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Slope Stability Analysis of Bench in Complete Construction Solid Concentrate (Quarry) Limited, Ilorin, Nigeria

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Abstract The slope stability of Complete Construction Solid Concentrate (Quarry) Limited has been carried out using DIPS software version 6.0. A kinematic analysis of planar discontinuity sets in a gneiss deposit was carried out to ascertain the degree of slope stability. Two hundred and fifty three dip and dip direction values were obtained using compass clinometer. Joints along the discontinuities were mapped. The average result of physical and mechanical properties such as specific gravity, unit weight, uniaxial compressive strength, point load index, and Schmidt rebound value was 2.64 g/m^3, 25.95 kN/m^3,156 MPa, 6.5 MPa, and 53.12 respectively. Also, a statistical model equation relating the rock strength such as unit weight, uniaxial compressive strength, and Schmidt rebound value was developed.The results of the investigation revealed evidence of potential slope failures from the two joint sets identified in the study area. Three possible types of slope failure (planar, wedge and toppling) were examined. The analyses stated that the rock face was susceptible to wedge failures having all the geometrical conditions associated with the occurrence of such failures were noticeable while planar and toppling had no noticeable failure. The inference deduced from slope analysis would be useful to management of Complete Construction Solid Concentrate (Quarry) Limited in having a proper understanding of the slopes analysis mechanism.
Keywords slope stability, rock failure, discontinuities, critical zone, intersection

Introduction

Slope stability analysis of bench plays an integral role in the design of various mining application including waste dumps, heap leach piles solution ponds and tailings dams as expressed by Propat and Elmouttie (2006). Slope stability analysis is performed to assess the safe design of a human made or natural slope (examples are embankments, road cut, open pit mining excavations, landfills etc.) and the equilibrium conditions according to Abramson (2003).

The basic importance of the slope stability analysis is to avoid any inconvenience during production, the geometrics of the slope are analysed by using software due to the complex geotechnical structure of slope.The slope is investigated in two different water conditions which are fully saturated and unsaturated, for the performance of the overall geometry of the slope that will be important for the safety and economy of the open pit mines. The slope in the study is based on the slope stability principles, and for computing the maximum dip angle for benches to stand up during the life of mine within optional safe and economic condition as stated by Kliche (1999).

According to Hartman (2002) many fatal accidents due to slope failure in Nigeria mines indicate the urgent need of conducting slope monitoring for the working benches as well as dumps. With the increasing depth of surface mining excavations, the problem of stability of slopes is becoming a major concern for the mining engineers. In mountainous regions, landslides are a major safety hazard, particularly during the rainy season. Stability analysis of benches is based on design of slope parameters: design ultimate pit limits, inter-ramps and safety berms, design of barrier between water bodies and open pit, and design of spoil dumps as suggested by Hoek and Bray (1981).

The economic impacts associated with an unstable slope may leads to the loss of production, extra stripping cost for recovery and handling of failed material, cost of clearing the area, cost associated with the re-routing the haul roads, production delays and loss of personnel. The stability of slopes is basically judged by the factor of safety. The factor of safety is defined as the ratio between the resisting forces to the distributing forces. Resisting forces depends on cohesion and angle of friction, while the distributing force is related to gravity and groundwater condition. If the factor of safety is greater than unity then the slope is stable but if it drops below unity the slope become unstable as stated by Singh (1987).

This project work is based on its finding on the associated slope failure and factor of safety for excavating the gneiss deposit by adopting a workable mine methods so as to improve machinery life and efficiency coupled with return of investment.

Study Area

The study area is situated in Ilorin East Local Government Area of Ilorin, Kwara State, Nigeria. It located between latitude (8^0 05' 00" N) and longitude (004^0 00' 00" E), situated in the transitional zone between the Northern and Southern parts Nigeria. The study area and its coordinates: Bode Quarry - latitude (8^0 32' 15" N) and longitude (004^0 34' 24" E) presented in Fig. 1.

