# SLOPE STABILITY ANALYSIS OF DANDOT PLATEAU, PUNJAB PAKISTAN

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**ABSTRACT:** Kinematic analysis was performed to assess the stability of mountainous limestone deposits of Dandot plateau being used as raw material for cement manufacturing process. The discontinuity data was collected for analysis using DIPS computer program to ascertain the stability of the limestone quarry site of M/s Dandot Cement Company Limited. The geological discontinuities in the area show the likelihood of plane and toppling failures at various slope face orientations. Furthermore, susceptibility of wedge failure is unlikely as indicated by the attitude of major discontinuities. It was assessed that recent failures of slopes were of circular type. It is recommended that prior analysis of the discontinuity data with the new face orientations must be conducted at each step in order to assure the stability of quarry slopes.

**Keywords:** Dandot Plateau, Kinematic Analysis, Slope Stability, Nammal Formation.

## INTRODUCTION

Developing countries need more and more raw material for the construction purposes. Cement being one of the essential components of construction materials requires limestone as raw material for its manufacturing. Generally limestone deposits are found in many countries in the form of elevated hills which are extracted using different quarrying techniques. Many exploitation problems are associated with production operations of engineering rock materials from quarry sites. In order to assure the safe environment for mine workers and mine machinery as well as for nearby establishments, critical investigations are needed from time to time so that exploitation problems can be identified and fixed by proposing workable solutions. Slope stability of production quarries need critical analysis in relation to the profitability of the exploitation process. Slope failure is a calamitous process of slope mass movement along dipping discontinuities which generally arise due to instability of slopes. Such hazards cause damage in two ways: direct losses to human life, buildings, bridges, roads, automobiles and other properties; and indirect losses which include property devaluation, loss of tax revenues, loss of industrial or agricultural productivity and increased maintenance costs (Shakoor and Weber, 1988).

The stability of slopes is affected by various geologic and geometric parameters like engineering and lithologic properties of rocks (unconfined compressive strength, slake durability of slope material, type and amount of clay minerals etc.), slope characteristics (slope angle, joint surface irregularities, surface runoff, ground water seepage etc.), rock mass characteristics (number of discontinuities and their roughness, nature of infilling material, discontinuity spacing, orthogonal blocks formed by discontinuities etc.), groundwater conditions, climate and rainfall history (Shakoor and Weber, 1988; Shakoor and Rodgers, 1995; Shakoor, 1995; Shakoor and Woodard, 2005).

Numerous methods are available for the analysis of rock slope stability. They are mainly divided into two categories; deterministic analysis methods and probabilistic analysis methods. Deterministic methods of analysis are dependent on fixed values of various parameters involved while probabilistic analysis methods are based on random variables in which various basic statistical parameters such as mean, variance and probability density function (PDF) are used for available geological and geotechnical data. Although probabilistic methods are appropriate for geotechnical stability analysis of slopes, they are rather limited in use for practical applications due to lack of data which is required for statistical evaluation of engineering properties of rocks. Since uncertainties and variability associated with discontinuity orientation and their shear strength data are unavoidable for the rock slopes in the real world, deterministic analysis methods are unable to account variations in various parameters but still they are preferred in various projects for being quick and simple to use (Park and West, 2001; Suchomel and Masin, 2009).

Conventional deterministic analysis methods include limit equilibrium analysis, kinematic analysis and rock fall simulators. Normally kinematic analysis followed by limit equilibrium analysis of slopes is sufficient to judge the stability of slopes.

The study presented in this paper is concerned with the evaluation of stability of Dondot limestone quarry slopes situated in the province of Punjab, Pakistan. Dandot quarry is mainly a succession of Nammal and Sakaser limestone formations. Nammal formation is currently being excavated for obtaining raw limestone by Dandot cement factory. During last few years, slope failures occurred in the southern parts of the Dandot Plateau some of which were very close to quarry workings of Dandot Cement Plant. The important nearby establishments at the quarry including quarry office, maintenance workshop and the main crusher building seem to be under direct threat of slope failure hazards if a similar slope failure occurs at the quarry site. The aim of this paper is to analyze the likelihood of various types of failures at the Dandot cement quarry using kinematic method of slope stability analysis.

