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Rock Fall Failure Model practical example of Umm Sid Plateau-Sharm El Sheikh area, Egypt

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Abstract— A severe rock fall in the upper jointed Reefal Limestone unit which represents the main foundation rock bed of Umm Sid plateau .The main causative factors of rock fall is the movement of the limestone blocks under the effect of deferential erosion (undercut) of the underneath sandstone unit. Photogeologic mapping and Geological Field measurements have been carried out for the Umm Sid plateau to investigate the factors controlling the rock fall of the uppermost layers of the plateau. The geological field measurements as well as geological disk studies are used to produce a model representing the joint orientations, stability model and failure mechanism geologic model. Kinematic analysis of the acquired data indicated that the topmost unit of the plateau is affected by three main sets of joints E-W, NE-SW and NW-SW trends. The hard Reefal Limestone unit is underlying with relatively soft sandstone unit. The sand stone unit is intercalated with marl and clays that increase the potentiality of deferential erosion. Kinematic analyses of the measured joints were studied by using Hoek and Bray failure methods (2004), Dips program Version 5.1.8 and RocPlane Version 2.0. The site observation and measurements indicated that the rock falls is seriously active and accordingly the scarp edge retreat and that may lead to a dangerous impact on the existing hotels and resorts located at this plateau.

Index Terms— Sharm El Sheikh (Umm Sid Plateau), Kinematic analyses, Rock fall and Failure model.

1

INTRODUCTION

Umm El Seed Sid Plateau is overlooking the Gulf of Aqaba. It is bounded from the west by Sharm El Maya and from the east by Marsa Menaisel. It is about 3.5 km2 in area. The average height of the plateau is 30 m above sea level. The general slope of the plateau is less than 5° toward southeast following the tectonic dipping of capping Reefal Limestone beds.

Rock falls represent one of the major cause of substantial damage to property and loss of life every year across the globe. They are one of the major geohazards and can be triggered by earthquakes, volcanic eruptions, heavy rainfall, or indeed by human activities. Umm Sid plateau is a high risk area for major rock fall events. The plateau is occupied and surrounded by several tourist resorts and hotels. The Umm Sid plateau scarp edges studied stretches are shown in Figure-1. The main objectives of this article are to evaluate the rock fall risk of plateau edges, modeling of the rock fall mechanism and giving the proposed stabilization measurements to minimize the risk of rock fall damages as well as the severely retreat of plateau scarp edges. It is also highlight to the geologic setting of the plateau with emphasis on the joints pattern and its relation to the stability of plateau edges.

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Figure 1 . Umm Sid Plateau-Sharm el-sheikh area .The marked zones represent the joint survey of studied critical scarps.

2 GEOLOGY AND TECTONIC SETTING OF SHARM EL SHEIKH AREA.

The main geological units exposed at Sharm El Sheikh area are mainly consists of igneous and sedimentary rocks .The youngest unit is Holocene surfacial Wadi deposits of sand and gravels, Pliocene Reefal Limestone and Lower Miocene alternate beds of sandstone and marls. The oldest rock units outcropping at the west side of Sharm El Sheikh is Late Proterozoic Igneous rocks of Quartz Syenite and Granite (Geological map of Sinai, 1994 and Omara, 1959).

Tectonically Sharm El Sheikh area had been affected by series of tectonic events related to the opening of Red sea, Gulf of Suez and Gulf of Aqaba. The area is under contours tectonic stresses of Red Sea lateral spreading of about 2 cm per year. The predominant faults have trends NNE-SSW and NW-SE. The area is subjected to moderate intensity earthquakes of magnitudes ranges .between 3 and 4 on Richter seismic Magnitude scale (Abou Elenean, 1997; Quennell, 1958; Garfunkel et al., 1981).

The seismicity of the region indicates that the Gulf of Aqaba has been the more active segment of the plate boundary between Arabian and Sinai plates. Since 1983, the Gulf region was affected by four major earthquakes sequences. The first swarm was on January 21, 1983 that lasted for a few months. There were 181 earthquakes listed in the IPRG bulletin and 60 shocks from the swarm were recorded by the Jordan University Seismological station. More than 500 shocks (Ml > 3.5) were recorded by Saudi local mobile network of 6 stations within a period of 72 days operation.

