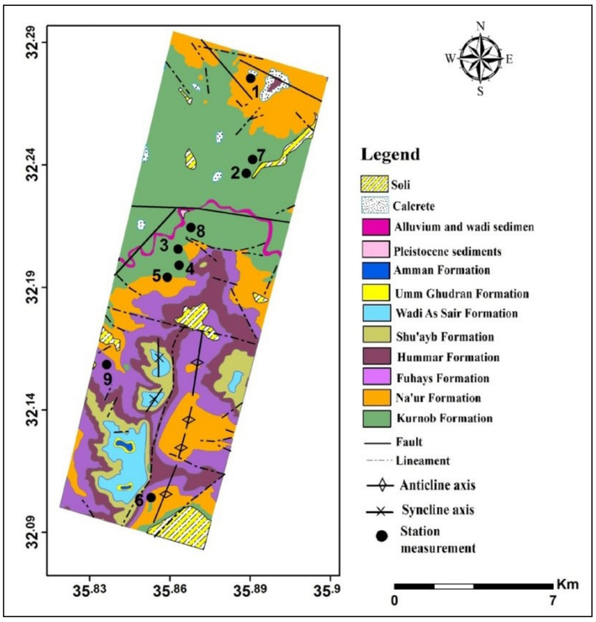

Figure 3. Geological map of the study area (modified after Sawariah and Barjous 1993, Abdelhamid 1993)

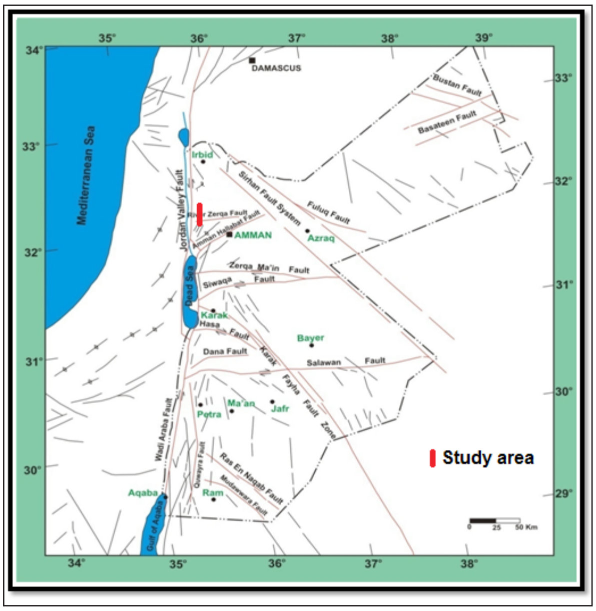

Figure 4. Structural pattern of Jordan (after Diabat and Masri 2005)

3. Methodology

Several field trips were carried out to collect orientation data on discontinuities. A detailed study of the geological features in the selected stations was carried out. Field observations and measurements of the attitude of discontinuities e.g., bedding planes, fractures (faults and joints), in addition to slope faces were directly measured in the field. The measurements of the discontinuities were taken by using a geological compass (CLAR) as dip direction/ dip. The measured discontinuities in the field have been analyzed using stereographic projection software. This helped in determining the pole plot of all measured discontinuities and the contour plot which represents the concentration of all discontinuity's readings (Fig. 5). The rock mass to be able to slide, it must be cohesionless i.e the cohesion between the plane of sliding and the sliding rock mass equal zero. The friction angle of the discontinuities in a rock mass is supposed to be 34 degrees based on Barton (1973) and Jaeger and Cook (1976) as shown in Table 2. The friction angles listed in this table should be used as a guideline only because actual values will vary widely with site conditions. Hoek and Bray (2003) classified rock slope failures into different types. The current study estimated the stability of slopes in nine stations as the same examples shown in figures (5and6).

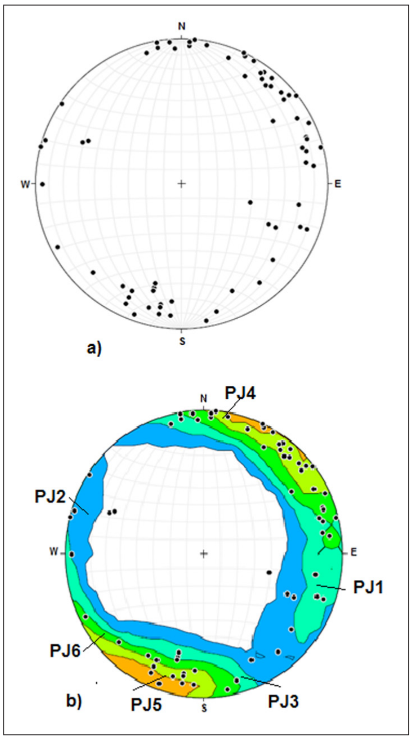

Figure 5. a) Poles of the discontinuities, b) Contour plot of main concentrations of poles.

Table 2. Typical ranges of friction angles for a variety of rock types (after, Barton 1973; Jaeger and Cook, 1976).

Typical rock types	Friction angle range	Rock class
Schists (high mica content), shale, marl	20–27°	Low friction
Sandstone, siltstone, chalk, gneiss, slate	27–34°	Medium friction
Basalt, granite, limestone, conglomerate	34–40°	High friction

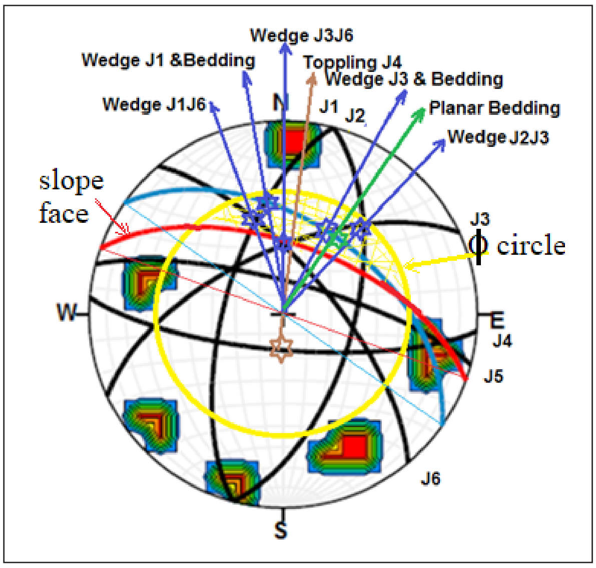

Figure 6. Example of stability estimate of the rock mass in station 5; black great circles represent planes corresponding to centres of pole concentrations of discontinuities probable to planar, wedge, and toppling failures, the blue great circle represents the bedding attitude, the red great circle represents the slope face and the shaded yellow sector represents the unstable area for sliding.

4. Slope stability analysis in the studied stations

The study area is located along Jerash- Amman highway, nine stations were selected based on the discontinuity properties which have indications of the impact on slope stability. These stations are located on the geological map (Fig. 3).