**Kinematic Analysis:** Kinematic analysis of slope failures is purely geometric technique which utilizes angular relationships between slope surfaces and discontinuities to examine the potential and modes of failures (plane, wedge, and toppling failures) (Kim *et al*., 2002). Conventional kinematic analysis consists of plotting of discontinuity data like slope face angle and orientation, discontinuity orientations, and representative friction angle on a stereonet. This analysis is entirely qualitative in nature and is based on representative orientation values of tight data clusters, uniform slope angle and orientation, uniform friction angle, even spatial distributions of discontinuities, unbiased values of discontinuity sets and lack of cohesion along discontinuity surfaces (Admassu and Shakoor, 2013).

Hoek and Bray (1981) described kinematic conditions for various types of failures as shown in Figure 1.

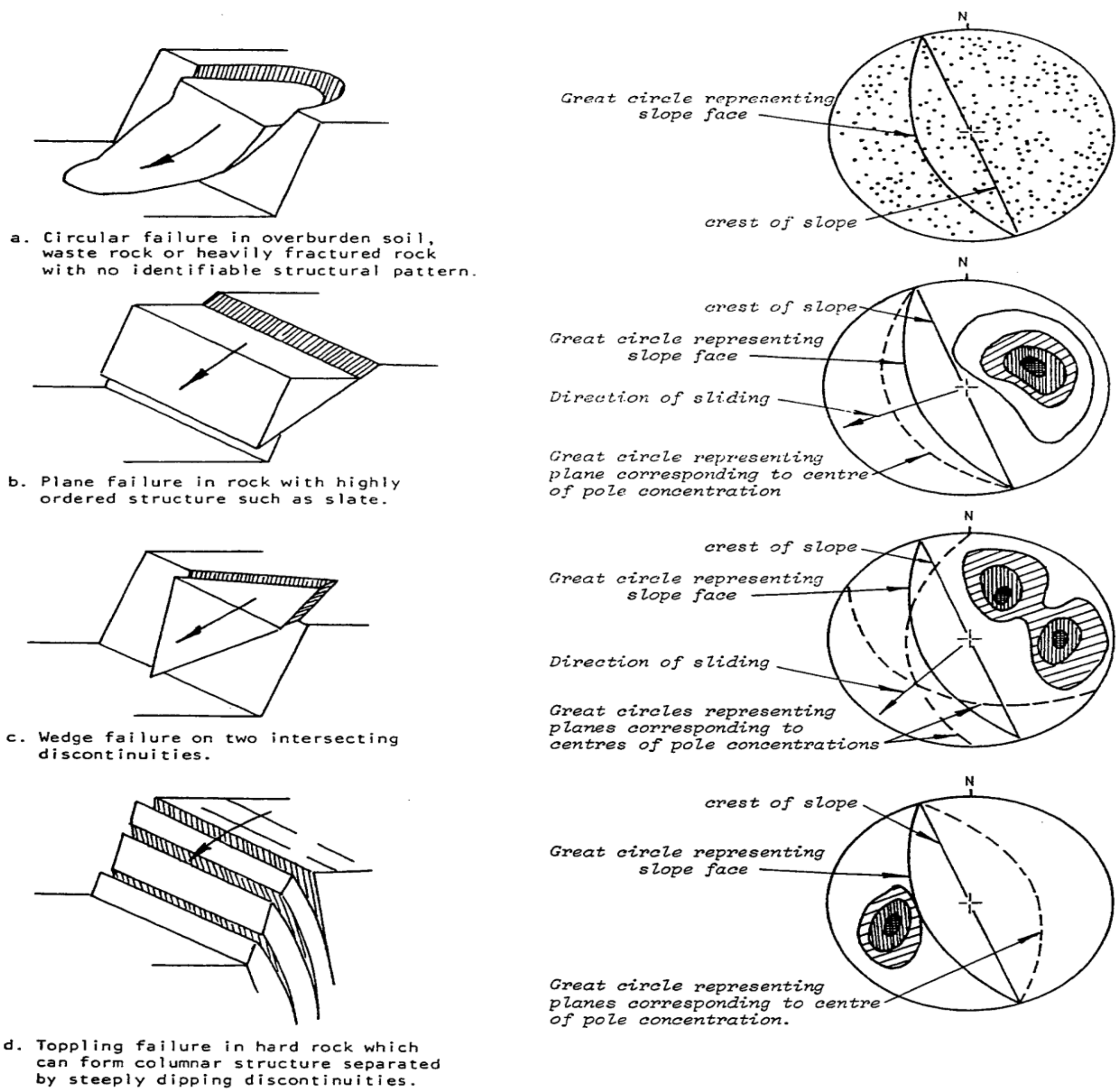


**Figure 1: Main types of slope failure and stereoplot of structural conditions responsible for these failures (Hoek & Bray, 1981).**

