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Slope Stability Analysis a Case of Chingola Open Pit-COP FD

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Abstract: ***The factor of safety has been traditionallyused as an indicator to assess the stability of the slope. For slopes, the factor of safety F is defined as the ratio of the actual soil shear strength to the minimum shear strength required to prevent failure. There are many factors that control the factor of safety. This includes thepresence of water; inherent discontinuities F is the factor by which the soil shear strength must be divided to bring the slope to the verge of failure. In this paper, the factor of safety of the slope COP FD at Nchanga mine is calculated using LEM and FEM and the results obtained compared as a check for consistency.***

Keywords: Factor of Safety, Limit Equilibrium Method, Finite Element Method,Slope stability Analysis

1. Introduction

In surface mining operations, the stability of the slope plays a significant role in pit optimization, thesafety of the workforce and equipment. As the slope gets steeper and deeper, the level of safety concerns tends to go up. The case of COP FD is to steepen the slope to reduce on stripping ratio in order to make the mining operations viable.The pit is planned to be deepened in order to access the ore at the pit bottom. The deepening of the pit attracts Mining of an additional overburden material and subsequently an additional operation cost. To minimize the waste mining and achieve the objective of mining at a lowest possible cost, the Pit is optimizedby introducing steeper angles for slope designs. i.e. 70^0 and 42^0 (face & overall slope).In open pit mining, it is accepted to trade off some failures for steeper bench face angles, without compromising safety, since it is more economical to deal with regular clean-ups than to have higher stripping ratios. This is generally referred to as a “managed” approach to slope design. A design reliability of 80% is generally accepted in open pit design, which means allowing 20% of all wedges actually to fail[1]. Two methods have been used to analyze the slope and the results compared to check for consistency.

1.1 Limit Equilibrium Method-LEM:

Limit-equilibrium methods are the most commonly used approaches for analyzing the stability of slopes. The fundamental assumption at their core is that failure occurs through sliding off of a block or mass along a slip surface. The popularity of limitequilibrium methods is primarily due to their relative simplicity, ready ability to evaluate the sensitivity of stability to various input parameters, and the experience geotechnical engineers have acquired over the years in interpreting calculated factor of safety values. However, Thetechnique neglects stress-strain behavior of soils and rocks. It also makes arbitrary assumptions (mostly regarding inter-slice forces) to ensure static determinacy.

1.2 Finite Element Method- FEM

The rapid development of computing efficiency has made several numerical methods gain increasing popularity in slope stability engineering. The most popular method of slope stability estimation is shear strength reduction technique (SSR). The factor of safety (FS) for slope may be computed by reducing the shear strength of rock or soil in stages until the slope fails. The SSR technique for slope stability analysis involves systematic use of finite element analysis to determine a stress reduction factor (SRF) or afactor of safety value that brings a slope to the verge of failure. The shear strengths of all the materials in FE model of a slope are reduced by the SRF. Conventional FE analysis of this model is then performed until a critical SRF value that induces instability is attained. A slope is considered unstable in the SSR technique when its FE model does not converge to a solution (within a specified tolerance).SSR technique is based on theuse of the Mohr-Coulomb strength models for materials. The criterion is readily used in the SSR technique for the following reasons:

(i) It can be expressed either in terms of principal stresses, or in terms of shear and normal stresses (this makes it amenable for use in both FE and limit equilibrium analyses)
(ii) Its linearity that allows reduced parameters to be readily calculated when an original shear strength model is reduced by a factor *F* (Griffith and Lane provide simple, closed-form equations for calculating reduced parameters), and
(iii) It is readily available in many existing finite element software[2].

1.3 Factor of Safety (FOS)

When the material’s shear strength ability loses its tendency to resist the actual shear strength in the slope, the slope tends to slip off along its sliding surface. In this state, the slope is considered to have failed. In slope stability analysis, the factor of safety value is a key indicator of the state of the slope. For the Factor of Safety value equals 1, the slope is considered to be in its state of equilibrium and when its value is above 1, it’s a positive indication that the slope is stable. However, the Factor of Safety of value less than 1, puts the slope in an unstable state. In accordance with the shear failure, the factor of safety against slope failure is calculated as:

$$FOS = \frac{\tau}{\tau_f}$$

Where τ is the shear strength of the slope material, which is calculated through Mohr-Coulomb criterion as:

$$\tau = C + \sigma_n \tan\phi$$

and τ_f is the shear stress on the sliding surface. It can be calculated as:

$$\tau_f = C_f + \sigma_n \tan\phi_f$$

where the factored shear strength parameters and $C_f \varphi_f$ are:

$$C_f = \frac{C}{SRF}$$

$$\phi_F = \tan^{-1}\left(\frac{\tan\phi}{SRF}\right)$$

Where SRF is strength reduction factor. This method has been referred to as the 'shear strength reduction method'. To achieve the correct SRF, it is essential to trace the value of FOS that will just cause the slope to fail.

