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GEOTECHNICAL INVESTIGATIONS FOR A SAFE SLOPE DESIGN: A CASE STUDY OF THE MIMBULA OPEN PIT II, ZAMBIA.

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ABSTRACT

This research describes the geotechnical investigations of a rock mass for an optimal slope design. It is directed to determine slope design parameters of the Mimbula pit 2, which is an important satellite pit of the Nchanga open pits. Attention has been drawn to the need to understand the failure mechanisms of slopes on this site and the need to determine acceptable risk of mining at the designed pit slopes. Kinematic and limit equilibrium analysis are looked at in detail and part of numerical analysis pertaining to the Mimbula slope design. The methodology in this research included the collection of information about the local and regional geology, structures, rock mass and the hydrogeology of the investigation area. Field work which comprised geotechnical core logging and mapping was carried out to determine the characteristics of the rock mass. Data analysis was done using specialized rock science software package (DIPS, SLIDE and PHASE 2). The critical slopes were mined predominantly in Arkose material which was subdivided into two main domains. Domain 1 comprising of weathered Saprolite. The Saprolite slopes stand at the natural angle of repose of Cohesionless material which is not less than 35 degrees (batter stack angle). Domain 2 comprises of Arkose formations. A series of slide analyses were run using mean parameter values. This analysis showed that a batter stack angle of around 47 degrees would be stable for slopes cut in the Arkose down to at least 100m depth. The Muntipa Tailings Dam (TD5) lies some 700m east of the pit and consists of relatively dense cohesiveless material. It was concluded that the risk of tailings liquefaction is low. The dam wall is in a stable state under the current conditions and blasting operations can be conducted under controlled blasting conditions. There is very low risk of any significant water flowing from the Muntipa Tailings Dam towards the open pit via groundwater flow. Tailings dams on the Copper belt are typically self-sealing and no instances of significant groundwater flow from a valley type dam have been reported historically. The paper highlights the results obtained for safe design for slopes under the current situation. The safety measures to keep the pit slope stable have also been considered.

Keywords: geotechnical investigations, slope design parameters, Kinematic and limit equilibrium analysis

INTRODUCTION

The Mimbula Open Pit II is located in KCM's Nchanga Mining Licence area towards to northern end of the Zambian Copperbelt. The mine lies in the vicinity of latitude 13˚ south and longitude 28˚ east, and forms a strip of country about 50kms wide adjacent to the Zaire Border. It stretches for about 150 kms from Konkola in the northwest to Roan Antelope and Bwana Mkubwa in the southeast (Figure 1).

Figure 1: Project location (Courtesy of KCM).

Mimbula Open Pits I and II were mined in the 1960's and 1970's. Recent drilling has established conventional and refractory ore resources between the two pits. The Mimbula II open pit has an estimated resource of around 7.2 million tonnes of treatable ore Mixed Oxide and Sulphide ore (Conventional). This is ore which responds to both Flotation and Leaching to an expected standard in the current plants (Below 70mB to 200mB)and 28 million tonnes of refractory ore indicating recoveries of < 30% in flotation and < 60% in leaching plants (ore above 70mB).

Geology

The Mimbula open pit II is located 10km south of Chingola as shown in figure 1 and can be accessed via major tar roads. The site is adjacent to the Muntipa tailings storage facility about 700m away from the pit, one of the several large tailings repositories operated by KCM. The Nchanga Mining License Area encloses a strike length of some 40km of the Lower Roan Group, which itself hosts the bulk of the copper mineralisation within the Zambian Copperbelt. The Lower Roan Group strata comprise mainly arenaceaous meta-sediments, principally arkose, greywacke, quartzite, shale, micaceous sandstone and Schists. These are frequently folded into major northwesterly plunging, asymmetrical synclines and anticlines draped around a hub of red granite and schist. Three principal structural elements are the Nchanga Syncline, the Chingola Anticline and the Mimbula-Chabwanyama Synclines, within which more than 14 known ore deposits occur at seven different stratigraphic horizons in a wide variety of rock types over a vertical interval of some 150m of the stratigraphic column.