The largest shock had a magnitude of 5 and about 10 events had a magnitude greater than or equal to 4.4. The second swarm occurred in the southern part of Aqaba on April 20-27, 1990 having a peak magnitude of Ml=4.2 (El-Isa, 1986 and El Hadidy, 2008).

3 GEOLOGICAL SETTING OF UMM SID PLATEAU

Umm Sid plateau cover an area of about 3.5 km² and facing to Sharm El Maeh from west and Gulf of Aqaba from east side. The plateau has general gentle slope toward the south and average height of 30 m above the sea level. Most sides of the plateau have nearly vertical side slope (scarps) facing the sea side. The main geological units encountered at Umm Sid plateau are shown in figures 2 and 3. The lithological description and stratigraphic setting of these units are as follows:

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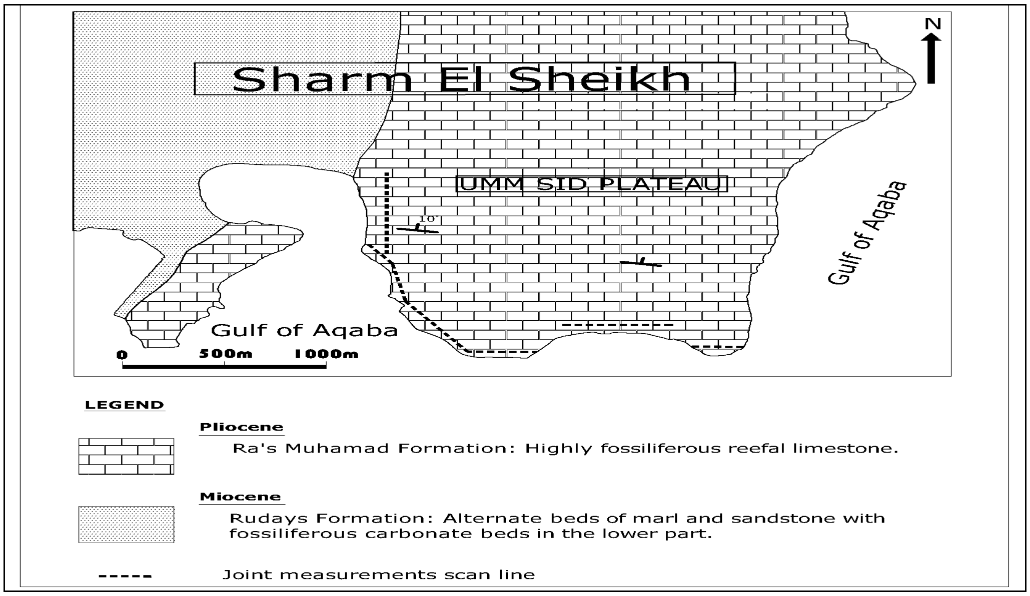

Figure 2 . Geologic map of Umm Sid plateau – Sharm El Sheikh area.

Figure 3 .The two rock units of Umm Sid Plateau, upper unit is reefal limestone and underlaying unit is interbeds of sandstone and marls.

3.1 Ras Mohamed Formation

This unit consists of creamy white Reefal Limestone of Pliocene age. This limestone is rich with corals and cephalopods fossils, bounded together by carbonate cement, formed as Reefal fringe during the Pliocene and the Pleistocene. The unit is very rich with varieties of fossils and has some Karstic features. Ras Mohamed Formation represents the foundation bed rock of Umm Sid plateau constructed buildings (Figure 3).

3.2 Radays Formation

This unit unconformably underlies the Pliocene Reefal Limestone of Ras Mohamed Formation. It mainly consists of alternate beds of sandstone, clays, marl and fossiliferous carbonate beds at the lower part. The age of this unit is belonging to lower Miocene. This unit is dipping 10^0 toward northeast measured at the cliff footwall of Batros Hotel beach (Figure3).

