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Analysis of Disposal Slope Safety Factor in Determining the Safe Distance of Dumping Sequence at Disposal X in Sorowako Area, East Luwu Regency, South Sulawesi Province

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ABSTRACTS

Slope stability assessment is essential in open discharge designs to prevent failure during discharge operations. This study investigated the safety factors of the disposal slope to determine the safe disposal sequence distance at Disposal X, Sorowako, South Sulawesi, Indonesia. Stability evaluation was carried out using the Limit Equilibrium Method with the Morgenstern–Price formulation at GeoStudio SLOPE/W 2022. The analysis incorporates slope geometry, laboratory-tested geotechnical parameters, equipment-induced soil pressure, and topographic data. Three representative cross-sections were analyzed to identify critical conditions. Preliminary results show that the calculated safety factor is below the minimum regulatory requirement of 1.3. Therefore, design adjustments are applied by modifying the elevation of the slope sequence and controlling the discharge distance. After the redesign, the safety factor increased to 1,360, 1,362, and 1,374, indicating stable conditions. The optimized configuration meets regulatory standards and provides a reliable technical reference for safe disposal operations in the disposal area.

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INTRODUCTION

Slope stability is an important aspect in open pit mining operations, especially in dump areas where materials are constantly being dumped and subjected to additional operational loads. Instability on the drain slope can lead to production disruptions, equipment damage, and safety hazards. The conditions of tilt stability are mainly governed by the parameters of shear strength, tilt geometry, and external loading conditions (Bowles, 1991). Therefore, a systematic evaluation of slope stability is necessary to ensure that disposal activities remain within acceptable safety limits. Assessment of slope stability in mining techniques is typically conducted using the Limit Equilibrium Method (LEM), which evaluates the balance between driving force and resistance along the surface of potential failures (Pangemanan et al., 2014).

Among the various lem approaches, the Morgenstern-Price method is widely applied because it satisfies the balance of force and momentum, resulting in a more stringent calculation of safety factors. The application of this method in the study of slope stability has demonstrated its reliability in analyzing complex slope geometry and loading conditions (Takwin et al., 2017). In addition, slope design in mining operations must be in accordance with regulatory standards. Based on Indonesian mining regulations, the minimum recommended safety factor for overall static slope stability is 1.3 (Ministry of Energy and Mineral Resources, 2018).

Previous studies have evaluated slope stability in discharge areas using numerical approaches and equilibrium boundaries (Herlambang et al., 2020; Cahyo, 2024). However, most analyses focus primarily on the overall slope configuration without specifically determining the safe discharge sequence distance under the operational load of the machine.

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In practice, discharge limits are often determined based on empirical considerations rather than integrated numerical verification that combines geotechnical parameters, slope geometry, and equipment-induced loading simultaneously. This condition indicates a gap in the optimization of the exhaust design, especially in determining technically justified safe discharge distances that meet the stability criteria.

Therefore, this study aims to analyze the safety factors of the X Disposal slope in Sorowako using the Morgenstern-Price method applied in GeoStudio SLOPE/W and to determine the safe discharge sequence distance based on the quantitative stability evaluation. The study seeks to provide technically validated recommendations that support safer and more efficient disposal operations in accordance with safety standard regulations.

METHODS

Study Area

The research was conducted at Disposal X located in the Sorowako area, East Luwu Regency, South Sulawesi Province. Geographically, the study area is located within an active mining operation characterized by an engineered dump slope formed by sequential material placement. The disposal material is mostly composed of a layer of cover and waste material derived from open-pit mining activities.

The discharge geometry analyzed in this study represents the actual configuration of the field, including slope height, slope angle, embankment width, and overall slope profile obtained from operational data and mine planning documentation.

Data Collection

The analysis uses primary and secondary data derived from company documentation and laboratory test results. Parameters required for tilt stability modeling include tilt geometry, unit weight (γ), cohesion (c), internal friction angle (φ), and operational additional load of the machine. The shear strength parameters are obtained from laboratory tests performed on representative samples of discharge materials and then used as input parameters in numerical models.

