A METHODOLOGY FOR GEOTECHNICAL DESIGN
- With Special Reference to COP FD Phase 1 Slope Design

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ABSTRACT

The steeply dipping Chingola Open Pits (COP) F and D orebodies; an even steeper foliation in the Basement Schist on the footwall; the geological structural influence of the Chingola Anticline, a complex thrust related northwest trending ridge of the Lufubu Gneiss and Schist; and the presence of groundwater; were among the difficulties that have been encountered in designing slopes for COP FD. Although much experience in design is available from Nchanga Open Pit (NOP) and other satellite pits, it was felt that due to the different geological environment of COP FD, design parameters could not simply be transferred from NOP and / or other satellite pits to COP FD.

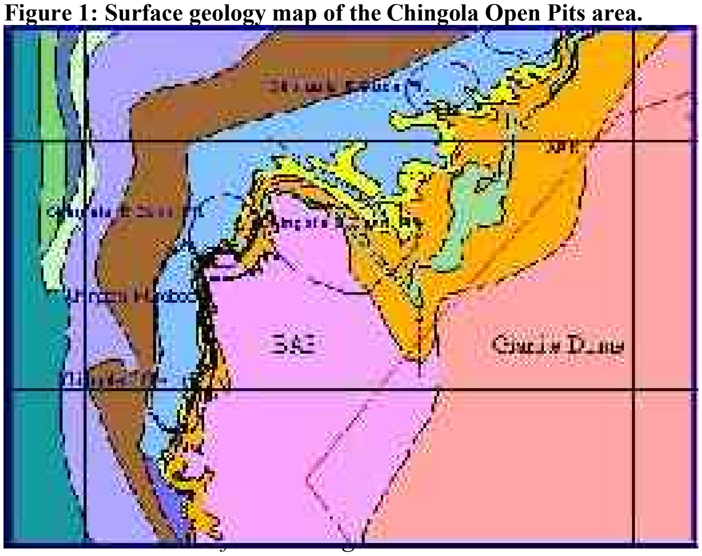
To overcome these difficulties, a design methodology was developed incorporating data gathering, rock mass rating classifications, geostatistical modelling and stability analysis techniques. The methodology aims at obtaining a better geotechnical understanding of the structural and geological implications as well as the spatial variability of the geotechnical parameters of the rock mass conditions and how these will be affected by creation of an excavation. The methodology is both comprehensive in addressing pertinent issues and auditable.

Although the design methodology has been developed to address the specific challenges encountered in the COP FD, an open pit mine, its applicability is not restricted to open pit design.

Introduction

The COP 'F' and 'D' orebodies are shallow lying orebodies which are to be mined by open pit method. They are situated on what traditionally has been described as the southwest limb of the Chingola Anticline, a complex northwest trending ridge of Lufubu Gneiss and Schist locally referred to as Basement Schist, BAS (Figure 1).

Figure 1: Surface geology map of the Chingola Open Pits area.



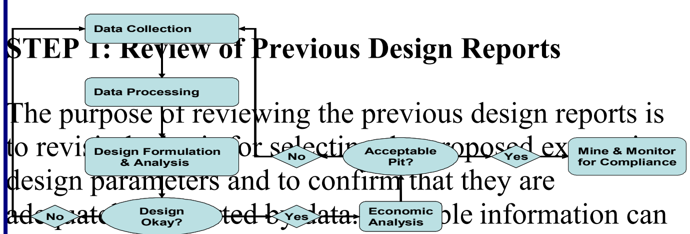
3. *Geotechnical Logging*
4. *Field Mapping*

B. Data Processing
5. *Rock Mass Classification*
6. *Geostatistical Analysis*
7. *Rock Mass Model Analysis*

C. Design Formulation and Analysis
8. *Determination of Excavation Parameters*
9. *Kinematic Analysis for Probable Failure Modes*
10. *Stability Analysis for Bulk Failure*

Figure 2 outlines the design process of the ten step methodology, which is discussed in detail in this paper.

Figure 2: Process diagram of the design methodology



STEP 1: Review of Previous Design Reports

The purpose of reviewing the previous design reports is to revi[illegible] for selecti[illegible] proposed ex[illegible] design parameters and to confirm that they are ad[illegible]ted by data. [illegible]ble information can be gathered from an early stage, which can be used to identify the strengths and shortcomings for further consideration in the design process.

