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ANALYSIS OF SIDEWALL SLOPE STABILITY USING THE BISHOP METHOD AT PT BATU HITAM JAYA, JAMBI PROVINCE

ANALISIS KESTABILAN LERENG SIDEWALL MENGGUNAKAN METODE BISHOP PADA PT BATU HITAM JAYA, PROVINSI JAMBI

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ABSTRACT

A slope failure occurred at the lowest bench of the open-pit coal mine operated by PT Batu Hitam Jaya in Jambi, Indonesia, in early February 2025. The failure, measuring 16 meters wide, 5 meters high, and sloped at 38°, critically impacted an access road to the disposal area, disrupting operations and escalating safety risks. This failure disrupted mining operations and increased safety risks, highlighting the need for slope stability analysis to evaluate the safety of the existing slope design and to prevent recurrent failures. This study aims to identify the geotechnical parameters of the sidewall material, analyze the stability of the existing slope, and propose a safer slope redesign. Slope stability analysis was conducted using Rocscience Slide software based on the Mohr–Coulomb failure criterion and the Bishop Simplified method, which was selected due to its effectiveness in evaluating slopes with circular potential failure surfaces in open-pit mining conditions. The critical failure surface was determined using the Grid Search method. Initial analysis revealed Factor of Safety (FoS) values of 0.927 and 0.942, confirming the slope's unstable condition. Following a geometry redesign, the FoS values successfully increased to 1.302 and 1.244. These enhanced values classify the slope as significantly more stable and safe, ensuring reliable support for ongoing mining operations.

Keywords*:* slope stability, safety factor, coal mining, bishop method

ABSTRAK

Pada awal Februari 2025, PT Batu Hitam Jaya, sebuah tambang batubara terbuka di Kabupaten Batanghari, Jambi, mengalami kegagalan lereng kritis pada bench terendah. Kelongsoran tersebut, yang memiliki lebar 16 meter, tinggi 5 meter, dan kemiringan 38°, terjadi tepat pada jalur akses menuju area disposal, yang secara langsung mengganggu operasi dan meningkatkan risiko keselamatan. Kondisi ini mengganggu operasional tambang dan meningkatkan risiko keselamatan, sehingga diperlukan analisis kestabilan lereng untuk mengevaluasi keamanan desain lereng eksisting dan mencegah terjadinya kegagalan berulang. Penelitian ini bertujuan untuk mengidentifikasi parameter geoteknik material sidewall, menganalisis kestabilan lereng eksisting, serta merekomendasikan desain ulang lereng yang lebih aman. Analisis kestabilan lereng dilakukan menggunakan perangkat lunak Rocscience Slide dengan kriteria keruntuhan Mohr–Coulomb dan metode Bishop Simplified, yang dipilih karena efektif dalam menganalisis lereng dengan potensi bidang gelincir melingkar pada tambang terbuka. Bidang longsor kritis ditentukan menggunakan metode Grid Search. Hasil awal menunjukkan nilai Faktor Keamanan (FK) lereng yang rendah, yaitu 0,927 dan 0,942, menggolongkannya sebagai tidak stabil. Setelah dilakukan perancangan ulang geometri, nilai FK berhasil ditingkatkan menjadi 1,302 dan 1,244, sehingga lereng tersebut kini dianggap lebih stabil dan aman untuk mendukung kegiatan operasional tambang.

Kata kunci: *stabilitas lereng, faktor keamanan, tambang batubara, metode bishop*

INTRODUCTION

Coal mining is one of the strategic sectors in meeting national energy needs. As the demand for this fossil energy continues to increase, open-pit mining activities have become more widespread, as this method is considered more efficient for accessing coal reserves located near the surface [1]. However, open-pit mining operations come with their own challenges, particularly concerning occupational safety and slope stability. One of the most significant risks in open-pit mining is slope failure, which can result in major losses, including threats to human safety, damage to heavy equipment, and disruption of mining operations [2]-[4].

Improper slope geometry design that does not align with the geotechnical conditions in the field is one of the main causes of slope failure [5]. Therefore, slope design must take into account several factors, such as the type of soil and rock material, slope geometry, and applicable safety regulations [6]. One of the key references in this regard is the Official decree from the Ministry of Energy and Mineral Resources, No. 1827 K/30/MEM/2018, which provides technical guidelines for Good Mining Practice, including slope stability aspects [7].

Similar research was conducted by Rusni, et al. (2019). The results from research indicate that the current design of the southern sidewall slope does not satisfy stability requirements, thereby necessitating a redesign. The revision was achieved by reducing the overall slope angle through crest setback, decreasing the height of each bench, and increasing the bench width [8]. Research by Santo Frans, et al. (2019) about the groundwater level shows an inverse relationship with the Factor of Safety, where a rise in the water table increases slope vulnerability to failure and results in a lower safety factor. Therefore, the recommended mitigation measure is to implement a dewatering system using drain holes, with the target of lowering the groundwater level to RL +40 in the sidewall area and RL +65 in the highwall area [9]. Antoher study by Santoso, et al. (2025). This study aims to design the slope angle of an open-pit coal mine located in the old surface area of the Mahakam Delta using the Finite Element Method. The research methodology combines limit equilibrium analysis and slope failure probability assessment. The geological materials present in the study area include topsoil, gravelly sandstone, siltstone, claystone, and coal [10].