Analytical Method

Slope stability evaluation was carried out using the Limit Equilibrium (LEM) Method. The Morgenstern-Price method was chosen because it meets the conditions of force and moment equilibrium, providing a rigorous calculation of safety factors. The modeling process is carried out using the GeoStudio SLOPE/W software through the following stages:

1. The geometry of the slope is determined according to the actual configuration of the field.
2. Material properties, including unit weight, cohesion, and internal friction angles, are assigned to the model.
3. Limit conditions and pore pressure assumptions are applied according to field conditions.
4. The operational surcharge burden representing the machine is simulated at varying horizontal distances from the slope top.
1. Stability analysis is performed to determine safety factors (FS) and to identify critical slip surfaces.

Dumping Distance Simulation

To determine the minimum safe discharge sequence distance, several scenarios are modeled by varying the horizontal distance between the discharge site and the top of the slope. Each scenario generates a corresponding security factor value.

1. The first scenario represents an existing configuration of dumping.
2. The next scenario progressively increases the horizontal discharge distance.
3. Each configuration is evaluated to determine whether the calculated security factors meet regulatory requirements.

The optimal discharge distance is defined as the minimum horizontal distance that results in a safety factor equal to or greater than the minimum FS value of ≥ 1.3 required under static conditions.

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Evaluation Criteria

The stability conditions are interpreted based on the calculated security factors as follows:

1. FS < 1.0 indicates unstable conditions.
2. 1.0 ≤ FS < 1.3 shows marginal stability.
3. FS ≥ 1.3 indicates stable and acceptable conditions for operational safety.

