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SLOPE STABILITY ANALYSIS OF PIT X USING THE MORGENSTERN-PRICE METHOD AND DUMP SLOPE RATING (DSR)

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Abstrak

Penelitian ini bertujuan untuk mengevaluasi kestabilan lereng di Pit X yang terletak di area tambang terbuka PT Bukit Asam, Kabupaten Muara Enim, Sumatera Selatan. Lokasi ini sebelumnya merupakan area *disposal* material tambang yang memiliki karakteristik geoteknik heterogen dan berpotensi menyebabkan ketidakstabilan lereng. Pendekatan yang digunakan dalam penelitian ini meliputi metode keseimbangan batas (*Limit Equilibrium Method*) untuk menghitung faktor keamanan (FK), dan metode *Dump Slope Rating* (DSR) untuk mengevaluasi tingkat risiko secara empiris. Data yang digunakan diperoleh dari pengamatan lapangan dan pengujian laboratorium terhadap parameter kekuatan geser. Hasil analisis menunjukkan bahwa sektor B–B' memiliki nilai FK terendah sebesar 1,11 dan DSR 59, yang dikategorikan sebagai stabil jangka pendek, sedangkan sektor D–D' memiliki nilai FK sebesar 3,36 dan DSR 64, yang menunjukkan kondisi sangat stabil. Konsistensi hasil kedua metode ini membuktikan bahwa pendekatan gabungan efektif untuk menilai kondisi lereng dan memberikan rekomendasi teknis pada kondisi geoteknik yang kompleks.

Kata kunci: d*ump slope rating,* faktor keamanan, geoteknik, kestabilan lereng, pertambangan terbuka

Abstract

This study evaluates slope stability in Pit X, located in the open-pit mining area of PT Bukit Asam, Muara Enim Regency, South Sumatra. The site was previously used as a disposal area for overburden material, resulting in heterogeneous geotechnical characteristics and a higher potential for slope instability. The approaches applied in this study include the limit equilibrium method to calculate the factor of safety (FoS) and the Dump Slope Rating (DSR) method to assess the risk level of the slope empirically. The data were obtained from field observations and laboratory testing of shear strength parameters. The results show that section B–B' had the lowest FoS of 1.61 and a DSR score of 63, classified as poorly stable, while section D–D' had a FoS of 3.36 and a DSR score of 93, indicating very stable conditions. The consistency between both methods confirms that the integrated approach is practical in evaluating slope conditions and providing technical recommendations under complex geotechnical settings.

Keywords: dump slope rating, factor of safety, geotechnical, open-pit mining, slope stability

I. INTRODUCTION

Open-pit mining activities generally result in significant changes to land morphology, including the formation of artificial slopes that have the potential to cause instability. Unstable slopes can lead to failures or landslides, which not only impact worker safety and mining operations but can also cause environmental damage and significant economic losses. Therefore, slope stability analysis is a crucial part of geotechnical risk management in open-pit mining [1].

Pit X is one of the open-pit mining areas located within the operational zone of PT Bukit Asam, Muara Enim Regency, South Sumatra. This area previously functioned as a disposal site for waste mining material, which is now being re-optimized for mining activities. The material resulting from disposal generally possesses heterogeneous physical and mechanical characteristics and is not fully consolidated, thereby increasing the risk of slope instability [2], [3]. This heterogeneity is caused by the variation in rock types and materials deposited, as the dumping process is often carried out using spreader equipment that distributes materials from various sources and of differing quality into a single disposal area. As a result, a single dump body may contain a mixture of fine-grained materials, sand, silt, and clay, each with non-uniform physical and mechanical properties. This condition necessitates a comprehensive and measurable evaluation of the slope stability in the area.

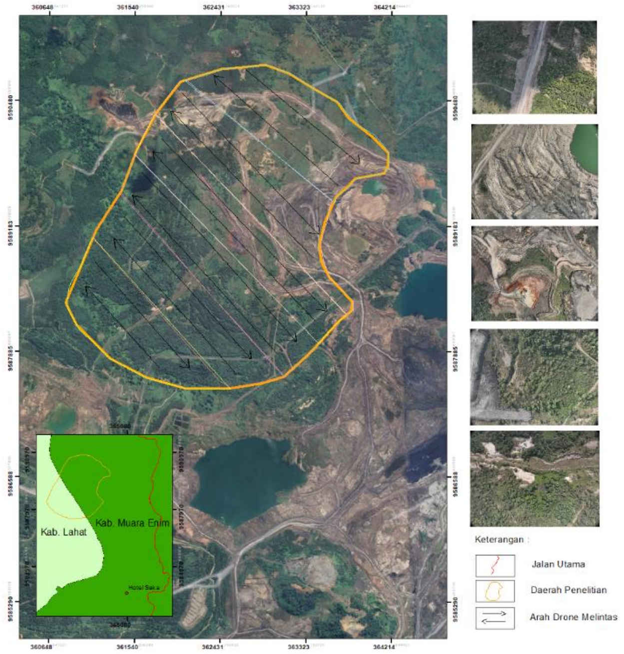

Figure 1. Research Location Map at Pit X, PT Bukit Asam, Muara Enim Regency, South Sumatra

