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Rock Fall Protection Measures of High Cuts in Chalky Limestone, Northern Border of the Pyramids Plateau, Egypt

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Abstract—the northern border of the Pyramids Plateau is an attractive location for new touristic resorts and developing settlements. This area suffers from extensive extension cracks that have resulted from uncontrolled blasting in limestone quarrying. The old quarrying activities resulted in unstable high rock cuts which impose safety risks during the construction activities in this area.

The geological conditions of the rock units and the discontinuity patterns have been mapped and measured in detail. A stereonet failure envelope technique is used to evaluate the instability of the existing rock cuts. The geotechnical parameters of the existing rock units are studied based on some boreholes drilled in the area of study. The discontinuities failure envelope analysis, geotechnical parameters of rock cuts as well as survey of the extension cracks, slope stability models are used to study the stability and to develop optimum engineering solutions for protection and stabilization measures of the existing rock cuts.

Index Terms— Rock failure, Geological mapping, Discontinuity stereonet and Kinematic analyses, Protection solutions.

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1 INTRODUCTION

The study area is located on the northern border of the Pyramids Plateau at the western side of km 22 Cairo-Alexandria desert road. The site is also bounded on the north by El-Hasana Dome natural reservation. This area suffered from extensive uncontrolled blasting for limestone quarrying. The governmental authorities stopped the quarrying activity to minimize the ground vibration risks that have a damaging effect on the monuments of the Pyramids Plateau. At the present time, the sites of the old quarries represent a good investment area for new touristic resorts and housing compounds.

Most of the existing steep high cuts (old quarry faces) are potentially unstable. The instability of these cuts is mainly attributed to the uncontrolled blasting which caused disturbance of the rock masses. The stabilization of these rocks cuts represents one of the major challenges that affect the development of this area. The main objectives of this study are to evaluate the geological, geotechnical and instability conditions of the existing rock cuts and to propose optimum engineering solutions for stabilizing these unstable rock cuts.

2 GEOLOGY OF THE SITE.

The study area is geologically located on the southwest corner of the Abu Roash province, which represents one of the most significant geological features outcropping on the tableland of the Western Desert. This province is characterized by intensive folding and faulting in the outcropping Cretaceous rocks.

The stratigraphic rock units outcropping in the Abu Roash area are differentiated into Khoman Formation overlying the Abu Raosh Formation (Figure 1). The Khoman Formation consists of chalky limestone. The Abu Raosh Formation mainly consists of limestone intercalated with shale at the top and interbeds of flint, shale and sandstone at the base. The outcropping Cretaceous units are folded and faulted. The folds have NE-SW trend and the faults have dominant NE-SW and NW-SE trends. Several authors studied the structural features and stratigraphic units of Abu Roash area. Some of the works are published by Strougo, 1985, Moustafa, 1988 and Abdel Khalek et al, 1989.

