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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

Nur Alifia Suparman[1*], Busthan Azikin[2]
[1-2]Department of Geological Engineering, Faculty of Engineering, Hasanuddin University, Indonesia
Correspondence e-mail: alifiasnur@gmail.com

ABSTRACTS

Slope stability assessment is essential in open disposal design to prevent failure during dumping operations. This study investigates the safety factor of disposal slopes in order to determine the safe dumping sequence distance at Disposal X, Sorowako, South Sulawesi, Indonesia. The stability evaluation was carried out using the Limit Equilibrium Method with the Morgenstern–Price formulation in GeoStudio SLOPE/W 2022. The analysis integrated slope geometry, laboratory-tested geotechnical parameters, equipment-induced ground pressure, and topographic data. Three representative cross-sections were analysed to identify critical conditions. The initial results showed that the calculated safety factors fell below the minimum regulatory requirement of 1.3. Design adjustments were therefore applied by modifying the slope sequence elevation and controlling the dumping distance. After the redesign, the safety factors increased to 1.360, 1.362, and 1.374, indicating stable conditions. The optimised configuration meets the regulatory standard and provides a reliable technical reference for safe dumping operations in the disposal area.

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INTRODUCTION

Slope stability is a critical aspect of open-pit mining operations, particularly in disposal areas where material is continuously dumped and subjected to additional operational loading (Irwandi, 2016). Instability of disposal slopes can cause production disruptions, equipment damage, and safety hazards. Slope stability conditions are primarily governed by shear strength parameters, slope geometry, and external loading conditions (Bowles & Johan, 1991).

A systematic slope stability evaluation is therefore required to ensure that dumping activities remain within acceptable safety limits.

Slope stability assessment in mining engineering is commonly performed using the Limit Equilibrium Method (LEM), which evaluates the balance between driving and resisting forces along a potential failure surface (Hoek & Bray, 1981; Pangemanan et al., 2014).

Among the various LEM approaches, the Morgenstern–Price method is widely applied because it satisfies both force and moment equilibrium, yielding a more rigorous safety factor calculation. The application of this method in slope stability studies has demonstrated its reliability in analysing complex slope geometries and loading conditions (Takwin et al., 2017). Other classification-based approaches, such as rock mass rating, have also been applied to slope stability assessment in different geological settings (Rohman et al., 2022).

In addition, slope design in mining operations must comply with regulatory standards. Under Indonesian mining regulations, the minimum recommended safety factor for overall static slope stability is 1.3 (Kementerian Energi dan Sumber Daya Mineral, 2018). Reliability-based approaches to open-pit slope stability in Indonesia have also been developed to complement this deterministic criterion (Azizi, 2014).

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Previous studies have evaluated slope stability in disposal areas using numerical and limit equilibrium approaches (Aprilia et al., 2019; Herlambang et al., 2020; Cahyo, 2024). Related work has examined disposal slope geometry and disposal volume (Arif, 2016), the influence of slope geometry on mining outcomes (Azizi et al., 2018), and the determination of safe dumping boundaries at disposal areas operated by PT Vale Indonesia Tbk (Yovita, 2024).

However, most analyses have focused primarily on the overall slope configuration without specifically determining the safe dumping sequence distance under operational loading from heavy equipment.

In practice, dumping boundaries are often determined on empirical grounds rather than through integrated numerical verification that simultaneously incorporates geotechnical parameters, slope geometry, and equipment-induced loading. This condition indicates a gap in disposal design optimisation, particularly in establishing a technically justified safe dumping distance that satisfies stability criteria.

This study therefore aims to analyse the safety factor of the Disposal X slope in Sorowako using the Morgenstern–Price method implemented in GeoStudio SLOPE/W, and to determine the safe dumping sequence distance based on a quantified stability evaluation. The study seeks to provide technically validated recommendations that support safer and more efficient dumping operations in accordance with regulatory safety standards.

METHODS

Study Area

This research was conducted at Disposal X, located in the Sorowako area, East Luwu Regency, South Sulawesi Province. Geographically, the study area lies within an active mining operation characterised by engineered disposal slopes formed by sequential material placement. The disposal material consists largely of overburden and waste material derived from open-pit mining activities. Regionally, the study area lies within the geological framework of Sulawesi described in regional mapping of the Malili sheet (Sukamto, 1975; Simandjuntak et al., 1991), a setting associated with Neogene plate convergence in eastern Sulawesi (Simanjuntak, 1993), while the nickel laterite profile of the Sorowako area has been documented in earlier deposit and engineering geology studies (Golightly, 1979; Kumarawarman, 2016). Disposal planning in this concession area has also been examined in previous work (Fajrin et al., 2019).