Structural y, the mode of deformation of the area is mainly related to the Red Sea Gulf of Aqaba tectonic regime. These

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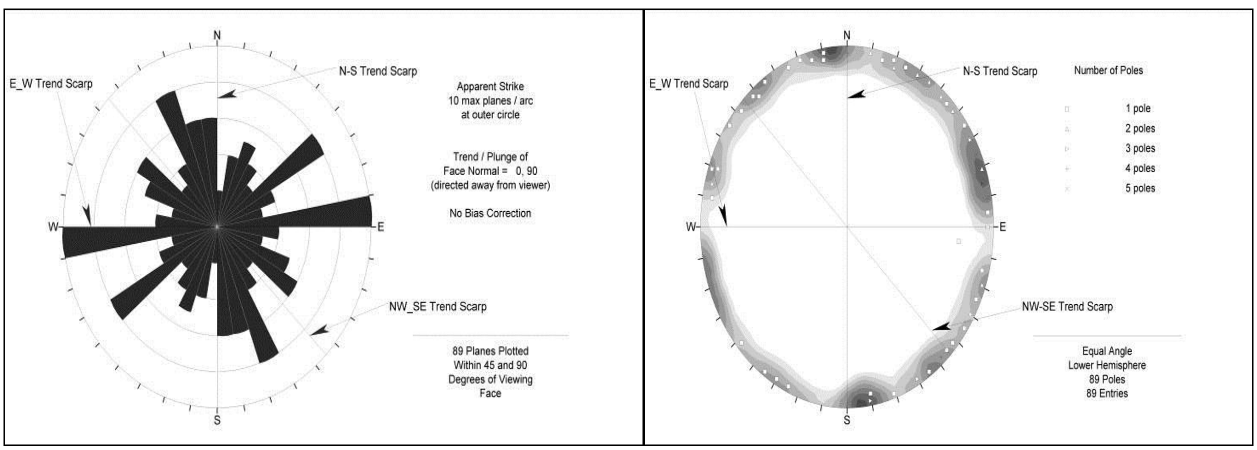
tectonic settings are reflected on the plateau as faults and joints. Um El Sid Plateau is affected by many recent faults related to Post Pliocene age tectonic regime .The trend of these faults are NE-SW direction and parallel to Gulf of Aqaba trend. The Older faults (related to Post Oligocene time) are numerous, but they cut only the underlying sandstone beds and no effect on the upper coralline limestone.

4 KINEMATIC ANALYSES

The term "Kinematic" in rock slope failures refers to the motion of rock blocks without reference to the forces that cause them to move (Goodman, 1989). Many rock cuts are stable on steep slope even thought they contain steeply inclined planes of weakness with exceedingly low strength; this hap pens when there is no freedom for a block to move along the weak surface because other ledges of intact rock are in the way.

Kinematic analysis is very useful to investigate possible failure modes of rock masses which contain discontinuities. Failure involving movement of rock blocks on discontinuities combines one or more of the three basic modes: plane sliding, wedge sliding and toppling. For the rock slope investigated at Umm Sid plateau west and south side scarps, kinematic analysis was performed to estimate the expected types of side slope failures.

The Joints mapping scan lines along the Umm Sid plateau west side and south side scarps have been used for measuring all encountered joints. A total of three hundred joints have been measured and used in the stereographic dip/dip direction plotting. The persistence of most of these joints is ranges between 10 m and 20 m. Most of them have steep dip angles varying between 80° and 85°. The joint opening is ranges between 0.5 cm and 10 cm with rough undulated surfaces. The stereographic projection of the Joint survey data (rose diagram and pole plot) revealed that the Reefal Limestone unit capping Umm Sid Plateau is affected with three major sets of joints trending E-W, NE-SW and NW-SE. Some subordinate joint sets have trends NNW-SSE and NNE-SSW .The stereographic projection (rose diagram and pole) of the clustered measured joints at plateau edges are shown in figure 4 A and B.



A **B**

Figure 4 A and B. Um Sid Plateau measured joints Rose diagram (A) and pole plot Diagram (B).

4.1 North-South Trending Scarp:

The dominant joints sets dissecting this scarp have trends of N-S and NE-SW. The intersection of these trends with scarp edge are form unstable free blocks. The expected types of failures are plain (dip/dip direction of 88/258), Toppling failure (88/105) and Wedge failure (80/275). The rose diagram and failure envelops of N-S trend scarp are shown in Figure 5 A and B.