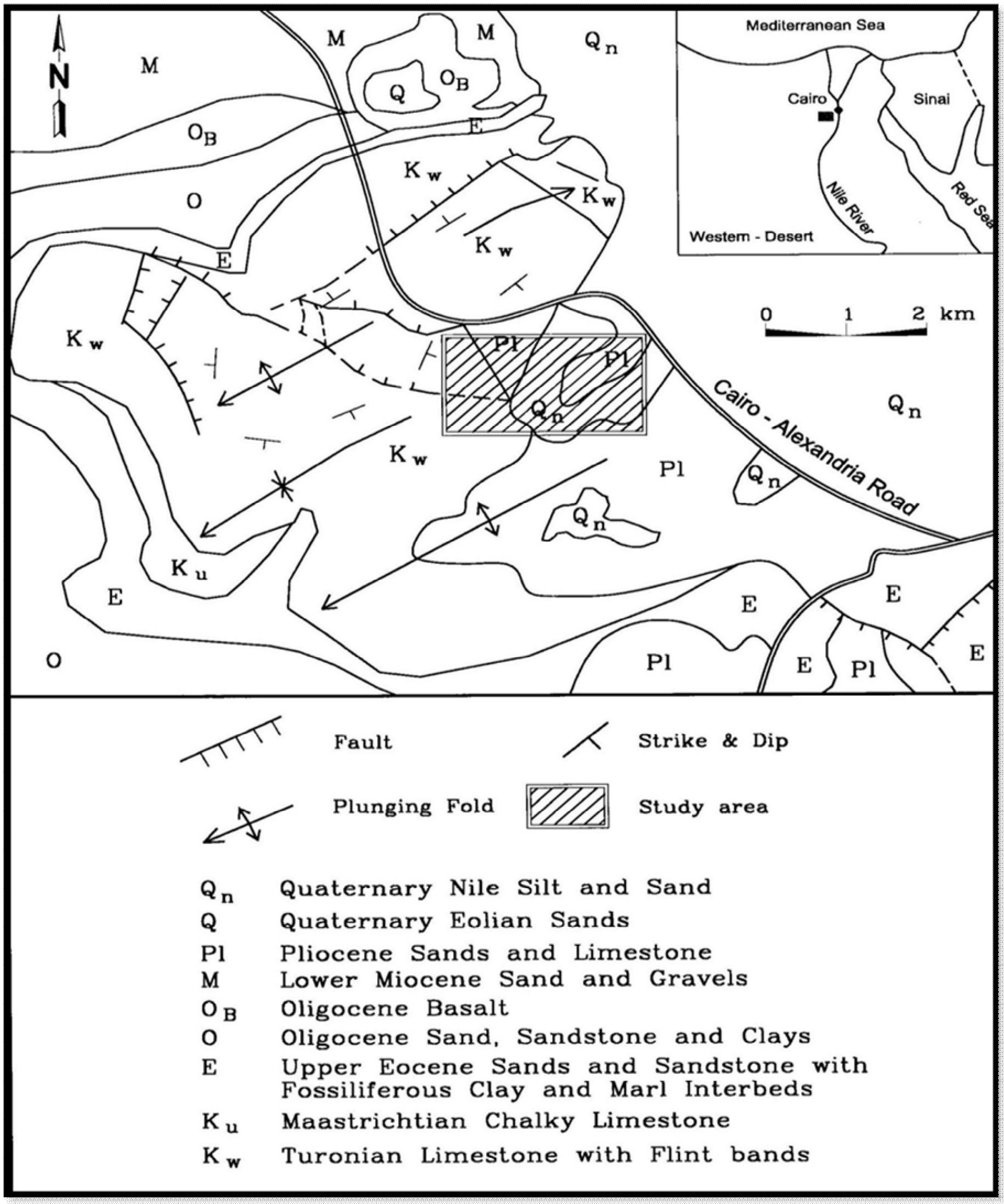

Figure 1. Geologic map of the studied area (modified after Geologic Map of Greater Cairo, Geological Survey of Egypt, 1983).

A geological map of scale 1:2000 has been prepared for the study area (Figure 2). The main outcropping unit is Upper Cretaceous Turonian white chalky limestone with flint bands and dolomitic limestone thick layer at the top. The other outcropping units are overburden materials of sand, rock fragments and quarried limestone blocks. The general dipping of the chalky limestone beds is towards NW with an average dip angle of 5^{o}. The chalky limestone is severally affected by three joint sets.

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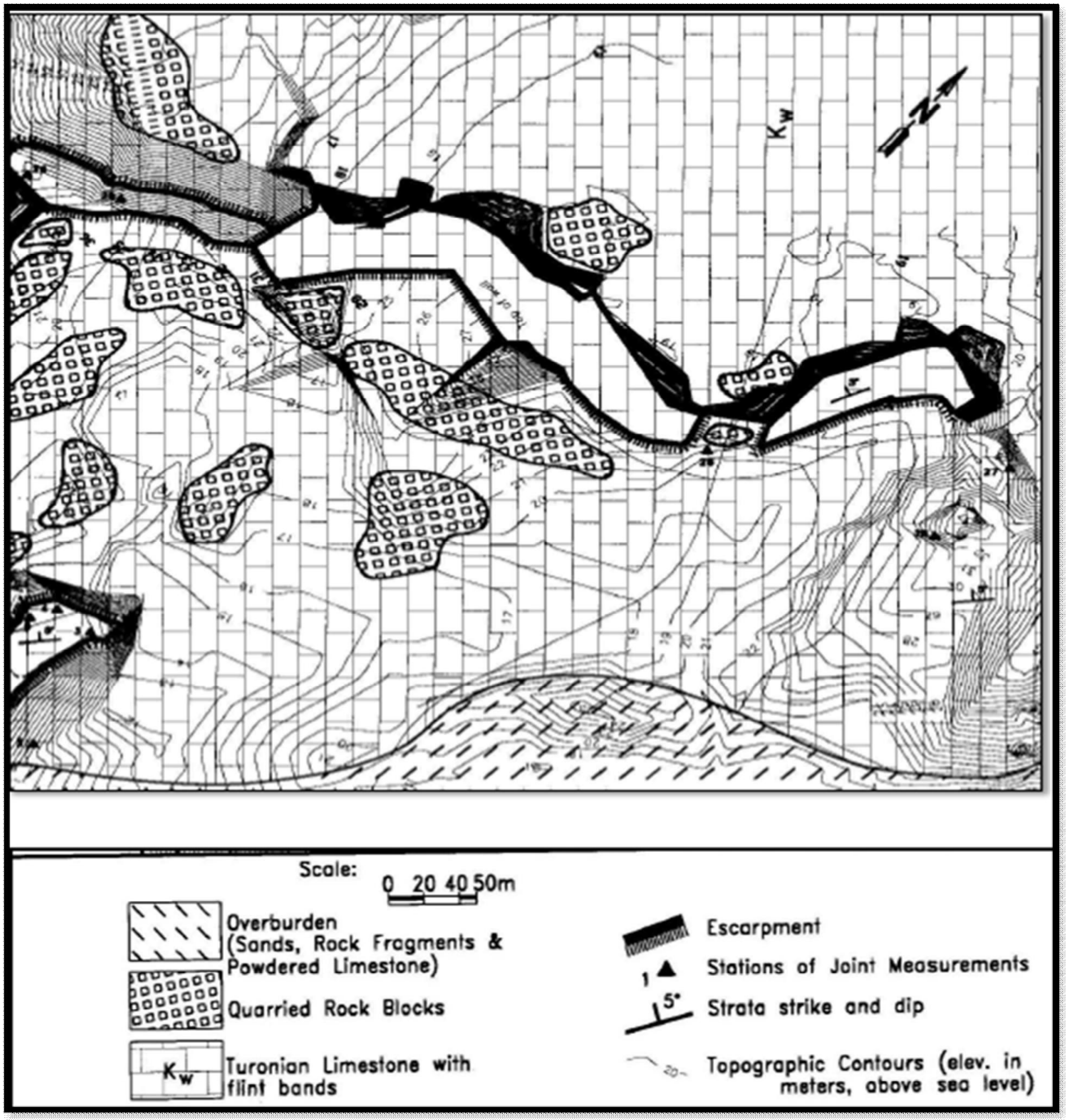

Figure 2. Geologic map of the studied area showing the risk lines of the unstable scarp edges.