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

Data Collection

The analysis used primary and secondary data derived from company documentation and laboratory test results. The parameters required for slope stability modelling include slope geometry, unit weight (γ), cohesion (c), internal friction angle (φ), and additional operational loading from heavy equipment (Das, 2010). The shear strength parameters were obtained from laboratory tests conducted on representative disposal material samples and were subsequently used as input parameters in the numerical model.

Analytical Method

The slope stability evaluation was carried out using the Limit Equilibrium Method (LEM). The Morgenstern–Price method was selected because it satisfies both force and moment equilibrium conditions, providing a rigorous safety factor calculation. The modelling process was performed using GeoStudio SLOPE/W software through the following stages:

1. The slope geometry was defined in accordance with the actual field configuration.
2. Material properties, including unit weight, cohesion, and internal friction angle, were assigned to the model.
3. Boundary conditions and pore pressure assumptions were applied in accordance with field conditions.
4. Operational surcharge loads representing heavy equipment were simulated at varying horizontal distances from the slope crest.
5. Stability analyses were performed to determine the factor of safety (FS) and to identify the critical slip surface.

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Dumping Distance Simulation

To determine the minimum safe dumping sequence distance, several scenarios were modelled by varying the horizontal distance between the dumping location and the slope crest. Each scenario produced a corresponding safety factor value.

1. The first scenario represents the existing dumping configuration.
2. Subsequent scenarios progressively increase the horizontal dumping distance.
3. Each configuration was evaluated to determine whether the calculated safety factor met the regulatory requirement.

The optimal dumping distance was defined as the minimum horizontal distance producing a safety factor equal to or greater than the required minimum value of FS ≥ 1.3 under static conditions.

Evaluation Criteria

Stability conditions were interpreted on the basis of the calculated safety factor as follows (Zakaria, 2009):

1. FS < 1.0 indicates an unstable condition.
2. 1.0 ≤ FS < 1.3 indicates marginal stability.
3. FS ≥ 1.3 indicates a stable condition that is acceptable for operational safety.

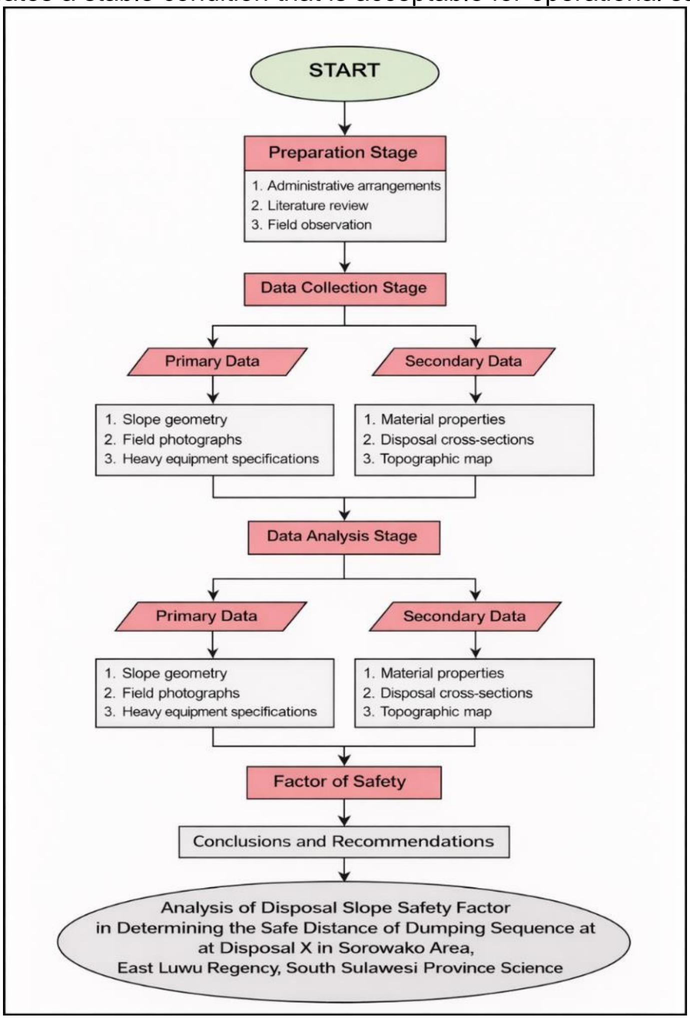

Figure 1. Research Flowchart

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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 investigation showed that the disposal slope consists of fill material previously deposited over saprolite and bedrock. The fill layer is generally brown with a variable thickness, reflecting several dumping stages and a heterogeneous material distribution.