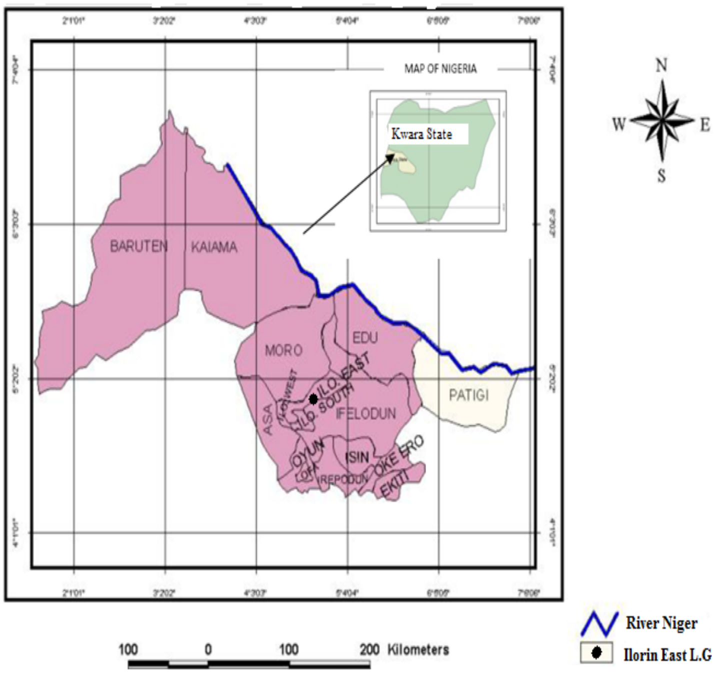

Fig. 1 *Map of Kwara State indicating Ilorin East Local Government Area*

Methodology

Physical properties of the rock mass

(1) Determination of mineral composition

The mineral composition of the rocks was estimated using modal analysis in accordance with procedure suggested by ISRM (1989). Chayes (1956) stated that modal analysis is a valuable tool in the precise determination of the proportion of minerals present rocks samples.

(2) Determination of bulk density

Rock samples were prepared for bulk density in accordance with ISRM (1981). The bulk density was calculated using Equation (1);

$$\text{Bulk Density}(\text{g/cm}^3)=\frac{M_{\text{d}}}{V_2-V_1} \tag{1}$$

Where: M_d is the mass of the sample, g; and $V_2 - V_1$ is the volume displaced, cm^3.

Physical properties of the rock mass

(1) Determination of rebound hardness

The rebounds hardness was carried in accordance with method suggested by ISRM (1981) using Schmidt hammer. The Type L hammer was used with this suggested method. The measured test values for the sample were arranged in descending order. The lower 50% of the values should be discarded and the average obtained of the upper 50% values. The average value was multiplied by the correction factor to obtain the Schmidt Rebound Hardness.

(2) Determination of uniaxial compressive strength

The uniaxial compressive test (UCS) was carried in accordance with method suggested by ISRM (1989) and ASTM (2001) D 2938. The uniaxial compressive strength was determined using Equation (2);

$$\text{Co(MPa)} = P/A \tag{2}$$

Where:
Co is the uniaxial compressive strength, MPa;
P is the applied peak load, kN;
A is the area, m^2

(3) Determination of point load index

The point load index was determined using Equation (3), According to Brook (1985), the formula to convert the force reading to $Is_{(50)}$ value.

$$Is_{(50)} = f\left[\frac{F}{(D_{\text{e}})^2}\right] \tag{3}$$

When:

f is the size correction factor $\left[\frac{\text{D}_\text{e}}{50}\right]^{0.45}$; De is the equivalent core diameter $\left[\frac{4\text{A}}{\pi}\right]^{0.5}$, m; F is the applied load, kN; and A is the minimum cross sectional area, mm^2.

