ROCK SLOPE STABILITY ANALYSIS OF QUARRY SITES AT WEST MALVERN, UK.

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ABSTRACT: This paper analyzes the scan line survey data of the geological discontinuities collected from three quarry sites of West Malvern in Malvern Hills, UK, which remaine done of the major resource of geological materials for building stones and aggregates in the area. The kinematic analysisof the discontinuity data of the quarry sites was performed by using the DIPS software, which showed the likelihood of wedge, plane and toppling failures of the slopes. However, no failure is likely even for the steepest slope faces if planned to cut in the dip direction range of 30^{o} to 70^{o} and 130^{o} to 230^{o}.

Keywords: Kinematic Analysis, Malvern Hills, Slope Stability, DIPS, Discontinuities.

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INTRODUCTION

Numerous methods are available for assessing the stability of slopes as reported by (Hoek and Bray, 1981; Park and West, 2001; Wyllie and Mah, 2004).Kinematic analysis is one of the analytical tools used for the assessment of a slope's stability (Olaleye and Ajibade, 2011).Normally, kinematic analysis is performed prior to detailed investigations in almost all slope stability analysis(Kulatilake *et al.*, 2011 and Aksoy and Ercanoglu, 2007).Kinematic analysis of rock slopes is purely a geometric technique which utilizes angular relationships between slope surfaces and discontinuity planes through their stereographic projections. The outcome of this kind of analysis is used to determine the likelihood and the modes of failures (Yoon *et al.*, 2002; Iqbal*et al.*, 2013; Park *et al.*, 2005).Generally four types of failures exist in rock slopes namely plane, wedge, toppling and circular. The conditions suitable for these failure types are elaborated in detail by (Hoek and Bray,1981).

The purpose of this study was to evaluate the geological discontinuities data gathered from old quarry sites near West Malvern in the Malvern Hills, UK. The location map of the site is shown in Figure-1. The data of discontinuities collected from the site was then used to perform kinematic analysis using the DIPS software to propose the safe slope orientations with steepest possible face angles.

Geology: The geology of the area is dominated by the metamorphosed granites of the Malvern Hills. The materials are described, according to BS5930 (British Standard, 1999) as pink, fresh, coarse grained, crystalline granites, extremely strong. Naturally some variations in the properties of these materials can be observed from location to location. Structurally and stratigraphically above the Malvern Hills Granites are sediments of Ordovician and Silurian age. These sedimentary rocks vary, but are characterized by sandstones, siltstones and mudstones in a deep water setting. Faults occur throughout the area and present varying levels of difficulty in construction (Murphy, 2005).

Geomorphology: The geomorphology of the study area is strongly controlled by the juxtaposition of rocks of different materials and mass properties. In addition to this the area has been affected by several periglacial periods during the quaternary and questions remain as to whether the Malvern Hills were a local ice center during the devencian. There is a fragmentary evidence of what has been interpreted as glacial tills throughout the area(Murphy, 2005).Description of the rocks found in the quarries is given in Table 1 as per BS5930(British Standard, 1999).

Figure 1 showing Location map of the study area (source: www.maps.google.com)

Table 1 showing rock description of quarry sites as per BS5930 (British Standard, 1999).

Quarry	Rock Description
Quarry 1	Pinkish gray, coarse-grained, fresh crystalline GRANITE, extremely strong
Quarry 2	Dark gray, medium grained, fresh crystalline GRANITE, strong
Quarry 3	Dark gray and brown, coarse grained, crystalline DOLERITE, very strong

MATERIALS AND METHODS

The discontinuities data was collected by scan line survey along the exposed cut faces of the old quarries. Dip and dip directions of geological discontinuities were measured and analyzed through stereographic projections using DIPS software. The data set consisting of 62 discontinuities was then used for pole plotting (Figure 2a), which was subsequently utilized for contour plotting (Figure 2b). Plotting of the data identified three major pole concentrations. The pole concentrations helped in identifying the representative great circles of the discontinuities (Figure 2c). A friction angle of 40° was assessed for calculation and analysis based on the recommendations of Hoek and Bray (1981).

Possible slope face orientations: The pole concentrations of the discontinuities data showed that the quarry sites had three major discontinuity planes (J1, J2 and J3); two of them were steeper while the other one was relatively flat (Table 2). Although all three major discontinuity planes were making wedges but two of them were lying outside the friction circle whereas the wedge formed by the intersection of J_1 and J_2, was inside the friction circle (Figure-3). Keeping in view the likely future orientations of the slope faces at the quarry sites (Table-3), different slope failure cases are discussed.