Meteoric water accumulation was observed at the slope toe. This condition is significant because the concentration of surface water can increase pore water pressure and reduce the effective shear strength, thereby affecting slope stability performance. The presence of water in the toe area is particularly important, as it coincides with the potential location of rotational slip initiation identified in the stability modelling.

The variability of the material composition, combined with the engineered slope geometry, governs the mechanical response of the disposal mass. Heterogeneous fill characteristics can result in a non-uniform stress distribution within the slope body, which must be represented accurately in the numerical simulation. These existing field conditions therefore constitute the principal boundary parameters controlling the safety factor calculated in the subsequent 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. The disposal area is therefore categorised as an in-pit disposal system.

Field conditions show that the former mining void intended for disposal placement has been partially filled with water originating from groundwater inflow and meteoric sources. This pre-existing water condition is an important geotechnical consideration, as it can affect the mechanical response of the disposal material.

Laboratory test results show that the fill material planned for disposal has a relatively low cohesion, with a value of 18 kPa. This low cohesion reflects weak interparticle bonding and a relatively loose particle arrangement, allowing water to infiltrate the pore spaces of the material readily. Such characteristics increase the potential for shear strength reduction when the material becomes saturated (Parker & Means, 1974). To ensure that dumping operations can be carried out safely and in accordance with the mine plan, a comprehensive geotechnical assessment is therefore required. A detailed slope stability evaluation was conducted to account for the combined effects of material properties, slope geometry, and groundwater conditions within the disposal area.

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Heavy Equipment Ground Pressure Calculation

The ground pressure generated by heavy equipment is a key factor in the geotechnical assessment and slope stability analysis of the disposal area. Calculations were performed to determine the loads imposed by the equipment operating at the disposal site. Two types of machinery were considered: the Caterpillar 785C dump truck and the D8R dozer.

Ground Pressure Dozer D8R

The D8R dozer imposes ground pressure differently from a dump truck because of its steel track shoes. According to the dozer specifications, the ground pressure generated is 100 kN/m³ (Caterpillar Inc., 2002; see the appendix of D8R dimensions).

Ground Pressure Dump Truck 785C

The ground pressure calculation for the dump truck requires details such as tyre type, empty weight, gross operating weight, and loaded tyre distribution. The specifications for the Caterpillar 785C dump truck are summarised in Table 1 (Caterpillar Inc., 2007).

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 kg
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

For use in GeoStudio, the ground pressure must be expressed in kN/m³. The volume of the loaded tyre was therefore calculated using a tyre diameter of 2.10 m and a width of 0.84 m. The tyre volume was calculated as:

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

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.	Specification	Front Tires	Rear Tires
1	Loaded Weight	806.82 kN	1,638.1 kN
2	Tire Diameter	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, and variations in slope geometry directly influence the resulting deformation and stability performance (Sugesti, 2019). In this study, slope modelling was carried out based on laboratory test data, and the Morgenstern–Price method in GeoStudio SLOPE/W 2018 software was used to analyse the slope and determine its safety factor. The simulation focused on the slope during the addition of embankment material in a south-west to north-east direction. The analysis specifically targeted sections A-A', B-B', and C-C' (Figure 4), as these sections represent the paths along which the disposal unit will carry out embankment operations.