2. Information about Chingola Open Pit - COP FD

The COP 'F' and 'D' orebodies are shallow lying orebodies which are 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. The Chingola 'D' & 'F' open pit is located to the southwest of the Nchanga Mine. Mining started in 2002 and the pit was designed to be mined in 5 mining phases with a Stripping Ratios of 7,9,12,16, & 15 for phases 1 to 5 respectively.

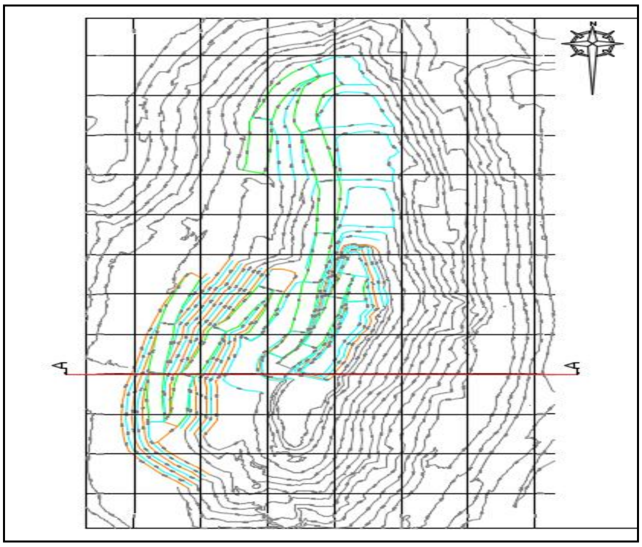

Figure 1: Showing the plan view of COP FD mine design

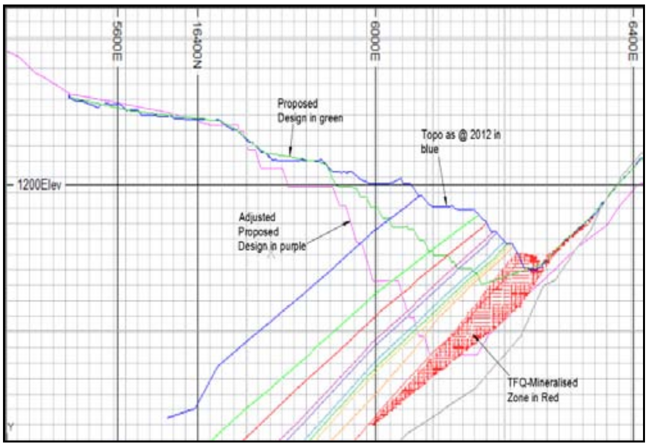

Figure 2: Showing the cross section A-A view of COP FD

The slope consists of eleven different geological units from Chingola Open Pit. The mechanical properties of the rock units involved in the slope are given in Table 1. Figure 2 shows the geometry of slope and its geology.

Table 1: Upper bound Mechanical properties of soil units.

No	Name	C kPa	ϕ Degrees	γ kN/m^3
1	URD	190	35	18.7
2	SWG	205	30	19.2
3	CDOL	150	25	24
4	DOLSCH	120	34	22
5	UBS	130	30	25
6	TFQ	150	36	24
7	BSSU	70	25	24
8	PQ	102	22	18.2
9	BSSL	70	25	24
10	LBS	270	25	24
11	ARK	225	30	25

Design parameters and pit geometry

Table 2: Design parameters of COP FD upper and Lower stacks.

Elevation	*Stack height (m)*	*Batter Angle (degree)*	*BH (m)*	*BW (m)*	*Overall Slope angle*
Upper Stack	101	60-65	15	8	36°
Lower stack	117	70-75	15	8	49°

The batter angle for the upper and lower stacks is variable as shown in Table 2. The changes are with respect to changes in overall slope angle.