The slope stability evaluation in this study was carried out using two main approaches: the Limit Equilibrium Method (LEM) and the empirical classification method known as Dump Slope Rating (DSR). The Limit Equilibrium Method is widely used in slope stability analysis and continues to provide accurate and reliable results under various slope conditions [4], [5]. This method is used to calculate the Factor of Safety (FoS), which serves as the primary indicator for assessing the stability of a slope.

Meanwhile, the DSR method was developed to provide a quick assessment of slope stability risk by simultaneously considering geotechnical parameters and slope geometry. DSR is particularly suitable for mine slopes with limited data or heterogeneous material lithology [6], [7].

This approach can provide a comprehensive overview of slope geometry conditions, geotechnical parameters, factor of safety values, and slope risk levels based on empirical classification. Thus, the analysis results can serve as a technical reference for slope design planning and the development of future landslide risk mitigation measures [8], [9].

II. LITERATURE REVIEW

A. Slope Stability

Slope stability in open-pit mining is a crucial aspect of mine design, as it directly affects both worker safety and operational efficiency. Slope instability can be caused by inappropriate slope geometry, unconsolidated material types, as well as the influence of groundwater and extreme weather conditions. Slopes formed from disposal material have a higher potential for instability due to the heterogeneous nature of the material and its susceptibility to deformation [3], [6].

Slope stability assessment is generally conducted by calculating the Factor of Safety (FoS), which is the ratio between resisting forces and driving forces along the slip surface. The FoS value is used to determine whether a slope is considered stable, critical, or unstable [7], [10].

B. Limit Equilibrium Method (Morgenstern-Price)

The Limit Equilibrium Method (LEM) is one of the most used techniques for calculating slope safety factors. This approach assumes that slope failure occurs along a specific slip surface, and the equilibrium of forces and moments is evaluated to determine its stability [8], [11].

One of the most widely used LEM methods is the Morgenstern-Price method, which simultaneously considers the equilibrium of horizontal and vertical forces on small elements within the slope body, in this approach. The slope is divided into vertical slices that intersect the slip surface, and each slice is analyzed for moment equilibrium, horizontal force, and vertical force in an integrated manner [4], [11].

This analysis can be used to model both saturated and unsaturated drainage conditions, as well as various slope geometries. Although the method has limitations in handling complex three-dimensional geometries, several studies have shown that the two-dimensional approach is still preferred for effective preliminary evaluations in such cases [3], [9]. This is because, although the waste material in the disposal area is heterogeneous, the variation in physical and mechanical properties is generally more dominant in the vertical (depth) direction and relatively uniform laterally.

C. Dump Slope Rating (DSR)

The Dump Slope Rating (DSR) method was developed by [6] as an empirical classification method used to evaluate the level of slope stability risk based on geometric and geotechnical parameters. This method incorporates six main parameters: slope height, slope angle, number of benches, drainage condition, cohesion, and internal friction angle — each of which is assigned a score based on its classification [6].

The total DSR score is used to classify slopes into four main categories: very stable, stable, moderate, and unstable. This method is advantageous in field conditions with limited data and is well-suited for application on mine disposal slopes [7], [12].

III. RESEARCH METHOD

This study was conducted at Pit X, which is part of the open-pit mining area of PT Bukit Asam, located in Muara Enim Regency, South Sumatra. The site was previously used as a final disposal area for mine waste material, resulting in complex geotechnical characteristics, including non-uniform material distribution, varying slope angles, and a high potential for pore water pressure [13]. Considering these geotechnical risks, the slope stability evaluation was carried out using two complementary approaches: the Limit Equilibrium Method and the empirical classification method [9].

The Limit Equilibrium Method was chosen because it has been proven to provide accurate results in calculating the Factor of Safety (FoS), predicting slip surfaces, and modeling the influence of geotechnical parameters in detail under complex soil and rock conditions [14], [15]. On the other hand, the Dump Slope Rating (DSR) method is used to provide a quick, practical, and complementary assessment by classifying slope risk levels based on geometric parameters and the condition of waste material [6], [7].

These two methods complement each other, as the Limit Equilibrium analysis provides quantitative results in the form of Factor of Safety values and potential failure modes. In contrast, the DSR method offers a qualitative risk classification that can serve as a guideline for field monitoring and mitigation prioritization. Thus, the combination of these approaches is expected to deliver a comprehensive overview of slope stability conditions in former disposal areas and support the development of more effective remediation plans.