In the Mimbula area the arkose is subdivided into several lithological units. Mineralisation is commonly found within the F2(4)(O) and also within the F2(4) and F2(1) units. The thickness of ore in these “footwall” orebodies is variable ranging from a few metres to over 40 metres. The Mimbula Chabanyama Syncline axis trends between 310 to 330 degrees with a plunge of some 15 degrees to the north-west. Potentially economic mineralisation occurs asymmetrically around the fold axis and is considered to be a secondary concentration of leached metals from the flanks, which has been redeposited in the hinge of the syncline. The ore is symmetrically disposed about a basement ridge, which helps form a local topographical “high” and mineralisation is controlled by sedimentary features. The limits of mineralisation have been closed off to the east and south-east, whilst the down-plunge limits to the west and north have still to be defined. The arkose formations will form both the footwall and the highwall of the open pit, and therefore their hydrological characteristics are important for open pit design and for on-going mine planning.

Problem statement

The main problem is that pit has many geologic structures (discontinuities) such as joints, bedding planes, faults etc. and poor rock mass quality in the highly weathered banded sand stone (BSS) formation as shown in figure 2, which forces the design of flattened slopes/angles thereby resulting in mining and handling of more waste which is uneconomical. Because of this it has led to the research topic in order to ensure safe and economic slopes.

Figure 2: research site (picture taken by author)

Research Objectives

The principal objectives of this research were:

1. To characterize the Mimbula rock mass for an optimal slope design
2. To classify the rock using Bieniawski 1989 and Laubsher 1976
3. To understand the geological structures that could cause different types of failures.
4. To recommend if at all the improvements to the stability and design parameters after considering all the outlined issues above.

2 RESEARCH METHODOLOGY

The research methodology involved were;

a) Visits to the research site
b) Literature review to know what is known about the study. Previous work done on the project information about the local and regional geology of the investigation area.
c) Use of collar survey points for depicting the sections on the Mimbula pit and planned drilled boreholes and geology logging
d) Data collection: Rock core logging, Field mapping, Hydrogeological investigations.
e) Data Processing

Rock Mass Classification
  Geostatistical Analysis
  Rock Mass Model Analysis

f) Design Formulation and Analysis (Application of software analysis tools (SLIDE, DIPS, PHASE 2 and DATAMINE)
Determination of Excavation Parameters
Kinematic Analysis for Probable Failure Modes
Stability Analysis for Bulk Failure

The design methodology for the slopes as show in the figure 3 below was used.

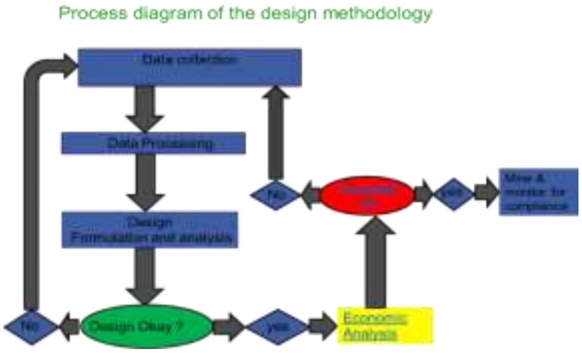


Figure 3: methodology flow chat

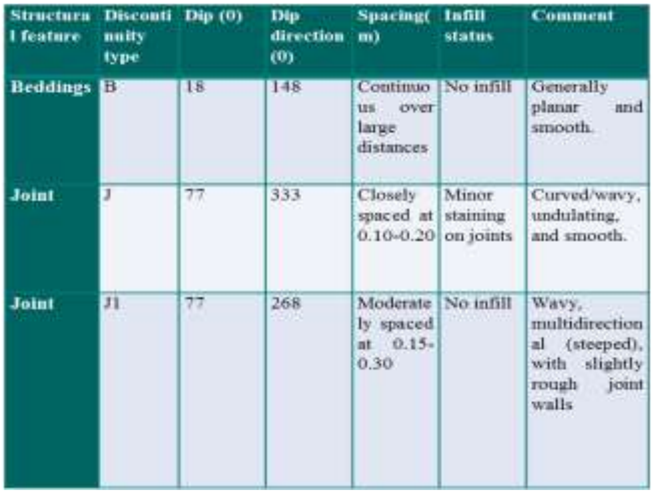
3 DATA ANALYSIS AND DISCUSSION

1. DESIGN PARAMETERS;

A. Geotechnical field mapping of discontinuities

Three rock formations exposed during the historical excavation of this pit are arkoses, shales and dolomitic Schists. Bedding is the major structural feature in all three rock types.The bedding dips at 18°towards the southeast (18°/148°). Other discontinuities noted are J and J1 dipping at 77°/333° and 77°/255° respectively (refer to DIPS structural analysis, Table 1 & Figure 4). This rock unit is fair to good with a GSI value range in places frequently over 40.