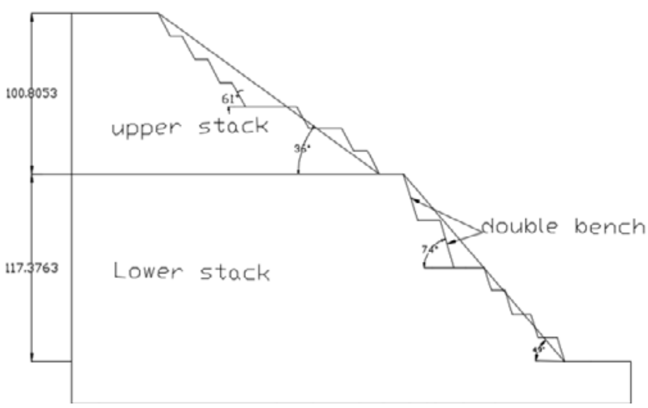

Figure 3: Pit Geometry of COP FD upper and Lower stacks section A-A in Figure 1.

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3. Slope Stability Analysis

In the analysis, Slides 6.0 and phase^{2}7.0 were used for Limit Equilibrium analysis and numerical calculations respectively. In phase^2, the effect of different element types to the accuracy of the results comes with 3 nodded triangle (T3), 6 nodded triangle (T6), 4 nodded quadrilateral (Q4) and 8 nodded quadrilateral (Q8). These were applied and the results compared to Bishop simplified, Jambu corrected and spencer limit equilibrium method as shown in Table 3 below:

Table 3: Factor of safety using different element types for different slope angles

Methods				Phase² 7.0			
Slope angle (°)	Bishop	Jambu	Spencer	T3	T6	Q4	Q8
39	1.294	1.279	1.305	1.31	1.18	1.37	1.18
40	1.253	1.24	1.265	1.24	1.15	1.31	1
41	1.217	1.207	1.23	1.2	1.11	1.24	1.11
42	1.182	1.173	1.196	1.18	1.08	1.21	1.08
43	1.151	1.144	1.164	1.14	1.05	1.17	1.04
44	1.12	1.117	1.133	1.11	1.02	1.17	1.02
45	1.093	1.089	1.107	1.08	0.99	1.13	0.098

As is presented in table3, the values obtained from SSR T3 and Q4 are relatively close to Bishop Simplified and Jambu Corrected, compared to the difference in values obtained between T6, Q8, and Limit Equilibrium Methods. The difference in FoS values lies between 0% and 6% when comparing T3 and Q4 with Limit Equilibrium Methods whereas the difference between T6, Q8, and Limit Equilibrium Methods is more than 7%. FEM results compare well with different Limit Equilibrium Methods.In some cases, the values for FoS by the application of LEM are higher than those produced by the application of FEM technique. The reason among others could likely be the small sensitivity of LEM on complex geological situation – especially the presence of thin and soft strata (Cala & Flisiak 2003 and Dolezalova et al. 2001). It must be also pointed out that failure surfaces identified by Shear Strength Reduction technique are sometimes considerably different than surfaces identified by LEM. In this analysis, the failure surfaces identified by both techniques are comparatively similar as presented in Figure3and Figure 4.

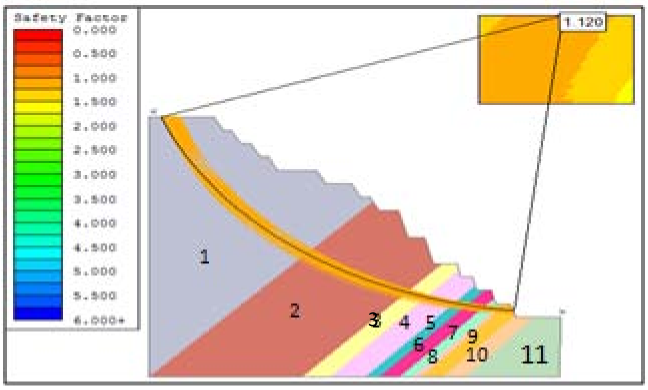

Figure 4: Circular Auto Refine Search Method, Jambu Corrected Method (FOS: 1.120). Materials 1 to 11.

