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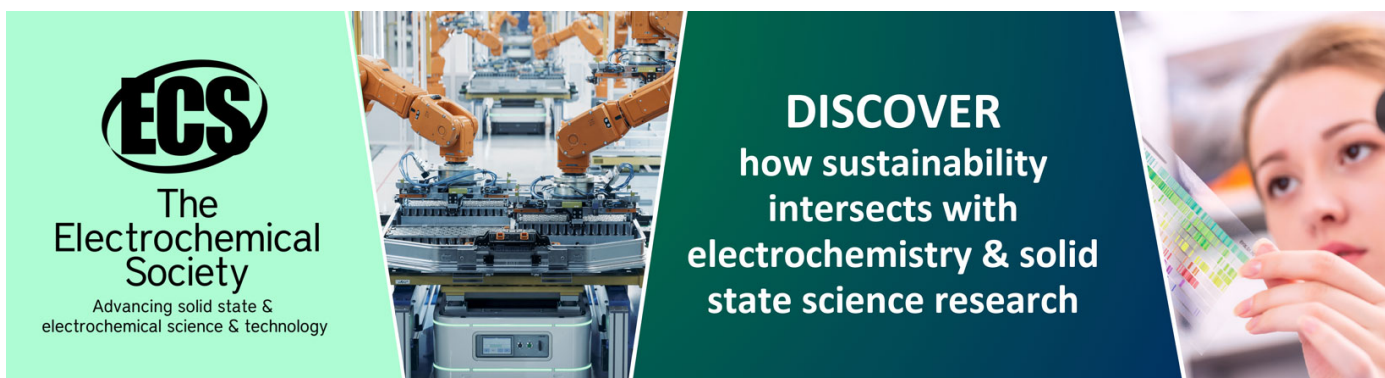
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Slope Stability Analysis Under a Complex Geotechnical Condition - A Case Study

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Abstract. Slope failures in a mining project will contribute to significant safety impacts and economic losses. Therefore, it is imperative for mining engineers to analyse and design an open pit mine considering safety purposes. In this study, a limit equilibrium method using GeoSlope-Slope/W program was used to investigate the stability of an open pit mining slope for a proposed mining activity based on a case study in Tanjung Enim, District of Muara Enim, Province of South Sumatera - Indonesia. The results of this study reveal that the slope design for the proposed mining activity is technically not in stable condition due to the shear force of the slope is higher than its shear strength. Such mechanism occurs due to the existence of a complex geotechnical condition beneath the surface, such as faults and discontinuities, which then lead to the reduction of slope strength. Having an inapplicable proposed slope design, this study proposes a re-design of slope for safety purposes in order to support the future mining operation. The analysis approach proposed in this study can be a viable alternative to assess the stability of slopes in any mining operation when a complex geotechnical condition exists.

1. Introduction

Slope stability analysis forms a critical part of any open pit mining operations during the life cycle of a mining project. Earlier studies present that the analysis and assessment of slope stability should be considered in an open pit mine operation [1]. Also, the previous extensive study reveals that slope failures in a mining project will contribute to significant safety impacts and economic losses [2–4]. Therefore, the slope stability analysis is imperative to be investigated before implementing an open pit project in a permitted mining area.

The case study of this project is located at the East Site of Tambang Air Laya (TAL), a mining operation site run by PT Bukit Asam, Persero, Tbk. The proposed mining operation at the project site was to excavate various lithology from the depth of 57-meters above sea level down to the lowest depth of -128 meters, which will form various multiple open pit slopes. From geological aspects, the geological structures at the mining site consist of various joints and normal faulting having a radial pattern due to intrusion in the subsurface. The effect of such subsurface intrusion resulted in the existence of various continuous faults at the bottom side of existing coal and rock layers. Having such complex of geotechnical and geological condition, the slope stability analysis for the proposed mining activity is a very critical aspect to be assessed in order to ensure that the proposed mining operation will be carried out in a proper manner considering safety purposes. This is according to the earlier studies' results stating that the complexity of a geological and geotechnical condition may control the



behaviour of rock and soil that can lead to a slope failure in a mining project [5–6]. Based on the problem statement, the current study aims to investigate and optimise the stability of the proposed slope design in order to propose an optimal final slopes design for the proposed mining activity.