4.1 Station1

This station is located in the city of Jerash, near Jerash University and 40 km north of the capital Amman (Fig. 3). The outcrop is part of the Na'ur Formation, it is highly fractured and highly weathered limestone (Fig. 7).

Figure 7. Highly fractured and weathered rocks in an outcrop of station-1.

Figure 8. Figure (8a) represents the pole plot of all measured discontinuities. The contour plot in Figure (8b) represents the concentration of all discontinuity readings. The fractures and bedding plane (dip/dip direction 05/090) with slope face oriented (65/240) and the supposed friction angle 34° according to Dames and Moore (1993), were kinematically analyzed using stereographic projection (Fig. 9).

Five joint sets were determined and analyzed for stability (Figs 8b and 9); J1(80/075), J2 (80/290), J3 (68/140), J4(80/150), and J5 (88/255). The result shows that probable toppling failure towards WSW (255 °) at J1 (Fig. 9), this is expected because the dip direction of the J1-set is in the opposite direction of the slope face. Figure (9) shows two wedge failure directions along the line of intersections of J2 and J3 (J23), J2 and J4 (J24), respectively towards 40/210° and 60/220°. It is important to note that the wedge sliding along J24 is in its critical case because the intersection point of J2 and J4 lies at the slope face (Fig. 9). Despite the dominance trend of J5 (Figs 8 and 9), the results of the kinematic analysis indicated that it is stable because the dip of discontinuity planes is greater than the slope angle and lying out of the area of probable failure. Figures 10 and 11 show examples of toppling and wedge failures in station 1, respectively.

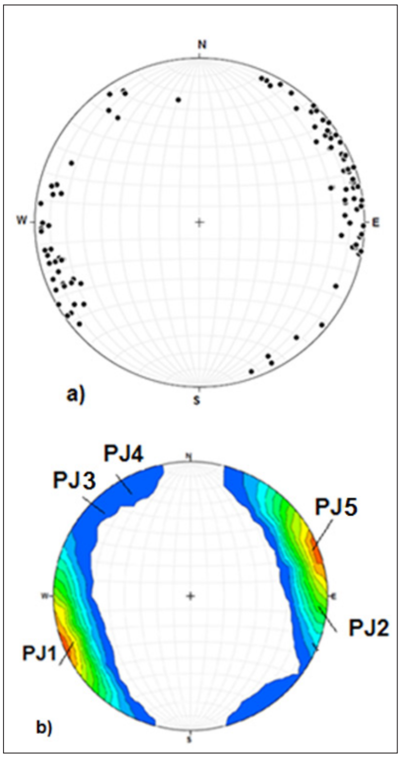

Figure 8. a) Pole plot of the discontinuities, b) Contour plot of main concentrations of poles.

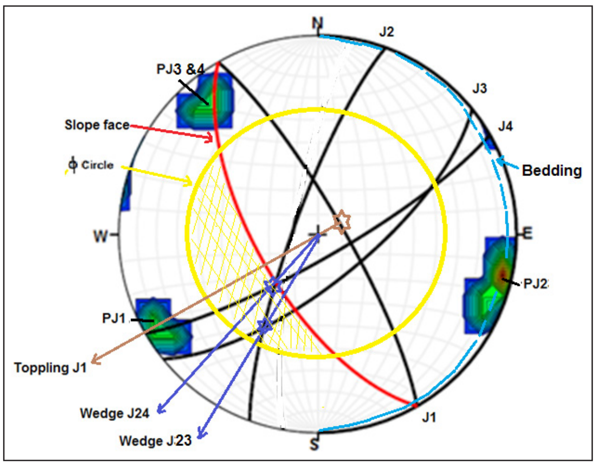

Figure 9. Stability estimates of the rock mass in station1; Great circles representing planes corresponding to centers of pole concentrations of discontinuities probable to toppling and wedge failure. The shaded yellow sector represents the unstable area for sliding.

Figure 10. Probability of toppling failure, vertical joints (red lines) show back release surfaces.

Figure 11. Shows wedge failure and the protruding overhanging rocks at the slope face.

4.2 Station2

This station is located 200 meters north of the Zarqa River. It is located at 32° 13. 375'N and 35° 53.536' E (Fig. 3). The outcrop is part of the Kurnub group, medium to thick-bedded white greyish to light brownish sandstone with clay lenses (Fig 12). Figure (13a) represents the pole plot of all measured discontinuities. The contour plot in Fig. (13b) represents the concentration of all discontinuity readings.

The fractures and bedding plane (dip/dip direction 245/25°) with slope face oriented (120/88°) and the supposed friction angle 34° according to Moor (1993), were kinematically analyzed using stereographic projection. Four joint sets were determined and analyzed for stability (Figs. 13b and 14); J1 (60/110), J2 (86/280), J3 (70/150), and J4 (75/ 090). The results show that probable plane sliding along J1 with an attitude of plunge/ plunge direction 60/110 (Fig. 14). Toppling failure towards ESE (100°) at J2 (Fig. 14), is expected because the dip direction of the J2-set is in the opposite direction of the slope face. Fig. 14, also shows a wedge failure along the line of intersection of J3 and J4 (J34) towards 75/125°.

Figure 12. Front view of the Kurnub outcrop with lenses of clay and shale in station 2.

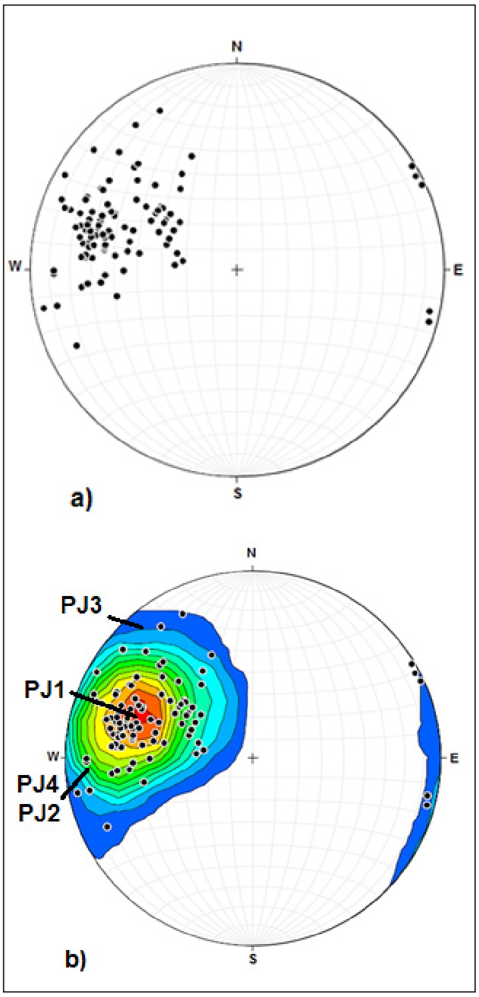

Figure 13. a) Pole plot of the discontinuities, b) Contour plot of main concentrations of poles.