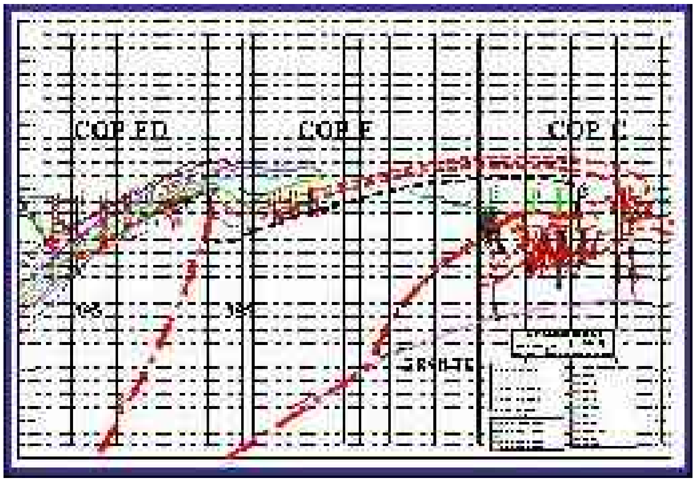
In the COP F and D area, four previous design reports had been prepared. Two of these reports, AMC *(1995)* and Hepworth *(1997)*, proposed slope angles based on very limited drilling information. One borehole, was geotechnically logged while groundwater conditions were based on information obtained from two other holes.

The third report, Leech *(1996)*, relied on geotechnical logs from one borehole and geotechnical parameters from about 60 geological borehole logs, to come up with the pit wall parameters. The final report, Tunono and Murphy *(2001)*, utilised extensive geotechnical logging data (i.e. 47 boreholes) to derive pit wall parameters.

STEP 2: Review of Geological Plans and Sections

The geological structure forms the basis for any geotechnical design, hence, it is imperative to obtain the correct interpretation. The geological structure has a strong influence on the rock mass conditions. The COP FD orebody lies on the south-western limb of the Chingola Anticline, a complex, thrust related, northwest trending ridge of the Lufubu Gneiss and Schist (BAS) which forms the basement on which the sediments were deposited (Figure 3). The thrusts are restricted to the BAS and have a general northwest-southeast orientation with a northeast vergence, while the sediments generally dip at 30-45° to the west.

Since the footwall of the COP FD Phase 1 pit is to be excavated in the BAS, an understanding of the influence of the thrusts and the foliation in the BAS on the footwall slope stability becomes important. The interpreted thrusts lie far back into the slope and as they do not daylight on the slope face, they are unlikely to have any significant influence on the stability of the footwall. The foliation in the BAS is likely to have a major influence on the footwall stability.



- Groundwater conditions.

The data collected ~~forms~~ the basis for rock mass classification, which is an important tool in evaluating the probable rock mass conditions. In the case of oriented core, discontinuity trends can be obtained, which are critical in structural and discontinuity analysis.

It is essential for an appropriate design to establish a level of confidence in the parameters obtained from geotechnical logs. For COP FD, the drilled cores, which had been kept, had suffered some deterioration due to handling. Hence, to establish confidence, the parameters from geotechnical logs were compared with those obtained from geological logs where these were available. More recent geotechnical logs were compared with the core to identify and rectify any inconsistencies.

To further improve the confidence levels in the logs, old geological logs containing geotechnical parameters were incorporated in the geotechnical parameter database.

STEP 4: Field Mapping

The purpose of field mapping is to collect data that can be utilized to confirm the general trends of major discontinuities identified in Steps 2 and 3. Exposed areas, such as old excavations in the proximity of the planned excavation, provide important sources of data. It is important that data pertaining to the dip/dip direction and spacing of discontinuities are collected during the exercise. Data pertaining to the condition of the excavation in which data is obtained must be noted as well as this can form the basis for justification of the design parameters.

For COP FD, mapping was undertaken in the mined out part of the COP FD pit and the adjacent COP E pit.