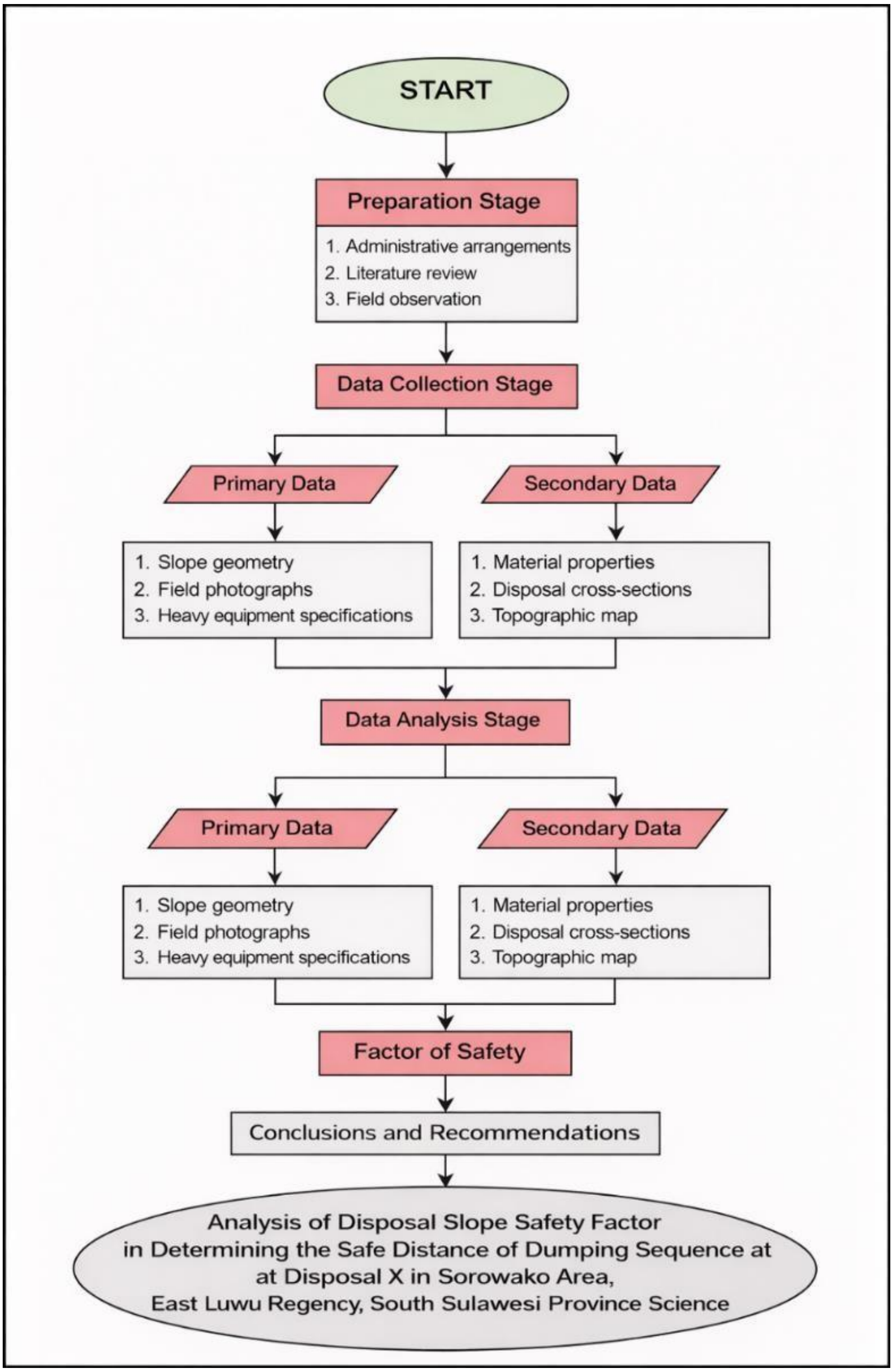

Figure 1. Research Flowchart

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RESULTS AND DISCUSSION

Existing Condition of the Study Area

Figure 2. Field Phograph of Disposal X

The research was conducted at Disposal X operated by PT Vale Indonesia. Field investigations showed that the discharge slope consisted of filler material previously deposited on top of saprolite and bedrock. The filler layer is generally brown in color with variable thickness, reflecting several heterogeneous stages of material removal and distribution.

Meteoric water accumulation is observed at the end of the slope. This condition is significant because the concentration of surface water can increase the pore water pressure and reduce the effective shear force, thereby affecting the stability performance of the slope. The presence of water in the toe area is critical, as it coincides with the potential location of the initiation of rotational slippage identified in stability modeling.

The variability of the material composition combined with the engineered slope geometry determines the mechanical response of the discharge mass. Heterogeneous charging characteristics can result in a non-uniform distribution of voltage within the tilt body, which must be accurately represented in numerical simulations. Therefore, these existing field conditions are the main boundary parameters that control the safety factors calculated in the next analysis.

Current Condition of the Disposal Slope

The study site is located at Disposal X operated by PT Vale Indonesia, which was developed within a former open-pit excavation that is no longer economically viable. Therefore, the drain area is categorized as an *in-pit drain system*.

Field conditions indicate that the former mining cavity intended for the placement of the discharge has been partially filled with water coming from groundwater inflows and meteoric sources. These pre-existing water conditions are an important geotechnical consideration, as they can affect the mechanical response of the discharge material.

The results of laboratory tests showed that the filler material planned to be disposed of had relatively low cohesion, with a value of 18 kPa. This low cohesion reflects weak particle bonds and relatively loose particle arrangements, allowing water to easily infiltrate the material's pore space. Such characteristics increase the potential for shear force reduction when the material becomes saturated. To ensure that the disposal operation can be carried out safely and in accordance with the mine planning, a comprehensive geotechnical assessment is therefore required. A detailed slope stability evaluation was performed to account for the combined effects of material properties, slope geometry, and groundwater conditions within the discharge area.

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Heavy Equipment Ground Pressure Calculation

The soil pressure generated by the machine is a key factor in the geotechnical assessment and slope stability analysis of the discharge area. Calculations are made to determine the load imposed by equipment operating in the landfill. Two types of engines were considered: the Caterpillar 785C dump truck and the D8R dozer.

Ground Pressure Dozer D8R

The D8R dozer provides ground pressure differently than a garbage truck due to its steel track shoes. According to the dozer specifications, the resulting soil pressure is 100 kN/m³ (see the D8R dimensional appendix).

Ground Pressure Dump Truck 785C

The calculation of ground pressure for a garbage truck requires details such as the type of tire, empty weight, gross operating weight, and distribution of loaded tires. The specifications for the Caterpillar 785C dump truck are summarized in Table 1.

Table 1. Dump Truck 785C Specifications

No.	Dump Truck 785C Specifications	Information
1	Tire type	33.00-R51 (E54)
2	Empty working weight	102.130 kg
3	Gross work weight	249.480
4	Loaded front tire	33%
5	Rear tire loaded	67%

The weight of the loaded dump truck was calculated as:
Weight = Gross Operating Weight × Gravity = $249{,}480$ kg × 9.8 m/s² = $2{,}444.90$ kN
The load distribution on the front and rear tires is as follows:

1) Front tires: $2{,}444.90$ kN × $33\% = 806.82$ kN
2) Rear tires: $2{,}444.90$ kN × $67\% = 1{,}638.1$ kN