PT Batu Hitam Jaya is one of the companies operating an open-pit coal mine in Jambi Province. The bench road, with a width of 10 meters, functions not only as a working area but also as an access road to the disposal area. However, field conditions showed that a slope failure occurred on this bench in early February 2025. The failure significantly disrupted mining operations by reducing safety levels.

The presence of slope failure on the bench, which also serves as a critical access route, demands an evaluation of both the design and the actual condition of the slope. The existence of a road above a previously failed slope increases safety risks if slope instability, such as landslides, occurs again. Therefore, a redesign of the slope geometry is necessary, taking into account technical factors such as soil and rock characteristics, slope angle, bench height, and relevant regulations.

Based on the above explanation, this research aims to analysis sidewall slope stability using the bishop method. This study focuses on the sidewall at Pit B2, where a slope failure occurred at a specific location that also serves as the main haul road for loading and hauling equipment traveling to the disposal area. Although slope stability studies have been widely carried out, the uniqueness of this research lies in the fact that the failure took place directly beneath an active access road. The slope geometry at this location is continuously subjected to heavy traffic from excavators and hauling trucks, as well as persistent vibrations generated by their movement. Therefore, this research not only examines the technical aspects of slope stability, but also considers the influence of the unit load imposed by the loading and hauling equipment that regularly passes over the slope. In addition, economic factors are taken into account, as any necessary slope remediation would inevitably disrupt mining production activities at the company. The results of this study are expected to contribute to improving workplace safety and operational efficiency in mining activities.

RESEARCH METHODOLOGY

This research was carried out at the time and place determined beforehand. The location used for obtaining data related to this study is PT Batu Hitam Jaya, Jambi. The journey to the site from Palembang can be taken via the main road passing through Pangkalan Balai, Betung, then through Sungai Lilin, Bayung Lencir, Kota Baru, Muara Bulian, and finally reaching Batanghari.

Regional Geology

PT Batu Hitam Jaya applies the strip-mining method, selected due to its efficiency in minimizing operational risks and optimizing production costs. The geological formation in this area is the Muara Enim Formation, which serves as a key stratigraphic unit for coal mining activities. The Muara Enim Formation is widely recognized as one of the primary coal- bearing formations within the South Sumatra Basin. Its dominant lithology consists of mudstone, sandstone, and multiple coal seams that form the main targets for extraction [11].

Stratigraphy

In general, the stratigraphy of this pit consists of a surface layer of soil, followed by a dominant clay unit,

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and two coal seams that serve as the main mining targets.

The uppermost layer consists of approximately 2 meters of brown, loose soil that is typically removed and stockpiled for post-mining reclamation purposes [12]. Beneath this layer lies about 4 meters of overburden clay, found between depths of 2 and 6 meters, which appears as green-banded material and is characterized by cohesive behavior and relatively high plasticity; however, its low internal friction angle can significantly reduce slope stability when saturated. At depths of around 6 to 8 meters, the first coal seam is encountered with an estimated thickness of ±2 meters and is represented in black within the stratigraphy (Figure 1). This is followed by a 5-meter-thick interburden layer of clay extending from 8 to 13 meters, which plays an important role in geotechnical assessments, particularly in slope stability analysis. The second coal seam occurs between 13 and 17 meters, with a thickness of about 4 meters, making it a more substantial mining target than the first seam. Below this unit, the stratigraphy continues with a thick clay layer extending from 17 meters to beyond 23 meters, forming the deeper foundation of the sequence.

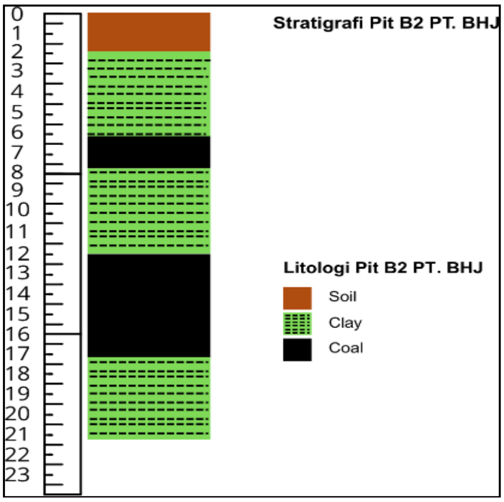

Figure 1. Stratigraphic of PT Batu Hitam Jaya

Consequently, mine planning must account for the volume of overburden, interburden thickness, and the geotechnical behavior of clay, as these factors play a critical role in maintaining slope stability throughout mining operations.

The data used in this study are divided into two categories, which are primary data and secondary data (Figure 1). Primary data refer to information obtained through direct field measurements. The primary data for this research include Unit Weight, Cohesion, and Internal Friction Angle. Meanwhile, secondary data refer to information that has been processed and provided by the company to support the research needs. The secondary data used in this study include the location and accessibility map of the research area, slope section data, and the regional geological map.