Earlier studies mainly focus on analysing the stability of an open pit mining slope without giving any alternative should the slope stability analysis results present that the slope is not safe [1–3]. The current study will not only focus on slope stability analysis aspect but will also propose an optimal design of slope for safety purposes in order to support the proposed mining operation given by the company. A cross-section representing the field condition was selected for analysis purpose. The Geo Slope-Slope/W program was used as a computational analysis tool due to its simplicity, and this program has been widely accepted in various slope stability analyses for the mining operation.

2. Case Study Description

2.1. Location and Accessibility

The current study is focussed on the East site of Tambang Air Laya (TAL), one of the mining operation sites operated by PT Bukit Asam, Persero, Tbk. It is geographically located in Tanjung Enim, District of Muara Enim, Province of South Sumatera, Indonesia. As shown in Figure 1, the distance from the Capital city of South Sumatera Province, Palembang to the project site is around 150 km and can be reached by terrain transportation in approximately four to five hours.

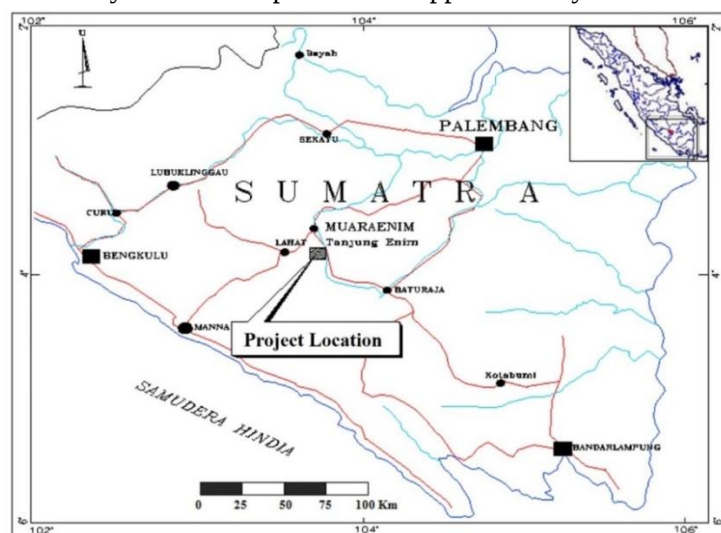


Figure 1. Location of the project site.

2.2. Local Geology

The geological structures at the mining site include various joints and normal faulting having a radial pattern due to intrusion in the subsurface. The effect of such intrusion also resulted in the existence of various continuous faults at the bottom side of the existing rock layer (Figure 2).

The formation distribution at the project site follows the subsurface rock formation with a general direction from north to south at an angle of 15 to 20 degrees. The previous study identifies the three main intrusive bodies near the Air Laya and Suban mining operation, namely: Bukit Asam dyke, Suban sill and a vertical parasitic cone to the west of Air Laya Dome [8]. The Bukit Asam dyke was found to be the largest intrusive body, and its outcrop forms a hill. The presence of the andesite intrusion in the Bukit Asam area has resulted in locally change the rank of the coals [9]. These coal seams can be classified into medium-volatile bituminous to anthracite coals [10].