For plane failure, the strike of the sliding plane must be parallel within 20˚ to that of slope face. The slope face must have a dip greater than that of sliding plane and less than the friction angle. Furthermore, release surfaces should be present (Hoek and Bray, 1981). Wedge failure is analyzed by using Markland's test (Markland, 1972), in which wedge shaped mass slides along the line of intersection of two planes. The dip of line of intersection should be greater than the friction angle and less than that of slope face. When rockmass of the slope contains relatively large number of closely spaced discontinuities reducing the overall shear strength of the rock mass, it results in a circular type of failure. The mass slides along the discontinuity of least resistance. The shear strength and cohesion of discontinuities play a pivotal role in the analysis of circular failure. Toppling failure is mostly associated with hard rocks in which steeply dipping discontinuities generally dip into face within 10˚of the dip of slope face. Number of discontinuities and their orientation play a decisive role in determining the mode of toppling failure like block toppling ,flexural toppling or flexural-block toppling etc. (Hoek and Bray, 1981).

**Location and Geology of the Area:** Dandot plateau is situated at the base of the Eastern Salt Range in the Southern Potwar region on the upper side of Jhelum River (Figure 2).

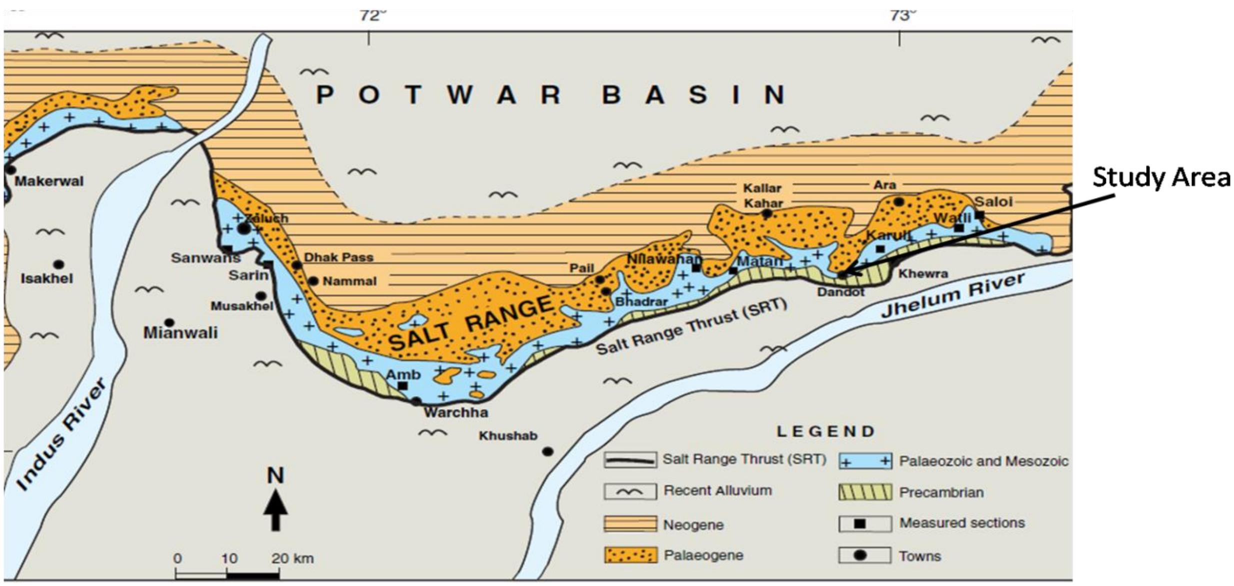


**Figure 2: Location map of the dondot plateau in outcrop belt of Salt Range(Ghazi *et al*., 2012).**

The study area lies about 5 kilometers South-West of Pidh (Figure 3). The typical geological cross section of the Dandot plateau is shown in Figure 4. The geological sequence in the investigated area ranges in age from Permian to Eocene. It is mainly consisted of Sakesar limestone, Nammal formation, Sardhai formation and Patala formation, first three of which are exposed in the study area. Sakesar limestone dominantly consists of limestone with subordinate marl. The limestone throughout its extent is cream colo red to light grey, nodular, usually massive, with considerable development of chert in the upper part. The marl is cream colored to light grey and forms a persistent horizon near the top. The Sakesar limestone beds are hard in nature and exhibit rock type behavior. The lower contact with the Nammal formation is conformable (Figure 5). Nammal formation, throughout its extent, comprises shale, marl, and limestone. The shale is grey to olive green, while the limestone and marl are light grey to bluish grey. The limestone is argillaceous in places. Nodular Nammal limestone is embedded in soft marls and shales which exhibit soil like behavior (Ibrahim, 2009). The past landslides had occurred in this Nammal formation.