To be used in GeoStudio, the soil pressure must be expressed in kN/m³. Therefore, the volume of loaded tires is calculated using a tire diameter of 2.10 m and a width of 0.84 m. The volume of the tire is calculated as:

$$\text{Tire Volume} = \frac{1}{4} \times \frac{22}{7} \times (2.10)^2 \times 0.84 = 6.5\ \text{m}^3$$

Thus:

1) Front tires: 806.82 kN$/6.05$ m³ $= 133$ kN/m³
2) Rear tires: $1{,}638.1$ kN$/6.05$ m³ $= 270.76$ kN/m³

Table 2. Parameters of Dump Truck 785C

No.	Spesification	Front Tires	Rar Tires
1	Loaded Weight	806.82 kN	1,638.1 kN
2	Tire Diamter	2.10 m	2.10 m
3	Tire Width Ground	0.84 m	0.84 m
4	Pressure	133 kN/m³	270.76 kN/m³

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Simulation of Embankment Addition

Before addressing the potential for landslides, it is important to determine a safe slope angle to ensure a stable safety factor. Slope stability analysis requires a model that represents the original slope conditions. In this study, slope modeling was performed based on laboratory test data, and the Morgenstern-Price method in the GeoStudio Slope/W 2018 software was used to analyze slope and determine its safety factors. The simulation focused on the slope during the addition of embankment material in a southwest-northeast direction. The analysis specifically targeted sections AA', B-B', and C-C' (Figure 4), as these sections represent the path where the disposal unit will carry out levee operations.

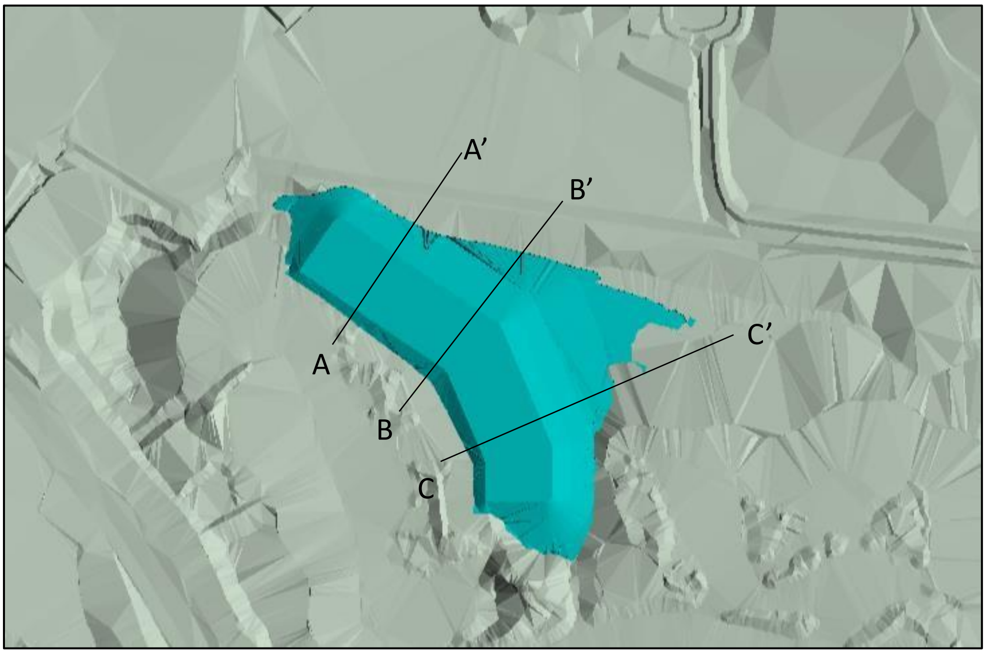

Figure 3. Cross-section as the Path for Embankment Operations (PT. Vale Indonesia Tbk)

Since the study area is located in a zone prone to water accumulation, the water level in the disposal material reaches a height of 501 m. According to SNI 8460 – 2017 Geotechnical Design Requirements, pseudo-static analysis of the cut slopes and embankments must incorporate seismic loads adapted to local geological conditions, regional seismicity, and slope functional importance. This ensures that the analysis accurately reflects the mechanisms of potential instability in combined static and dynamic loading conditions.