The next stage after collecting the data is data processing and analysis, which involves processing and analyzing information from field observations and laboratory tests. The data processing aims to determine the appropriate slope geometry design and the factor of safety for the observed slope failure surfaces using Geoslope or Slide software. To support the smooth execution of this research, a flowchart has been prepared as a guide for the research framework, as shown in Figure 2.

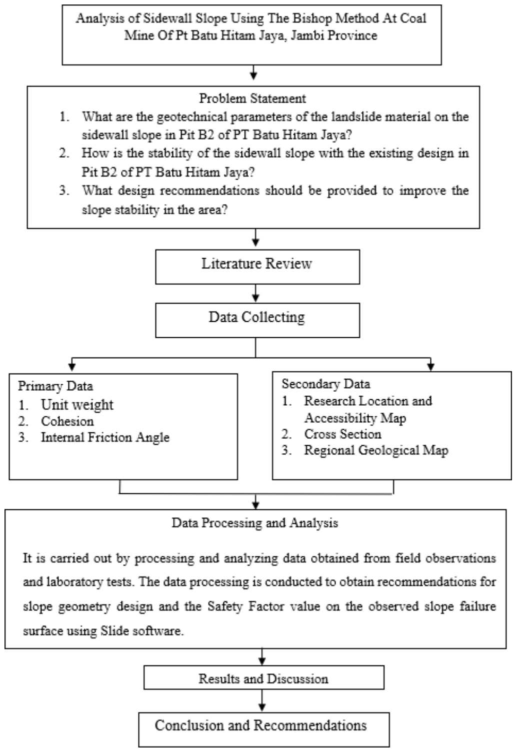

Figure 2. Research Flowchart

RESULTS AND DISCUSSION

Geotechnical Parameters of the Sidewall Slope at Pit B2

The slope stability analysis relies on key geotechnical parameters-specifically unit weight (γ), cohesion (c), and internal friction angle (φ). These parameters are essential inputs and are determined directly from the results of laboratory tests conducted on samples taken from each distinct material layer present at the study site. The values of these parameters serve as the basis for slope stability modeling using geotechnical software. The

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description of the geotechnical parameters for each lithology, arranged according to the stratigraphic sequence found in the field, is presented in (Table 1).

Table 1. Material Properties

Material Properties	Soil	OB Clay	Coal Seam 18	IB Clay	Coal Seam 19
Unit weight (kN/m³)	16,03	19,20	9,48	20,41	10,10
Cohesion (kPa)	5,15	11,77	8,23	20,79	12,37
Friction Angle (°)	12,56	14,76	16,73	8,969	20,85

In the Mohr-Coulomb failure criterion, the shear strength of soil is determined by two main parameters: cohesion (c) and internal friction angle (φ). In clay materials, cohesion plays a more dominant role than the friction angle, as clay tends to be plastic and easily deformable. The relatively low φ value limits the soil's shear resistance. As a result, even when the soil is still dry and not yet affected by pore water pressure, the driving forces generated by the soil's self-weight and additional loads can exceed the resisting forces, leading to slope instability.

Pit B2 Situation in the Coal Mine

Pit B2 is one of the coal mining areas located in the southeastern part of PT Batu Hitam Jaya's concession area. Geographically, this pit is situated at the lower right section of the company's site map, with its boundaries clearly marked by a polygon line. The area is surrounded by vegetation cover on the outer side of the concession, while the inner section has been designated as a production zone for coal mining activities. A clearer illustration of the location can be seen in (Figure 3).

Location of Cross-Sections A–A' and B–B' at Pit B2

The creation of a cross-section is carried out to observe the transverse profile of the pit geometry at a specific location. The cross-section location is determined in the sidewall area, as this section represents the pit's side wall, which has a higher potential risk of slope instability compared to other areas. The location of the cross-section can be seen in Figure 4.

The cross-section lines A–A' and B–B' were selected to pass through areas with significant elevation differences, allowing the slope geometry to be illustrated more clearly. These cross- sections are used to evaluate the slope angle, bench height, and overall slope inclination to ensure they comply with the established geotechnical recommendations. Moreover, this analysis is essential to ensure the stability of the sidewall throughout the mining process. With the selection of cross- section lines A–A' and B–B', the slope characteristics can be analyzed more accurately for design and safety assessment purposes.