## METHODOLOGY

The data of geological discontinuities was collected by means of a Brunton Compass. A total of 151 readings were taken at site. All these readings were corrected for the magnetic declination in the field. The data was graphically analyzed using DIPS software. Pole plot, contour plot and mean discontinuity planes along with friction circle are presented in the Figure 6. An angle of internal friction of 36° and a value of cohesion of 11 kPa were calculated by the back analysis of the past failed slopes in the study area.

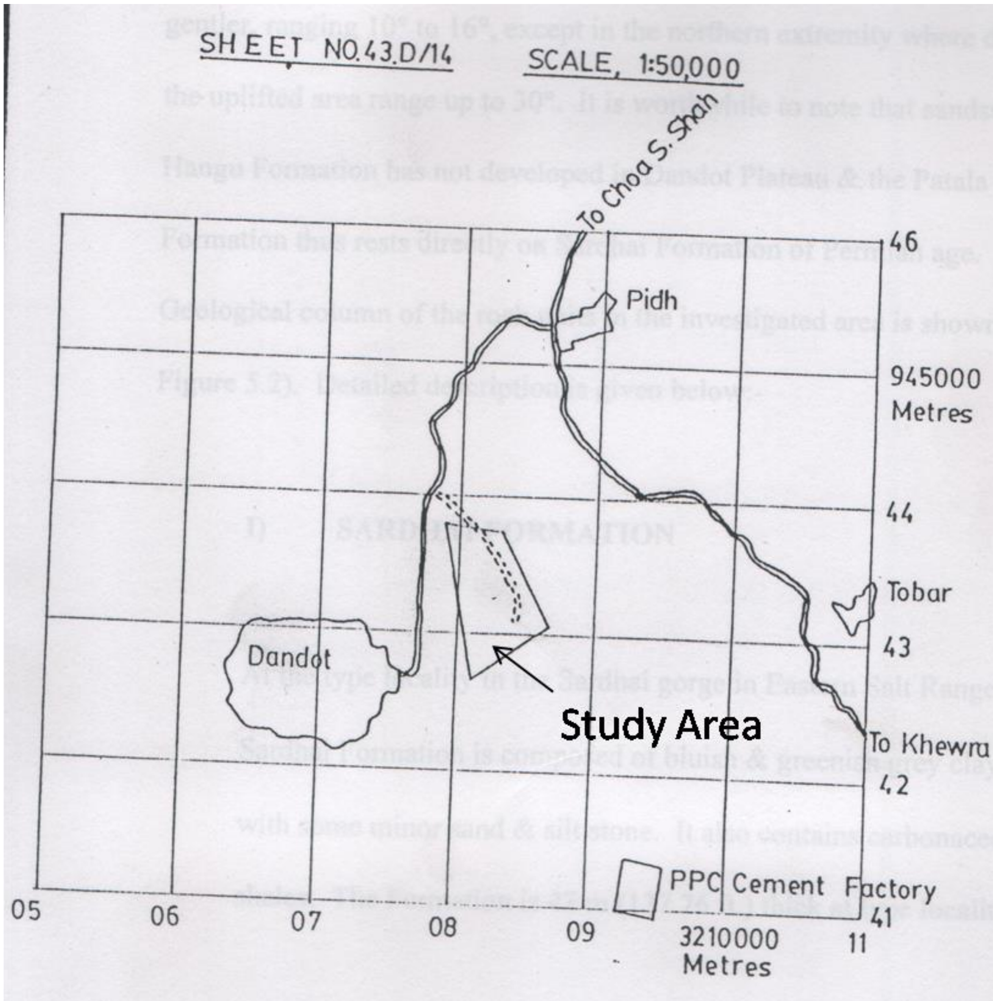


**Figure 3: Typical section of study area**

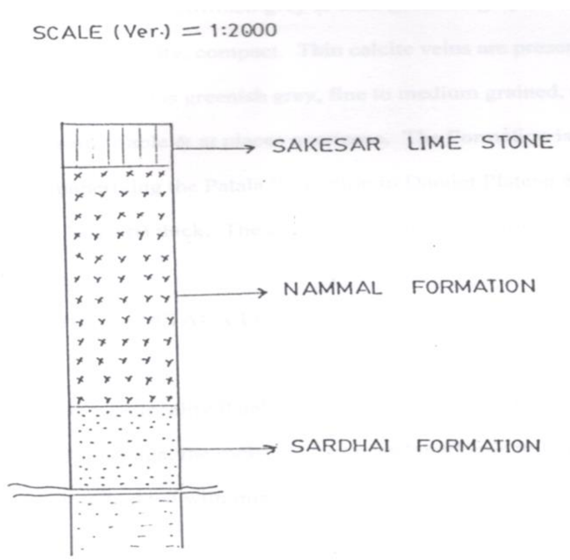


**Figure 4: Typical vertical cross section of the Dandot plateau.**

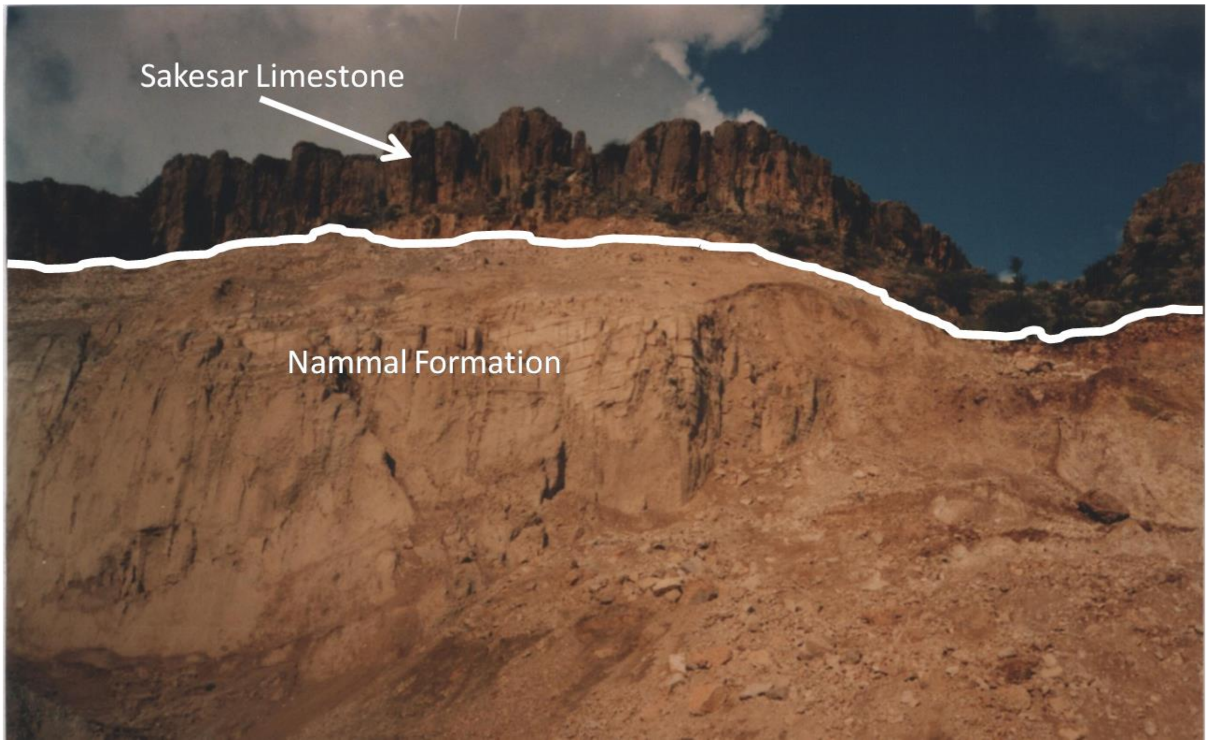


**Figure 5: Conformable contact between Nammal formation and Sakesar limestone**

## RESULTS AND DISCUSSIONS

The stereographic plots of the discontinuity data indicated three major discontinuity sets in the study area (Figure 6). The averaged dips and dip directions of the major discontinuity sets are given in Table 1.