Table 1: input parameters in DIPS



Structural feature	Discontinuity type	Dip (0)	Dip direction (0)	Spacing(m)	Infill status	Comment
Beddings	B	18	148	Continuous over large distances	No infill	Generally planar and smooth.
Joint	J	77	333	Closely spaced at 0.10-0.20	Minor staining on joints	Curved/wavy, undulating, and smooth.
Joint	J1	77	268	Moderately spaced at 0.15-0.30	No infill	Wavy, multidirectional (steeped), with slightly rough joint walls

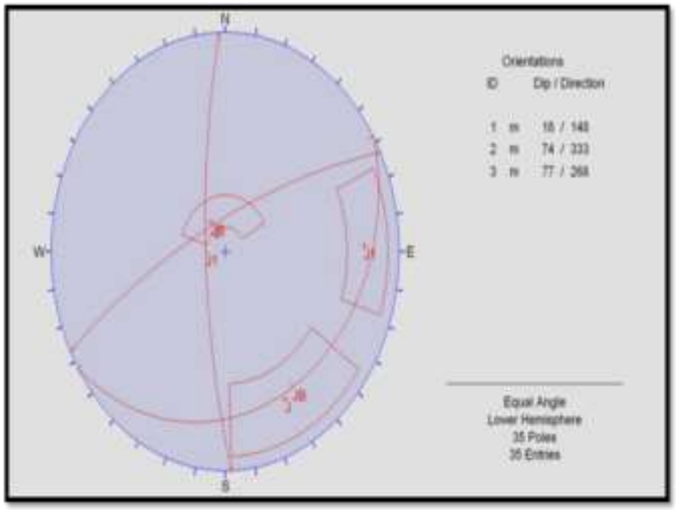


Figure 4: stereographic plot

The geotechnical ground condition zoning had been worked out using Bieniawski(appendix 4) 89 and 76.The rock mass ratings (RMR) are represented in Table 2 as follows:

Table 2: Summary of the Rock Mass Ratings for Mimbula Open Pit II

ZONE	RMR RANGE	COLOR CODE	DESCRIPTION
I.	**≤21 -40**	**Red**	**Weak Ground**
II.	**41-60**	**Orange**	**Fair Ground**
III.	**61≥ 80**	**Green**	**Good Ground**

B. Geotechnical core logging

This part of the open pit is weathered down to 25-30m below surface (1370m elevation) on the north eastern side of the pit. Two of the drill holes on the north east side of the pit, M377 and M376, exhibit generally low unconfined compressive strengths (UCS) in the range on 1-25 MPa in this saprolitic zone. At the lower end of these values, UCS will clearly be the major control on ground stability. RQD 55- 60% and GSI averaging 38.RQD and intact strength generally increase with depth so that by 50m depth the rock can be described as fair.

C. Hydrogeological investigation of the area

Based on a combination of topographical, geological, structural and meteorological data, the basic groundwater flow conditions are:

- Mean annual rainfall of 1280 mm (April and November)
- May to September(dry months) receive no rain
- One water bearing formation: Bandedstone (BSS) aquifer (k-value 5 x 10-6 and s-value=0.01)
- Estimated pan evaporation is 2240mm per annum

2. GEOTECHNICAL DOMAINS:

DOMAIN 1 SAPROLITE OR LATERITE

Based on geotechnical core logging and in-pit mapping at the Project, The near surface domain is clearly weak. It is characterised by a high degree of weathering and the fabric of the original rock may be completely destroyed. UCS values range from 0-5MPa and are typically less than 2 MPa. Stability of any slopes in the material is controlled intact strength (UCS) of the weathered material and by the presence or absence of water in the slope. Assuming that drainage can be effected during the early stage ofmining, these saprolite slopes will stand at thenatural angle of repose of cohesive material, which is not less than 35 degrees. But for the purposes of initial open pit optimisation, it can be assumed that a slope angle of 35 degrees should be used for batter stack design down to 1340m elevation