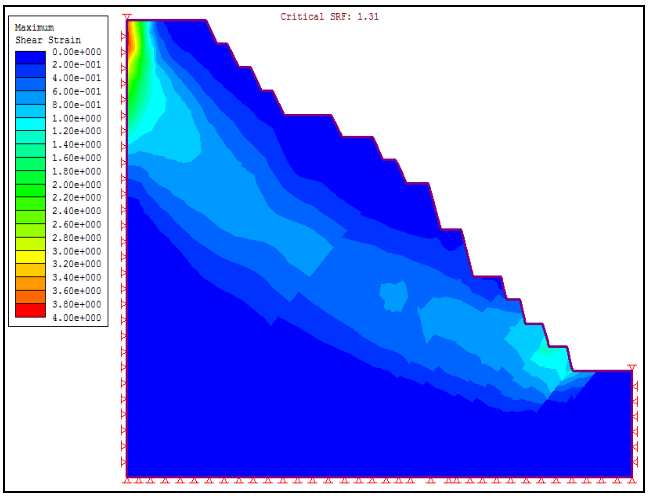

Figure 5: Contours of maximum shear strain in the slope. The contours reveal the failure mechanism predicted by the SSR method

Figures 5 and 6 indicates the correlation between Limit Equilibrium Methods and Finite Element Methods with respect to achange in slope angle. Figure 5 presents 2D values of Factor of Safety with 3 Noded (T3) triangles mesh discretization while Figure 4 presents the same but with 4 Noded (Q4) quadrilateral mesh discretization.

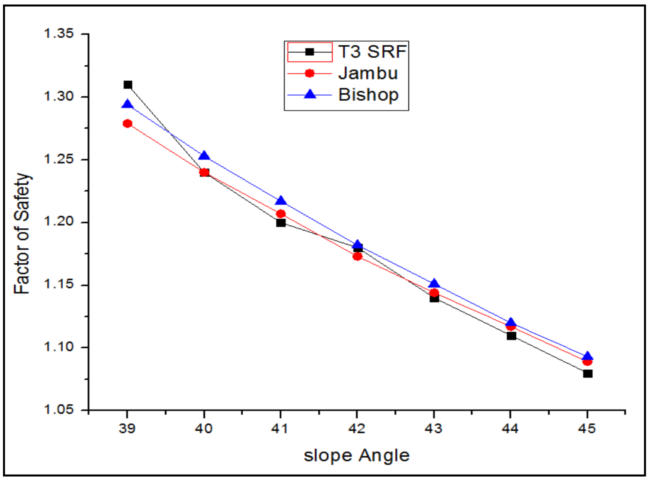

Figure 6: Shows the Factor of Safety values for LEM and FE (T3) against slope angles

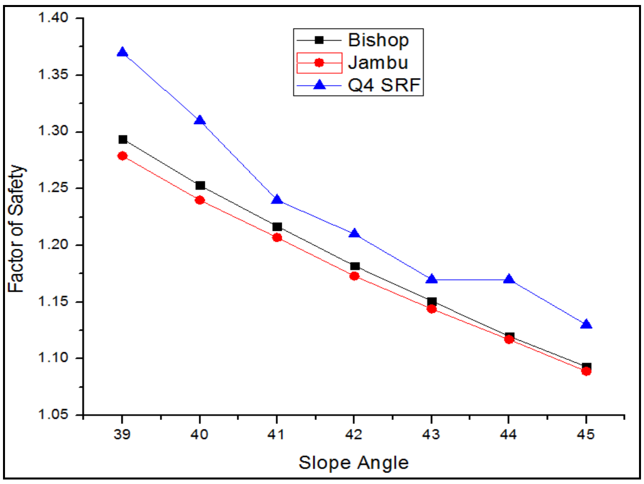

Figure 7: Shows the Factor of Safety values for LEM and FE (Q4) against slope angles

4. Results and Discussion

To some extent, Limit Equilibrium Methods can still be used traditionally to calculate the Factor of Safety and as a complementary to Finite Element Method which has recently evolved due to high computer performances on the market. In this case, the results obtained in Table 1 and in Figure 6 and 7 show close correlations between Limit Equilibrium Methods and Finite Element Method.Based on the results, Chingola COP FD slope geometrycan still be adjusted upwards (the slope angle utmost to 44° but 42° could be more ideal) to achieve the objective of reducing waste mining while maintaining the Pit Slope stable. The upper stack angle should be maintained within the range 30 to 36 degrees with the bench angle maintained within 60 to 65 degrees and the lower stack angle within the range 47 to 50 degrees with bench angle within 70 to 75 degrees depending on the overall slope angle. The localized bench scale failures that may be caused by poor blasting and the presence of the inherent discontinuities might occur but that could easily be managed by putting up operations stringent measures like water control, enforce blasting control standards, slope cutting where necessary and to reorient the design to avoid the effects of discontinuities on the pit slope. However, certain localized bench scale failure must be traded off and be managed by clean ups activities to maintain the minimum production costs otherwise costs of operations would be high if stripping ratio goes up.

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