The stations of the field-measured joints are shown on the geological map (Figure 3). The chalky limestone unit is extensively quarried in the site by using blasting materials. The quarrying process not follows the safety standers of quarry benching face geometry which normally used in open quarries. The blasting process disturbed the existing rock mass. Most of the quarried faces are steep with a rock cut face angle ranges between 80º and 90⁰.

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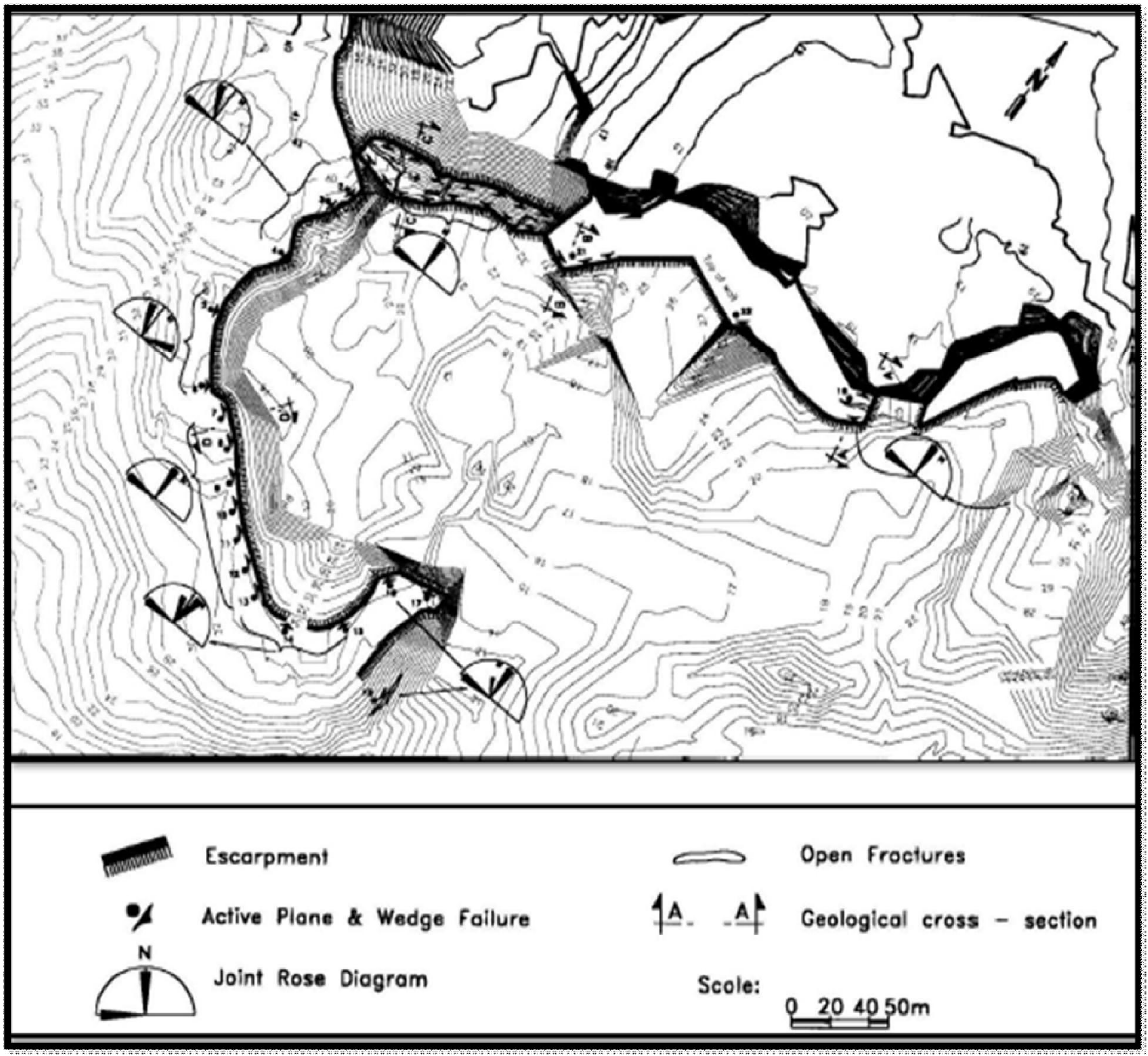

Figure 3. Dominant site measured joint sets rose diagram dissecting the unstable scarp edges of the study area.

The heights of these cuts range between 20 and 50 m from the flat ground surface of the site. The topographical and geological features of the existing cuts are illustrated in the rock cuts geomorphplogical map, geological sketches cross-sections and site representative photos Figures 4 and 5.