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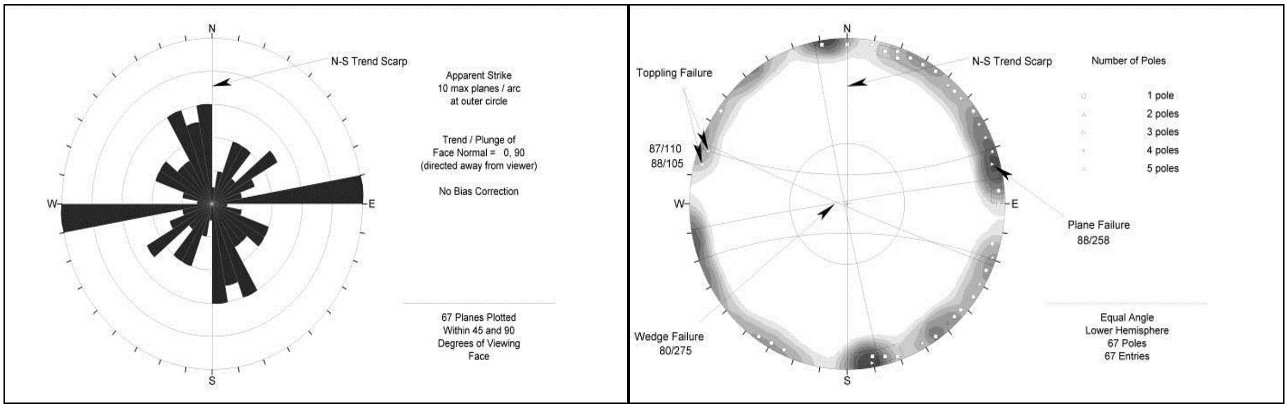
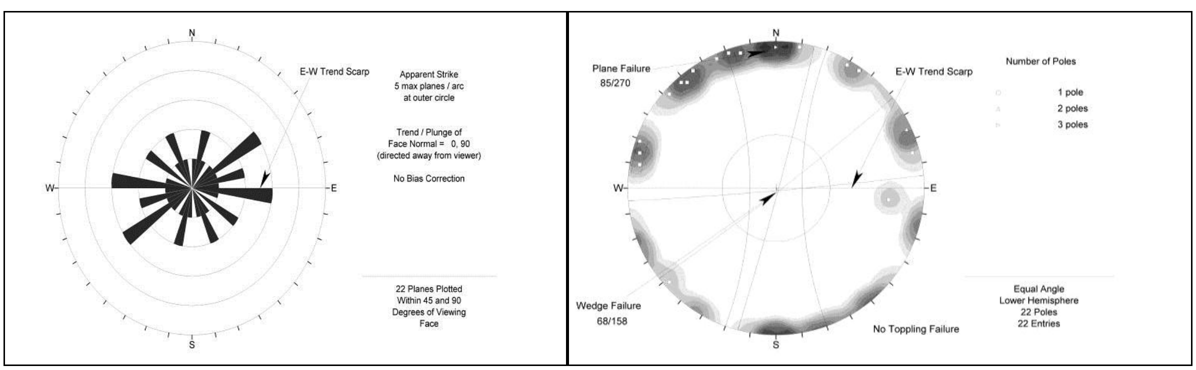


A B

Figure 5 A and B. North-South Scarp Rose Diagram –A and failure envelop -B (showing toppling, plane and wedge Failures).

4.2 East-West Trending Scarp:

The dominant joints sets dissecting this scarp have trends of E-W and NNE-SSW. The intersection of these trends with scarp edge are form unstable free blocks. The expected types of failures are plane (85/270) and wedge (68/158). The rose diagram and failure envelops of E-W trend scarp are shown in figure 6A and B.



B **A**

Figure 6 A and B. East-West Scarp Rose Diagram -A and daylight failure envelops –B (showing plane and wedge failures).