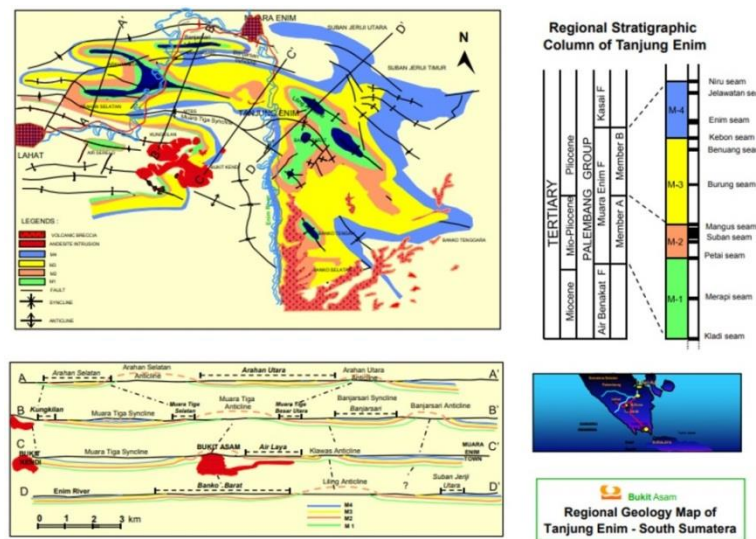


Figure 2. Regional geology map of Tanjung Enim, South Sumatera.

3. Methodology

The methodology used in this study involves three main works, including field investigation, data collection and data analysis. The three main works and their details are described in the subsequent sections.

- 1) A field investigation was conducted to assess the slope geometry and identify the lithology of the project site. The individual slope has a height and angle of 9 meters and 45 degrees, respectively, with a total overall slope height of 184 meters. The lithology at the project site was identified by assessing borehole information from fifteen exploration borehole data.
- 2) Data collection was conducted to obtain the required input data parameter for the analysis. The required data for the current study is the geometry of the proposed open pit slope (height and angle of slopes and berm width), physical and mechanical properties of soil and rock, water level condition, and normal load caused by the weight of mining equipment. The physical and mechanical properties data were obtained from the laboratory analysis results for various soil and rock samples from fifteen exploration boreholes.
- 3) The slope was assumed to be at the fully saturated condition in order to obtain the most conservative analysis results, while the normal load for the weight of equipment was identified to be 600 kN/m². The representative cross-section for the proposed open pit slope design and required input data parameters be shown in Figure 3 and Table 1, respectively.

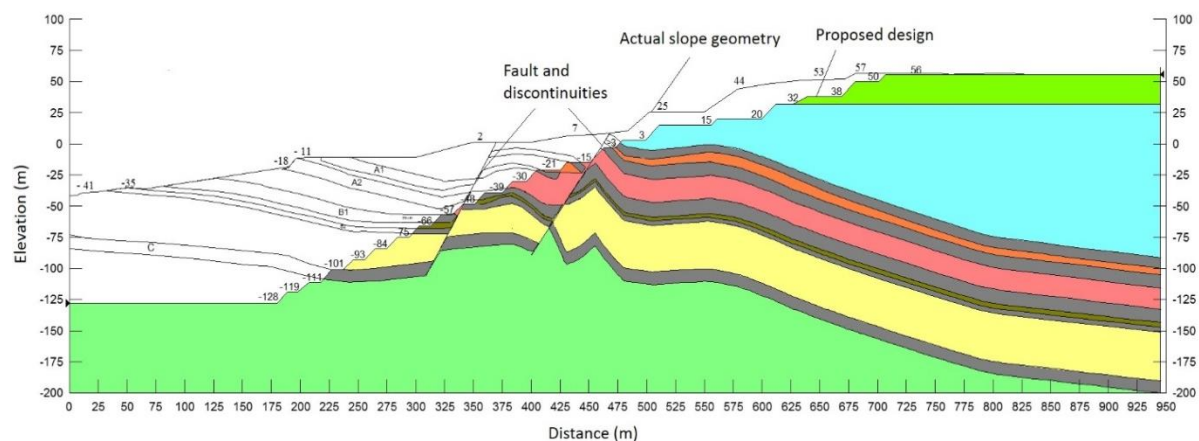


Figure 3. A typical representative cross-section for the proposed mining operation.

- 4) After all required input data parameter for analysis are obtained, slope stability analysis was performed using the Limit Equilibrium Method in GeoSlope/Slope-W program. This program was selected for this study due to its simplicity, and it has been globally accepted for analysing the stability of various open pit mining slopes. The output of the analysis is a factor of safety, which defined as the ratio of the shear strength to the shear stress required for equilibrium. For this study, the minimum required mining safety factor is 1.25, standardised by the Geotechnical Department of PT Bukit Asam (Persero) Tbk.

