Stability Analysis of Hongsa Coal Mine's Pit Walls, Xaignabouli Province, Laos PDR

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ABSTRACT

The slope stability analysis is an important requirement for routine geotechnical safety design prior to mine operation especially for the open-pit mine because of its significant influence on mine's operability, productivity and longevity. Hongsa coal mine in Lao PDR is situated in the Tertiary basin filled with a series of semi- to unconsolidated deposits of sands, silt, clays, and organic strata. The Hongsa coal mine may potentially be vulnerable to slope failure because current pit walls' slope design was based on limited soils' strength parameters. However, as the mining operation progresses deeper, pit's slope should be redesigned based on updated soil's engineering properties. This research attempts to analyze pit's slope stability based on newly determined soils' engineering properties using simplified Bishop's limit equilibrium method. The results indicate that under dry condition, the pit's slope is stable with the minimum factor of safety is 1.787. However, when pit's slope becomes saturated water with increasing unit weight and decreasing soils' shear strength, the slopes become more vulnerable to failure with the minimum factor of safety of 0.864. This finding indicates mitigation measures such as slope water drainage system should be implemented to avoid slope failure during wet season.

Keywords: Hongsa Coal Mine, Slope Stability, Safety Factor

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Introduction

Slope failure, slope instabilities or landslide are phenomena of the soil movement which impacts serious damage in mining activity. Slope failure occurs when the downward movements of material depend on geologic condition, loss of soil strength, external loads and pore water pressure (Prakash, 2009). Therefore, different processes can lead to the reduction in the shear strengths of soil mass, increased pore pressure, cracking, swelling, leaching and strain softening. In addition to these reasons, other factors contributing to failure of slope include properties of rock mass, slope geometry, state of stress, temperature and erosion (Duncan, 2014).

The Hongsa coal deposit, which is recognized as one of Lao's major energy resources, is located in the north-western region of Lao PDR. It is located near the village in Muang Hongsa, Xaignabouli province (see Figure 1). The basin's shape structure, strata dipping and fault systems altogether may impact geotechnical stability of pit walls. Thus, slope stability analysis based on detailed geological and geotechnical surveys are essential in designing slope and necessary support systems. Slope stability analysis can be done using either limit equilibrium (balance of moments) or finite element methods (Aryal, 2006). The finite-element method is a more powerful computational tool due to the ability to simulate physical behaviors without the need to simplify the problem especially when soils or rocks have heterogeneous properties but it requires detailed information of the outcrops. The limit equilibrium, on the other hand, is widely used because it simplifies the analysis where failure can occur due to moment imbalance. This research aims to preliminarily assess the stability of the open-pit walls of the Hongsa coal mine based on the updated engineering properties of soils from new borehole surveys. The result of this analysis can be used to recommend mitigation measures or implement the appropriate support systems.

Figure 1 The location of study area (modified from Laos PDR political map, 2003)

Objective of the study

This research aims to analyze slope stability of soil mass on Hongsa coal mine's pit walls based on simplified Bishop's limit equilibrium method (Bishop, 1955) and updated soils' engineering properties, and to evaulate the suitaility of existing design for both dry and wet conditions.

Methodology

Slopes in Hongsa Coal Mine and Engineering Properties of Soil Masses

Hongsa open-pit mine was previously analyzed for their instabilities using borehole and site investigation data (EGAT, 2009). The plane failure was obtained by using lower-bound residual shear strength whereas the circular failure was obtained by using mean residual shear strength. It is unfortunately still unclear which method(s) of slope analysis was employed to obtain failure mechanisms of pit walls presented in EGAT (2009). Slopes in Hongsa open-pit mine can be subdivided into 7 sections (Figure 2). In this study we analyzed slope stability in section No.2 which was reported in EGAT (2009) to be the steepest slope with the least stability.