Formation	Ratings for Insitu Conditions				RMR_L	Adjusted for			*Total Adjustment*	Final MRMR	Initial Slope Angle (°)
	IRS	RQD	*JR*	JC		*Weathering*	*Orientation*	*Blasting*			
Laterite	2.6	0.7	*13.5*	*12.7*	29.5	0.70	0.80	0.90	0.50	14.9	37.0
URD	2.5	6.3	*13.5*	*12.7*	35.0	0.70	0.85	0.90	0.54	18.7	39.0
SWG	2.0	9.4	*13.5*	*12.7*	37.6	1.00	0.90	0.94	0.85	31.8	45.5
CDOL	3.4	5.6	*13.5*	*12.7*	35.2	0.95	0.90	0.94	0.80	28.3	44.0
DOLSCH	3.4	8.7	*13.5*	*12.7*	38.3	1.00	0.96	0.94	0.90	34.6	47.0
UBS	2.7	5.9	*13.5*	*12.7*	34.8	1.00	0.97	0.94	0.91	31.8	45.5
TFQ/TFQT	4.3	6.7	*13.5*	*12.7*	37.3	1.00	0.95	0.94	0.89	33.3	46.5
BSSU	4.0	6.5	*13.5*	*12.7*	36.8	1.00	0.96	0.94	0.90	33.2	46.5
PQ/SM	5.6	4.7	*13.5*	*12.7*	36.5	1.00	0.95	0.94	0.89	32.6	46.0
BSSL	3.4	5.0	*13.5*	*12.7*	34.6	1.00	0.96	0.94	0.90	31.2	45.5
LBS	4.0	4.9	*13.5*	*12.7*	35.2	1.00	0.97	0.94	0.91	32.1	46.0
TR	5.2	8.1	*13.5*	*12.7*	39.5	1.00	0.95	0.94	0.89	35.3	47.5
ARK	6.2	9.5	*13.5*	*12.7*	41.9	1.00	0.95	0.94	0.89	37.4	48.5
BCONG	5.9	8.8	*13.5*	*12.7*	41.0	1.00	0.95	0.94	0.89	36.6	48.0
BAS	5.7	10.1	*13.5*	*12.7*	42.0	1.00	0.95	0.94	0.89	37.5	48.5

Table 1: Summarised Laubscher's rock mass rating (RMR_L) and mining rock mass rating (MRMR) per formation for COP FD Phase 1

STEP 5: Rock Mass Classification

To analyse the rock mass conditions, geotechnical parameters obtained from logging and/or mapping (Steps 3 and 4) are processed into rock mass classification systems. Rock mass classification systems provide useful tools in the quantification, derivation and selection of rock mass properties and excavation parameters.

The COP FD geotechnical data was processed into two classification systems; Bieniawski's (1989) Rock Mass Rating (RMR_B) and Laubscher's (1977) Rock Mass Rating (RMR_L). Since the groundwater environment for the COP FD area is not yet fully defined, assumptions for groundwater were made in both classifications systems. These assumptions were based on the available information. The RMR_B and the RMR_L classifications systems were used to assess the rock mass conditions of COP FD. Laubscher's RMR_L classification was further adjusted for weathering, orientation and blasting effects to obtain the Mining Rock Mass Rating (MRMR), which was ultimately used in assessing the initial slope angles of COP FD Phase 1 (see Table 1).

STEP 6: Geostatistical Analysis

The whole purpose of rock mass classification systems is to obtain rock mass conditions of the entire area in which the excavation is to be made. Geostatistical tools such as those used for orebody modelling can be employed to model the rock mass conditions of an area utilizing point and/or line data obtained from drill core and/or mapping.

The rock mass classification data (from Step 5) for COP FD was modelled and the resulting RMR_B and RMR_L Models (Figure 4) were used to analyse the rock mass conditions and to obtain the geotechnical zones prevailing in the COP FD rock mass.

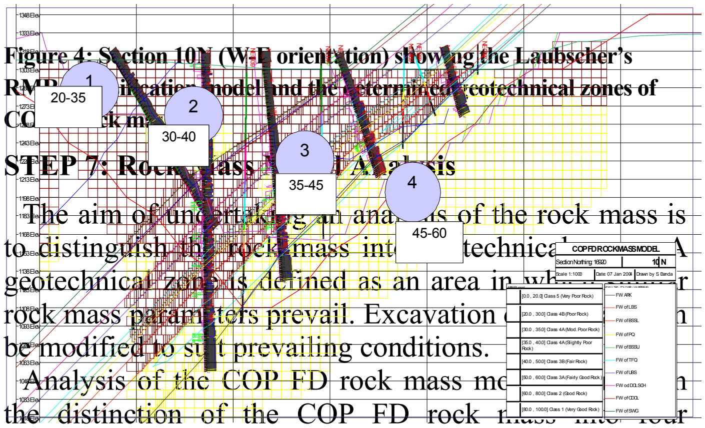


Figure 4: Section 10N (W-E orientation) showing the Laubscher's RMR classification model and the determined geotechnical zones of COP FD rock mass