4.3 Northeast-Southwest Trending Scarp:

The dominant joints sets dissecting this scarp have trends of E-W and NNW-SSE. The intersection of these trends

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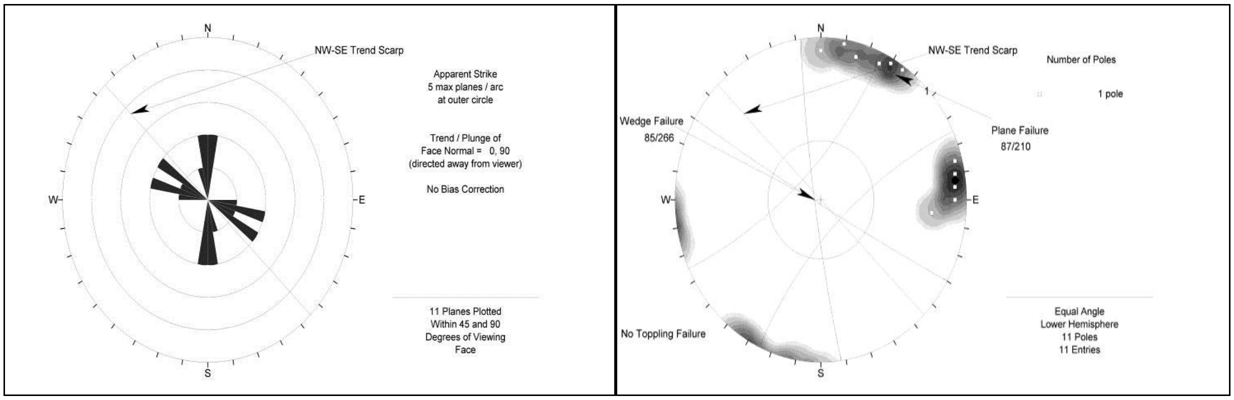
with scarp edge are form unstable free blocks. The expected types of failures are plane (87/210) and wedge (85/266). The rose diagram and pole plot of NE-SW trend scarp are shown in figure 7 A and B.



B

Figure 7A and B. NW-SE Scarp Rose Diagram -A, daylight failure envelops -B (showing Plan and Wedge failures).

A

5 ROCK MASS GEOTECHNICAL PARAMETERS

5.1 Reefal Limestone unit:

This unit is characterized by the followings:

- Highly fractured.
- Has a Kartstic feature (solution cavities and fractures).
- This unit represents the foundation bed of all upper plateau buildings.
- Highly weathered and altered due to surface water seepage as well as septic tanks in some areas.
- Classified as Moderately Strong (unconfined strength 15 Mpa measured by using Schmidt hammer).
- RMR (Rock Mass Rating after Bieniawski, 1989) = 48, Rock mass class 3.
- The intersections of existing master joints create free unstable large rock blocks of Weight ranges between 5 and 100 tons.

5.2 Sandstone unit:

This unit is characterized by the followings:

- Moderately fractured.
- Presence of weak thin layer of clays and marls.
- Highly weathered and altered due to surface water seepage as well as septic tanks in some areas.
- Presence of deferential erosion (under cut) between this unit and the overlaying cap of Reefal Limestone.
- This unit can be classified as Moderately Weak (unconfined strength ranges between 5 Mpa and 10 Mpa measured by using Schmidt hammer).
- RMR(Rock Mass Rating after Bieniawski,1989) = 40 ,Rock mass class 4

6 PLATEAU SCARP EDGES STABILITY

Field measurements as well as kinematic analysis revealed that the plateau edges are unsafe and retreating continually by block failures. The steep scarp (nearly vertical slope for most plateau edges), intersection of tectonic joints, recent seismic activities as well as upper edge urbanization and construction activities are all triggering the existing free blocks to create unstable plateau edges. Several stretches along the plateau edge have severe rock failures. Some unstable blocks at plateau edges are shown in figure 8.

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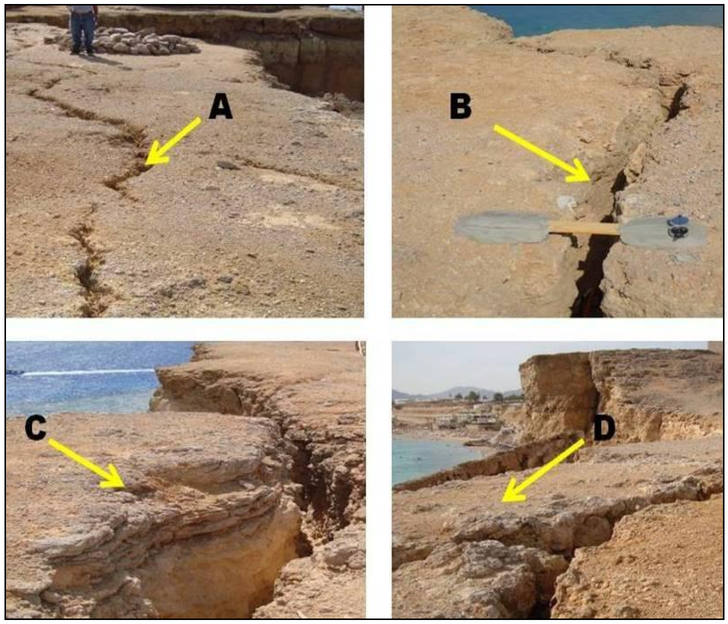