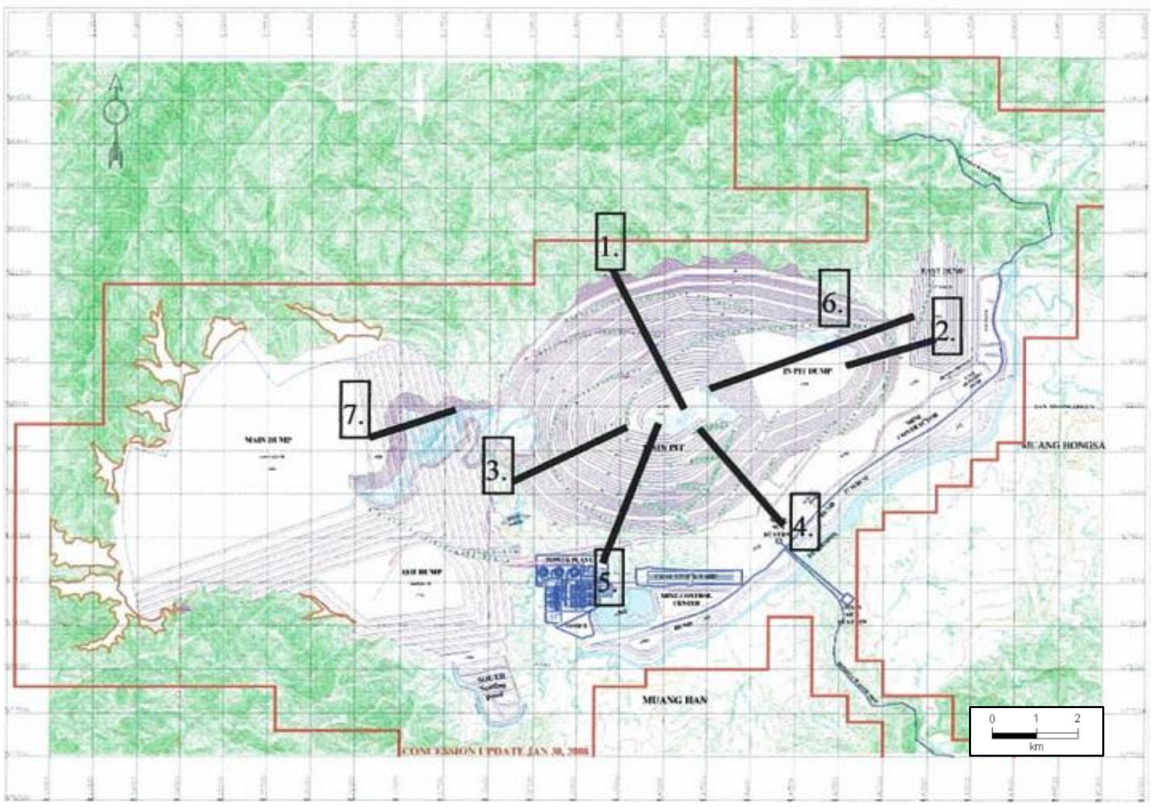


Figure 2 Cross-section lines to slope stability analysis in Hongsa area (EGAT, 2009).

Hundreds of soil samples from boreholes were analyzed in laboratory for shear strength (direct shear test), Young modulus (uniaxial compression test), unit weight, and grain size distribution. Based on soil types, the samples were classified in to 6 categories and some of their important engieering properties are also listed in Table 1.

Table 1 Soils' engineering properties obtained from laboratory test.