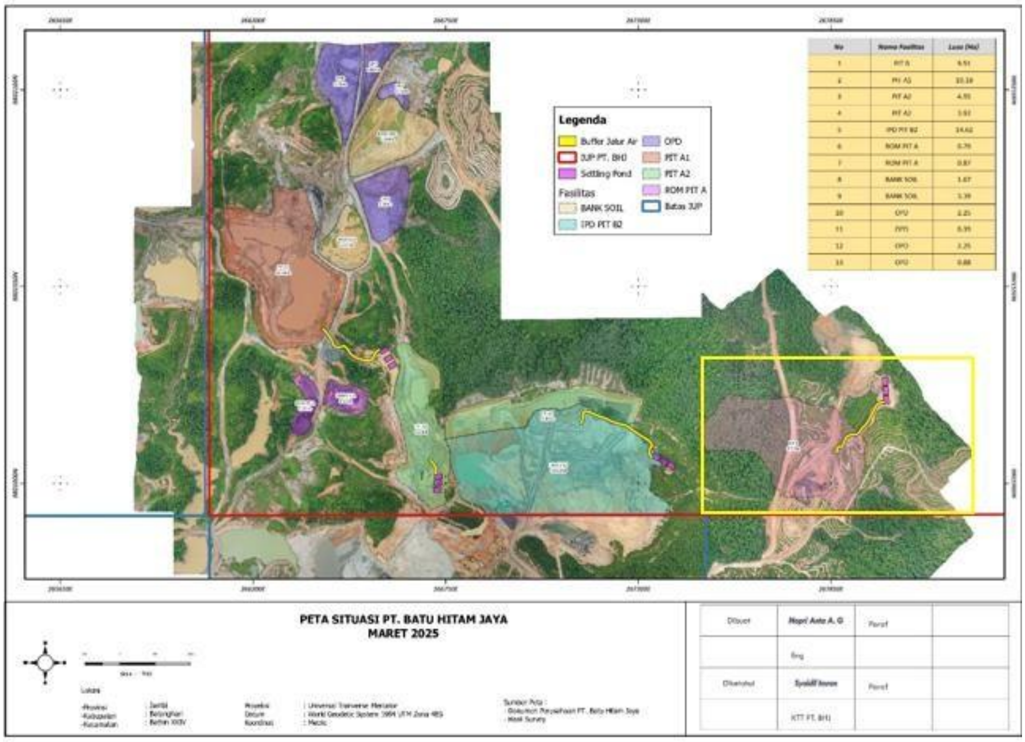

Figure 3. Pit B2 Mine Situation Map

Figure 4. Cross Section Location

Slope Stability Analysis of Cross-sections A–A' and B–B'

The sidewall slope stability analysis at Pit B2 was carried out using Rocscience Slide software, employing the Limit Equilibrium Method (LEM) and the Grid Search technique to determine the Factor of Safety (FoS). The objective of this analysis is to assess the viability of the current slope design by comparing it against the regulatory benchmarks established by the Official decree from the Ministry of Energy and Mineral Resources, No. 1827 K/30/MEM/2018. This decree mandates a minimum Factor of Safety (FoS) of 1.3 for static conditions and 1.1 for dynamic conditions (Figure 5).

Provides a visual illustration of the existing slope configuration for cross-section A–A'. Then, the slope geometry table and the resulting factor of safety values can be seen in (Table 2).

Table 2. Slope Geometry for Section A-A'

Type of Slope	Slope Geometry			Safety Factor
	Height	Width	Angle	
2	5	16	38	0.927

An analysis was conducted on section A–A', which includes the overall slope and slope 2. The results of the analysis on slope 2 indicate a potential for slope failure due to a combination of weak material properties and unsafe slope geometry.

The critical slip surface was formed within the overburden clay layer, which has a low internal friction angle (14,76°) and a high unit weight (19,20 kN/m³). This condition is further aggravated by the geometry of the third bench (height of 4,6 m and width of 16 m) and an additional surface load of 60 kN/m², which increases the shear stress on the clay layer, resulting in a factor of safety (FoS) of 0,927, indicating a near-critical condition and the value remains below the minimum stability threshold (FoS < 1.0).

Analysis Results of the Design Existing Single Slope on bench 2 Section B–B and the slope geometry table can be seen in (Figure 6) and (Table 3).

Table 3. Slope Geometry for Section B-B'

Type of Slope	Slope Geometry			Safety Factor
	Height	Width	Angle	
2	4.6	16	39	0.942

A similar analysis was also carried out on section B–B', which includes slope 2. Based on the stability analysis results for slope 2, the factor of safety (FK) was found to be 0,942, which is below the minimum standard set by the Official decree from the Ministry of Energy and Mineral Resources, No. 1827 K/30/MEM/2018, requiring FK ⩾ 1,1 for dynamic slopes.

The low Factor of Safety (FoS) value can be explained from several technical aspects as follows:

1. Slope Geometry
   A slope that is too steep relative to the strength of the material will result in instability.
2. Material Mechanical Properties
   The slope is composed of a combination of clay soil and weathered rock with low mechanical parameters. Laboratory tests yielded a cohesion (c) of 11,77 kPa, an internal friction angle (φ) of 14,76°, and a unit weight (γ) of 19,20 kN/m³. According to the Mohr-Coulomb theory, these parameters directly influence the material's shear resistance, where low cohesion and friction angle weaken the slope's ability to resist mass movement.

Cohesion (c) and internal friction angle (φ) act as resisting forces along the slip surface, while the unit weight (γ) increases the driving forces. In this case, the combination of low resisting forces and high driving forces creates an unbalanced force ratio, resulting in a factor of safety (FK) less 1.