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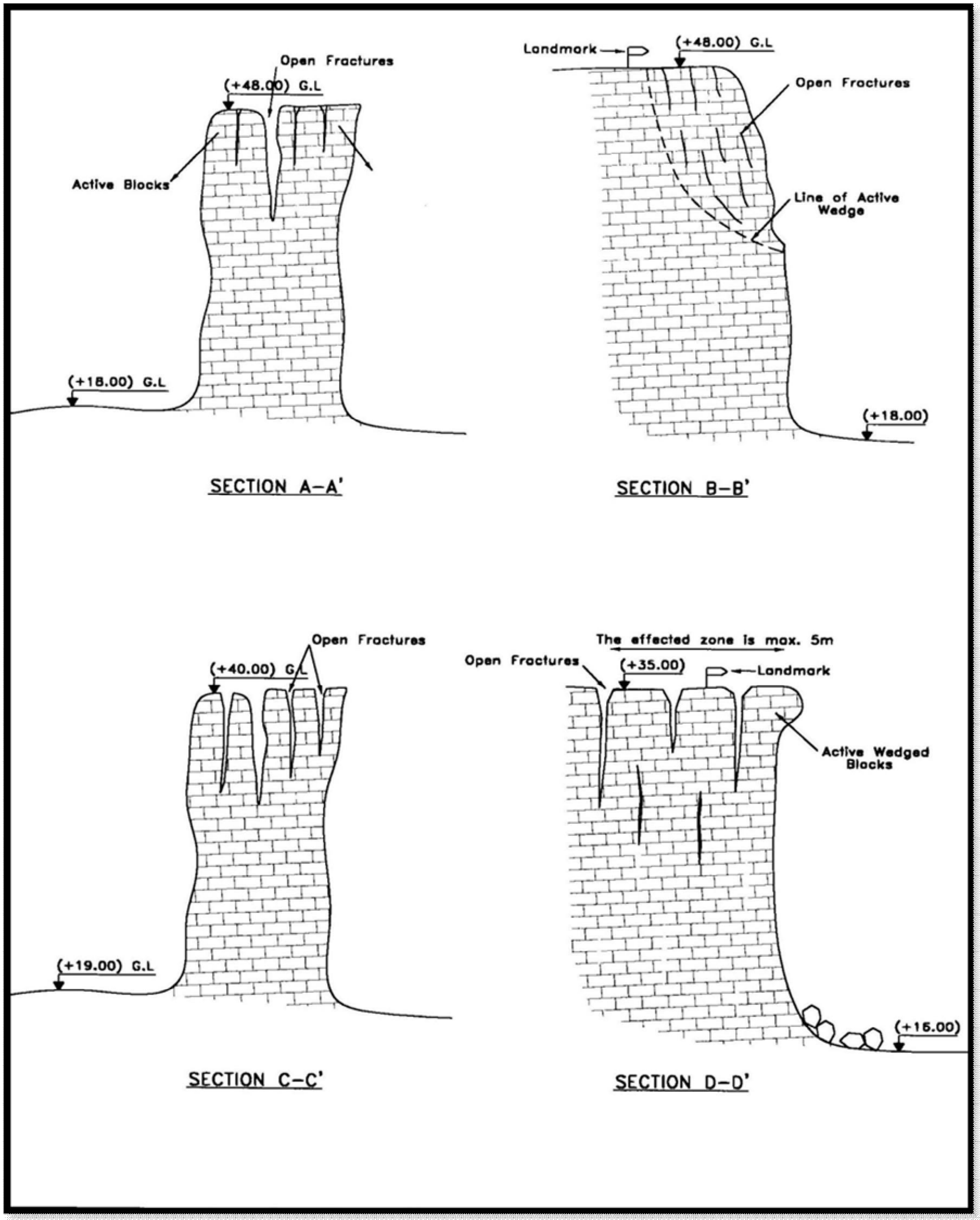

Figure 4. Geological cross-sections of the high risk slope cuts of the studied area (location of these sections are indicated in figure 3).