Smith (1997) proposed for both strong and weak core sample Equation (4) while Equation (5) for strong cut blocks according to ASTM (2003). Finally, tensile strength (*T*o) was determined using Equation 6 proposed by Brook (2003).

$$Co = 24\ Is_{(50)} \tag{4}$$

$$Co = 25\ Is_{(50)} \tag{5}$$

$$To = 1.5\ Is_{(50)} \tag{6}$$

Determination of slope stability

Dips version 6.0 Software was used to determine the type of possible failure associated to the gneiss deposit slope face. It's a comprehensive kinematic analysis toolkit for planar, wedge and toppling analysis; significant improvements to the user interface and graphical interactivity; dip vector and intersection plotting; fuzzy cluster analysis and much more.

(1) Factor of safety

The factor of safety for wedge assuming that sliding is resisted by friction only and that the friction angle Φ is the same for both planes is given by Equation (7);

$$F = \frac{(R_A + R_B)\mathrm{Tan}\phi}{W\mathrm{Sin}\phi_i} \qquad (7)$$

Where: R_A and R_B are the normal reactions provided by plane A and B (where the flatter of the two planes is called Plane A while the steeper plane is called Plane B); W is the weight of block; Φ_i is the slope angle; and Φ is the friction angle.
Factor of safety for wedge failure is more conveniently carried out using Equation (8), with wedge stability charts for friction only (if the cohesive strength of the plane A and B is zero and the slope is fully drained).

$$F = A\mathrm{Tan}\phi_A + B\mathrm{Tan}\phi_B \qquad (8)$$

The dimensionless factors A and B are found to depend upon the dips and dip directions of the two planes. Wyllie and Mah (2004).

Results and discussion

Physical properties results

(1) Results of Mineral Composition

The modal analysis of the samples was presented in Table 1 according to their percentage composition.

Table 1 *Modal Analysis of the Samples*

Mineral	Gneiss Composition
Quartz	30%
Microcline	18%
Plagioclase	22%
Opaque Minerals	5%
Hornblende	16%
Biotite	9%
Total	100%

From Table 1, the petrographic description of rock samples indicates it’s a gneiss rock. The mineral in the thin sections include majorly quartz, biotite, microcline, orthoclase, plagioclase and opaque minerals.

(2) Results of bulk density

The results of the bulk density is presented in table 2

Table 2 *Results of bulk density*

Samples	Bulk density (g/cm^3)
A1	2.72
A2	2.55
A3	2.56
A4	2.69
A5	2.71
Average	2.64

From Table 2, the bulk density value ranged from 2.55 g/cm^3 – 2.72 g/cm^3.

Mechanical Properties Results

(1) Results of hardness

The Schmidt rebound hardness result is presented in table 3 respectively.

Table 3 *Rebound value of upper 50%*

S/N	A1	A2	A3	A4	A5
1	57	54	56	56	56
2	56	54	54	55	55
3	56	54	54	54	55
4	55	53	54	54	54
5	55	53	53	53	54
6	54	52	52	53	53
7	54	52	52	52	53
8	53	51	50	52	52
9	53	50	50	51	51
10	52	50	50	50	50
Ave.	54.5	52.3	52.5	53.0	53.3

(2) Results of strength parameters

The strength parameter results is presented in table 4.

Table 4 *Results of strength parameter*

Sample	Rebound value	Unit veight (kN/m^3)	UCS (MPa)	Point load index (MPa)
A1	54.5	26.67	175	7.29
A2	52.3	25.00	149	6.21
A3	52.5	25.10	125	5.21
A4	53.0	26.40	165	6.87
A5	53.3	26.57	166	6.92
Ave.	53.12	25.95	156	6.5

From table 4, the rebound value ranged from 53.0 – 54.5 while 53.12 was the average rebound value for the study. Also, results of uniaxial compressive strength ranged from 125 – 175 MPa. The average uniaxial compressive strength of the study is 156 MPa. It was classified as strong rock. Finally, results of point load index varied from 4.8MPa – 5.28MPa. The average point load index of the study areas is 5.09 MPa. It was classified as having very high strength. The computed unit weight ranged from 25.00 – 26.67 kN/m^3