Table 1. Physical and Mechanical properties of rock strata, Bali [7].

Lithology	Density (kN/m ³)	Cohesion (MPa)	Friction angle (degree)
Top soil	19.5	37.2	12
Overburden	20.2	79	23
Coal layer (A1)	11.3	64.8	25
Interburden A1 - A2	20.7	132.2	30
Coal layer (A2)	11.9	64.8	25
Interburden A2 - B1	21.7	114.1	26
Coal layer (B1)	12.1	64.8	25
Interburden B1 - B2	22.2	62.2	25
Coal layer (B2)	11.9	64.8	25
Interburden B2 - C	22.2	144.5	27
Coal layer (C)	13.7	64.8	25
Underburden C layer	22.4	86.1	22

Note: Interburden layers is the lithology located in between two coal seam layers.

4. Results Analysis and Discussion

4.1. Results Analysis

Scholarly literature presents that the predicted safety factor of 1.5 indicates a high safety condition of a slope [11]. The possibility for slope to fail is high when the predicted safety factor is close to 1.0 [12]. For this study, the minimum safety factor for slope to be considered in technically safe condition is 1.25, based on the standard operation guideline given by the geotechnical department team of PT Bukit Asam (Persero) Tbk.

The slope stability analysis results for this study are shown in Table 2. From the analysis results showing on Figure 3, it can be noted that the factor of safety from the depth of 56-meters down to the depth of -15-meters sea level is 1.436, which account for 71-meters height of multiple slopes, while the safety factor from the depth of -15 meters to -128 meters sea level is 1.0. The predicted overall slope safety factor is 1.018. In other words, the top portion of the proposed open pit slopes from the depth of 56-meters down to the depth of -15-meters sea level is predicted to be in stable condition. However, the analysis results reveal that the bottom portion of the proposed open pit slopes from the depth of -15 to -128 meters sea level is not in stable condition due to the shear strength of the slope is lower than its shear force, which than lead to a low safety factor.

Table 2. Slope stability analysis results for the proposed mining activity.

Slope Geometry				
Height (meter)	Slope angle (degree)	Maximum altitude (meter)	Minimum altitude (meter)	Predicted safety factor (SF)
71	15	56	-15	1.436
113	24	-15	-128	1.000
184	19	56	-128	1.018

This study found out that the mechanism leading to a low safety factor for the bottom portion of the open pit is due to the presence of faults and discontinuities. Faults and discontinuities persistence reduce the shear strength of the slope formation, which then leads to the reduction of slope shear strength. This study concludes that the critical horizon where a slope could fail is concentrated at the slope horizon where a complex geologic structure, such as faults and discontinuities, exist.

Since the analysis results reveal that the proposed mining activity is in the high possibility to fail especially at the bottom part of the proposed slope design, a redesign of slopes for safety purposes is required. This step should be considered in order to ensure that the future mining operation will be carried out in a proper manner considering safety purposes.

4.2. Re-design of Slopes for Safety Purposes

The general pit slope design rules presented by Hoek and Bray [13] is that the ultimate objective of an open pit slope design is to achieve an optimum design, which should compromise between a slope that is steep enough to be economically acceptable and one which is flat enough to be technically safe. Both design aspects should be considered when designing a slope for a mining operation. The approach for re-design of slopes for this study is to design the slope to be flat enough for safety purposes as proposed by Hoek and Bray [13].

Based on the results of slope stability analysis, the slope design, especially in the bottom part of the overall slope height, is technically not stable due to the existence of fault and discontinuities, which then lead to a low predicted safety factor. Therefore, it is imperative to re-design the current proposed slope design in order to support the future mining operation. The re-design of for safety purpose is presented in Figure 4.