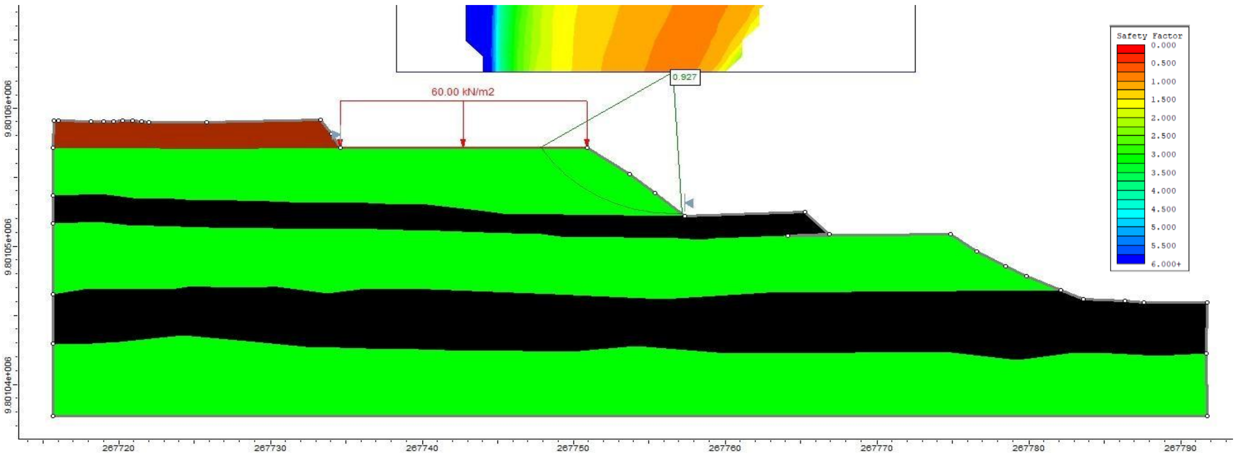

Figure 5. Analysis Results of the Design Existing Single Slope on Bench 2 Section A–A

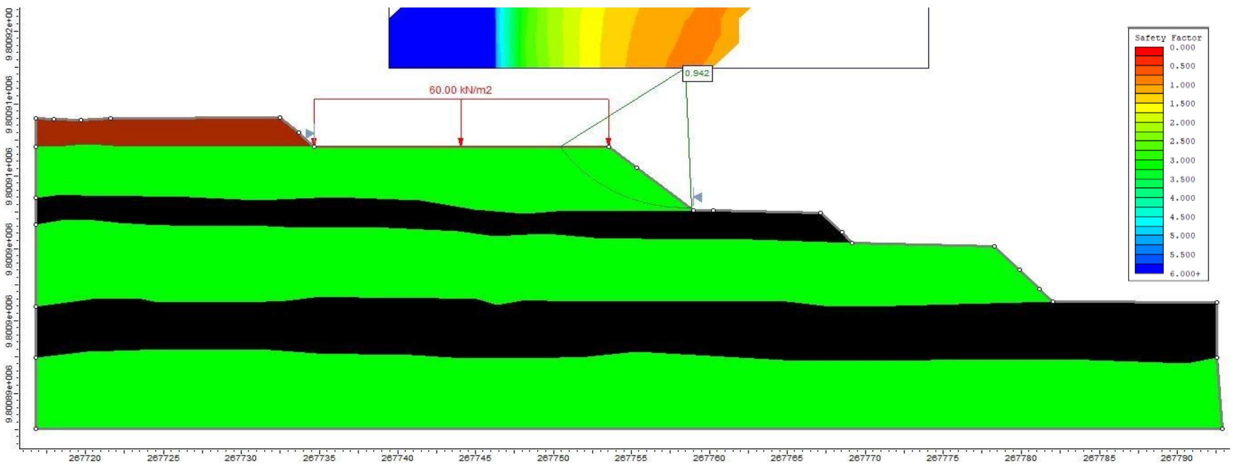

Figure 6. Analysis Results of the Design Existing Single Slope on Bench 2 Section B–B

Recommended Sidewall Slope Design

based on the evaluation of the existing conditions and referring to the technical safety standards stated in Official decree from the Ministry of Energy and Mineral Resources, No. 1827 K/30/MEM/2018, it is necessary to carry out a slope geometry redesign to achieve a Factor of Safety (FoS) that meets the minimum requirement, namely FoS ⩾ 1,1 under dynamic conditions. The recommended slope design for section A－A’ can be seen in (Figure 7), (Figure 8), and (figure 9) also recommended Slope Geometry for Section A－A can be seen in (Table 4).

Table 4. Recommended Slope Geometry for Section A-A’

Type of Slope	Slope Geometry			Safety Factor
	Height	Width	Angle	
1	1.9	7	51	
2	2	17	35	1.249
3	3	8	35	1.337
Factor of Safety (FK) of Both Redesigned Slopes				1.302

The analysis results show that the factor of safety (FK) increased to 1,302. Thus meeting the stability criteria for dynamic slopes according to Official decree from the Ministry of Energy and Mineral Resources, No. 1827 K/30/MEM/2018K/30/MEM/2018 (FK ⩾ 1.3). This improvement is influenced by the adjustment of the slope geometry and the properties of the constituent materials, where the overburden material with low cohesion and low internal friction angle is the main factor contributing to potential slope failure. With the new geometry, the stress distribution becomes more uniform, enhancing the material's ability to withstand loads. Therefore, the new design for section A–A' can be recommended as a safer and more stable configuration for mining operational conditions.