STEP 7: Rock Mass Model Analysis

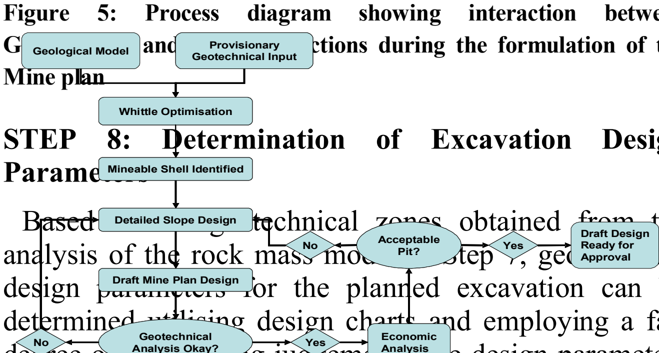
The aim of undertaking an analysis of the rock mass is to distinguish the rock mass into geotechnical zones. A geotechnical zone is defined as an area in which similar rock mass parameters prevail. Excavation design can then be modified to suit prevailing conditions.

Analysis of the COP FD rock mass model resulted in the distinction of the COP FD rock mass into four geotechnical zones (Figure 4):

1. *The upper hanging wall stack* – comprising the Laterite and Upper Roan Dolomites (URD) with RMR_L with values averaging 29 and 35 (i.e. MRMR values of 15 and 19), respectively,
2. *The intermediate hanging wall stack* – comprising the Shale with Grits (SWG) and the Chingola Dolomites (CDOL) with RMR_L values averaging 38 and 35 (i.e. MRMR values of 28 and 35), respectively,
3. *The lower hanging wall stack* – comprising units below the CDOL from Dolomitic Schist (DOLSCH) to Arkose (ARK) with RMR_L values averaging from 35-42 (i.e. MRMR values of 31 to 37) and
4. *The footwall stack* – comprising the Basal Conglomerates and the Basement Schist and Gneiss (BAS) with RMR_L values averaging 41 and 42 (i.e. MRMR values of 37 and 38), respectively.

These geotechnical zones were used to determine the initial slope angles for COP FD Phase 1.

Figure 5: Process diagram showing interaction between Geotechnical and Planning sections during the formulation of the Mine plan



STEP 8: Determination of Excavation Design Parameters

Based on the geotechnical zones obtained from the analysis of the rock mass model in Step 7, geotechnical design parameters for the planned excavation can be determined utilising design charts and employing a fair degree of engineering judgement. The design parameters are then given to Mine Planning section who then come up with the geometry of the excavation. The excavation geometry is then reassessed for compliance to the geotechnical design parameters and pit economics. This is an interactive process as illustrated in Figure 5.

For the COP FD Phase 1, the design chart, reproduced from Haines and Terbrugge's paper (Figure 6), was used to determine the pit slope angles. This chart has been used extensively in designing slope excavation by the authors and has been continually upgraded whenever more data has become available. Table 2 gives the design parameters for COP FD, which were determined utilising this chart.

Figure 6: Design chart used to determine the slope parameters for COP FD Phase 1 (*after Haines and Terbrugge*)

Table 2: COP FD Phase 1 slope design parameters determined using the design chart shown in figure 4 (note: bench height of 15m was used throughout based on the dig height of the machinery used on the site)

Pit Slope Area	Stack	Formations	Maximum Stack Height	MRMR	Stack Angle	Berm Width
Hanging Wall	Upper Stack	Laterite, URD & weathered SWG	60m	16.8	35-37°	12.0m
	Intermediate Stack	SWG & CDOL	60m	30	40-43°	9.5m
	Lower Stack	DOLSCH, UBS, TFQ, BSS, LBS & ARK	60m	34	45-47°	8.0m
North And South Side Walls	Upper Stack	Laterite, URD & SWG	60m	16.8	35-37°	12.0m
	Intermediate Stack	SWG & CDOL	60m	30	40-43°	9.5m
	Lower Stack	DOLSCH, UBS, TFQ, BSS, LBS & ARK	60m	34	45-47°	8.0m
Footwall	Footwall Stack	BAS	180m	35	38-39°	15.0

STEP 9: Kinematic Analysis

Once the geometry of the excavation has been determined, based on the design parameters obtained in Step 8, it becomes now prudent to carry out a rigorous structural and discontinuity analysis. This exercise is aimed at identifying possible failure modes. The orientation of the major structural features and discontinuities relative to excavation walls determine the stability of the excavation and their effects are analysed utilising stereographic plots. By employing engineering judgement and/or statistical analysis, the likelihood of each identified failure mode occurring can be determined.