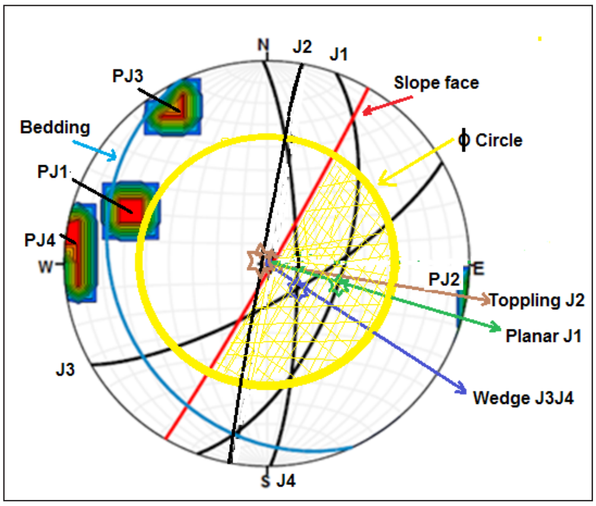

Figure 14. Stability estimates of the rock mass in station-2; Great circles representing planes corresponding to centers of pole concentrations of discontinuities probable to toppling and wedge failure. The shaded yellow sector represents the unstable area for sliding.

4.3 Station 3

This station is located south of Zarqa River and opposite King Talal Dam, 10 km south of Jerash city. It is located at 32° 12. 048'N and 35° 51.932' E (Fig. 3). The outcrop is part of the Kurnub group, massive yellowish to white grey cliffs separated by poorly exposed friable sandstone (Fig. 15). Figure 16a represents the pole plot of all measured discontinuities. The contour plot in Fig. (16b) represents the concentration of all discontinuity readings.

The fractures and bedding plane (dip/dip direction 260/10°) with slope face oriented (270/75°) and the supposed friction angle 34° according to Moor (1993) were kinematically analyzed using stereographic projection (Fig. 17). Three joint sets were determined and analyzed for stability (Figs 16b and 17); J1(70/ 270), J2 (50/ 300) and J3 (50/ 220). The results show that probable plane sliding along J1 with an attitude of 85/ 270 and a wedge failure along the line of intersection of J2 and J3 (J23) towards WNW (60/ 280°).

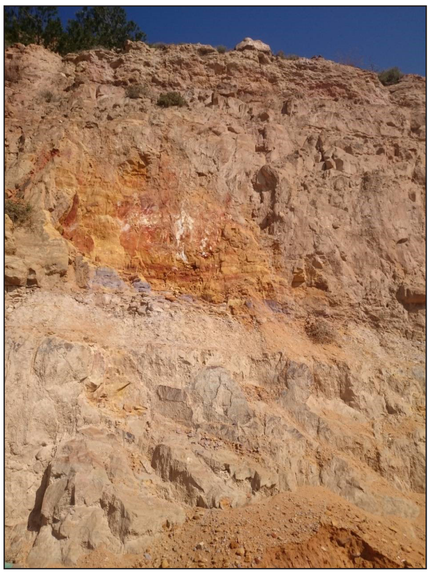

Figure 15. Very steep slope face towards the highway in the Kurnub outcrop of Station-3.

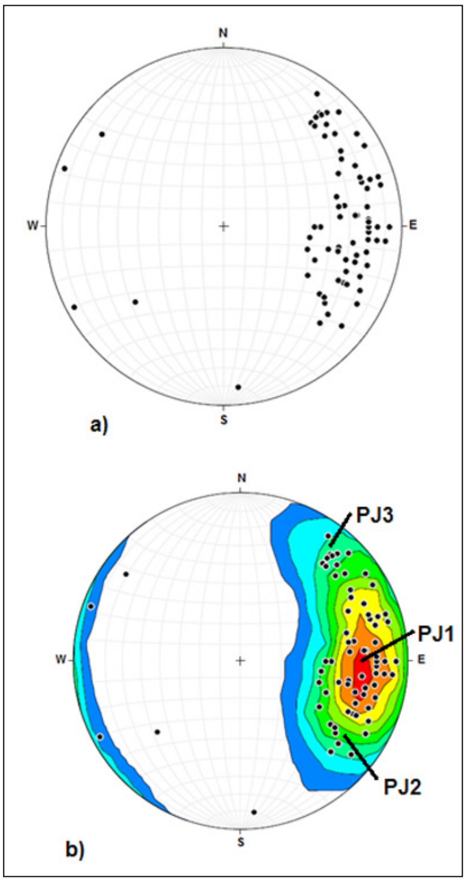

Figure 16. .a) Poles of the discontinuities, b) Contour plot of main concentrations of poles.

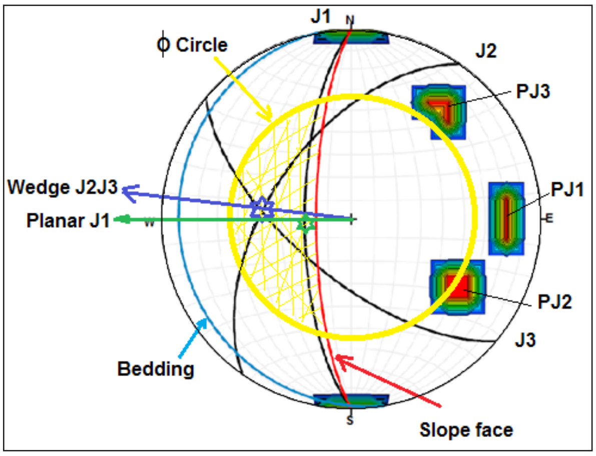

Figure 17. Stability estimate of the rock mass in station-3; Great circles representing planes corresponding to centers of pole concentrations of discontinuities probable to toppling and wedge failure. The shaded yellow sector represents the unstable area for sliding.

4.4 Station 4

This station is located along Jerash-Amman Highway about 15 Km to the south of Jerash. It is located at 32° 11. 713' N and 35° 51.878' E (Fig. 3). The outcrop is part of the Kurnub group, massive yellowish to white grey cliffs separated by poorly exposed friable sandstone (Fig. 18). Figure (19a) represents the pole plot of all measured discontinuities. The contour plot in Fig. (19b) represents the attitude of all concentration discontinuities.

The fractures and bedding plane (dip/dip direction 10/270°) with slope face oriented (270/85°) and the supposed friction angle 34° were kinematically analyzed using stereographic projection (Fig. 20). Six joint sets were determined and analyzed for stability (Figs 19b and 20); J1(80/310), J2 (70/330), J3 (75/050), J4 (75/230), J5 (70/270) and J6 (vertical, strike 140). The results show that a probable plane sliding along J5 toward the west with an attitude of 70/ 270 (Fig. 20) and three wedge failure directions; the first along the line of intersection of J1 and J4 (J1J4) towards WNW (70/ 260°), the second along J2J4 (70/290) and the third along J3J5 (40/330).