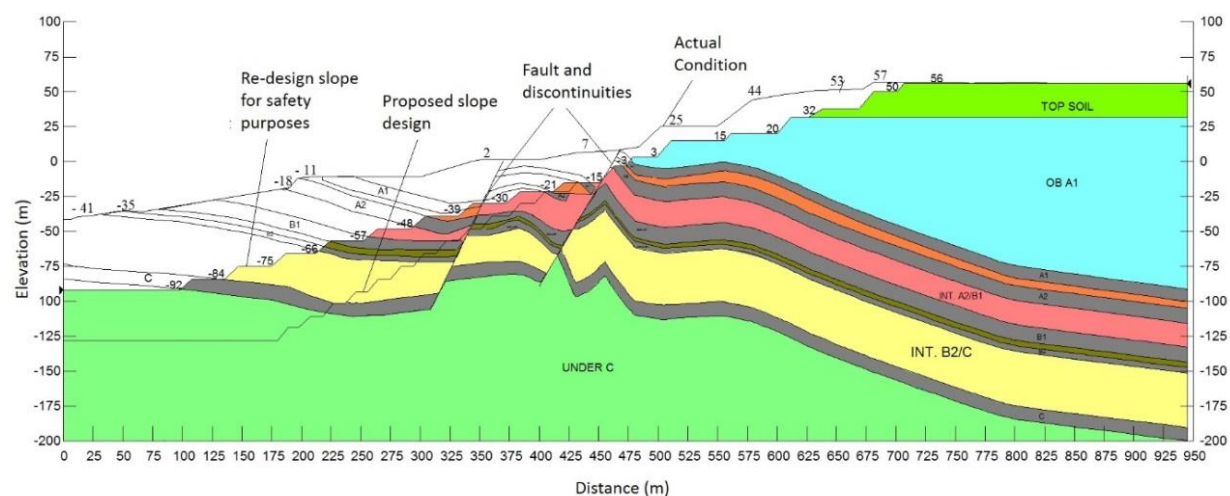


Figure 4. A typical cross-section for the re-design of overall slope geometry.

The stability analysis result for the re-design of the slope is shown in Table 3. From the analysis results shown in Figure 4, it shows that after re-design slope is made, the predicted factor of safety for the overall slope is increased to 1.388, while the predicted factor of safety for the top and bottom side of the overall slope height is 1.436 and 1.360, respectively. Therefore, it can be concluded that the proposed re-design slope is technically stable for the proposed mining operation. This study suggests that even though the re-design of slope approach proposed in this study will reduce the target of production of the company, but this approach still can be implemented for the safety of mining workers and equipment purposes.

Table 3. Slope stability analysis results for the proposed re-design of overall slope height.

Slope Geometry				Predicted safety factor (SF)
Height (meter)	Slope angle (degree)	Maximum altitude (meter)	Minimum altitude (meter)	
71	15	56	-15	1.436
77	13	-15	-92	1.360
148	14	56	-92	1.388

5. Conclusion

In the current study, a Limit Equilibrium Method in GeoSlope-Slope/W program was used to investigate and optimise the proposed open pit slopes design, based on a case study in Tambang Air Laya mining Site, South Sumatera, Indonesia.

This study reveals that the critical horizon where a slope could fail is concentrated at the slope horizon where a complex geologic structures such as faults and discontinuities exist. In addition, it was assessed that the slope design for the proposed mining operation cannot be applied for future mining operation due to the proposed open pit slopes from the depth of -15 to -128-meters sea level is technically not in stable condition. This happen due to the shear strength of the slope is lower than its shear force, which then lead to a low safety factor. Such mechanism occurs due to the existence of faults and discontinuities in the subsurface at the mining site which than lead to the reduction of the shear strength of the slope. Due to having an inapplicable slope design for the proposed mining operation, a re-design of slope approach was proposed and its analysis was performed accordingly in order to ensure that the future mining operation will be carried out in a proper manner considering safety purposes.

The main significance of this study is that it not only proposes an analysis approach for assessing the stability of slopes for the case study, but it can also be used for other similar projects where a complex geotechnical condition such as faults, discontinuities and folds exist and require a geotechnical investigation and assessment for mine safety purposes.