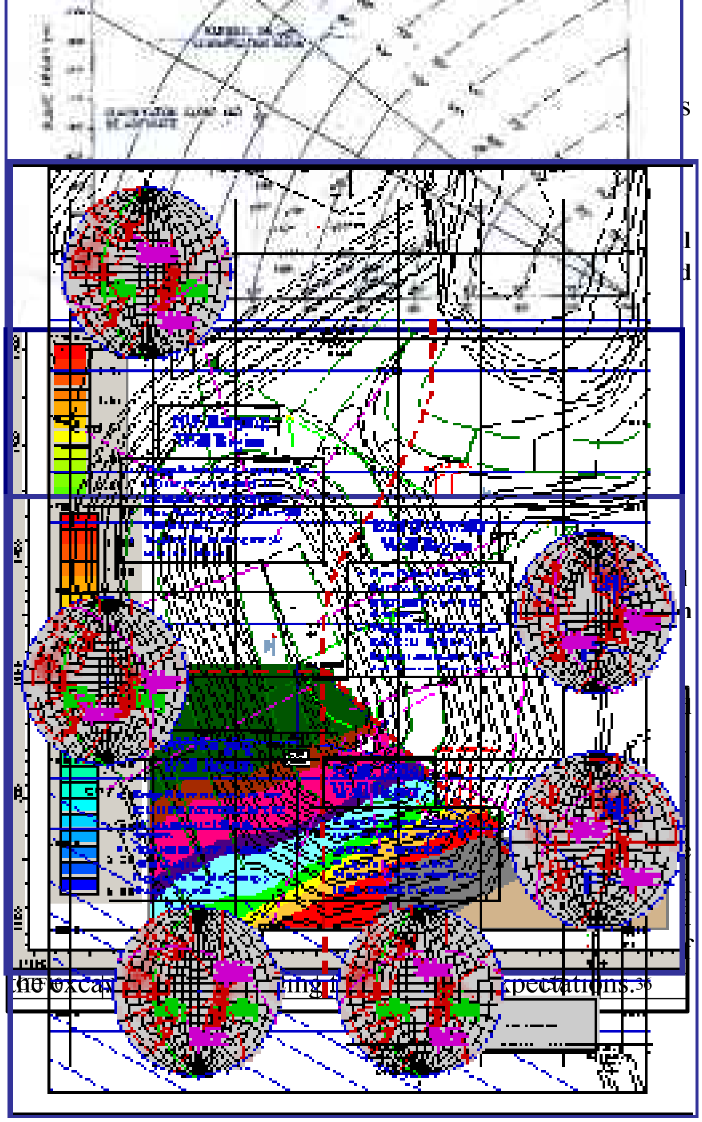
The stereographic analysis of the COP FD Phase 1 structural and discontinuity data yielded the failure mechanisms which are summarised in Figure 7. From these analyses (based on engineering judgement), plane slide and to a less extent wedge failure came out as the most probable failure mechanism due to the relative orientation of discontinuities and the pit wall slope in various parts of the pit.

STEP 10: Stability Analysis

In order to perform a stability analysis, the following steps are taken:

1. Obtain a correct interpretation of the structural geological conditions in the rock mass (Steps 2-7),
2. Identify the blocks and wedges which can be released by the creation of the excavation (Step 9),
3. Analyse the stability of the blocks and wedges using an appropriate model.
4. Evaluate the design in terms of safety factor and probability of failure. The risk analysis results can be compared with the company criteria and the acceptability of the design assessed.

Limit equilibrium analyses of different slope geometries for COP FD Phase 1 was done using Slide 4.0, which is a 2D slope stability program for evaluating the safety factor of circular or non-circular failure surfaces in soil and rock slopes. Figure 8 and Figure 9 show typical analysis results obtained for COP FD Phase 1 using Slide 4.0, while Table 3 summarises the safety factors obtained for the critical slope components of the COP FD Phase 1. The minimum



Conclusion

To undertake a comprehensive geotechnical design process of COP FD Phase 1, that addressed the pertinent issues, required the formulation of a design methodology.

Although the design methodology has been developed to address the challenges encountered in the COP FD, which is an open pit mine, its applicability is not restricted to open pit design alone. Since the methodology aims at obtaining a better geotechnical understanding of the structural and geological implications and spatial variability of the geotechnical parameters of the rock mass conditions and how these will be affected by creation of an excavation, the methodology should be applicable to both open pit and underground geotechnical designing. Moreover, best practice calls for a design process that is not only comprehensive in addressing pertinent issues, but auditable as well (Appendix 1). This methodology aims to address this challenge.