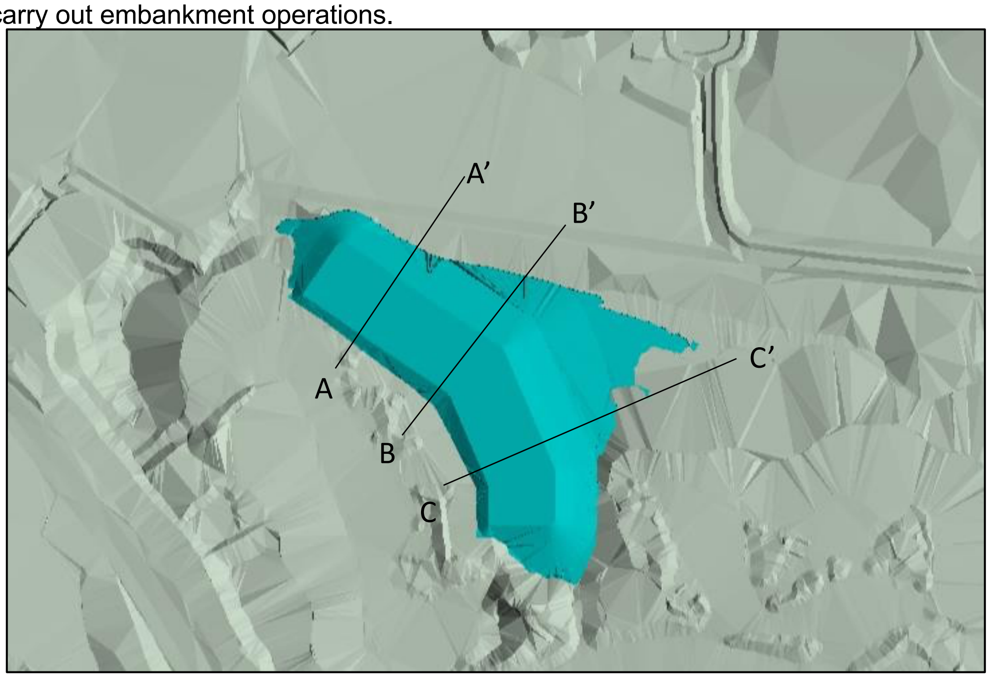

Figure 3. Cross-section as the Path for Embankment Operations (PT Vale Indonesia Tbk, 2018)

Because the study area is located in a zone prone to water accumulation, the water level within the disposal material reaches an elevation of 501 m. According to SNI 8460:2017 on geotechnical design procedures (Badan Standardisasi Nasional, 2017), the pseudo-static analysis of cut slopes and embankments must incorporate seismic loading adjusted to local geological conditions, regional seismicity, and the functional importance of the slope. This ensures that the analysis accurately reflects potential instability mechanisms under combined static and dynamic loading conditions.

In this study, the analysis accounted for both static and dynamic loads. The static load consisted of the weight of the heavy equipment operating at the disposal site, including the Caterpillar 785C dump truck and the D8R dozer, the latter imposing a ground pressure of 100 kN/m³. The dynamic load was applied to simulate seismic forces, using a peak ground acceleration of 0.1 g as derived from the local seismic hazard map. The design earthquake for cut and fill slopes was defined for a 10-year design life with a 20% probability of exceedance, corresponding to a 50-year return period, according to the 2017 Indonesian Seismic Source and Hazard Map (Pusat Studi Gempa Nasional, 2017) (Figure 5).

Seismic activity is an important factor affecting slope stability because it increases the driving forces acting on the slope mass. Earthquake-induced vibrations can significantly alter the internal stresses within the soil, affecting pore water pressure and reducing effective stress, which in turn can lower the safety factor. Incorporating both static and dynamic loading in the stability analysis provides a more realistic assessment of slope behaviour, particularly in areas where water accumulation and heavy equipment operations interact to affect overall stability.

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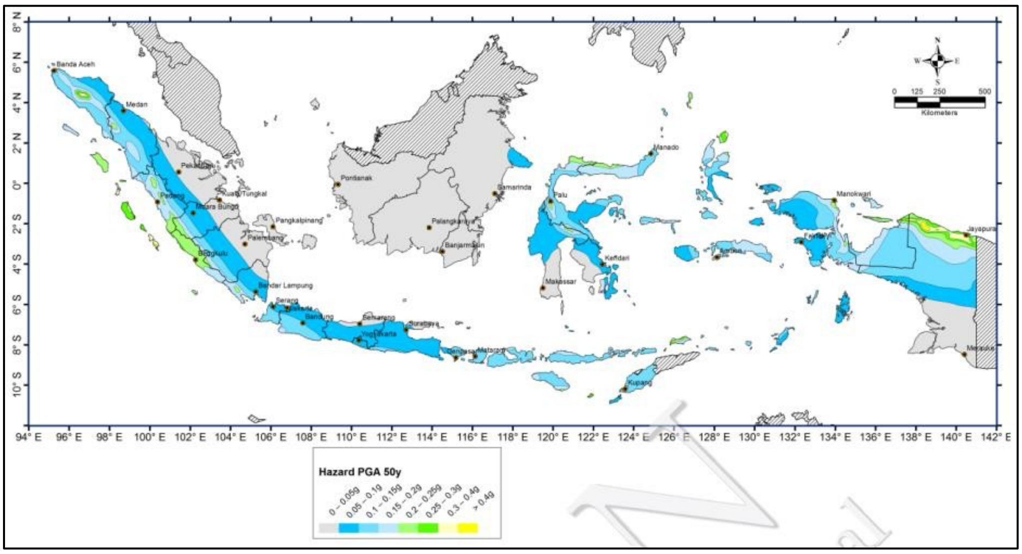

Figure 4. Map of Peak Ground Acceleration in Bedrock (SB) with a 20% Probability of Exceedance in 10 Years (Pusat Studi Gempa Nasional, 2017).