For section B–B' recommended slope design for section B– B' can be seen in (Figure 10), (Figure 11), and (figure 12), the improvement in the factor of safety focused on the slope geometry, including slope height, width, and inclination angle. The recommended slope geometry can be seen in (Table 5).

The analysis results show that the factor of safety increased to 1,244, which meets the criteria set by Official decree from the Ministry of Energy and Mineral Resources, No. 1827 K/30/MEM/2018 for dynamic slopes (FoS ⩾ 1,1). This improvement was achieved because dividing the critical slope into two benches successfully reduced the load on a single large slip surface, while combining the upper benches helped decrease stress concentration at the crest area.

Table 5. Recommended Slope Geometry for Section B-B'

Type of Slope	Slope Geometry			Safety Factor
	Height	Width	Angle	
1	1.9	7	51	
2	2	16	35	1.222
3	2.6	8	35	1.443
Factor of Safety (FK) of Both Redesigned Slopes				1.244

The material properties also played a significant role, where the overburden clay layer with a previously low internal friction angle acted as the weak zone of the slope. With the new geometry, load distribution on the clay layer became more uniform, allowing its shear strength to perform more effectively and reducing the potential for failure. Therefore, the redesigned slope of section A-A' can be recommended for implementation under operational conditions, provided that material parameters are verified through field testing and deformation monitoring is conducted regularly.

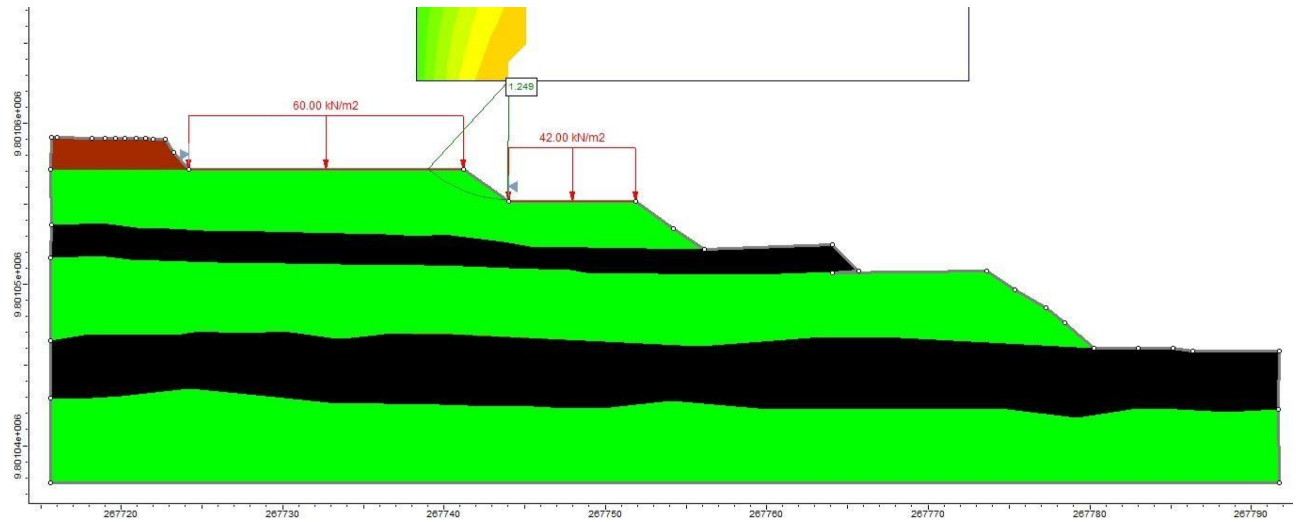

Figure 7. Analysis Results of the Redesign Existing Single Slope on bench 2 Section A–A'

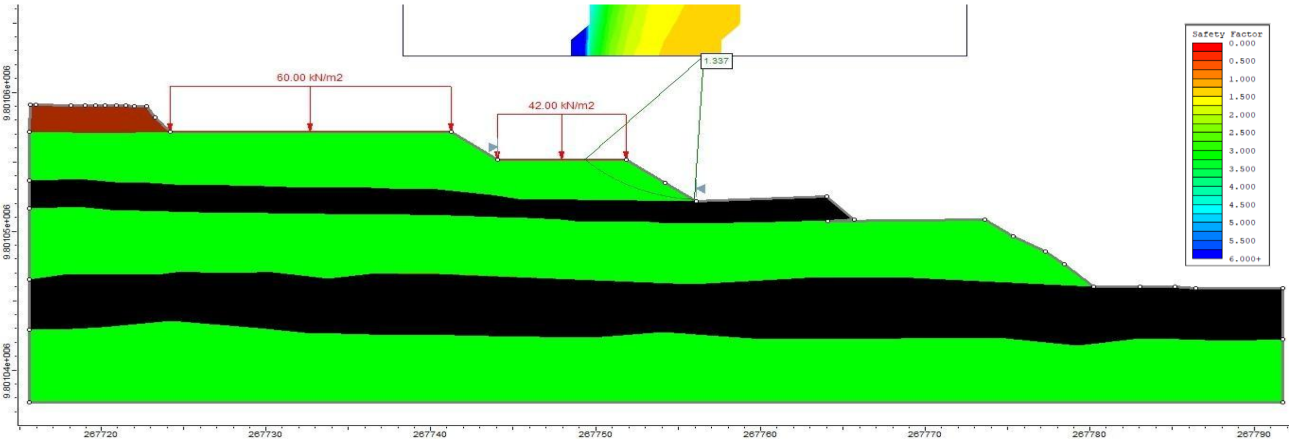

Figure 8. Analysis Results of the Redesign Existing Single Slope on bench 3 Section A–A'