In this study, the analysis takes into account static and dynamic loads. Static loads consist of the weight of machines operating at the dump site, including Caterpillar 785C garbage trucks and D8R dozers, each providing a ground pressure of 100 kN/m³. Dynamic loads were applied to simulate seismic forces, using a 0.1g peak ground acceleration as derived from local seismic hazard maps. Earthquake designs for cut and fill slopes are defined for a design life of 10 years with a probability exceeding 20%, corresponding to a 50-year return period, according to Indonesia's 2017 Seismic Source and Hazard Map (Figure 5).

Seismic activity is an important factor that affects slope stability because it increases the driving force acting on the slope mass. The vibrations caused by earthquakes can significantly change the internal tension in the soil, affect the water pressure of the pores and reduce the effective pressure, which in turn can lower the safety factor. Combining static and dynamic loading in stability analysis provides a more realistic assessment of slope behavior, especially in areas where water accumulation and machine operation interact to affect overall stability.

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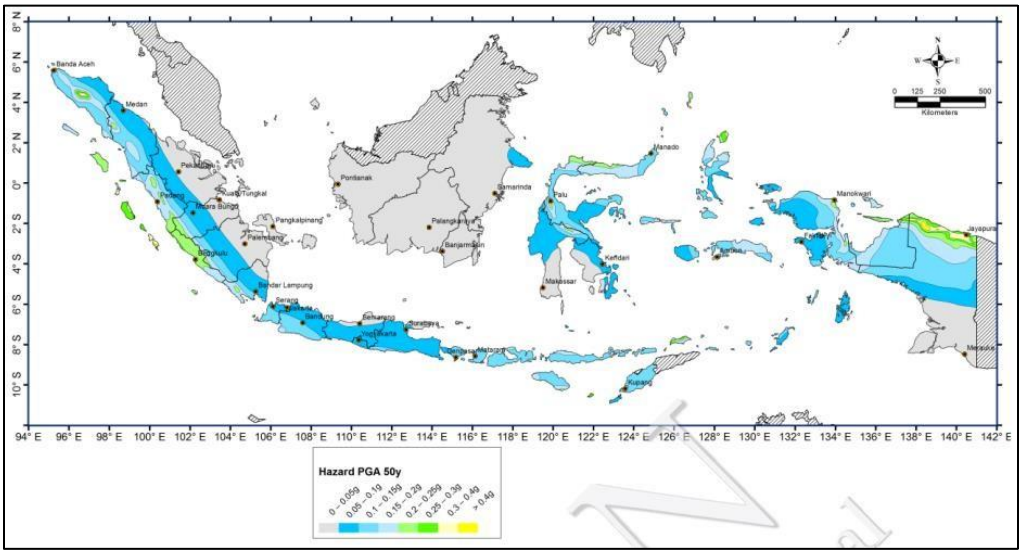

Figure 4. Map of Peak Ground Acceleration in Bedrock (SB) with a 20% Probability of Exceedance in 10 Years (PusGem, 2017).

Table 3. Additional Data

Value Parameters	Groundwater Level (m)	Tool Load (kN/m^3)			Seismicity (g)
		Dump Truck 785C		*Doozer*	
		Front Tires	Back Tires		
	501	133 kN/m^3	270,76 kN/m^3	100 kN/m^3	0,1

Analysis of Section A-A'

In the slope simulations performed for Sections A-A', the analysis considered the specifications of the overslope, including the properties of the material, the dynamic load represented by the 0.1g seismic acceleration, and the static load of the machine. Static loads include a Caterpillar 785C garbage truck, with the front tyre exerting 133 kN/m³ and the rear tyre 270.76 kN/m³, as well as the D8R dozer at 100 kN/m³. The results of the analysis showed that the slope had a safety factor (FS) of 1.010 (Figure 6), which does not meet the safety standards required for slopes. According to KEPMEN 1827K/30/MEM/2018, the minimum acceptable safety factor is >1.3. Therefore, a slope redesign is necessary to achieve safety factors that comply with regulatory requirements.