Table 3. Additional Data

	Groundwater Level (m)	Equipment Load (kN/m³)			Seismicity (g)
Parameter Value	501	*Dump Truck 785C*		*Dozer*	0.1
		Front Tire	Rear Tire	100 kN/m³	
		133 kN/m³	270.76 kN/m³		

Analysis of Section A-A'

In the slope simulation performed for Section A-A', the analysis considered the over-slope specifications, including material properties, dynamic loading represented by a seismic acceleration of 0.1 g, and static loading from heavy equipment. The static load included the Caterpillar 785C dump truck, with the front tyres exerting 133 kN/m³ and the rear tyres 270.76 kN/m³, together with the D8R dozer at 100 kN/m³. The analysis results show that the slope has a factor of safety (FS) of 1.010 (Figure 6), which does not meet the safety standard required for slopes. According to KEPMEN 1827.K/30/MEM/2018, the minimum acceptable safety factor is > 1.3. A slope redesign is therefore required to achieve a safety factor that complies with the regulatory requirement.

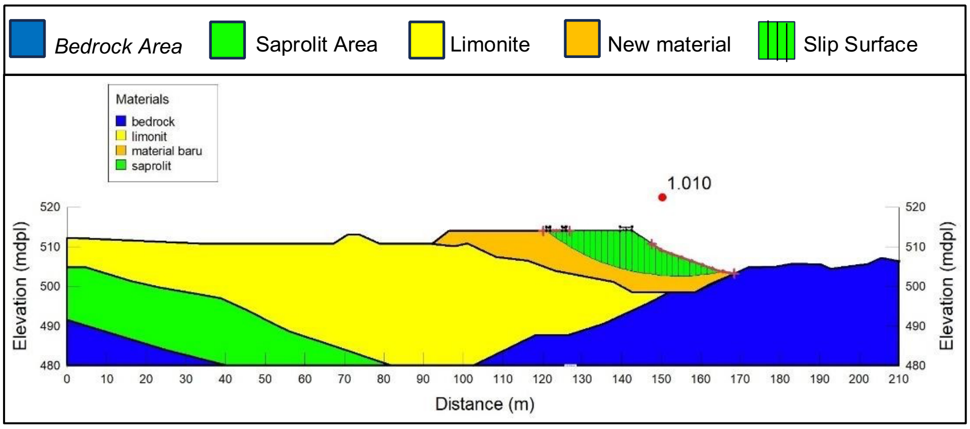

Figure 5. Section A-A' Showing a Factor of Safety Below the Required Standard.

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Based on the slope stability analysis, by lowering the embankment elevation from 514 m to 512 m and setting back the dumping boundary by 4.5 m from the minimum dumping distance of 12.5 m (PT Vale Indonesia Tbk, 2018) relative to the actual crest, the dumping boundary becomes 20 m. With these adjustments, the safety factor was calculated as 1.360 (Figure 7), which exceeds the required minimum safety factor of > 1.3 under KEPMEN 1827.K/30/MEM/2018. This indicates that the analysed slope condition is stable and satisfies the established safety criteria.

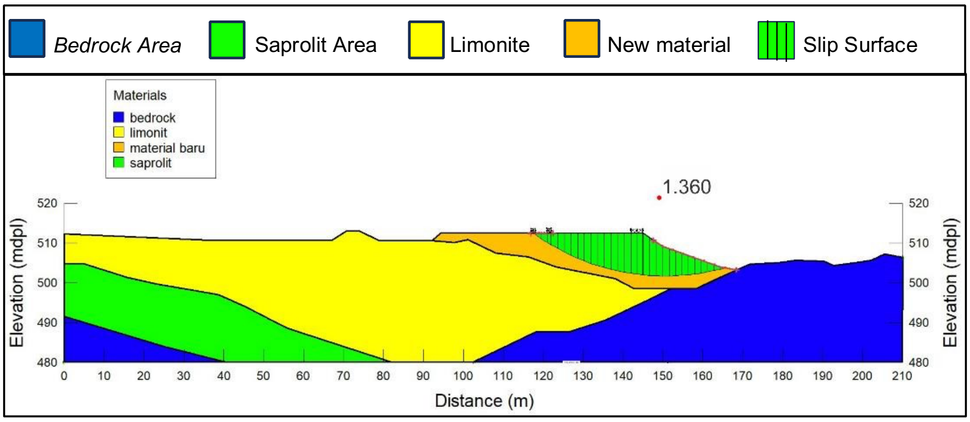

Figure 6. Section A-A' Showing a Factor of Safety Meeting the Required Standard.

Analysis of Section B-B'

In the embankment slope simulation performed for Section B-B', the analysis incorporated the over-slope specifications, including material properties, dynamic loading represented by a seismic acceleration of 0.1 g, and static loading from heavy equipment. The static load consisted of the Caterpillar 785C dump truck, with a front tyre pressure of 133 kN/m³ and a rear tyre pressure of 270.76 kN/m³, together with the D8R dozer exerting 100 kN/m³.