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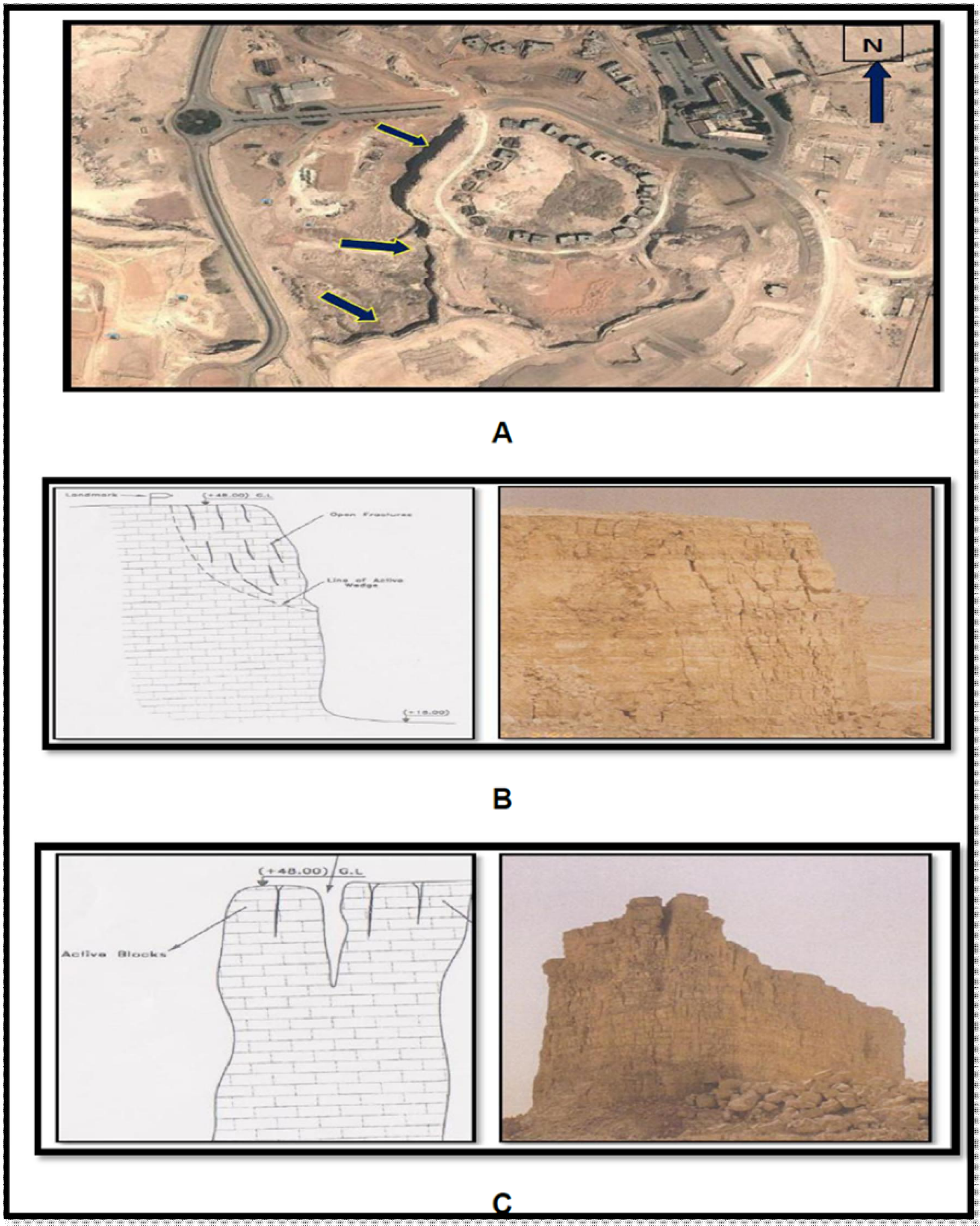

Figure 5. Geological sketches and site photos A and B showing the risk of rock falls for the majority of studied area rock cuts.

3 DISCONTINUITIES PARAMETER OF ROCK CUTS

The discontinuities parameters of the rock cuts are measured in the study area at 28 stations. The rose diagrams of these measurements indicate that there are three dominant joint sets (Figure 3). These joint sets are trending to N355° to N360°, N265° to N270° and N325° to N300°. The detailed site measured joint parameters are shown in table No.1.

Table 1: Joint Sets Parameters of the Study Area.

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Joint Set	Strike	Dip amount and direction	Spacing m	Opening mm	Persistence m	Roughness	Fréquences
J_1	N355-N360°	75° E	1 - 2	2 - 5	2 – 4	Irregular undulated	500
J_2	N265-N270°	80° S	0.5 - 1	1 - 4	1 – 2	Irregular undulated	350
J_3	N325-N330°	90°	0.5 - 1	1 - 5	2 – 4	Irregular undulated	250

The two joint sets J_1 and J_2 are conjugate in many of the measuring stations. Most of the measured joints are not filled except some conjugate sets filled with calcite and brown silt and clay material. The joints are dry because the groundwater table is relatively deep (more than 100 m below the ground surface) as recorded from groundwater wells in the neighboring sites. The measurements and observation along the edges of the existing rock cuts reveled that there are several unstable rock blocks.

4 STEREONET AND KINEMATIC ANALYSES OF DISCONTINUITIES

A stereographic projection (using equal area stereonet) technique is used to identify the expected type of rock failures.The kinematic analysis stage is followed the stereont plotting stage and uses for determination of the direction in which the block will be slide as well as its stability consideration (Wyllie and Mah, 2005). The adopted technique (streonet projection - kinematic diagrams) is give good quantitative information about the stability conditions of the examined rock cuts. However this technique does not account for external forces, water pressure and enforcement comprising tensioned rock bolts (Wyllie, 1992)

The dominant joint sets measured along the rock cuts of the study area (J_1, J_2 and J_3) are firstly plotted as poles on a stereonet plot (Figure 6 A). The rock cut faces are divided into six stretches based on their geographic azimuth trend. As slope angle of all the rocks cuts are nearly the same, one-stereonet daylight failure envelope of the rock cut is drawn on a transparence sheet (Figure 6 B). The transparence sheet is overlayed on the stereonet joint set pole plot and rotated to the trend angle of each rock cut stretch (Figure 6 C). The results of expected types of rock failure by using stereographic technique are summarized in Table No.2.

Table 2: Type and direction of expected failure along the existing rock cuts.