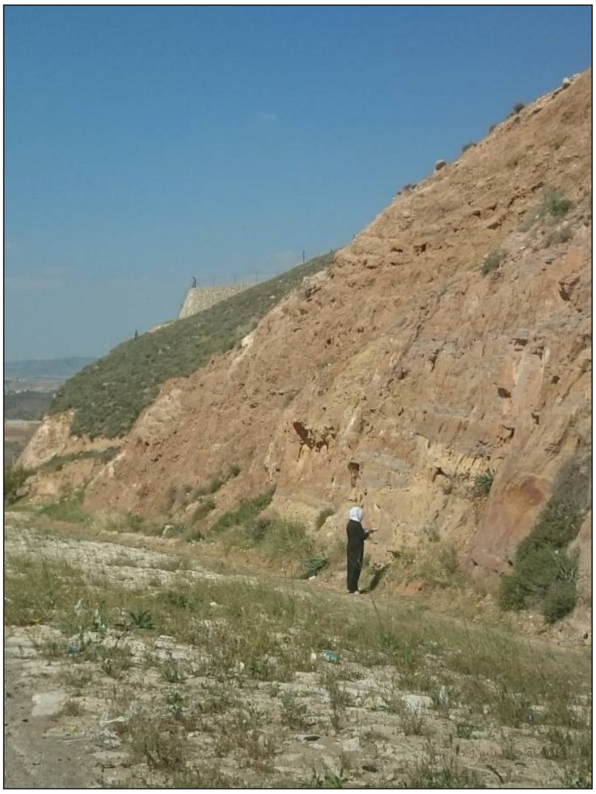

Figure 18. Kurnub outcrop in station-4.

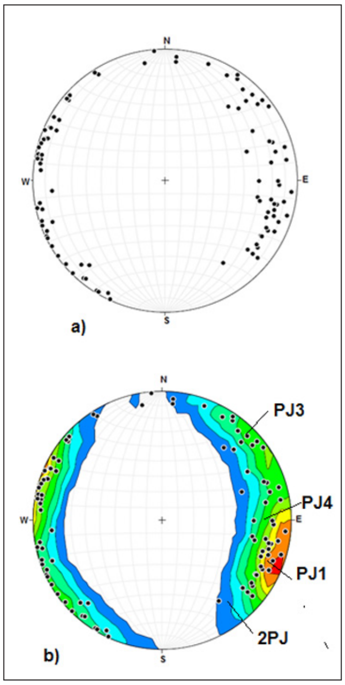

Figure 19. a) Poles of the discontinuities, b) Contour plot of main concentrations of poles.

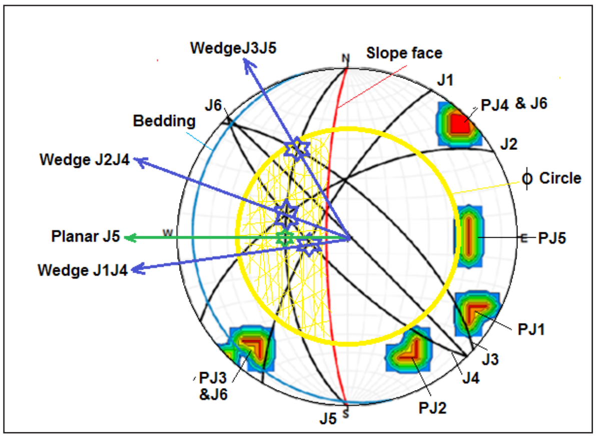

Figure 20. Stability estimate of the rock mass in station-4; Great circles representing planes corresponding to centers of pole concentrations of discontinuities probable to toppling and wedge failure. The shaded yellow sector represents the unstable area for sliding.

4.5 Station5

This station is located along Jerash-Amman Highway about 25 Km south of Jerash.

It is located at 32° 11. 502 'N and 35° 51.621' E (Fig. 3). The outcrop in the study site belong to Na'ur Formation, it consists of thick-bedded limestone forms the vertical cliffs in the area (Fig. 21), highly fractured, limestone alternating with grey to yellow-grey marl. Fig. 22a. represents the pole plot of all measured discontinuities. The contour plot in Fig. 22b represents the concentration of all discontinuity readings.

Figure 21. Vertically jointed Naur limestone cliff (blue lines) probable to topple in station-5

The fractures and bedding plane (dip/dip direction50/ 035°) with slope face oriented (60/ 020°) and the supposed friction angle 34° according to Moor (1993) and (Table 2), were kinematically analyzed using stereographic projection (Fig. 23). Six joint sets were determined and analyzed for stability (Figs 22b and 23); J1(65/ 280), J2 (65/ 100) and J3 (60/ 330), J4 (70/ 185), J5 (70/ 020) and J6 (70/050). The results show that probable plane sliding along bedding planes with an attitude of 50/ 030, because the strike of bedding is sub-parallel to the strike of slope face (Figs 23 and 24), and a toppling failure of J4 towards NNE (010) (Figs 23 and 25). In figure (25) a tension crack acting as a back release surface was observed. Five wedge failure directions are expected; the first is along the line of intersection of J2 J3 (J23) towards (30/ 040), the second is along the line of intersection of J1J6 towards (35/ 342), and the third is along the line of intersection of J3J6 toward the north, the fourth is along the line of intersection of J1 and bedding towards 30/350, and the fifth is along the line of intersection of J3 and bedding towards 40/ 058 (Fig. 23).

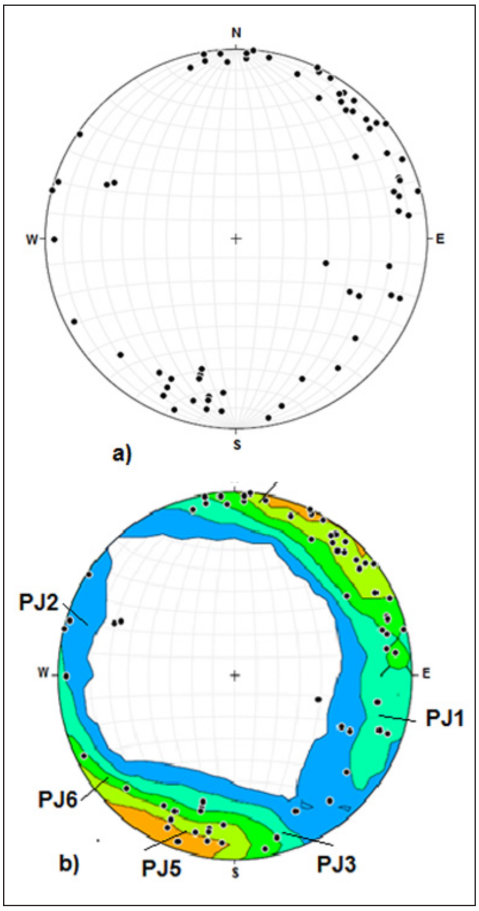

Figure 22. a) Poles of the discontinuities, b) Contour plot of main concentrations of poles.