Figure 8 .Unstable blocks at Umm Sid plateu scarp edges,A and B-opening of tectonic joints ,C and D start of telting and rock fall.

Quantitative analysis of rock fall at Umm Sid plateau was carried out by using RocPlane stability analysis software (RocPlane - Version 2.0). The analyses include the existing condition, anchor force at static condition, and anchor force at dynamic condition by using horizontal seismic coefficient factor (Kh) of 0.2 (kh = a/g, where a (study area seismic acceleration, after Abou Ele nean, 1997) = 2.0 m/s² and g (ground gravitational acceleration) = 9.8 m/s²) . The analysis model is based on joint sets measured on site as well as the existing slope geometry of the plateau. The analysis output models are shown in Figures 9 and10.

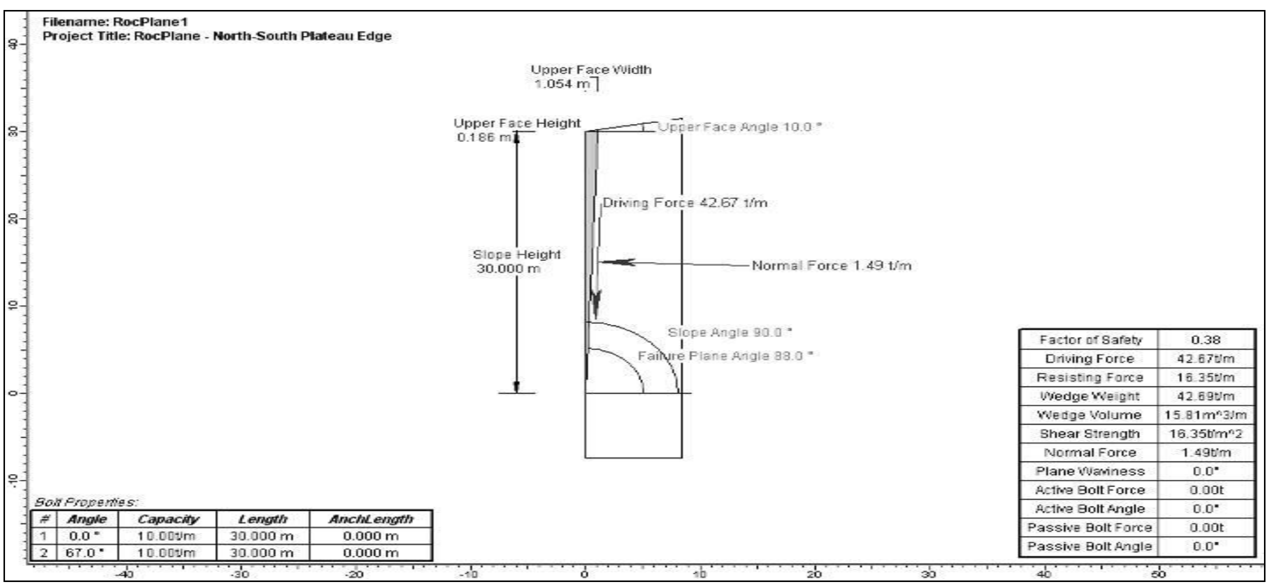

Figure 9. North-South Scarp edge plane failure model at existing condition the FOS = 0.38.