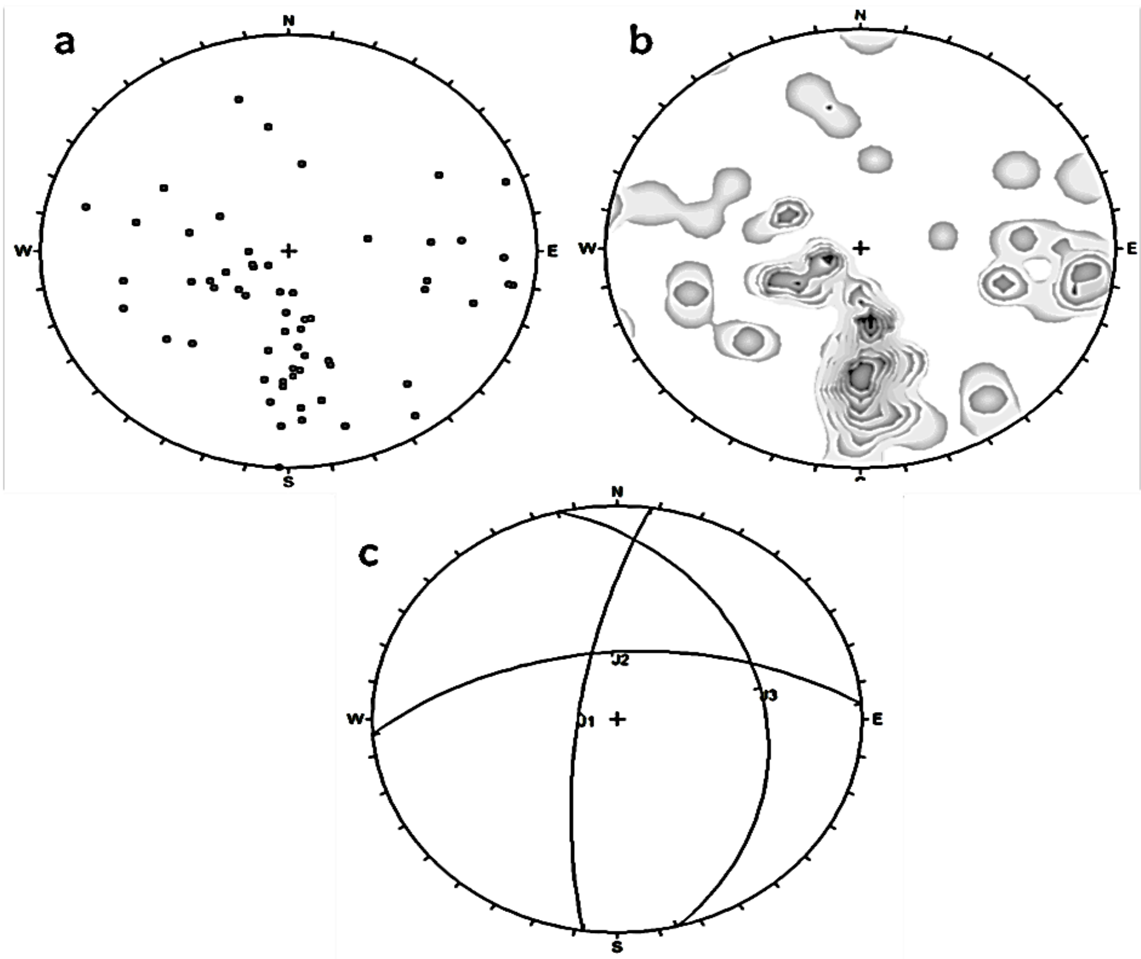

Figure 2 showing (a) Pole plot, (b) Contour plot, and (c) Great circles of dominant discontinuities.