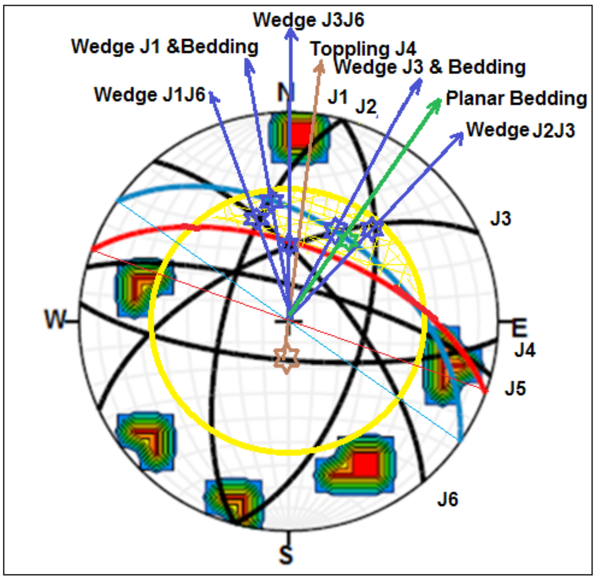

Figure 23. Stability estimate of the rock mass in station-5; Great circles representing planes corresponding to centers of pole concentrations of discontinuities probable to planar, wedge, and toppling failures. The shaded yellow sector represents the unstable area for sliding

Figure 24. Plane sliding in station- 5.

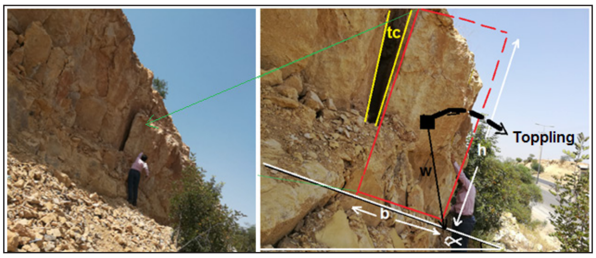

Figure 25. Toppling failure; tension crack (tc) acts as back release surface in station-5.

4.6 Station 6

This station is located along Jerash-Amman Highway about 30 Km from Jerash, near the Salhub village. It is located at 32° 06. 955'N and 35° 51.262' E (Fig. 3). The outcrop in the study site is Na'ur Formation. It consists mainly of hard thick-bedded limestone, dolomite, dolomitic limestone, and also fossiliferous marly limestone with a thin-bedded soft green clay at the base (Fig. 26). Fifty fractures were measured and represented in the rose diagram and shows the main trend of NW-SE (Fig. 27). The attitude of the slope face and bedding planes are parallel and equal 280/30° (Fig. 28). The kinematic analysis of this station, shows that the outcrop was stable and at the critical case for plane sliding because the great circles of the bedding and slope face are less than the friction angle and located out of the friction circle (Fig. 28). The measured joints in this station do not affect the sliding as their strikes are making an angle about 60 with bedding and the intersection line is out of the friction circle (Fig. 28).

Although the dip angle of bedding planes are not exceeding 30 to 35°, landslides have occurred. This station represents an ideal example of an active man-made landslide failure, the outcrop was stable before cutting the foothill during the construction of the highway in the 1990s. The cutting process of the foothill led to increasing the shear forces against the normal and resistance forces, and creating tension cracks a few meters in depth and width (Fig. 29). The thick-bedded limestone in Naur Formation, and the presence of some thin marl beds which has high susceptibility of water absorption and seepage during the rainfall led to lubricate and facilitate the plane sliding (Fig. 30).

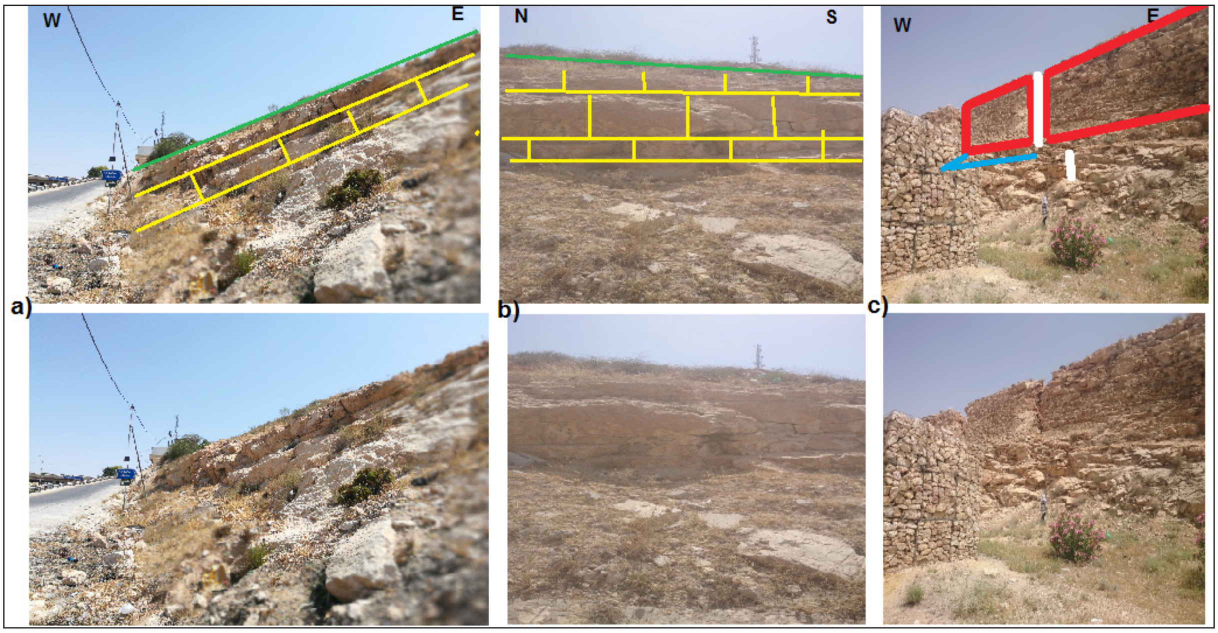

Figure 26. Side view of stable rock mass unaffected by cutting, b) Front view, c) Sliding rock mass has been affected by the direct cutting of the slope foothill in station-6.