**Table 1. Major discontinuity planes in Dandot plateau**

| Name of Discontinuity | Symbol | Dip | Dip Direction |
|---|---|---|---|
| Joint Plane 1 | $J_1$ | 88° | 076° |
| Joint Plane 2 | $J_2$ | 84° | 346° |
| Joint Plane 3 | $J_3$ | 86° | 024° |

All three discontinuity sets are steeply oriented in different directions. For the purpose of stability check in the study area, a critical steep slope face having dip of 75° with its orientation at 128° is analyzed by applying Markland's test for the existence of any wedge or plane failure (Figure 6c). Since the dip of line of intersections formed by the juncture of any two major discontinuity planes is steeper than the slope face, therefore the possibility of wedge failure is out of question, even for other orientations of face slope. Moreover, very steeply dipping joint planes do not pose the likelihood of plane failure as the slope face is relatively gentler i.e. less than 75°. So, the conditions of plane failure are not fulfilled i.e. dip of slope face greater than dip of sliding plane. Although the discontinuity planes are steeply dipping, there is no indication of toppling failure in the current scenario as slope face has different orientation in relation to discontinuity planes. However, future limestone excavations would create favorable conditions for toppling failure (Figure 7) with the possible slope face orientations given in Table 2.

**Table 2: Possible face orientations liable to toppling failure**

| Face Slope Orientation | Dip | Dip Direction |
|---|---|---|
| Case I | 55° | 204° |
| Case II | 56° | 165° |
| Case III | 57° | 256° |

Since there is no possibility of plane, wedge and toppling failure in the current situation, it was assessed that past failure could have been the result of circular failures (Figure 8). Soft nature of Nammal formation also favors this possibility. Perhaps the occurrence of boulders in soil-like material in Nammal formation and ground water conditions played the prime role in circular failure. In dry situation, the slope is absolutely stable but in wet conditions, most probably in rainy season, soft mass was easily eroded resulting in circular failure. Furthermore, the effect was enhanced by the weight of boulders on the eroded mass resulting in lower shear strength of the rock mass.