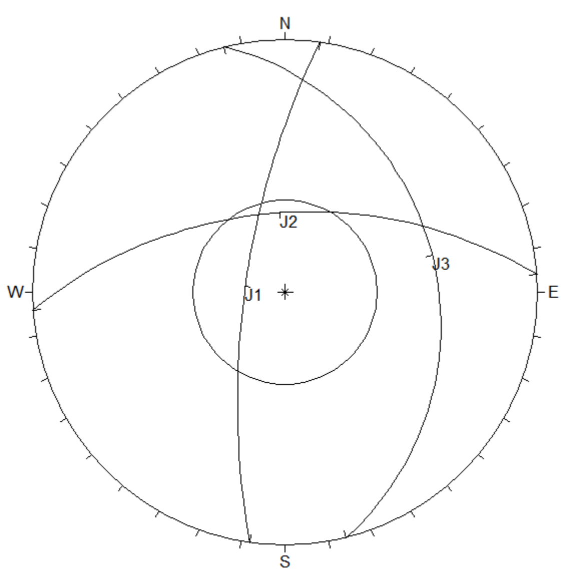

Figure 3 showing Stereographic plot of major discontinuity planes along with friction circle

Table 2: showing mean discontinuity planes based on major pole concentrations.

Name of Discontinuity	Symbol	Trend	Plunge
Joint Plane 1	J_1	098°	18°
Joint Plane 2	J_2	176°	35°
Joint Plane 3	J_3	256°	62°

Table 3: showing possible face orientations:

Face Slope Orientation	Dip	Dip Direction
Case I	69°	318°
Case II	71°	004°
Case III	78°	268°
Case IV	72°	097°

CASE I: Considering slope face orientation of 69/318 and stereographic projection of mean discontinuity planes drawn through DIPS showed a phenomena of kinematic instability (Figure-4). Sliding envelope shown by shaded area represented the conditions of Markland's wedge failure (Markland, 1972) i.e. plunge of line of intersection of two joint planes must be less than the slope face angle and greater than friction angle. In the current situation the plunge of line of intersection of J_1 and J_2 measured was 54°, greater than the 40° (the friction angle) and less than 69° (plunge of slope face). Therefore, potential of sliding movement of block shown by dark shaded area existed at quarry site having a plunge of slope face greater than 60° and dip direction between 315° and 355°. In this particular case the wedge block was likely moving in the direction of N19°W along the line of intersection (Figure-4).

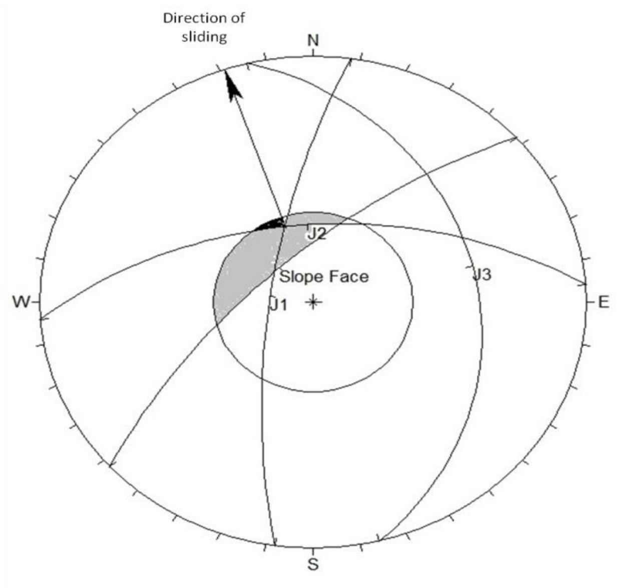

Figure 4 showing description of wedge failure.

CASE II: Kinematic analysis was performed for another possible orientation of slope face of 71/004. In this case, there was likelihood of plane and wedge failures (Figure-5). Another important aspect was the fulfillment of (Hocking's refinement 1976) which was introduced to differentiate between the sliding of a wedge along the line of intersection or along one of the planes forming the base of the wedge. According to Hocking, if the dip direction of either of plane fell between the dip direction of the slope face, the trend of the line of intersection, sliding will occur on that plane instead of along the line of intersection. Therefore, in this case, the wedge block moved along J_2 instead of line of intersection of J_1 and J_2. Figure-5 clearly fulfills the Hocking's refinement where:

α_1 = Trend of the line of intersection

α_2 =Dip direction of joint plane 2

α_f=Dip direction of slope face

Moreover, J_2 satisfied the conditions of plane failure as described by (Hoek and Bray, 1981). The dip of sliding plane should be less than the dip of slope face and greater than friction angle, and the trend of sliding plane should be within 20° of the slope face trend. In this particular case, dip of J_2 was 55° which was less than that of slope face that was inclined at 69° and greater than the friction circle i.e. 40°. Both wedge block and sliding mass by plane failure are shown by relatively dark shaded area (Figure-5).