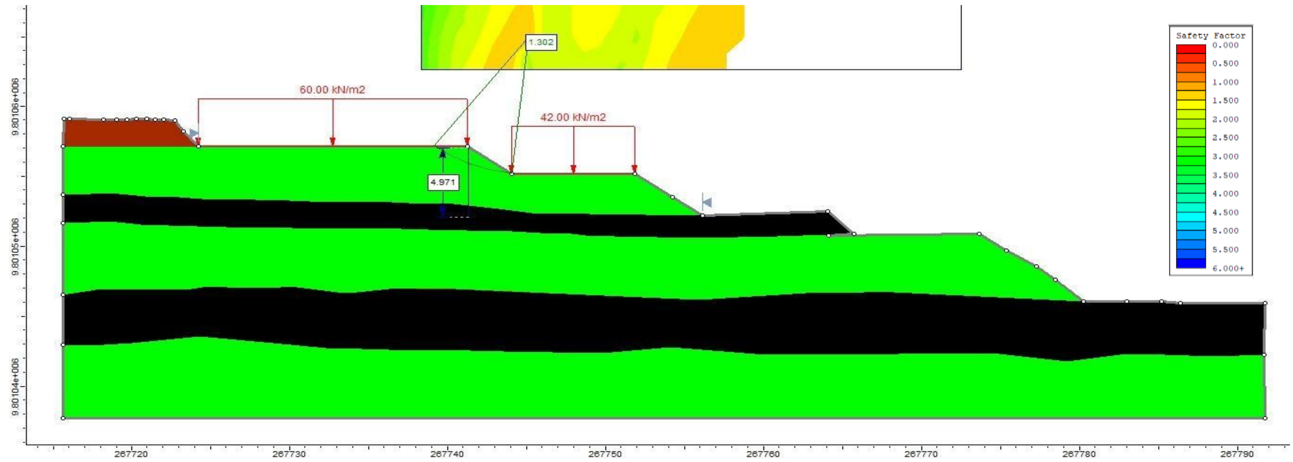

Figure 9. Analysis Results of the Redesign Existing Single Slope on Section A–A'

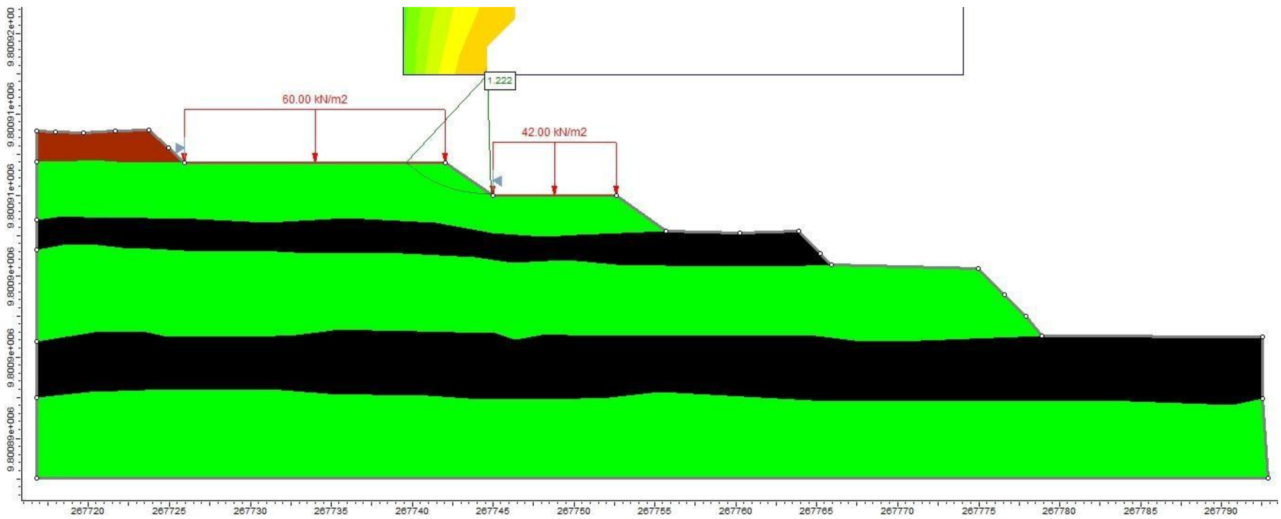

Figure 10. Analysis Results of the Redesign Existing Single Slope on bench 2 Section B–B'