Rock Cut No.	Rock Cut Trend	Type of Expected Failure	Direction of Failure	Effective Joint Set
1	N40° W	Plane	East	Joint set No.3
2	N360°	Plane	East	Joint set No.1
3	N65° E	Wedge Failure	South South-East	Joint set No.2
4	N40° E	Wedge Failure	South East	Joint sets Nos.1 & 2
5	N85° E	Plane Failure	South	Joint set No.2
6	N20° E	Plane Failure	East East-North	Joint set No.1

From this table we can conclude that the stereonet daylight failure envelope of all the rock cuts have the potentiality of plane and wedge failures.

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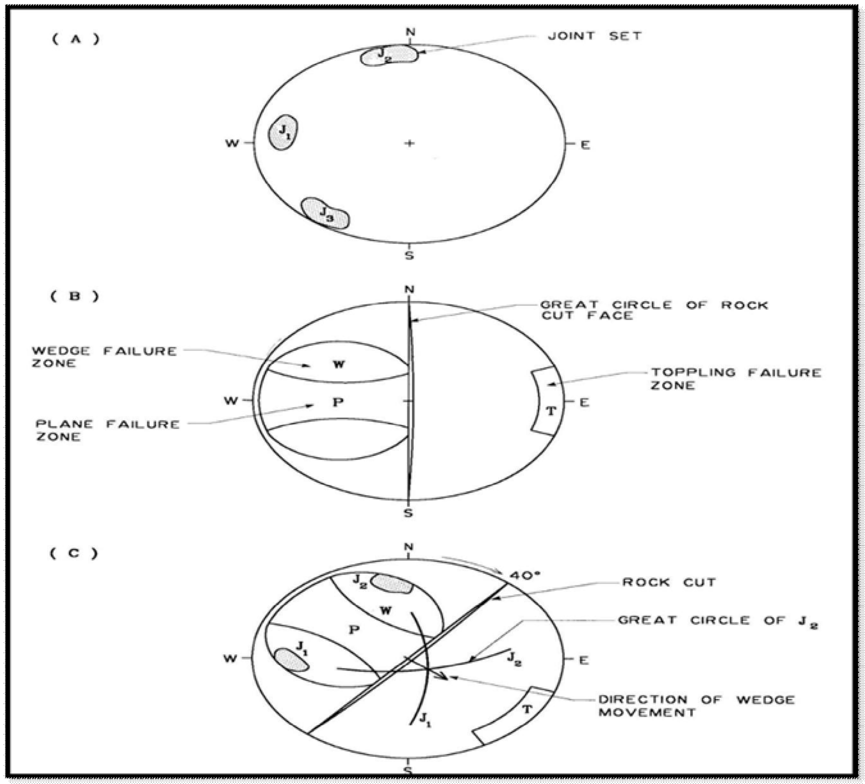

Figure 6. Stereographic projection and Kinematic analyses of the main joint sets effecting the rock cuts of the studied area (Pole plots of joints (A),Daylight envelops (B) and Wedge failure joints (C).

5 GEOMECHANICAL CHARACTERISTICS OF THE CHALKY LIMESTONE

The rock cuts of the study area have a scarp face of an average height of about 25 m. The lithological unit of these cuts is mainly white moderately hard to soft chalky limestone. The open fractures (extension cracks) in some locations are filled with brown silt, clay and sand.

The geomechanical parameters of the rock units of the existing slopes are determined from the intact core samples of the boreholes drilled up to 20 m depths in the chalky limestone unit. The average values of the laboratory and in-situ measured parameters are as follows:

- Unconfined Compressive Strength = 8 MPa
- Tangent Young's Modulus = 1440 MPa
- Bulk density = 0.24 MN
- Rock Quality Designation (RQD) = 18 %

5.1 ROCK MASS CLASSIFICATION

Several rock mass classification systems have been developed based on civil engineering case histories in which all of the components of the engineering geological characters of the rock mass were included. Some of these classifications were introduced by Wickham et al (1972), Bieniawski (1973 and 1989) and Barton et al (1974).

The geomechanics rock mass classification system (Bieniawski, 1973 and 1989) is based on the integrated Rock Mass Rating (RMR) parameters and this classification system is considered practical and easier to apply in the rock slopes design. The geomechanical RMR classification system is based on six parameters that are determined from the laboratory and in-situ tests. The RMR classification of rock cuts in the chalky limestone of the study area is given in Table No.3.

Table 3: Rock mass classification (RMR) of the chalky Limestone cuts of the study area.

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Para-meter No.	Classification Parameters	Measured Values	Rate
1	Strength of intact core sample	8 MPa	(2)
2	Drilling core quality (RQD)	18%	(3)
3	Spacing of discontinuities	0.6 to 2 m	(15)
4	Condition of discontinuities	Slightly rough surface	(25)
5	Groundwater	Completely dry	(15)
6	Effect of discontinuities attitude	Fair to unfavorable	(-30)
		Total Rate	30

The summation of the six parameters illustrated in the RMR Classification (Table No.3) reveals that the rock cuts are classified as poor rocks of rating values ranging between 21 and 40. The cohesion strength of this poor rock ranges between 100 and 200 Kpa and the friction angle is ranges between 15° and 25°.