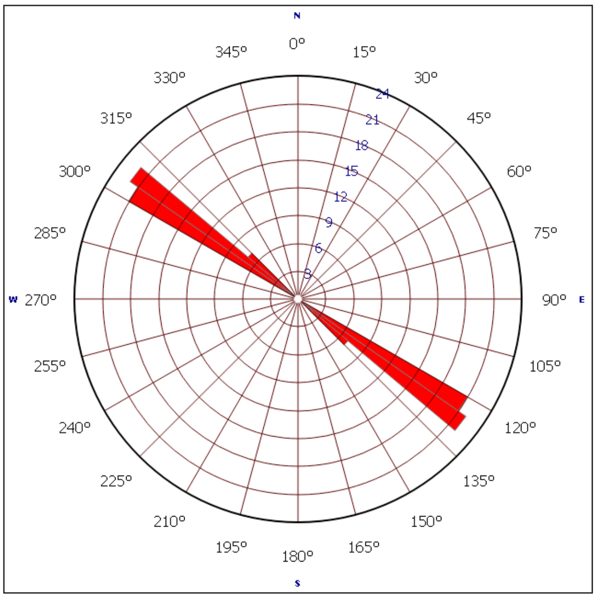

Figure 27. The strike of the main trend of the fractures in station-6.

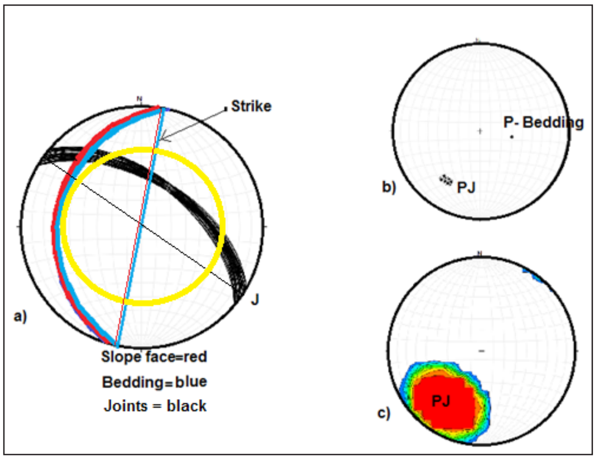

Figure 28. Stereonet diagrams represent the discontinuities (black great circles), slope face (red great circle), and plane sliding along bedding planes (blue great circle) in station 6.


Figure 29. The active landslide along the highway in the Salhub area after cutting the foothill in station-6.

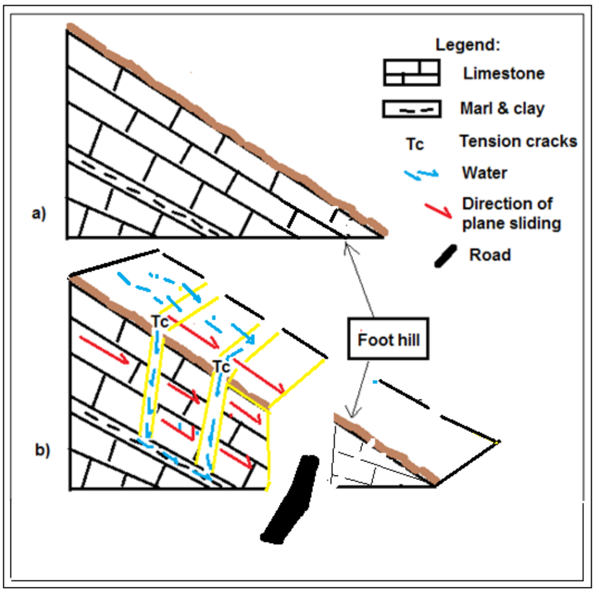

Figure 30. Schematic diagram showing what happened and to shed light on the manmade problem in station 6.

4.7 Station7

This station is located along the old Jerash-Amman road about 2 Km south of Jerash city. It is located at 32° 13. 705'N and 35° 53. 605' E (Fig. 3). The outcrop is part of the Kurnub group, medium to thick-bedded, yellow to dirty white, friable, fine to medium grained, quartzitic, massive and cross-bedded, interbedded with shale beds and clay lenses (Fig. 31). It was difficult to take orientation data measurements in this station because it characterized by friable sandstone and has highly weathered and fractured rock blocks. It also has a steep slope, therefore rock falls and toppling is probable in this station (Fig. 32).


Figure 31. Front view of the outcrop with lenses of clay in station 7.

4.8 Station 8

This station is located about 500 m south of Zarqa River. It is located at 32° 12. 343'N and 35° 52.251' E (Fig. 3). The outcrop is part of the Kurnub Group, which is characterized by highly weathered and friable sandstone. It was difficult to take orientation data measurements from this station. It is characterized by a steep slope with a smooth surface, which led to easier fall down limestone blocks from the Na'ur Formation above (Fig. 33).

Figure 32. Side view of the Kurnub outcrop in station-7, it is yellow to dirty white, friable sandstone (red circle), highly weathered, and highly fractured (red ellipses). The block highlighted blue will topple, the black stars show the topple and slide the block from location 1 to 2.

Figure 33. Kurnub outcrop in station- 8; a) side view, b) front view.

4.9 Station 9

This station is located along Jerash-Amman Highway about 25 Km south of Jerash. It is located at 32° 9.76'N and 35° 50.835' E (Fig. 3).The outcrop in the study site is Fuheis Formation, which is dominated by marls and marly nodular limestone. It also consists of soft, friable marls intercalated with lenses of calcareous--mudstone, thin beds of nodular and fossiliferous limestone. The outcrop is highly fractured in all directions, and highly weathered (Fig. 34). The high density of the fractures and the cohesionless of these fractures led to the circular failure as there is no preferred orientation for them (Fig. 35). Some fractures with preferred orientation NNW-SSE to N-S are also present in this station (Fig. 36). These fractures (J1) beyond the rock mass act as back release (tension cracks), and will be topple in this station (Fig. 36). The kinematic analysis of this station is shown in (Fig. 37).

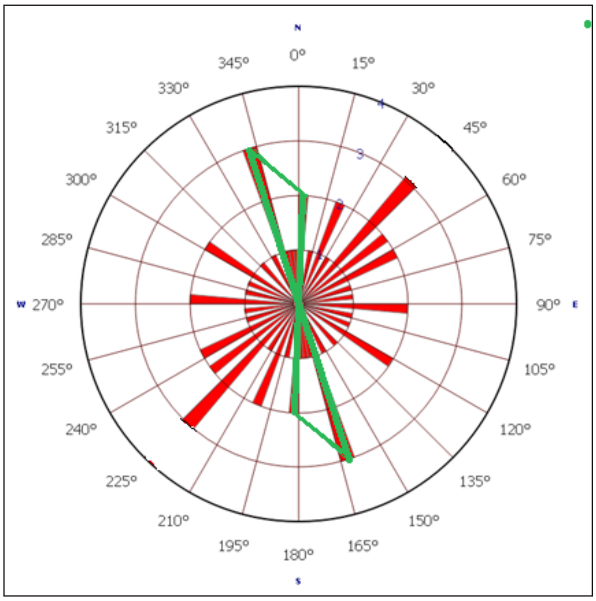

Figure 34. Strike measurements of randomly (no preferred orientation) oriented fractures in station-9; the green marked trend represents the toppling fractures set.