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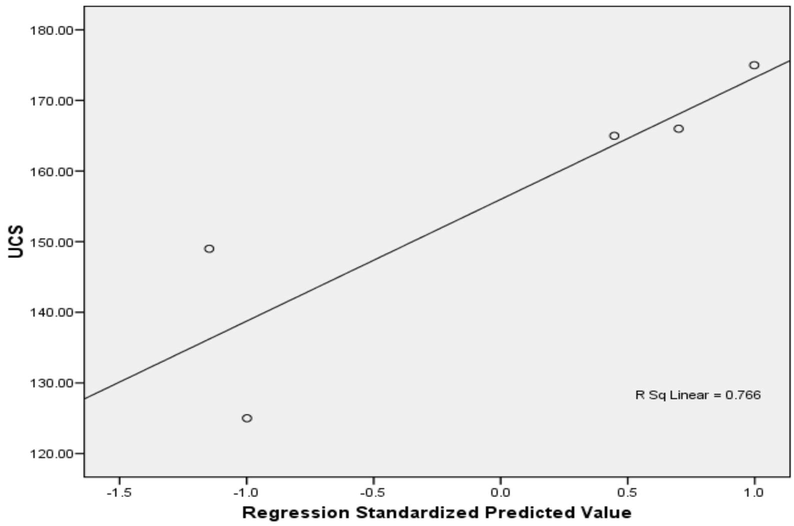

Fig. 2 *UCS against regression standardized predicted value (Gneiss rock)*

The correlation model equation for determining the relationship between uniaxial compressive strength, unit weight and rebound values is expressed in Equation (9)

$$UCS = -513.168 + 3.981RBV + 17.647UW \qquad (9)$$

Where: *UCS* is the uniaxial compressive strength, MPa (dependent variable);

RBV is the rebound value (predictor); and *UW* is the unit weight (predictor).

The result of uniaxial compressive strength test was correlated with unit weight and rebound values so as to check their correlation. The relationship between uniaxial compressive strength, unit weight and rebound values is shown in fig. 2. A linear trend line exist between them and the value of multiple correlation coefficient is R^2 = 0.766 (77 %) which is positive.

Analysis on slope stability

DIPS software was used for both statistical and kinematical analyses of the orientation data to determine the stability of the excavated slopes under study and results were presented in fig. 3 - 9. Fracture orientation data were collected along 83.85 m straight scanline on a rock slope which was tagged, as trend one. Rocscience Inc. (1999).