The results show that the slope has a factor of safety (FS) of 1.039 (Figure 8), which does not meet the minimum safety requirement for slope stability. According to KEPMEN 1827.K/30/MEM/2018, the minimum required safety factor is > 1.3. A slope redesign is therefore required to achieve compliance with the established safety criteria.

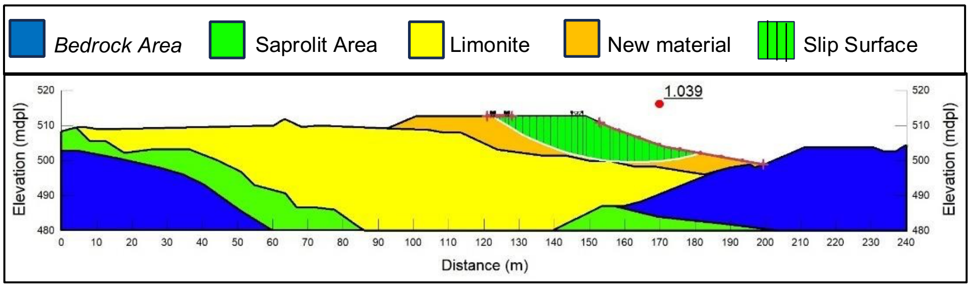

Figure 7. Section B-B' Showing a Factor of Safety Below the Required Standard.

Based on the results of the slope stability analysis, the embankment elevation was reduced from 513 m to 511 m, and the dumping boundary was set back by 4.5 m from the minimum dumping distance of 12.5 m (PT Vale Indonesia Tbk, 2018) measured from the actual crest, resulting in a final dumping boundary of 20 m. Following these modifications, the calculated factor of safety (FS) increased to 1.362 (Figure 9), which exceeds the required minimum value of > 1.3 in accordance with KEPMEN 1827.K/30/MEM/2018. This result indicates that the analysed slope condition is stable and has met the specified safety criteria.

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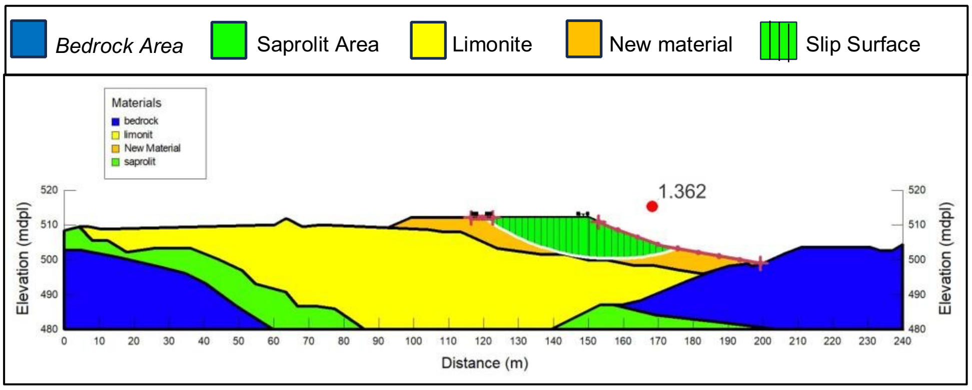

Figure 8. Section B-B’ Showing a Factor of Safety that Meets the Required Standard.

Analysis of Section C-C’

In the embankment slope simulation performed for Section C-C’, the analysis used the over-slope specifications, comprising material properties, dynamic loading in the form of a seismic acceleration of 0.1 g, and static loading from heavy equipment consisting of the dump truck with a front tyre pressure of 133 kN/m³ and a rear tyre pressure of 270.76 kN/m³, and the dozer with a ground pressure of 100 kN/m³.

The analysis results show that the slope has a factor of safety (FS) of 1.028 (Figure 10), which does not meet the safety factor criterion required for a slope under KEPMEN 1827.K/30/MEM/2018, which requires a value greater than 1.3. A slope redesign is therefore required to achieve the safety factor stipulated by this regulation.

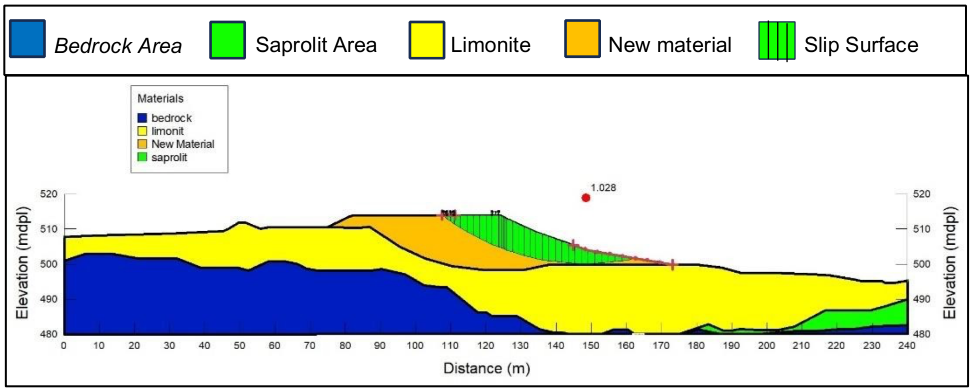

Figure 9. Section C-C’ Showing a Factor of Safety Below the Required Standard.