Figure 35. The outcrop shows the circular failure in station- 9.

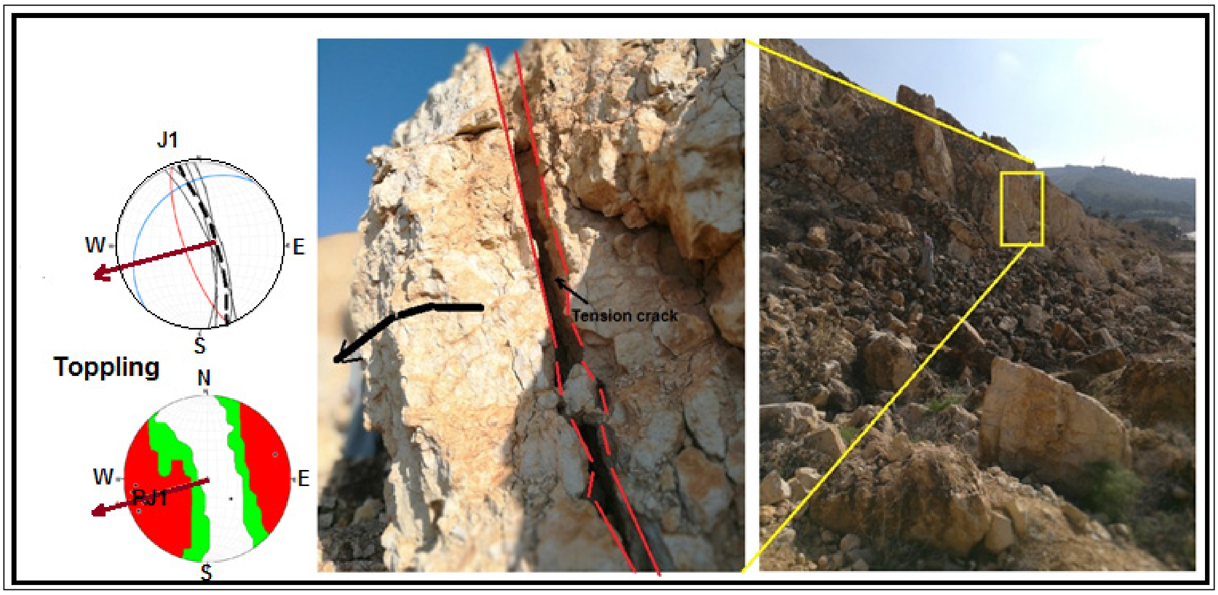

Figure 36. Toppling failure along J1 towards WSW (see the tension crack acts as back release surface) in station-9.

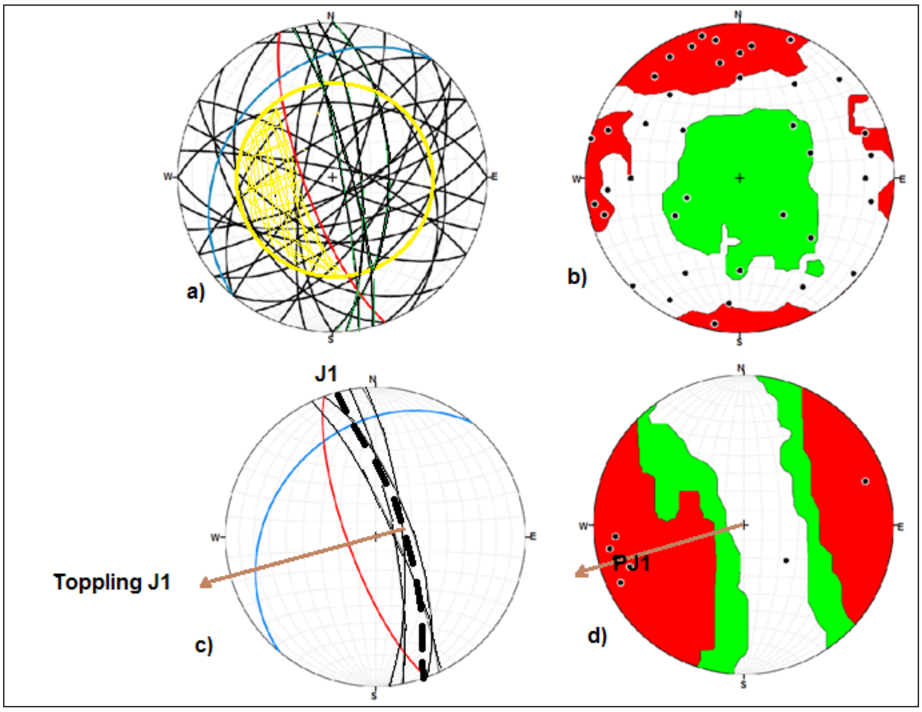

Figure 37. a) Stereographic projection (great circles) of the fractures, b) Poles of the fractures (no preferred orientation), c) Toppling failure along J1 towards WSW, d) poles of J1 (PJ1).

5. Discussion

5.1- Kinematic analysis

The study area is located along Jerash–Amman highway. The formations that outcrop in the study area are of Cretaceous (Fig. 3). The data were collected from nine measurement stations of the study area based on the discontinuity properties which have indications of the impact on slope stability.

Based on the kinematic analysis; there are five major joint sets (dip/ dip direction) that can be identified in Station1. Their attitudes are as follows: J1(80/075), J2 (80/290), J3 (68/140), J4(80/150), and J5 (88/255). While in Station-2 four major joint sets can be identified in this site with attitudes as follows: J1(60/110), J2 (86/280), J3 (70/150), and J4 (75/ 090). In Station-3 three major joint sets were identified with attitudes as follows: J1(70/ 270), J2 (50/ 300), and J3 (50/ 220). In Station-4 six major joint sets can be identified with attitudes as follows: J1(80/310), J2 (70/330), J3 (75/050), J4 (75/230), J5 (70/270), and J6 (vertical, strike= 140), and in station-5 six major joint sets were also identified with attitudes of J1(65/ 280), J2 (65/ 100), J3 (60/ 330), J4 (70/ 185), J5 (70/ 020) and J6 (70/050).

Station-6 which represents a major active landslide was analyzed through this study to show an ideal example (of mistake) of the active man-made landslide failure, that happened during road construction. In Station-7 it was difficult to take measurements of data orientation because it is characterized by friable sandstone and has highly weathered and fractured rock blocks. In Station-8 it was also difficult to take measurements of data orientation because it is characterized by a steep slope with a smooth surface and highly weathered rocks.