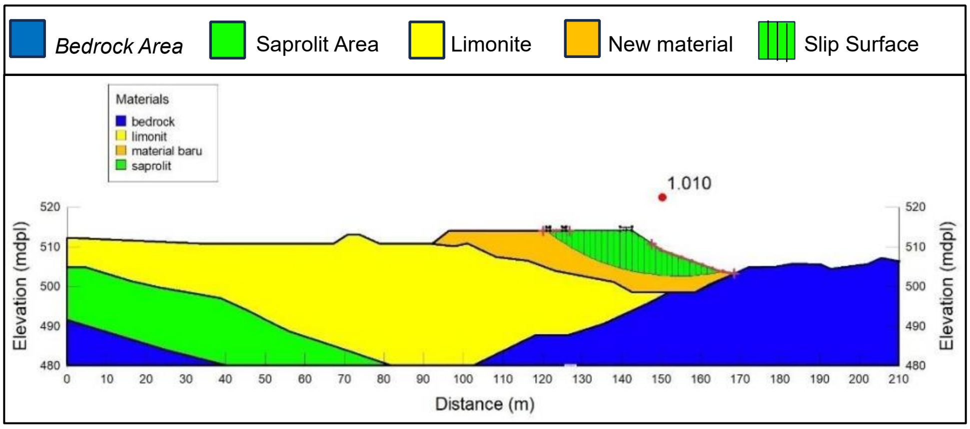

Figure 5. Section A-A' Showing a Factor of Safety Below the Required Standard.

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Based on the slope stability analysis, by lowering the elevation of the embankment from 514 m to 512 m and resetting the dumping limit by 4.5 m from the minimum dumping distance of 12.5 m (PT Vale, 2018) relative to the actual peak, the dumping limit is 20 m. With these adjustments, the safety factor is calculated to be 1,360 (Figure 7), which exceeds the minimum required safety factor of >1.3 according to KEPMEN 1827K/30/MEM/2018. This indicates that the condition of the analyzed slope is stable and meets the established safety criteria.

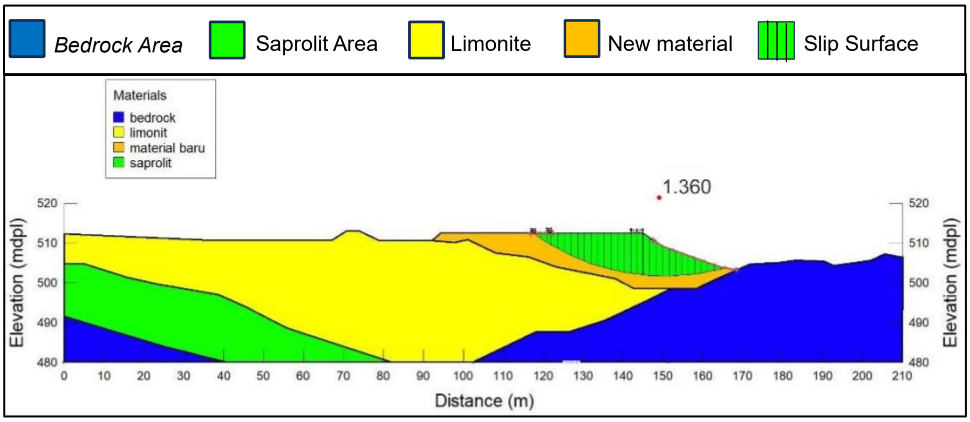

Figure 6. Section A-A' Showing a Factor of Safety Meeting the Required Standard.

Analysis of Section B-B'

In the levee slope simulation performed for Sections B-B', the analysis incorporated the overslope specifications, including material properties, dynamic loading represented by a seismic acceleration of 0.1g, and static loading of the machine. The static load consists of a Caterpillar 785C garbage truck, with a front tire pressure of 133 kN/m³ and a rear tire pressure of 270.76 kN/m³, as well as a D8R dozer exerting 100 kN/m³.

The results showed that the slope had a safety factor (FS) of 1.039 (Figure 8), which did not meet the minimum safety requirements for slope stability. According to KEPMEN 1827K/30/MEM/2018, the minimum security factor required is >1.3. Therefore, a redesign of the slope is necessary to achieve compliance with the established safety criteria.