Based on the slope stability analysis conducted, by lowering the embankment elevation from 514 m to 513 m and setting the dumping boundary back by 6.5 m from the minimum dumping distance of 12.5 m (PT Vale Indonesia Tbk, 2018) measured from the actual crest, the dumping boundary becomes 19 m.

As a result, a factor of safety (FS) of 1.374 was obtained (Figure 11), which is above the required minimum safety factor of > 1.3 under KEPMEN 1827.K/30/MEM/2018. This indicates that the analysed slope condition is stable and has met the established safety criteria.

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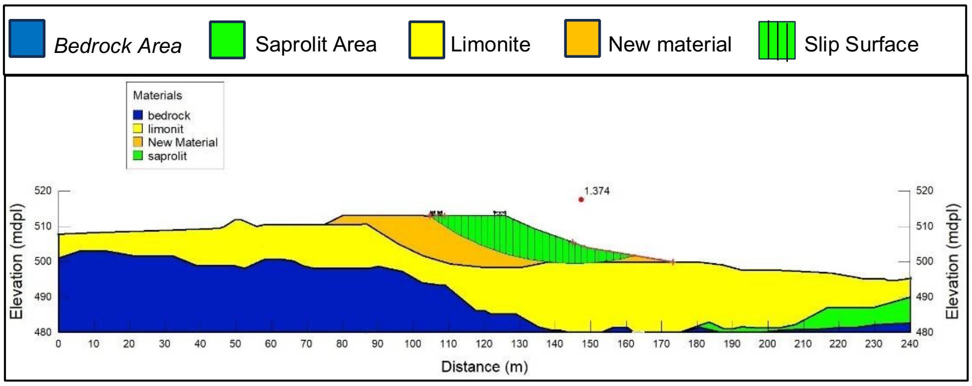

Figure 10. Section C-C’ Showing a Factor of Safety that Meets the Required Standard.

The recommended dumping sequence direction was determined on the basis of the factor of safety results and the dumping distances obtained from the final embankment addition analysis. The safe dumping boundary and direction can be implemented by modifying the elevation and dumping boundaries of the initial disposal plan.

Based on the results of the final embankment addition simulation, and because the factor of safety (FS) values indicate safe conditions, the recommended factor of safety values and safe dumping distances were 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 disposal slope sequence, the design volume obtained is 194,231,106m³. Analysing the volume of the designed slope sequence helps ensure the stability of the material disposal structure. By knowing this volume, planning for 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 Disposal X slope analysis, the FS value obtained for Section A-A’ is 1.010, Section B-B’ has an FS value of 1.039, and Section C-C’ has an FS value of 1.028. The FS values found in this analysis do not meet the safety factor requirement for a slope, namely FS > 1.3, under KEPMEN 1827.K/30/MEM/2018.
3. The results of the Disposal X slope stability analysis for Section A-A’ show that the elevation was cut from 514 m to 512 m and the recommended dump truck dumping boundary is 20 m from the actual crest boundary, producing an FS value of 1.360. In Section B-B’, the elevation was cut from 513 m to 511 m and the recommended dump truck dumping boundary is 20 m from the actual crest boundary, producing an FS value of 1.362. In Section C-C’, the elevation was cut from 514 m to 513 m and the recommended dump truck dumping boundary is 19 m from the actual crest boundary, producing an FS value of 1.374.

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REFERENCE

Aprilia, J., Dicky, M., Zulfiadi, Z., & Osmon, T. (2019). Evaluasi kestabilan lereng tambang batubara Pit "XY" menggunakan metode kesetimbangan batas PT Bukit Asam Tbk. *Padjadjaran Geoscience Journal, 3*(3).

Arif, N. (2016). Analisis faktor keamanan geometri lereng disposal dan mengetahui jumlah volume disposal. *Jurnal Geomine, 4*(3).

Arif Irwandi. (2016). *Geoteknik tambang*. Gramedia Pustaka Utama.

Azizi, M. A. (2014). *Pengembangan metode penentuan reliabilitas kestabilan lereng tambang terbuka di Indonesia* (Disertasi doktoral, Institut Teknologi Bandung).