Station-9 has highly fractured rocks which resulted in a circular failure, whereas some fractures with preferred orientation in NNW-SSE to N-S resulted in toppling. These fractures (J1) beyond the rock mass act as the back release (tension cracks) and will lead to toppling. The results of the kinematic analysis in the study area show that the wedge failure in stations 1, 2, 3, 4, and 5 between joints (J2 and J4, J2 and J3), (J3 and J4), (J2 and J3), (J1 and J4, J2 and J4, J3 and J5), (J1 and J6, J1 and bedding, J3 and J6, J3 and bedding, J2 and J3). Toppling failure in stations 1, 2, 5, and 9 between the joint sets J1, J2, J4, and J1, respectively. Plane failure in stations 2, 3, 4, and 5 along the joint sets J1, J1, J5, and bedding, respectively. Whereas, circular failure was only observed in station 9. Based on the results of the current study the landslides were delineated and displayed on the land sat and on the geological map of the study area (Fig. 38).

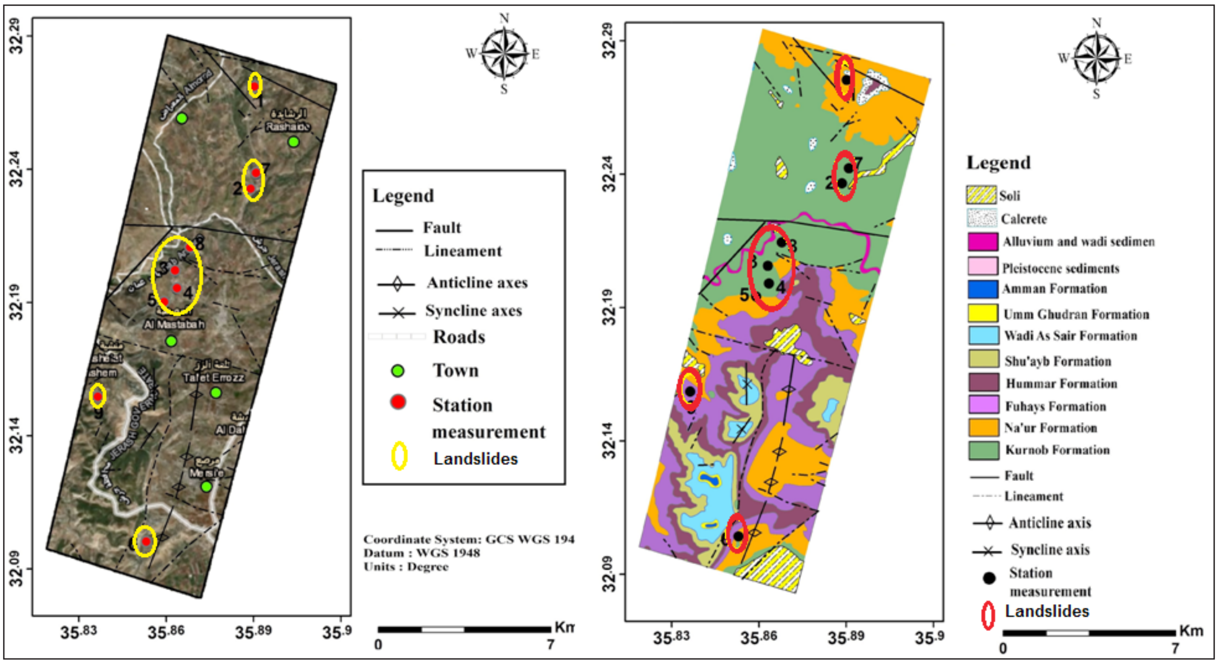

Figure 38. The delineated landslides (red and yellow ellipses) displayed on the land sat satellite image(Explorer 2018)and geological map, respectively.

5.2 Relationship between the measured fractures and the landslides in the study area

All measured microfractures with a total of 500 readings were represented in a rose diagram (Fig. 39). From the figure it can be inferred that the main trend is generally NNE - SSW. It is observed that the strike of the main trend of the fractures in stations 2, 3, and 4 (NNE to N) is parallel to sub-parallel to the strike of the slope face. In stations 1 and 5, the minor trends (NNW to NW) are sub-parallel to the slope face. In station-6 the fractures are oblique to slope face at about 45 degrees. In station-9 it is parallel to the toppling planes only in the NNW-SSE direction. This indicates the major role of the structures in rock landslides, particularly those related to planar, and toppling failures as they are sub-parallel to slope faces.

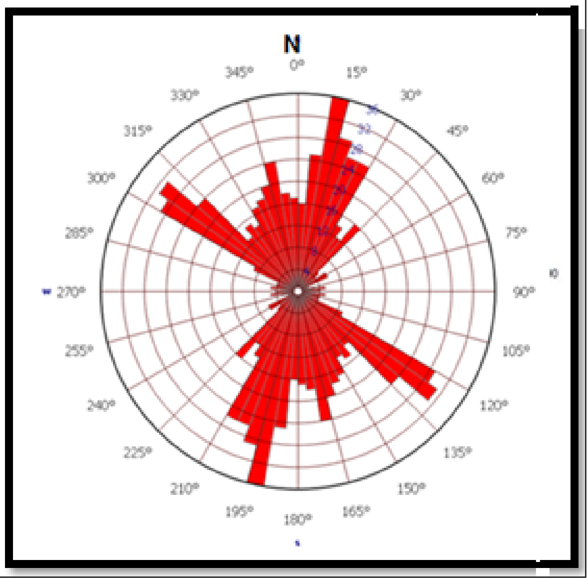

Figure 39. Strike measurements of all measured fractures in the study area

6. Conclusions

This study has pointed out and elaborated the kinematic analysis of slope stability in the study area. Results show that wedge failure in stations 1, 2, 3, 4, and 5 between joints (J2 and J4, J2 and J3), (J3 and J4), (J2 and J3), (J1 and J4, J2 and J4, J3 and J5), (J1 and J6, J1 and bedding, J3 and J6, J3 and bedding, J2 and J3). Toppling failure in stations 1,2,5 and 9 along the joint sets J1, J2, J4, and J1, respectively. Plane failure in stations 2, 3, 4, and 5 along the joint sets J1, J5, and bedding, respectively. In addition to circular failure in station 9. The 500 fracture measurements show a major NNE- SSW trend, and minor trends NNW- SSE, and NW- SE, which often are sub-parallel to slope faces. It is observed that the strike of the main trend of the fractures in stations 2, 3, and 4 (NNE to N) is parallel to sub-parallel to the strike of the slope face. This creates the most dangerous rock landslides in the study area, particularly those related to the planar and toppling failure. The dominant type of rock slope failure in the study area is wedge failure followed by toppling and planar failure. This enhances the role of the geological structures in land sliding. The study area has artificial (man-made) cut steep slopes in some stations, which led to landslide failure.

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