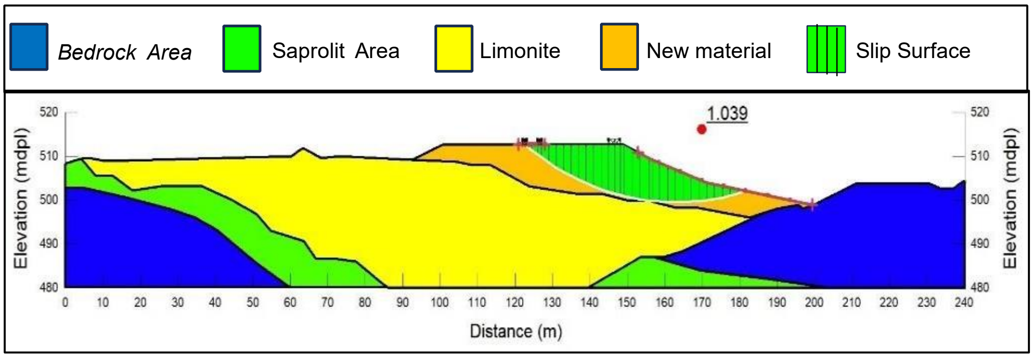

Figure 7. Section B-B' Showing a Factor of Safety Below the Required Standard.

Based on the results of the slope stability analysis, the elevation of the embankment was reduced from 513 m to 511 m, and the dumping limit was reversed by 4.5 m from the minimum dumping distance of 12.5 m (PT Vale, 2018) measured from the actual peak, resulting in a final dumping limit of 20 m. After the modification, the calculated safety factor (FS) increased to 1.362 (Figure 9), which exceeded the minimum required value of >1.3 in accordance with KEPMEN 1827K/30/MEM/2018. These results show that the analyzed slope conditions are stable and have met the specified safety criteria.

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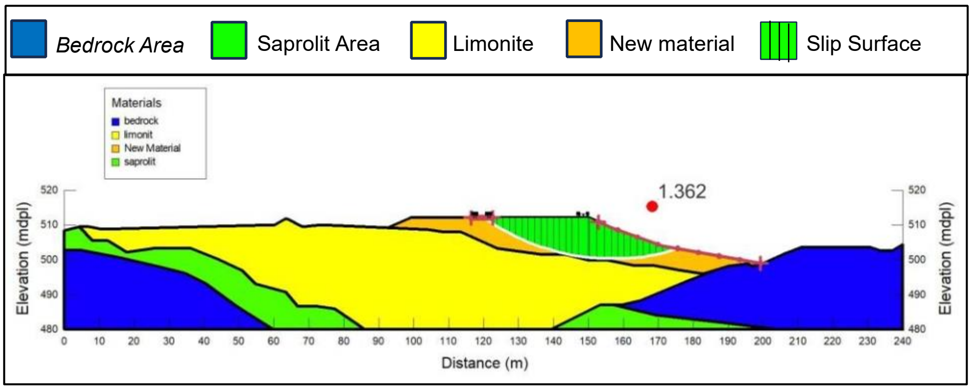

Figure 8. Section B-B’ Showing a Factor of Safety that Meets the Required Standard.

Analysis of Section C-C’

In the embankment slope simulation carried out in Section C-C', analysis was carried out using overslope specifications in the form of material properties, dynamic loads in the form of seismic acceleration of 0.1g, and static loads from heavy equipment consisting of dump trucks with front tire pressure of 133 kN/m³, rear tire pressure of 270.76 kN/m³, and dozer with ground pressure of 100 kN/m³.

The results of the analysis show that the slope has a Factor of Safety (FS) value of 1.028 (Figure 10), which does not meet the safety factor criteria required for a slope based on the KEPMEN regulation 1827K/30/MEM/2018, which requires a value greater than 1.3. Therefore, the redesign of the slope is necessary to achieve the necessary safety factors in accordance with these regulations.

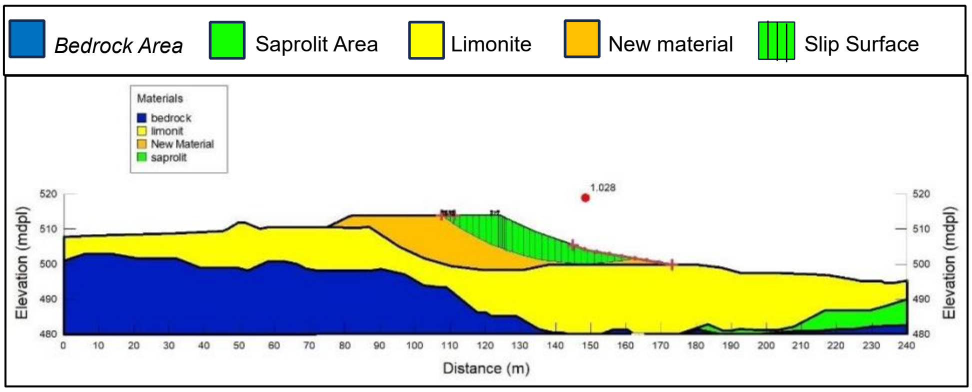

Figure 9. Section C-C’ Showing a Factor of Safety Below the Required Standard.