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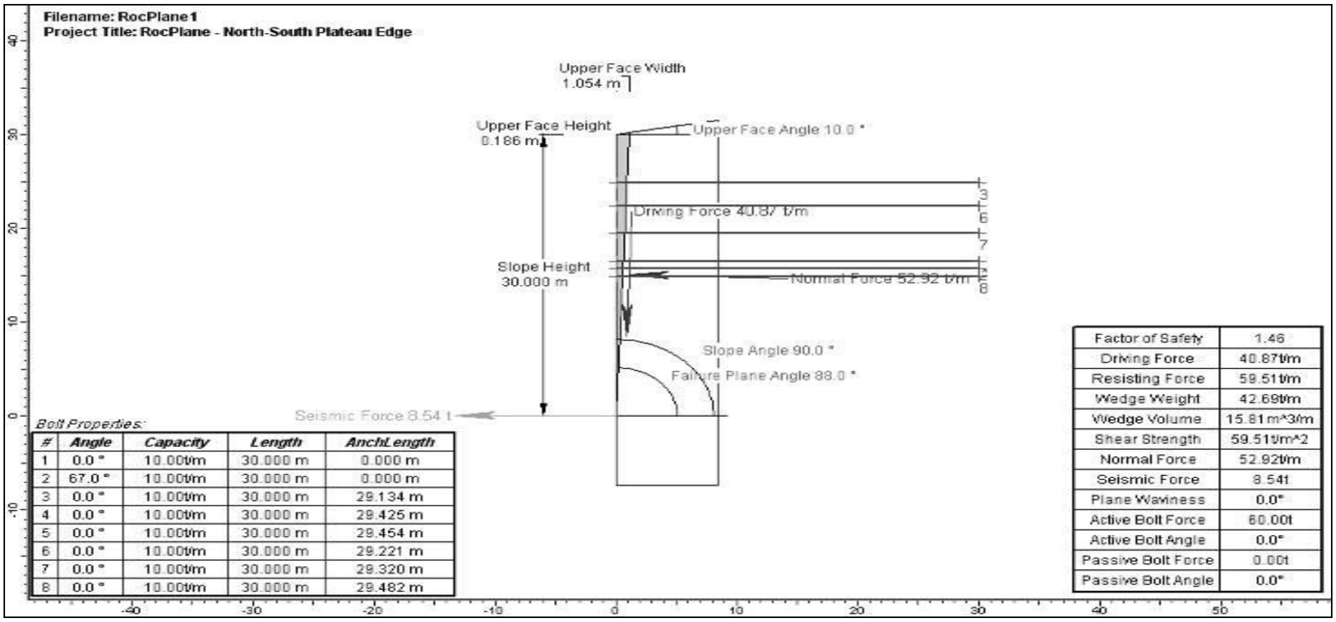

Figure 10. North-South Scarp edge plane failure model at dynamic condition and adding support anchors (FOS at static = 1.64 and dynamic FOS = 1.48).

The program calculated results are summarized as follows:

6.1Existing condition Stability of North-South Plateau Edge (Figure 9):

Analysis Results:-

Analysis type = Deterministic
Normal Force = 1.48992 t/m
Resisting Force = 16.3523 t/m
Driving Force = 42.6656 t/m
Factor of Safety = 0.383267

Geometry:

Slope Height = 30 m
Wedge Weight = 42.6916 t/m
Wedge Volume= 15.8117 m^3/m
Rock Unit Weight = 2.7 t/m^3
Slope Angle = 90 °
Failure Plane Angle = 88 °
Upper Face Angle = 10 °
Bench Width: Not Present
Waviness = 0 °
Intersection Point (B) of slope and up
Per face = (-1.04745e-013, 30)
Intersection point (C) of failure
Plane and upper face = (1.05411, 30.1859)
Failure plane length (Origin-->C) = 30.2043 m
Slope length (Origin-->B) = 30.0001 m
Tension Crack: Not Present

6.2 Strengthparameters:

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Shear Strength Model: Mohr-Coulomb
Friction Angle = 40 °
Cohesion = 0.5 t/m^2
Shear Strength: 16.3523 t/m^2
External Forces: Not Present

6.3 Stability of North-South Plateau Edge after adding support anchors (Figure 10):

Factor of Safety at Static with anchor force = 1.64
Factor of Safety at Dynamic with anchor force = 1.48

7 ROCK FALL MECHANISM AT UMM SID PLATEAU

Based on the detailed field study, kinematic analysis as well as determined factor of safety by using the RocPlane software, a failure mechanism model for Umm Sid plateau is presented in Figure 11.