Soil Strata	Soil Types	Unit Weight, γ (t/m^3)		Cohesion, c (kPa)		Frictions Angle, ϕ (°)	
		Range	Average	Range	Average	Range	Average
S1	Soft clay	1.81-2.17	2.01	19.5-42.4	29.8	9.7-22.7	16.2
C1	Coal Seam 1	1.15-1.63	2.08	48.9-71.6	46.8	9.8-11.1	15.3
S2	Stiff Clay	1.62-2.26	1.60	18.9-74.5	34.1	10.5-21.1	17.9
C2	Coal Seam 2	1.33-1.77	2.11	12.5-51.6	43.9	12.7-26.5	16.8
S3	Stiff Clay	1.92-2.24	1.58	24.3-74.1	67.6	13.5-19.7	26.3
S4	Stiff Clay	1.94-2.36	2.21	29.4-74.9	51.3	10.8-26.3	19.0

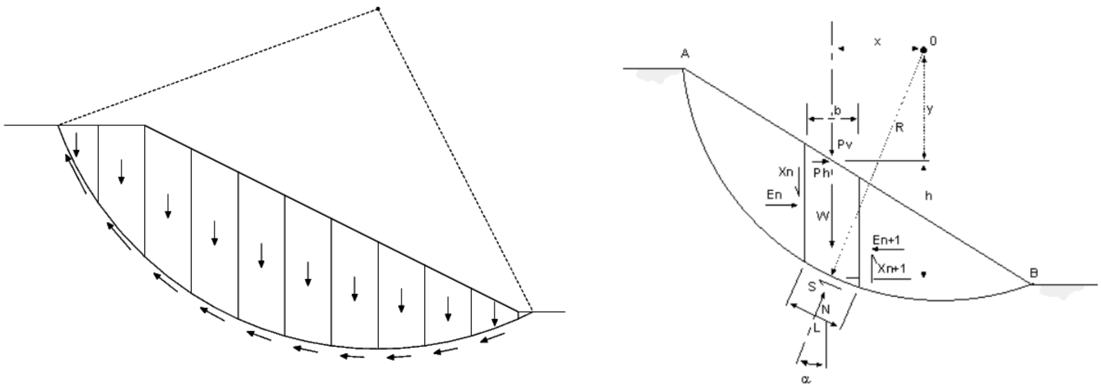
Stability Analysis

This study employed simplified Bishop's method (Bishop, 1955) which is based on the limit equilibrium method (LEM). The method assumes that soil is rigid-plastic; which means that is no strain at any point until the failure occurred. A stage of limit equilibrium is related by Mohr-Coulomb failure criterion (Ritthison, 2004). In the LEM method, the factor of safety (*F.S.*), which is a factor by which the shear strength of the soil would have to be divided to bring the slope into a state of barely stable equilibrium (Duncan, 1996), is defined as follows:

$$F.S. = \frac{\text{Shear strength of soil}}{\text{Shear stress required for equilibrium}}$$

The shear stress at the slip surface or τ is defined by $\tau = \tau_f / F.S. = (c' + \sigma' \tan\phi')/F.S.$, where σ' is effective normal stress at the slice of the slip surface, c' and ϕ' are the cohesion and internal friction angle, respectively.

The method of slice for stability analysis is based on the LEM method but the soild domain is analyzed by dividing the sliding mass into a number of vertical slices (Figure 3). The factor of safety is calculated by the summation of all moments acting all slices. This study used a software OASYS (2015) to analyze slope stability of the pit wall No.2 (see Figures 2 and 4).



(a) slope is divided into slices. (b) each slice has forces aciting on it.

Figure 3 The method of slice based on the LEM method (Oasys, 2015).

The studied slope (No. 2) has a current maximum height of 125 m (measured from pit floor) extending over a distance of approximately 500 m and its slope angle is close to 45°. Cross-section of the slope is illustrated in Figure 4. The stability analysis will be conducted under both natural condition (moisted soils) and under the conditions where water content increases to full saturation (as well as the decrease of soil's shear strength) which is considered to be a worst-case scenario.