CASE III: Case III was concerned with the stability of slopes having face orientation of 78/268. In this case the possibility of plane failure was apparent (Figure-6). The angle difference between the dip direction of J_1 and the slope face was only 10°. Sliding of the mass shown by the shaded area was along the joint plane J_1. Along with other conditions, role of the release surfaces in plane failure of the slopes was critical. Release surfaces may exist if some other discontinuities intersect the sliding plane.

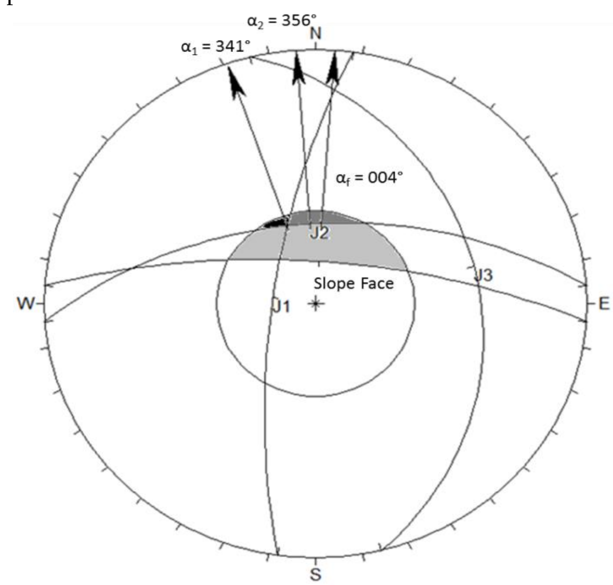

Figure 5 showingdescription of combination of plane and wedge failure

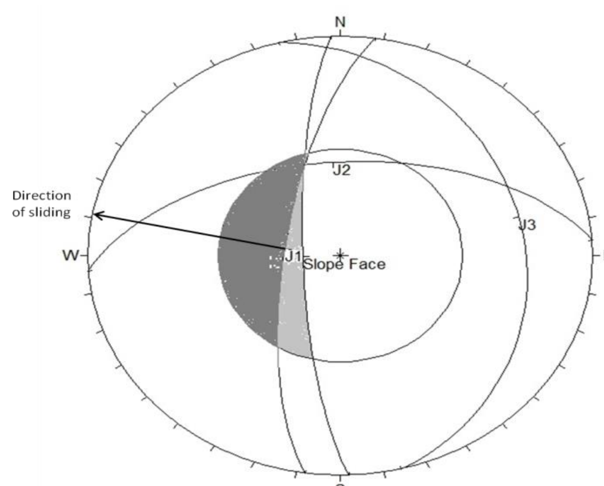

Figure 6 showing description of plane failure.

If other discontinuities intersected the sliding plane at two points in the sliding envelope bounded by the region between slope face and sliding plane (shown by shaded area), then plane failure was evident. In this case J_2 intersected J_1 only at one point in the sliding envelope, which suggested a relatively remote chance of plane failure of the slope. However, other factors such as strength of rock mass and ground water conditions should be considered to check the factor of safety.

CASE IV: If the slope face had a dip angle in the range of 80^o to 90^o and dip direction of 80^o to 100^o then there were fair chances of toppling failure (Figure-7). This was due to the reason that great circle of J_1 had a steeper angle of 72° which dipped into the slope face.

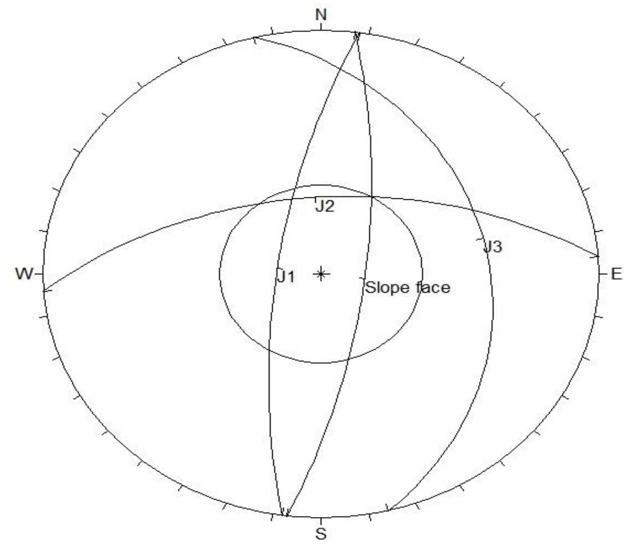

Figure 7 showing description of Toppling Failure.