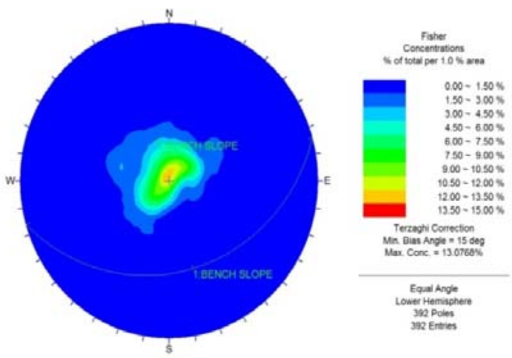

Fig. 3 *Fisher concentrations (Terzaghi Correction)*

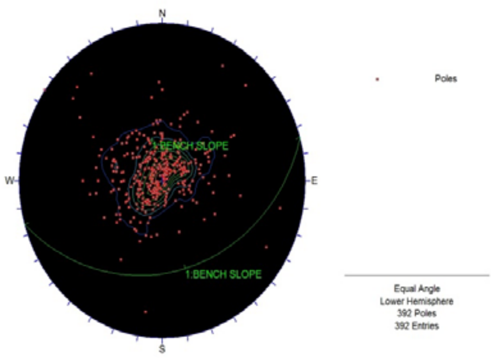

Fig. 4 *Overlaid line contours on pole plot*

Fig.3 shows that the fracture normal in lower hemisphere projection. The fractures are thought to be of approximately the same size, and orientations to follow the Fisher distribution. Orientation of cut faces 1 was $30^{\circ}/164^{\circ}$. Since all fractures belong to a well-defined set, the "Terzaghi bias" associated with sampling along a straight scanline as stated by Priest (1993) is approximately the same for all fractures, and is therefore neglected here. With the aid of spread sheet, a basic program with Microsoft excel was written to process the data. However *DIPS* software has inbuilt program for statistical analyses, but sometimes it is not always handy hence the basic excel program was very useful.

From fig.4, contour pole plot where used for analyses of possible failure (toppling, plane and wedge failure). The poles concentrate at the center of the hemisphere, indication of close value of the 392 poles worked upon by the software.

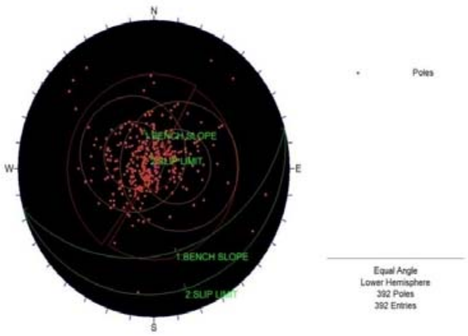

Fig. 5 *Toppling – Principal Joint set with slip limit of the Quarry Face*

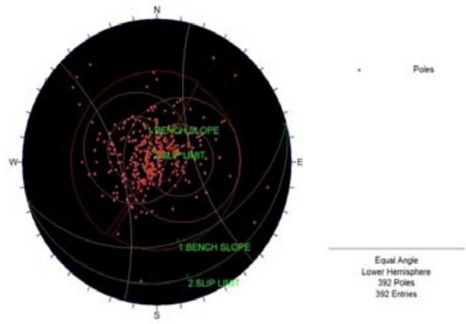

Fig. 6 *Toppling - Principal Joint set with added cone of the Quarry Face*

It was observed that Figure 5 has no bias correction while fig. 6 has min bias angle of 15° using terzaghi correction method. These depict the failure plane that is having the same orientation with one another. The conditions for occurrence of toppling failure are not satisfied therefore toppling failure is not likely to occur.

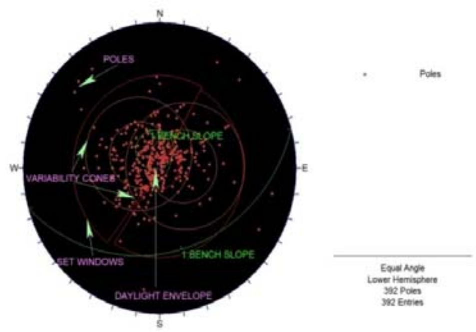

Fig. 7 *Planar - Pole Plot with Daylight Envelope*

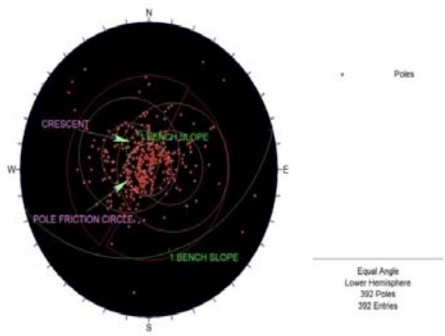

Fig. 8 *Planar - Pole Plot with Pole Friction and Crescent*

From figs. 7 and 8, the plane failure indicates that failure plane daylight on the slope face but the angle of friction is greater than the dip of the sliding plane (which is greater than dip of the slope face). Therefore, plane failure is not likely to occur. Finally, the intersection of planes 1 and 2 fall outside the crescent (critical area) produced by overlapping cut face and friction angle by a very small margin. This indicates that wedge failure is not expected and very unlikely to happen. The Quarry Face is more stable kinematically as far as wedge failure is concern as presented in fig. 9.