The effectiveness and robustness of the methodology thus formulated, remains to be tested, since COP FD Phase 1 mining is currently in progress.

References

1. *Rock Slope Engineering (revised second edition)* by E. Hoek and J.W. Bray – The Institution of Mining and Metallurgy, London (1977)
2. *A geomechanics classification system for the rating of rock mass in mine design* by D.H. Laubscher – Journal of the South African Institute of Mining and Metallurgy, vol. 90, no. 10, pp 257-273 (October 1990)
3. *Rock Mass Classification System (After Bieniawski 1989) – obtained from Chapter 3: Rock Mass Classifications of Rock Engineering Course Notes* by Evert Hoek
4. *Preliminary estimation of rock slope stability using rock mass classification systems* by A. Haines and P.J. Terbrugge – SRK Consulting Engineers and Scientists, Johannesburg, South Africa
5. *Hydrogeological Investigation of Chingola Open Pit F* by J.J. Van Hooydonck and P.J. Terbrugge – SRK Report No. 299716 (December 2001)
6. *COP FD Phase 1 Slope Design Report* by Samuel Banda – KCM Internal Report (January 2004)
7. *Investigation for Determination of Preliminary Slope Angles for Proposed COP's D and F* by African Mining Consultants Ltd (April 1995)
8. *Assessment of COP D and F Slope Angles* by N. Hepworth – KCM Internal Report (July 1997)
9. *Recommended final pit wall design for COP D 110m Interim Pit* by Simon J. Leech – KCM Internal Report (July 1996)
10. *Proposed Slope angles for Satellite Pits – COP F* by A.B. Tunono and B. Murphy – KCM Internal Report (2001)

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Appendix 1: Suggested Audit Checklist for the Ten Step Design Methodology

A. Data Gathering			
1. Previous Design Reports			
i.	Are they available?	Yes	No
ii.	If yes to 1, have they being reviewed?	Yes	No
2. Geological Plans and Sections			
i.	Are they available?	Yes	No
ii.	If yes to above, have they being reviewed?	Yes	No
iii.	If yes to above, have structural and discontinuity trends being identified?	Yes	No
3. Core Logging			
i.	Does drill core for the area exist?	Yes	No
ii.	If yes to above, has it being logged geotechnically?	Yes	No
iii.	Are geological logs available for the same core?	Yes	No
iv.	If yes to above, are the geotechnical logs consistent with geological logs?	Yes	No
v.	Have comparisons with core being done to identify and ratify inconsistencies in the logs?	Yes	No
4. Field Mapping			
i.	Are there exposed areas in the proximity of the planned excavation?	Yes	No
ii.	If yes to above, have they being mapped for structural and discontinuity trends?	Yes	No
iii.	Have the conditions of the exposed areas being recorded?	Yes	No
B. Data Processing			
5. Rock Mass Classification			
i.	Has the logging and/or mapping data being processed into rock mass classifications?	Yes	No
ii.	Has any assumptions being made in the classification system?	Yes	No
iii.	If yes to above, state the assumptions:______________________________		
6. Geostatistical Analysis			
i.	Has the rock mass rating data being modelled?	Yes	No
7. Rock Mass Model Analysis			
i.	Have geotechnical zones being identified from the models?	Yes	No
ii.	If yes to above, are they consistent with geological boundaries?	Yes	No
C. Design Formulation and Analysis			
8. Determination of Excavation Parameters			
i.	Are the excavation parameters obtained by use of a design chart?	Yes	No
ii.	If yes to above, state the design chart used:__________________________		
9. Kinematic Analysis			
i.	Has a structural and discontinuity analysis of the planned excavation being undertaken?	Yes	No
ii.	If yes to above, have probable failure modes being identified?	Yes	No
iii.	Have the identified failure modes being ranked in terms of likelihood of occurrence?	Yes	No
10. Stability Analysis for Bulk Failure			
i.	Has a correct interpretation of the structural geological conditions in the rock mass being obtained?	Yes	No
ii.	Have the blocks and wedges that can be released by the creation of the excavation being identified?	Yes	No
iii.	Has the stability of the blocks and wedges being analysed using an appropriate model?	Yes	No
iv.	Has the design being evaluated in terms of safety factor and probability of failure?	Yes	No