Table 4: showingsummary of results of kinematic analysis of quarry slope

Orientation of quarry slope	Dip of Slope face	Failure/Stable	Mode of Failure	Recommended safe quarry slope
000^o to 020^o	60^o to 90^o	Failure	Plane	$\psi_f < 50^o$
030^o to 070^o	Any	Stable	-	-
080^o to 100^o	80^o to 90^o	Failure	Toppling	$\psi_f < 45^o$
130^o to 230^o	75° to 90°	Stable	-	-
260° to 275°	75^o to 90^o	Failure	Plane	$\psi_f < 65^o$
310^o to 350^o	60^o to 90^o	Failure	Wedge	$\psi_f < 50^o$

Conclusions and Recommendations: The results of analysis performed on the discontinuities data collected from the old quarry sites of West Malvern along with the recommended dip angles for safe slope faces are summarized in Table 4. It was noted that slope faces were stable with the steepest slope angles within the range of orientation from 030° to 070°. If there is a need of cutting slope faces for any purpose in future, then these faces should not be cut with the resultant orientations within the range of 000- 020°, 080-100°, 260-275° and 310-350°. If there is no choice other than these orientations, then the slope angle should be less than 45°. Among the most important parameters describing the discontinuities are orientation, spacing, persistence, roughness, aperture and infilling materials (Zhou and Maerz, 2002). Usually the kinematic analysis suffers from the inability to consider most of these parameters except the orientations of the discontinuities. For a detailed stability analysis inclusion of all important discontinuity features into the analysis is warranted.

REFERENCES

Aksoy, H. and M. Ercanoglu. Fuzzified Kinematic Analysis of Discontinuity-Controlled Rock Slope Instabilities. Engineering Geology, 89, 206–219: (2007).

British Standard (BS 5930).Code of practice for site investigations (1999).

Hocking, G.A Method for Distinguishing between Single and Double Plane Sliding of Tetrahedral Wedges. International Journal of Rock Mechanics and Mining Science, 13, 225–226: (1976).

Hoek, E. and J. W. Bray. Rock Slope Engineering. The institute of Mining and Metallurgy, London, (1981).

Iqbal, M. M., M. Z. Abu Bakar, M.Akram, M. Shahzad and Y. Majeed.Slope Stability Analysis of Dandot Plateau, Punjab Pakistan. Pakistan Journal of Science, 65(4): 531-538, (2013).

Kulatilake, P.H.S.W., L. Wang, H. Tang and Y. Liang. Evaluation of Rock Slope Stability for Yujian River Dam Site by Kinematic and Block Theory Analyse. Computers and Geotechnics, 38: 846–860, (2011).

Markland, J. T. A Useful Technique for Estimating the Stability of Rock Slopes when the Rigid Wedge Sliding Type of Failure is Expected. Imp. Coll. Rock Mech. Res. Rep., 19: 10, (1972).

Murphy, W.; Broadway and the Malverns Field Course, The University of Leeds, UK, (2005).

Olaleye, B.M and Z.F Ajibade. Kinematic Analyses of Different Types of Rock Slope Failures in a Typical Limestone Quarry in Nigeria. Journal of Emerging Trends in Engineering and Applied Sciences, 2(6): 914-920, (2011).

Park, H. and T. R. West. Development of a Probabilistic Approach for Rock Wedge Failure. Engineering Geology, 59: 233-251, (2001).

Park, H. J., T. R. West and I. Woo. Probabilistic Analysis of Rock Slope Stability and Random Properties of Discontinuity Parameters, Interstate Highway 40, Western North Carolina, USA.Engineering Geology, 79: 230-250, (2005).

www.maps.google.com

Wyllie, D. C and C. W Mah. Rock Slope Engineering: Civil and Mining (4thed.). Spon Press, 270 Madison Avenue, New York, NY 10016, USA (2004).

Yoon, W.S., U.J. Jeong and J.H. Kim.Kinematic Analysis for Sliding Failure of Multi-Faced Rock Slopes.Engineering Geology, 67: 51–61, (2002).

Zhou, W. and N.H. Maerz. Implementation of Multivariate Clustering Methods for Characterizing Discontinuities Data from Scanlines and Oriented Boreholes. Computers and Geosciences, 28: 827-839, (2002).