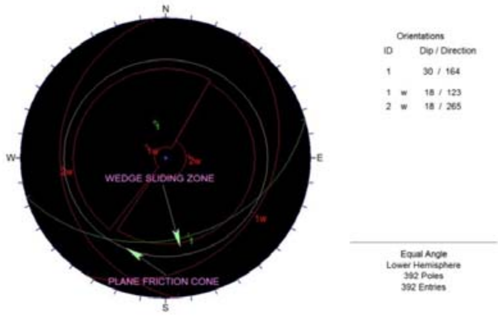

Fig. 9 *Plot indicating Wedge Sliding Zone*

(1) Analysis on slope failure (wedge failure)

Table 5, presents dip and dip direction values obtained from Dips version 6.0 software for the determination of factor of safety of the slope face, the wedge stability chart in fig. 5 which its selection depends on dip differences.

Table 5 *Wedge stability data*

Planes	Dip (degree)	Dip direction (degree)	Friction angle (degree)
Plane A	18	123	10
Plane B	18	265	10
Differences	0	142	

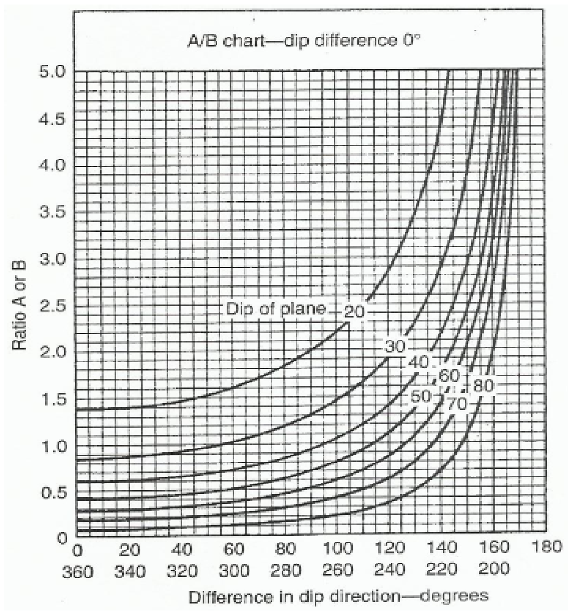

Fig. 10 *Wedge Stability Chart (From Hoek and Bray, 1981)*

From table 5 and fig. 10, the chart with heading "Dip Difference 0^0 " and reading off the values of *A* and *B* for a difference in dip direction of 142^0, it was found that the dimensionless factors *A* and *B* is 4.9 on the chart of dip difference 0^0. This gives the computed factor of safety to be 1.7 (the values of *A* and *B* give a direct indication of the contribution which each of the planes makes to the total factor of safety). The factor of safety is economically stable eliminating possibility of slope failure.

Conclusion

The strength characterization of the gneiss rock was carried out in accordance to standards procedure suggested by International Standard Rock Mechanics. Quartz has the higher percentage in the gneiss rock mineral composition as compared to other mineral present. The strength characterization results for uniaxial compressive strength and point load ranged from 125 – 175 MPa and 5.21 – 7.29 MPa respectively. It indicates that the rock sample is having very high strength due to the presence of quart and plagioclase. The bulk density ranged from 2.55 – 2.72 g/cm^3 while the unit weight ranged from 25 – 26.67 kN/m^3. The regression analyses show that the unit weight and rebound value has influence on the uniaxial compressive strength of the intact rock mass (gneiss).

The intersection of planes 1 and 2 fall outside the crescent (critical area) indicates that wedge failure is not expected and very unlikely to happen. The computed factor of safety is 1.7. The quarry face is more stable kinematically as far as wedge failure is concern, eliminating possibility of slope failure. It highly recommended that operators in the mineral industries should incorporate the use of Dips software and all other rock software in their day to day activities.

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