Azizi, M. A., Nas, C., & Oktavia, D. (2018). Pengaruh geometri lereng terhadap perolehan batubara tertambang di PT Arutmin Indonesia Site Kintap Kalimantan Selatan. Dalam *Seminar Nasional Pakar ke-1 Tahun 2018*.

Badan Standardisasi Nasional. (2017). *SNI 8460:2017 Tata cara perencanaan geoteknik*. BSN.

Bowles, J. E., & Johan, K. H. (1991). *Sifat-sifat fisik dan geoteknis tanah (Mekanika tanah)* (Edisi ke-2). Erlangga.

Cahyo, R. D. (2024). *Analisis faktor keamanan lereng disposal dalam penentuan arah dan jarak aman sequence dumping pada IPD BC3, PT Arutmin Indonesia Tambang Kintap, Kalimantan Selatan* (Skripsi sarjana, Universitas Hasanuddin).

Caterpillar Inc. (2002). *Caterpillar performance handbook*. Caterpillar Inc.

Caterpillar Inc. (2007). *Off-highway truck 785C*. Caterpillar Inc.

Das, B. M. (2010). *Principles of geotechnical engineering* (7th ed.). Cengage Learning.

Fajrin, D., Amalia, R., Anas, A. V., & Alimuddin, H. (2019). Perencanaan disposal semi induced flow dan finger flow di PT Vale Indonesia Tbk, Kabupaten Luwu Timur, Provinsi Sulawesi Selatan. *Jurnal Penelitian Enjiniring, 23*(2), 170–176.

Golightly, J. P. (1979). *Geology of Soroako nickeliferous laterite deposit*. INCO Metals Company.

Herlambang, Rizka, S., Mryanto, & Indra, K. W. (2020). Analisis kestabilan lereng disposal menggunakan metode kesetimbangan batas di tambang terbuka nikel, Kabupaten Konawe, Provinsi Sulawesi Selatan. Dalam *Prosiding Teknik Pertambangan*.

Hoek, E., & Bray, J. W. (1981). *Rock slope engineering* (3rd ed.). The Institution of Mining and Metallurgy.

Kementerian Energi dan Sumber Daya Mineral. (2018). *Keputusan Menteri ESDM Nomor 1827.K/30/MEM/2018 tentang pedoman pelaksanaan kaidah teknik pertambangan yang baik*.

Kumarawarman, B. (2016). *Engineering geology of Sorowako and Petea*. PT Vale Indonesia Tbk.

Pangemanan, V. G. M., Turangan, A. E., & Sompie, O. B. A. (2014). Analisis kestabilan lereng dengan metode Fellenius (Studi kasus: Kawasan Citraland). *Jurnal Sipil Statik, 2*(1), 37–46.

Parker, J. V., & Means, R. V. (1974). *Soil mechanics and foundation*. Prentice Hall of India.

PT Vale Indonesia Tbk. (2018). *Management disposal*. PT Vale Indonesia Tbk.

Pusat Studi Gempa Nasional. (2017). *Peta sumber dan bahaya gempa Indonesia tahun 2017*. Kementerian PUPR.

Rohman, M. A., Arief, R., & Harimurti. (2022). Analisis stabilitas lereng di KM 258 Ponorogo–Pacitan menggunakan metode rock mass rating (RMR). *Jurnal Teknik Sipil*.

Simandjuntak, T. O., Rusmana, E., Surono, & Supandjono, J. B. (1991). *Geologi lembar Malili, Sulawesi*. Pusat Penelitian dan Pengembangan Geologi.

Simanjuntak, T. O. (1993). Neogene plate convergence in eastern Sulawesi. *Jurnal Geologi dan Sumberdaya Mineral, 8*(25), 2–15.

Sugesti, D. B. (2019). *Analisis deformasi dan stabilitas lereng dengan variasi geometri dan perkuatan geotekstil pada proyek gedung Fakultas Hukum UII* (Skripsi sarjana, Universitas Islam Indonesia).

Sukamto, R. (1975). *Geologi Sulawesi*. Direktorat Jenderal Geologi dan Sumber Daya Mineral.

Takwin, G. A., Turangan, A. E., & Rondonuwu, S. G. (2017). Analisis kestabilan lereng metode Morgenstern–Price (Studi kasus: Diamond Hill Citraland). *Tekno, 15*(67).

Yovita, A. (2024). *Analisis kestabilan lereng disposal Lembo East 02 PT Vale Indonesia Tbk tipe semi induced flow dan induced flow sebagai acuan penentuan batas dumping yang aman* (Skripsi sarjana, Universitas Hasanuddin).

Zakaria, Z. (2009). *Diklat kuliah analisis kestabilan lereng tanah*. Universitas Padjadjaran.