DOMAIN 2 ARKOSE:

Slopes will be mined mainly within the Arkose formations, either as push-backs to access deeper ore, or as final end-of-life pit slopes.It is clear from the geotechnical logs examined that the degree of weathering decreases with increasing depth, however, at higher levels in the proposed pit, the degree of weathering and jointing can be relatively high, as indicated in RMR tables. In order to assess a basic overall slope angle for the arkose formations below 1340m elevation a series of slide analyses were run using mean parameter values. The analyses showed that a batter stack angle of around 47 degrees would be stable for slopes cut in the arkose down to at least 100 m depth.

3. STABILITY AND DESIGN

Basic parameters used for initial slope design are shown in appendix A. The UCS, mi and GSI parameters were selected based on the review of geotechnical data. Statistical information on the potential variability of Hoek-Brown parameters, mb and s were obtained using the Monte Carlo simulation package @Risk. Hoek-Brown parameter *a* was ascribed a value of 0.5 for these preliminary analyses.A disturbance factor D=1 (production blasting of open pit mine slopes) was used as a conservative assumption during estimation of the failure criterion. Clearly, there is scope to increase the Hoek-Brown parameters (and hence overall slope angles) if more cautious mining /blasting techniques are likely to be used during actual mine production.In order to assess a basic overall slope angle for the arkose formations below 1340m elevation a series of slide analyses were run using mean parameter values.

The stability analysis was done using a limit equilibrium algorithm and numerical modelling contained in SLIDE 5.0 and Phase 2 6.0 respectively. In this analysis, Bishop simplified and Janbu methods were used for analysis of circular and non-circular slip surfaces respectively. These types of failure surface were specified due to isotropic and anisotropic effects of different formations occurring in the slope.The stability analysis was conducted assuming undrained and drained conditions. The stability analysis was conducted on four design sections that form highest inter ramp slope heights as shown in figure 5 below.

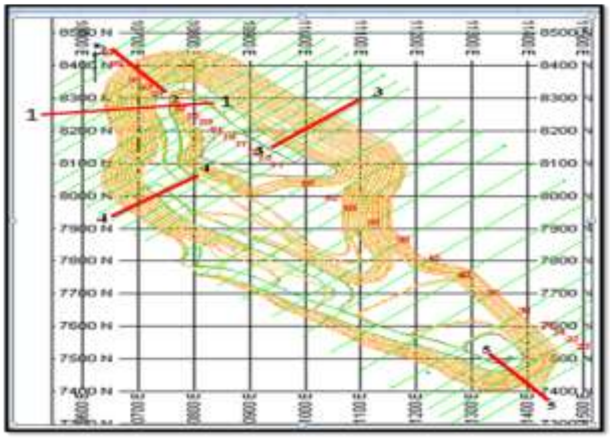


Figure 5: locality plan showing Mimbula sections

These analyses showed that a batter stack angle of around 47 degrees would be stable for slopes cut in the arkose down to at least 100 m depth. However, until we have collected more representative geotechnical information at depth, an overall slope angle of greater than 47 degrees cannot be recommended for slopes predominantly in arkose. The probabilistic option in SLIDE was then used to further analyse the probability of failure for a 47 degree slope assuming the potential variability of the rock mass parameters outlined in the table above.The geometry of the slope analysed and the critical failure surfaces for a static analysis using slide are shown in the Figure 6 below.

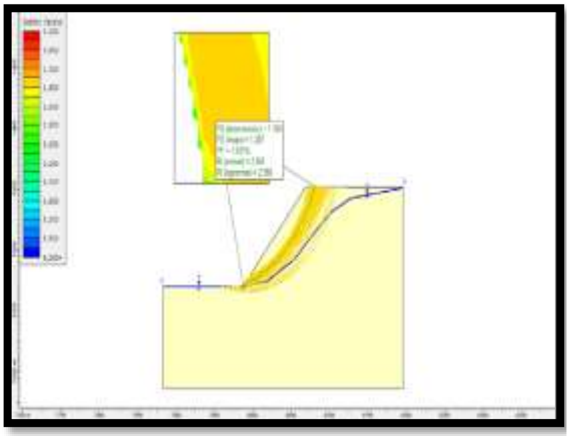


Figure 6: The Geometry of the Slope Analysed and Critical Failure Surfaces for a Static Analysis using SLIDE

The distribution of the Factor of Safety from the probabilistic analysis is shown in the relative frequency Figure 7 below.