Based on the slope stability analysis that has been carried out, by lowering the elevation of the embankment from 514 m to 513 m and moving the discharge limit of 6.5 m backwards from the minimum discharge distance of 12.5 m (PT Vale, 2018) from the actual peak, the discharge limit becomes 19 m. As a result, a Factor of Safety (FS) value of 1.374 was obtained (Figure 11), which is above the minimum required safety factor value of >1.3 according to KEPMEN 1827K/30/MEM/2018. This indicates that the analyzed slope conditions are stable and have met the established safety criteria.

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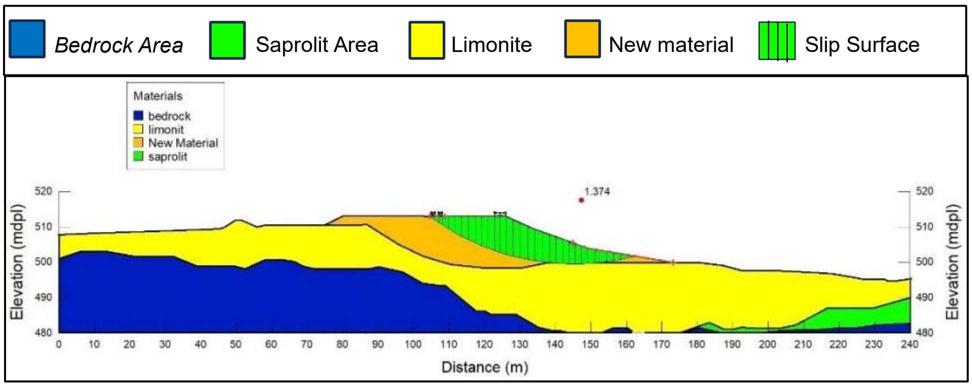

Figure 10. Section C-C' Showing a Factor of Safety that Meets the Required Standard.

The direction of the recommended discharge sequence is determined based on the results of the Safety Factors and the discharge distance obtained from the final analysis of the addition of the embankment. Safe discharge limits and directions can be implemented by modifying the height and discharge limits of the initial discharge plan.

Based on the results of the final simulation of the addition of the embankment, and since the Factor of Safety (FS) value indicates safe conditions, the recommended Factor of Safety value and safe disposal distance are obtained as presented in Table 4.

Table 4. Factor of Safety (FS) and Safe Dumping Distance After Determining the Safe Dumping Boundary

No.	Section	Initial Dumping Limit (m)	Initial Elevation (m)	Initial FS	Recommended Dumping Limit (m)	Recommended FS	Recommended Elevation (m)	Actual Slope Angle (°)
	A-A'	12.5	514	1.010	20	1.360	512	34.56
2	B-B'	12.5	513	1.039	20	1.362	511	12.98
3	C-C'	12.5	514	1.028	19	1.374	513	19.37

CONCLUSION

Based on the results of the analysis, it can be concluded that:

1. Based on the design of the discharge slope sequence, the design volume obtained is 194,231,106 m³. The volume analysis of the designed slope sequence can ensure the stability of the material discharge structure. By knowing the volume, planning in waste material management can be carried out more effectively, reducing the potential for accidents, and maintaining operational safety and environmental sustainability in the mining area.
2. Based on the results of the analysis of the discharge slope X section A-A', the FS value obtained is 1.010, the B-B' section has an FS value of 1.039, and the C-C' section has an FS value of 1.028. The FS value found in this analysis does not meet the requirements for the safety factor of a slope, namely FS > 1.3 based on KEPMEN regulation 1827K/30/MEM/2018.
3. The results of the discharge X slope stability analysis for section A-A' show that the elevation is cut from 514 m to 512 m and the recommended garbage truck discharge limit is 20 m from the actual peak limit, resulting in an FS value of 1,360. In section B-B', the height was trimmed from 513 m to 511 m and the recommended garbage truck disposal limit was 20 m from the actual peak limit, resulting in an FS value of 1,362. In the C-C' section, the elevation was cut from 514 m to 513 m and the recommended garbage truck disposal limit was 19 m from the actual peak limit, resulting in an FS value of 1,374.

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