5.2 TWO-DIMENSIONAL MODEL OF EXTENSIONAL CRACKS

Hoek and Bray (1981) introduced an analytical model to predict the response of rock slopes to a range of geotechnical parameters. This model and their equation are used for evaluating the rock cut stability of the study area.

A simple Excel spreadsheet for the Hoek and Bray (1981) equations is used to determine the optimum Factor of Safety.

The two-dimensional model is given in Figure 7 and the input parameters and their factor of safety (FOS) of the rock cut of the study area are summarized in Table No.4.

Table 4: Two- dimensional model spread sheet parameters and their factor of safety for the rock cuts of the study area.

(C) Cohesion (C MN)	ϕ Friction Angle	γr Density of rock MN/m^3	γr Density of water MN/m^3	α Horizontal Earthquake Acceleration	U Water Uplift Force (MN)	T Anchorage Force MN	F Factor of Safety
0	25°	0.024	0.01	0.09	0	0	0.08
0	25°	0.024	0.01	0.09	0	0.2	1.87
0	25°	0.024	0.01	0.09	0.036	0.2	1.55
0	30°	0.024	0.01	0.09	0.036	0.2	1.92

The output results as indicated in Table No.4 reveal that the investigated rock cuts are unsafe. The determined factor of safety is 0.08. Using anchorage force of about 0.2 MN (20 tonne / linear meter) increases the factor of safety up to a safe value, which equals 1.87. In the worst case where the extension cracks are filled with water, the FOS is also a safe with value of 1.55.

Based on the rock cut geotechnical parameters, stereonet and two-dimensional model analysis the following conclusions are summarized:

1- The existing rock cuts adopted geotechnical parameters are as follows:

- cohesion force (extension cracks) = 0
- extension cracks friction angle ϕ = 25°
- The horizontal earthquake acceleration force = 0.09

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- Unit weight of rock = 0.024 MN/m³
- Unit weight of water = 0.01 MN/m³

2. The rock mass parameters based on site and laboratory measures are as follows:
   - Rock mass cohesion ~ 150 KPa
   - Rock mass friction angle ~ 25º
3. The stereonet daylight failure envelope analysis indicates the probability of plane and wedge failure along the rock cuts of the study area.
4. The two-dimensional model analysis predicts that the existing rock cuts are unsafe with a factor of safety equal to 0.08 (the accepted FOS in rock slopes is not less than 1.5).

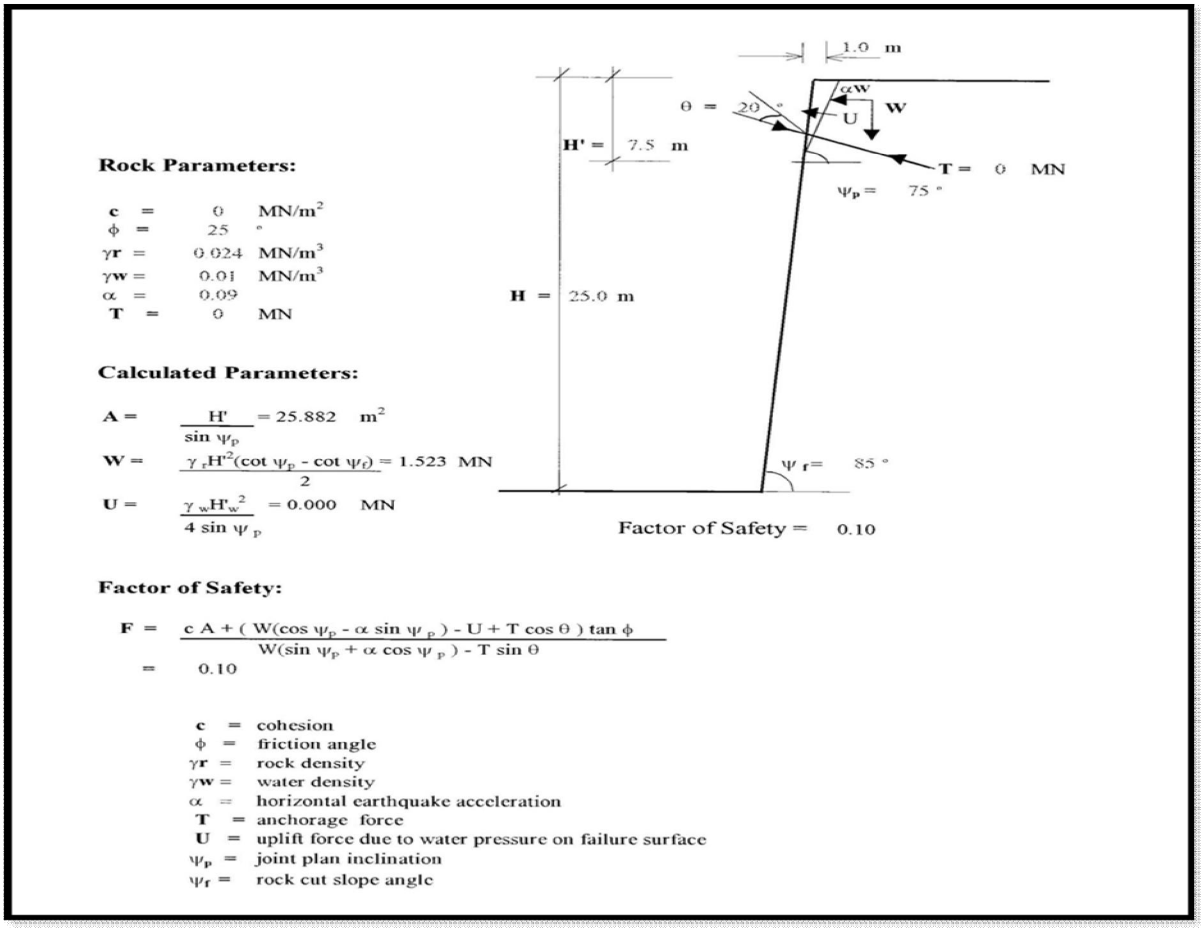

Figure 7. Two dimensional model of jointed unstable scarp existing in the studied area to calculate the side slope cuts Factor of Safety.