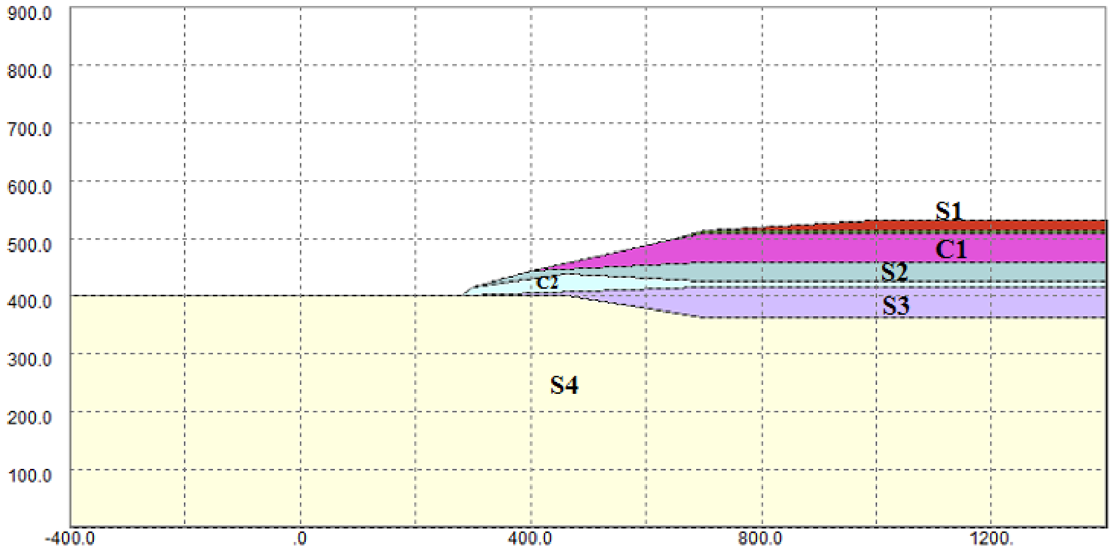


Figure 4 Geometry of slope No.2 used to analyze its stablility by Oasys software (horizontal axis is shown in local coordinate in meter; vertical axis is measured elevatioin in m above mean sea level).

Results and Discussion

The analysis of slope stability was divided into two cases: current soil conditiion (dry condition) and wet condition. Under dry condition, the stability of pit walls' slope is considered to be safe with the minimum factor of safety of 1.787. Figure 5 shows several possible circles (varying radii and centers) of the analysis and none has shown vulnerability to failure. When the moisture or water content of the soil materials increases as a result of precipitiation which results in the decrease in effective stress and hence shear strength, the stability analysis shows that pit's slope becomes more vulnerable to failure with the minimum factor of safety in saturated water condition is 0.864 as shown in Figure 6.

The analysis agrees with theoretical consideration where the presence of water in pore space can reduce effective stress of the soil materials and, hence, the apparent shear strength of soils is reduced causing the possiblity of the failure. This analysis however oversimplifies the problem by assuming that the slope materials' behavior is similar to soils. This may not always be the case for deep geologic materials because some of the materials have been solidified and compact and should bear some engineering properties or behavior similar to rocks. Nevertheless, this simply analysis indicated that, for worst-case scenario, the pit's slopes could be subjected to failure. Further investigation is underway to analyze the slope stability more comprehensively by using a finite-element method which does not oversimplify the problem and major cracks, joints, and fractures can be incorporated in the analysis.