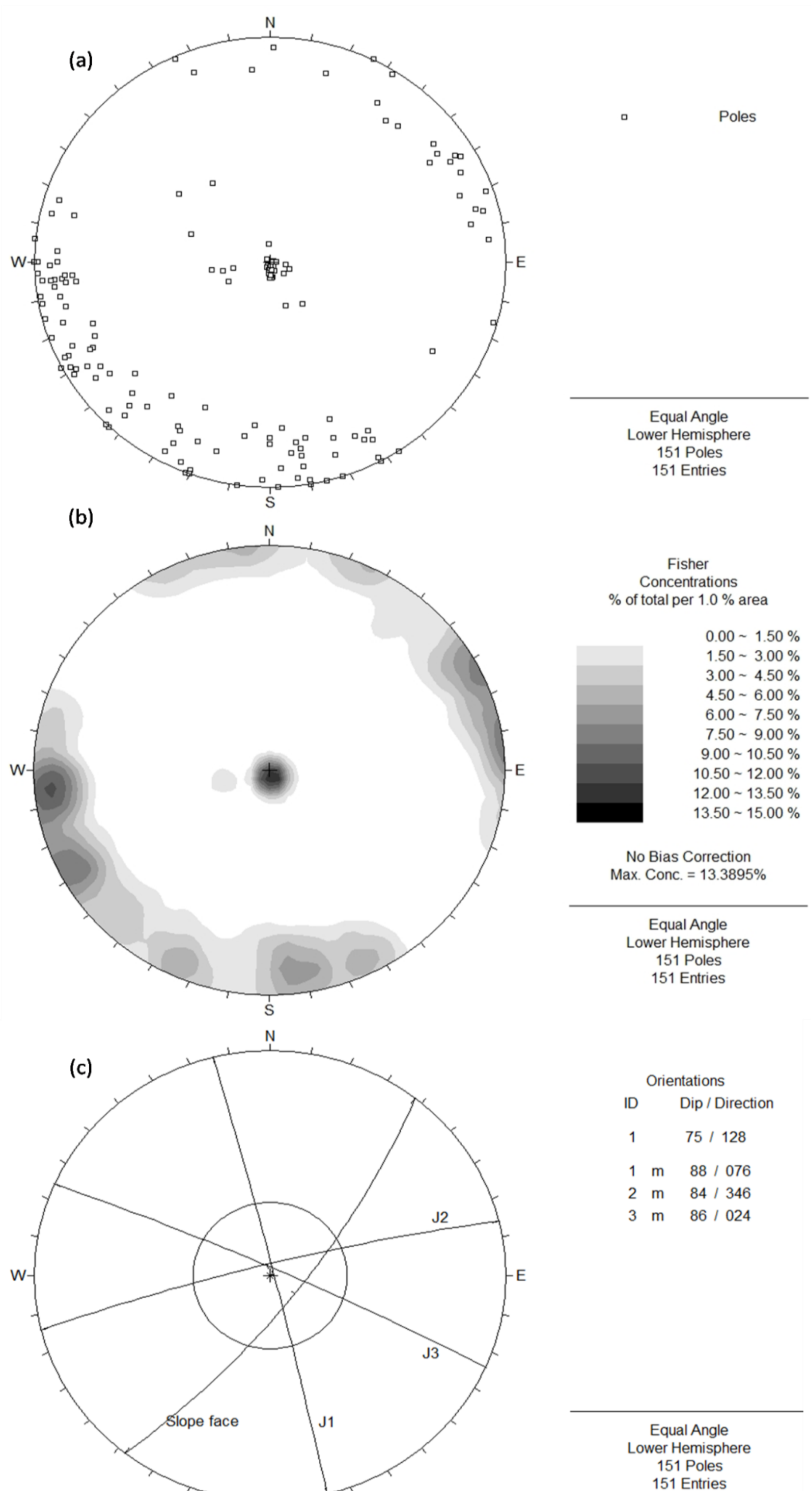


**Figure 6: (a) Pole Plot, (b) Contour Plot, and (c) Major plane plot along with friction circle**

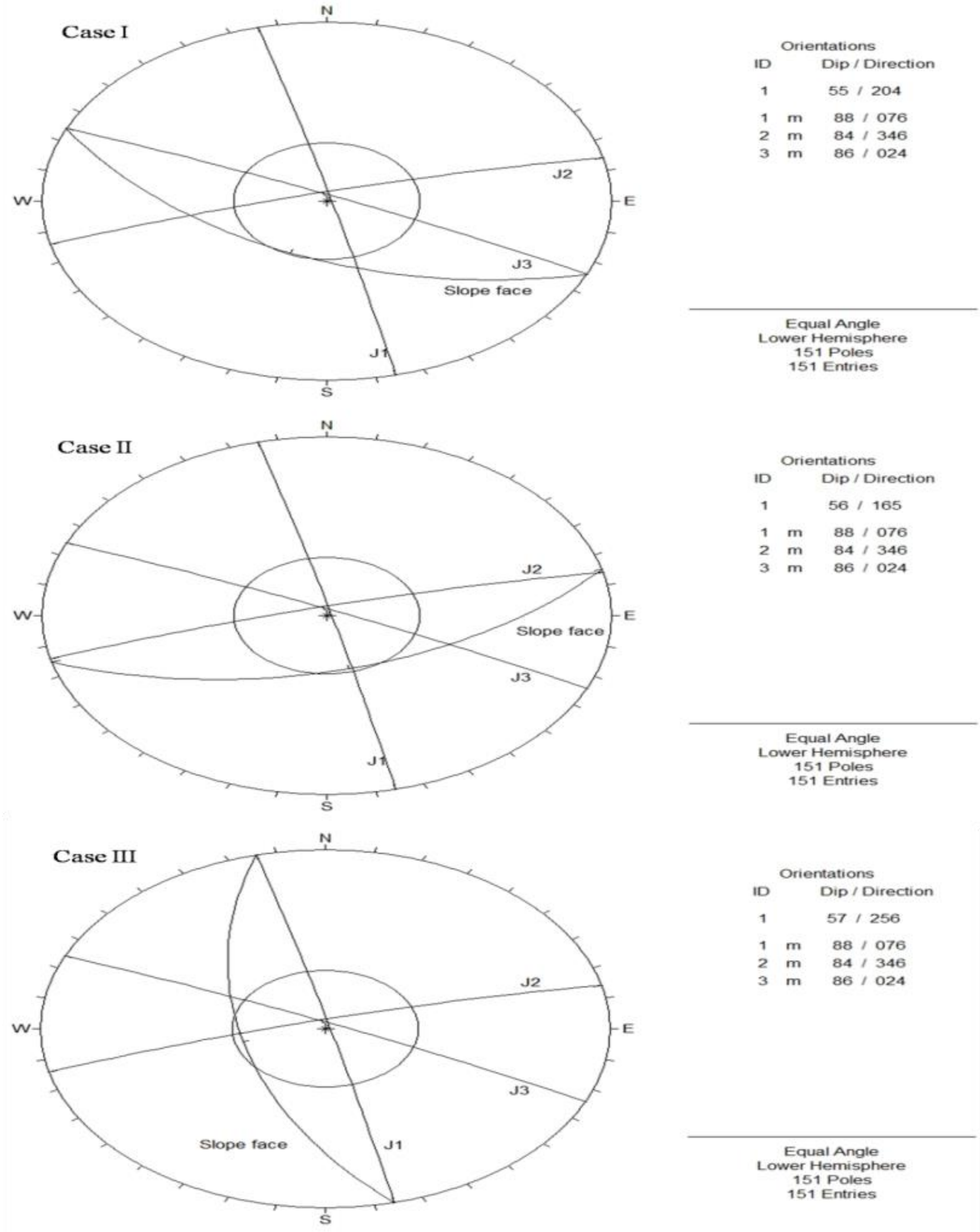


**Figure 7: Favorable face orientations for possible toppling failure**

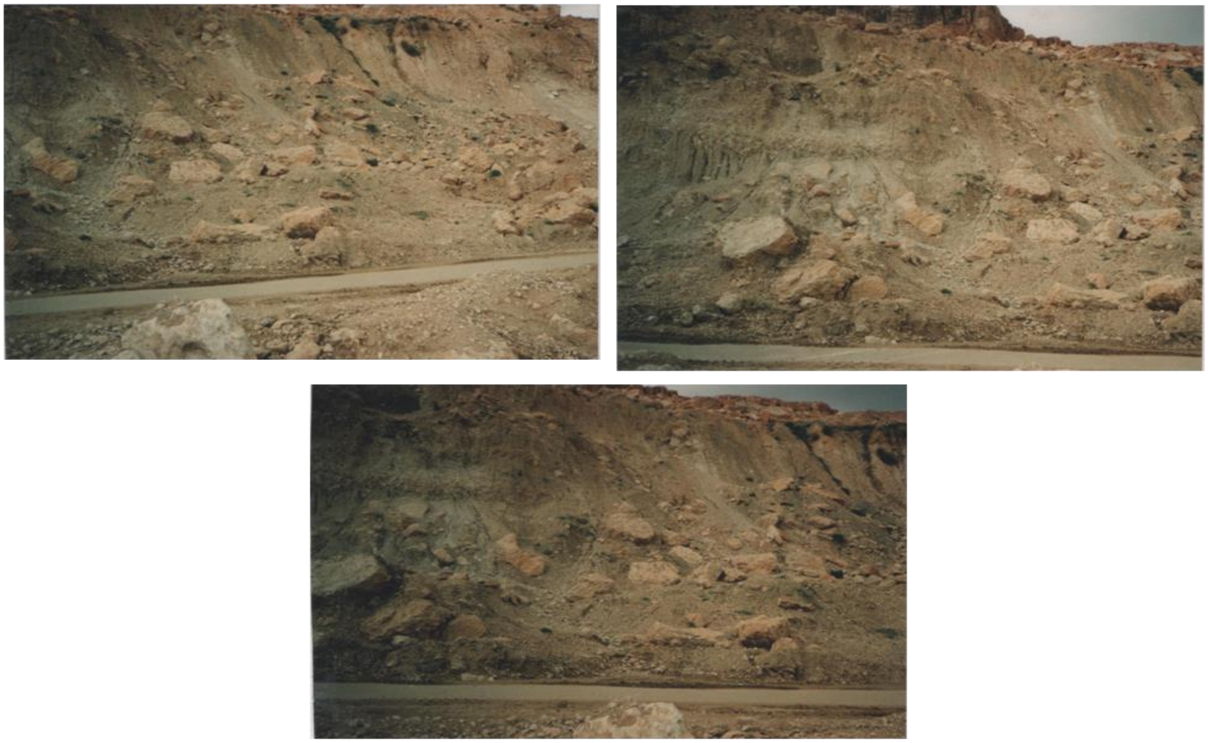

**Figure 8: Circular type failures in Nammal formation**

**Conclusions:** Through the analysis of discontinuity orientations and fracture pattern in the investigated area, it was concluded that currently slopes are stable with slope face orientation of 75/128. There is no indication of plane, wedge or toppling failure. But slope face having dip greater than 55° and dip directions in the range of 250° - 260°, 200° - 210° and 160° - 170° should be avoided, otherwise toppling failure may occur. Since there is risk of circular failure in extremely wet conditions, therefore surface water should not enter the cracks from the top side and some diversion techniques should be employed.

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