6 EXISTING SIDE SLOPE CUTS REMEDIAL PROTECTION MEASURES

The presence of significant extension cracks in the investigated rock cuts may cause eventual slope failure.

The proposed methods or alternative solutions of stabilization and protection can be summarized as follows:

1. Re-grading the rock cuts:

   This solution is based on dividing the existing cut (25 m high) using three berms of an average height equal to 8 m and berm width of 3 m and rock cut face angle of about 3V:1H (see Figure 8 a).

2. Rock anchors and reinforced shotcrete:

   The principle of this solution is to cover and anchor, the existing rock cuts by a minimum 10 cm reinforced shotcrete layer and systematic 1m x 1m horizontal and vertical spacing cement grout rock bolts. The upper half of the rock cut

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is systematically anchored and the lower one is only shotcreted. The design criteria of rock bolts and shotcrete are given in (Figure 8 b).

3. Catchment Ditch:

This solution is mainly based on cleaning the rock cuts from the loose unstable blocks. Filling the open fractures by cement grout along the five meter corridor of the rock cut top edgeas well as constructing a minimum 5m width catchment ditch as per the design criteria of rock fall protection ditch chart (Ritchie, 1963). The catchment ditch can be cleaned and maintained periodically from the expected rock falls (Figure 8 c).

The author believes that, the third solution is more practical and economic. It has no serious effect on the environment and the natural view of the site.

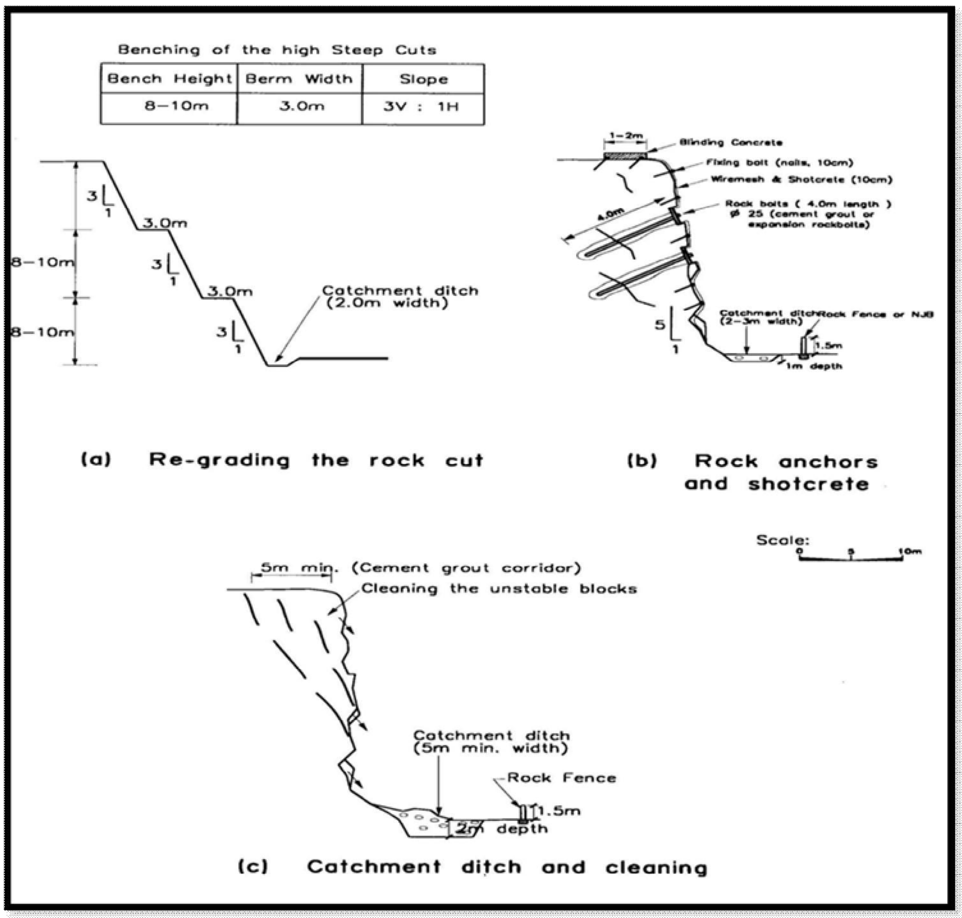

Figure 8. Proposed rock slope protection measures of the existing unstable cuts (a- benching and re-shape the vertical cuts, b-protection of free blocks with anchors and shotcrete and c- foot slope rock fall catchment ditch).

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