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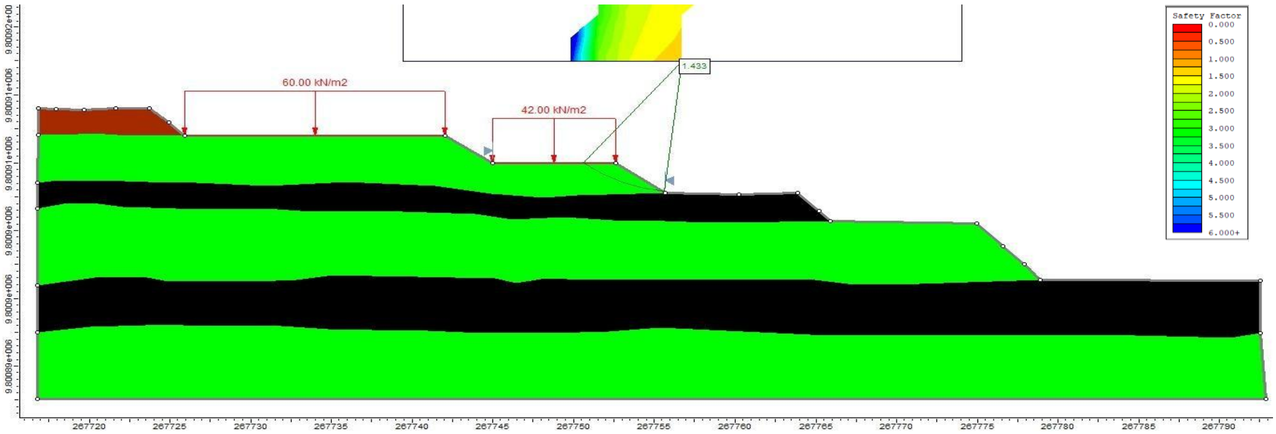

Figure 11. Analysis Results of the Redesign Existing Single Slope on bench 3 Section B-B'

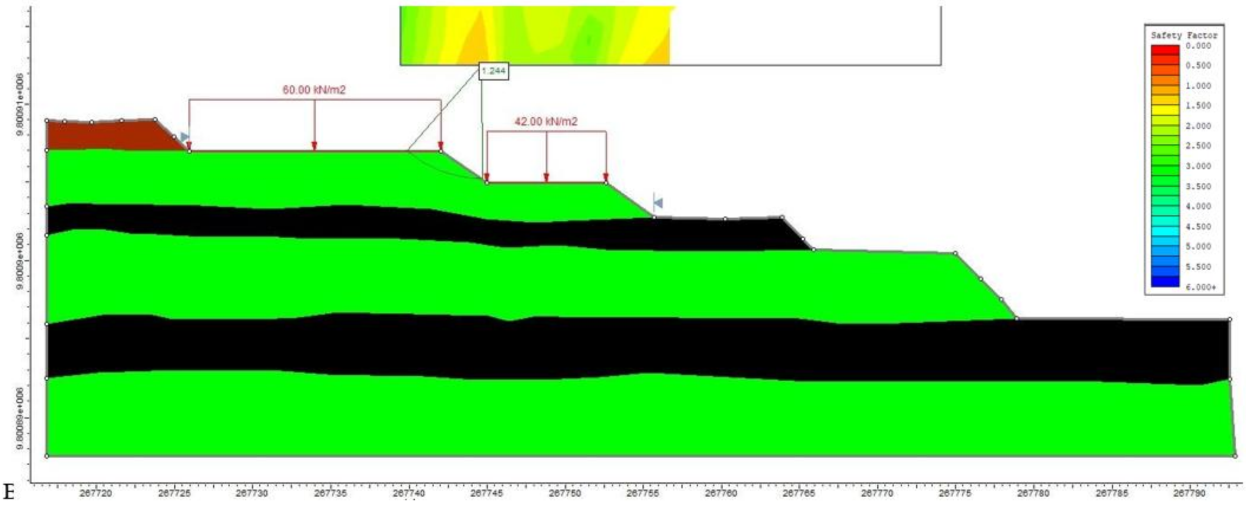

Figure 12. Analysis Results of the Redesign Existing Single Slope on Section B–B'

CONCLUSION

Based on the geotechnical analysis of the failed sidewall slope material at Pit B2, PT Batu Hitam Jaya, the slope is composed mainly of overburden clay with a unit weight (γ) of 19.20 kN/m³, cohesion (c) of 11.77 kPa, and an internal friction angle (φ) of 14.76°, which indicates a relatively low shear strength and a high susceptibility to instability. The existing slope condition, analyzed using the Bishop Method, is categorized as unstable, with Factors of Safety (FoS) of 0.927 for section A– A' and 0.942 for section B–B', both of which are below 1.0 and demonstrate the slope's inability to resist the acting forces; this condition is further aggravated by weak material properties and the presence of an external load of 60 kN/m². To improve slope stability, a redesign of the slope geometry was implemented by dividing the critical 5 m bench into two sub-benches of 2 m and 3 m, and the subsequent analysis shows a significant increase in stability, with FoS values rising to 1.302 for section A–A' and 1.244 for section B–B', confirming that the modified slope geometry meets the required stability criteria and provides a safer condition.

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