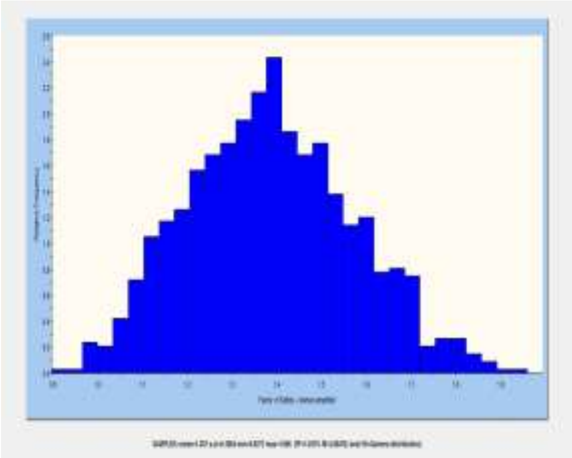


Figure 7: Distribution of the Factor of Safety from the Probabilistic Analysis

The Factor of Safety is best represented by a gamma distribution with a mean value of 1.387, a standard deviation of 0.185 and a maximum value of 1.956. The probability of failure is extremely low (around 1%) and this is considered more than acceptable at this stage.

4 CONCLUSIONS AND RECCOMENDATION

1. The ultimate aim of this study was to characterize and classify the rockmass for an optimal slope design, particular domains were considered based on the lithostratigraphic unit and two major geotechnical domains were identified:
   a) **Domain 1 – Saprolite and Laterite**: A slope angle of 35 degrees should be used for batter stack design down to 1340m elevation.

   b) **Domain 2 – Arkose:** In order to assess a basic overall slope angle for the arkose formations.
   c) below 1340m elevation a series of slide analyses were run using mean parameter values. The analyses showed that a batter stack angle of around 47 degrees would be stable for slopes cut in the arkose down to at least 100 m depth. The stability analysis indicate that the proposed design is stable with factor of safety in excess of 1.2 with an exception of design section 2-2 which has a FoS of less than 1.Numerical modelling results for the proposed design profile show major indications of shear strains with SRF of 0.98
2. Mimbula rock mass described by Bieniawski and Laubsher is generally fair to poor rock
3. Prominent geological structures at Mimbula are the bedding planes which are highly prone to plane failures

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Appendix 1: summary of key input parameters

PARAMETER	Mean (KPa)	Std Deviation	Upper Bound	Lower Bound
UCS	10,000	2,500	15,000	3,000
Mi	16	1	19	13
GSI	48	4	65	38
Mb	0.390	0.1205	0.633	0.244
S	0.0001772	0.00016	0.00217	0.0000325

Appendix 2: summarized Mimbula shear strength parameters

Rock unit	Unit weight(KN/m^3)	Cohesion C (kPa)	Friction angle ϕ (Degree)
LAT	18	45	25
BSS	24	70	25
LBS	25	120	30
ARK	25	150	30
GR(BAS)	27	400	35

Appendix 3: geotechnical design parameters

Description	Location	Topo as@27/09/10	Mimbula proposed design
Batter angles (degrees)	NW	55	70
	SW	42	70
	NE	42	70
	SE	NIL	70
Berm width	All sectors	17m	5m
Bench height	All sectors	10m	10m
Ramp Width	All sectors	28m-30m	25m
Overall slope angle (degrees)	NE Sector	30	47-48
	SW Sector	28	47-48
	NW Sector	22	47-48
	SE Sector	15	47-48
Inter-ramp angle	All sectors	28	50

Appendix 4: Mimbula geotechnical information

Lithology	Rock Mass Classification	
	Bienawaski's	Laubscher
Undifferentiated	20	18
Upper Banded Shale (UBS)	22	22
Feldspathic Quartzite (TFQ)		
Banded Sandstone Upper , Pink Quartzite and Banded Sandstone Lower Upper (BSSU, PQ,BSSL)	15	15
Lower Banded Shale (LBS)	19	18
Arkose (ARK)	53	50
Basement (BAS)	62	60