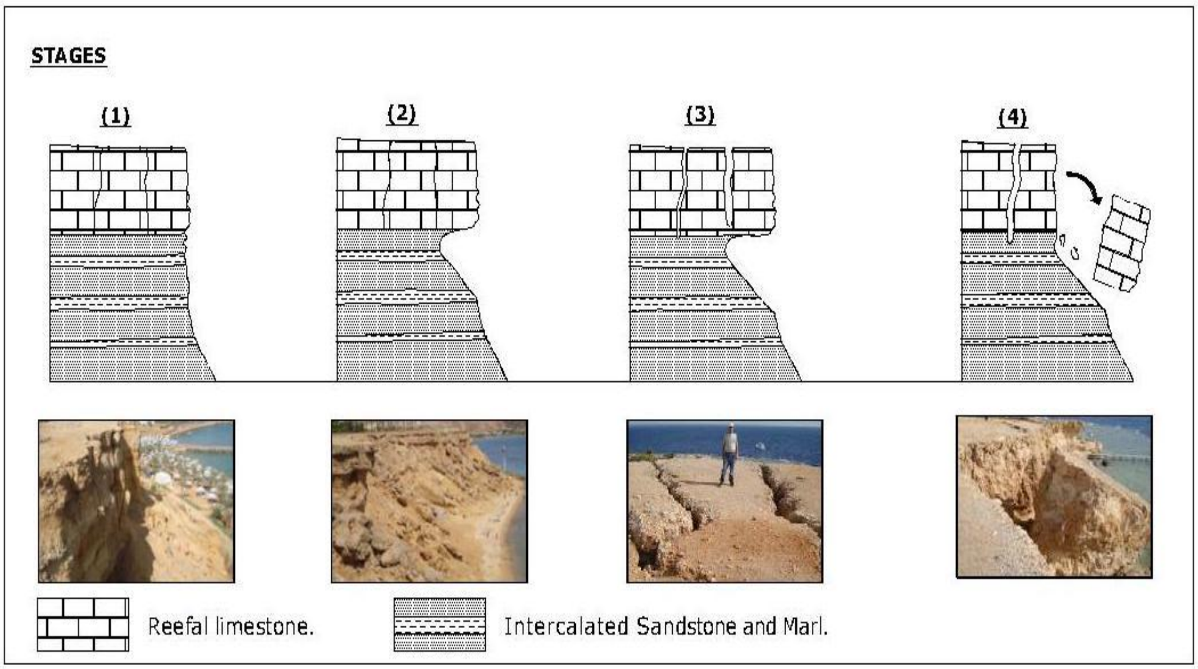

Figure 11. Model proposed for mechanism of side slope rock fall at Umm Sid lateau.Stage-1 Jointed Reefal limestone capping soft sandstone,2- Differantial erosion undercut,3- Opening the existing joints and 4- Rock fall.

The stages of plateau edges rock fall and retreat are summarized as follows:

1. Tectonic joint sets dissecting the plateau capping unit of moderately hard Reefal limestone.
2. Differential weathering for soft sandstone unit underneath the Reefal Limestone relatively hard unit.
3. Reefal Limestone deferential weathering under cut and opening the preexisting joints.
4. Rock fall under the effect of jointed free faces heavy limestone blocks.

8 CONCLUSIONS

Umm Sid plateau has dangerous rock fall stretches which have a severe impact on human life and safety of the constructed touristic projects. The plateau side edges should be immediately treated to minimize the risk of rock fall and retreat. The rock fall

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failure mechanism includes plane, toppling and wedge failures. The plane and toppling failures represent the dominant type of failure affecting the plateau scarps. The treatment measures should be complying with the environmental restrictions and parameters of this National Guard zone. The treatment process may include side slope re-shaping by adding intermediate berms and safe slope angle not exceed than 3 V: 1 H in all zones that have safe distance (minimum 30m) between scarp edge and existing buildings. The restricted stretches (less than 30m) which cannot be re-shaped can protect by using anchoring system, shotcrete and wiremesh to support all free unstable blocks.

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