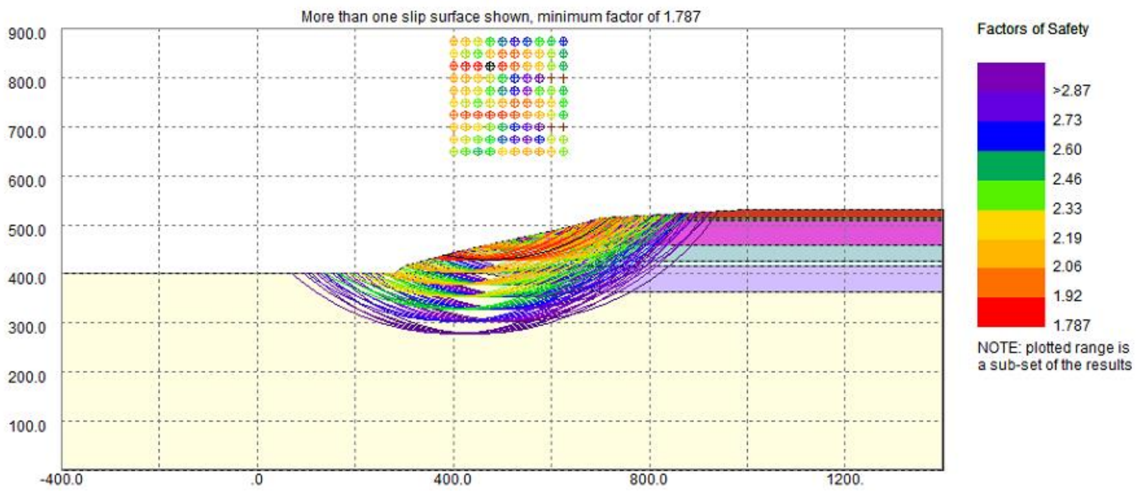


Figure 5 Failure surface profiles before excavation in dry condition with the minimum factor of safety 1.787.

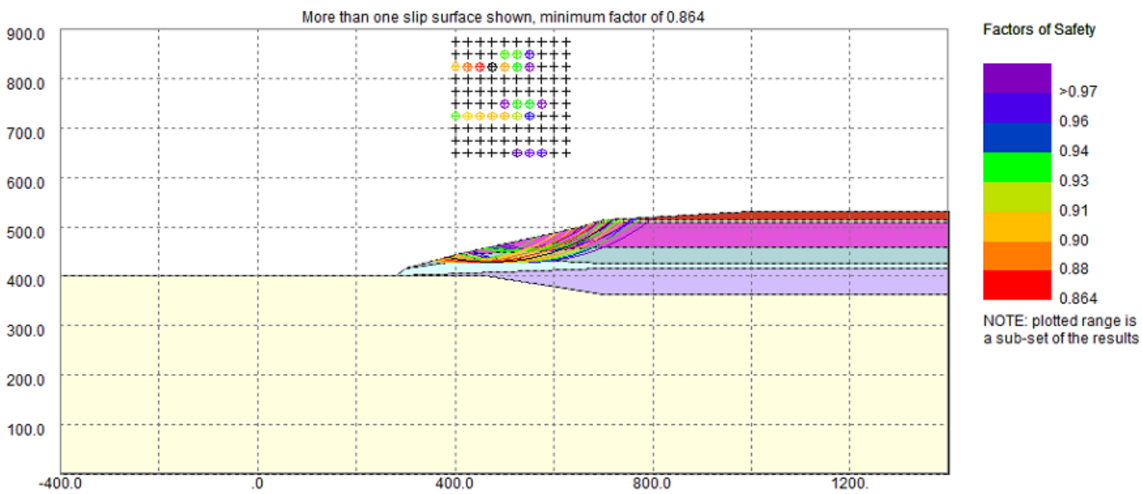


Figure 6 Circular failure surface profiles under saturated conditions (i.e., decreasing of shear strength accordingly) with the minimu, factor of safety of 0.864.

Conclusions

The soil's slope stability analysis of the Hongsa Coal Mine pit walls based on updated engineering properties with the use of simplified Bishop's limit equilibrium method found that (1) under current (relatively dry) condition, pit wall was stable with minimum factor of safety of 1.787, and (2) under saturated conditions when soil's unit weight increases and shear strength decreases, pit wall became vulnerable to failure with minimum factor of safety of 0.864. This, worst-case scenario, finidng cautions geotehnical engineers to be concerened about the safte and, hence, should re-design the slopes of the mine. Future work will include the use of finite-element method for a more comprehensive analysis of slope stability which should be more realistic since it does not oversimplify the behavor or the soil/rock materials.

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