6. Reference

- [1] Satyanarayana. I., Budi. G., Sen. P., & Sinha, A.K. (2018). Stability Evaluation of Highwall Slope in an Opencast Coal Mine - A Case Study. *AMSE JOURNALS - AMSE IIETA publication*. Vol. **78**, 253-273. Retrieved from http://iieta.org/sites/default/files/Journals/MMC/MMC_C/78.03_01.pdf.
- [2] Kumar. V, and Parkash. V. (2015). A Model Study of Slope Stability in Mines Situated in South India. *Pelagia Research Library - Advances in Applied Science Research*, **6** (8), 82-90. Retrieved from <http://www.imedpub.com/articles/a-model-study-of-slope-stability-in-mines-situated-in-south-india.pdf>.
- [3] Bye. A. R., & Bel. F. G (2001). Stability assessment and slope design at Sandsloot open pit, South Africa. *International Journal of Rock Mechanics and Mining Science*, Vol. **38**, 449-466. Retrieved from www.elsevier.com/locate/ijrmms.
- [4] He. M. C. Feng. J. L., & Sun. X. M. (2008). Stability evaluation and optimal excavated design of rock slope at Antaibao open pit coal mine, China. *International Journal of Rock Mechanics and Mining Science*, Vol. **38**, 289-302. doi:10.1016/j.ijrmms.2007.05.007.
- [5] Al-saadi. S. N., Hijab. R. B. and Ajjothari. J. H. (2007). The Relationship between Geological Structure and Failure Type in the Rock Slopes of Parts of Anah Monocline, West of Iraq. *Journal of Kirkuk Universit-Scientific Studies*, Vol. **2**, 1-16. Retrieved from <https://www.iasj.net/iasj?func=fulltext&aId=43432>
- [6] Fleurisson. J. (2012). Slope Design and Implementation in Open Pit Mines: Geological and Geomechanical Approach. *Procedia Engineering*, Vol. **46**, 27-38. doi: 10.1016/j.proeng.2012.09.442

- [7] Bali, B. A. M. (2013). Analisa Kestabilan Lereng Rencana Penambangan Pada Desain Geometri Lereng Rencana Penambangan di PT. Bukit Asam Unit Pertambangan Tanjung Enim Site Tambang Air Laya (TAL) Ekstension Sisi Timur Sumatera Selatan. *Bachelor Degree Thesis submitted to Mining Engineering Department at Insitut Teknologi Adhi Tama Surabaya*.
- [8] Pujobroto, A. and Hutton, A.C. (2000). Influence of andesitic intrusions on Bukit Asam coal, South Sumatra Basin Indonesia. *Proceedings of Southeast Coal Geology Conference, Directorate General of Geology and Mineral Resources of Indonesia, Bandung*, 81-84.
- [9] Santoso, B. and Daulay, B. (2005). Coalification trend in South Sumatra Basin, *Proceedings Joint Convention Surabaya, The 30th HAGI, The 34th IAGI and The 14th PERHAPI, Annual Conference and Exhibition, JCS2005-M004*.
- [10] Amijaya, H. and Littke, R. (2006). Properties of thermally metamorphosed coal from Tanjung Enim area, South Sumatra basin, Indonesia with special reference to the coalification path of macerals. *International Journal of Coal Geology*, Vol. **66**, 271-295.
- [11] Islam, M. R., & Faruque, M. O. (2013). Optimization of slope angle and its seismic stability: A case study for the proposed open pit coal mine in Phulbari, NW Bangladesh. *Journal of Mountain Science*, Vol. 10(6), 976-986. doi:10.1007/s11629-012-2483-6.
- [12] Wyllie, D. C., & Mah, C. W (2004). Rock slope engineering: Civil and mining 4th edition. London: Spon Press. Retrieved from <https://www.google.com/search?q=ISBN+0-203-57083-9&ie=utf-8&oe=utf-8#>
- [13] Hoek, E. and Bray J.W. (1981). Rock Slope Engineering, The Institute of Mining and Metallurgy, London, 3rd edition.