The data used in this study consists of both primary and secondary data. Primary data include direct field observations, such as slope geometry, number of benches, and drainage conditions, as well as laboratory data on material shear strength parameters, namely cohesion (c) and internal friction angle (φ). Meanwhile, secondary data include slope cross-section profiles, borehole logs (lithology), geotechnical parameters (cohesion, internal friction angle, and unit weight), groundwater levels obtained from piezometer measurements, and maximum daily rainfall data. These parameters were used as input for slope stability modeling [12], [16]. The values of the geotechnical parameters used are presented in Table 1 below:

Table 1. Geotechnical Data of Disposal Material at Pit X

Stratigraphy	Unit *Weight* (kN/m³)	Phi (°)	*Cohesion* (kPa)
BLU1	16,69	15,68	27,28
BLG1	15,43	17,42	24,11
BLU2	15,77	15,09	38,33
BLG2	16,53	16,00	16,51
BLU3	17,19	11,77	22,78
BLG3	17,01	7,40	41,3
BLU4	14,56	19,48	36,95
BLG4	16,40	19,56	31,93
BLU5	16,61	21,39	31,65
BLG5	16,15	17,76	35,14

Table 2. Geotechnical Data of In-Situ Material at Pit X

Stratigraphy	Unit *Weight* (kN/m³)	Phi (°)	*Cohesion* (kPa)
OB A1	20,52	126,68	22,55
Seam A1	12,01	174,21	26,21
IB A1-A2	19,67	212,84	29,36
Seam A2	12,02	223,56	13,7
IB A2-B1	21,93	122,55	27,87
Seam B1	12,16	165,29	28,87
Stratigraphy	**Unit *Weight* (kN/m³)**	**Phi (°)**	**Cohesion (kPa)**
Seam B2	11,95	284,67	24,71
IB B2-C	20,51	161,46	23,56
IB B2-B1	20,75	128,46	26,6
Seam C	11.79	173.61	25.35

These parameter values were used to calculate the slope's Factor of Safety (FoS) based on stress distribution and force equilibrium along the slip surface. Slopes were classified into three categories based on FoS values, following the Indonesian Ministry of Energy and Mineral Resources

Regulation No. 1827 K/30/MEM/2018: stable (FoS ≥ 1.3), moderate (1.1 ≤ FoS < 1.3), and unstable (FoS < 1.1). The calculations considered both saturated and unsaturated slope conditions to illustrate the hydrological impact on stability.

On the other hand, the DSR method is a quantitative classification approach that assesses slope stability based on the scoring of several parameters: slope height (H), slope angle (α), number of benches (N), hydrological condition (U), cohesion (c), and internal friction angle (φ) [6].

Each parameter is assigned a score based on the value ranges defined in [6] and adjusted according to field conditions. The total DSR score is calculated using the following formula:

$$DSR = H_s + \alpha_s + N_s + U_s + c_s + \phi_s$$

Table 3. DSR Weighting Classification Based on [6]

Overall dump height							
Dump height (m)	Up to 40	41-80		81-120	121-160		Above 160
Rating	20	15		10	5		0
Overall slope angle							
Slope angle (°)	<18	18–22	22–26	26–30	30–34	34–38	>38
Rating	30	25	20	15	10	5	0
Number of Benches							
No of Benches	2-4			>4			
Ratings	5			10			
Ground water table (w.r.to total dump height)							
Kondisi Air Tanah	**Tidak ada muka air tanah**		**Hingga 15% dari tinggi**		**15–30% dari tinggi**	**30–40% dari tinggi**	**Lebih dari 40% dari tinggi**
Rating	15		10		5	0	-5
Geothecnical properties of dump							
Kohesi (kPa)	<1		1-10	10-30	30-50	50-70	>70
Rating	0		2	4	6	8	10
Sudut Geser Dalam (°)	<10		10-20	20-24	24-28	28-32	>32
Rating	0		3	6	9	12	15

The score for each parameter is determined based on the DSR classification table modified from [6]. The assessment is carried out for each cross-section using actual geotechnical data and field observations.

The DSR method was developed as an empirical classification approach that is particularly well-suited for conditions with limited geotechnical data and has been widely applied to open-pit mine slopes in Indonesia [17], [18]. The strength of this method lies in its ability to provide a rapid and efficient preliminary assessment, making it a valuable technical reference before conducting more advanced numerical analyses. Integrating the results of DSR with numerical analysis provides cross-validation that enhances the overall accuracy of the slope stability evaluation [5], [13].

Table 4. Dump Stability Class and Recommendations [6]

Kelas Stabilitas Timbunan	Tingkat Bahaya Kegagalan	Tingkat Usaha yang Direkomendasikan untuk Investigasi, Desain, dan Konstruksi	Rentang Nilai Timbunan
A	Diabaikan (Stabil Jangka Panjang)	• Pengujian laboratorium minimum diperlukan • Pembatasan konstruksi minimal • Pemantauan visual sudah cukup	>80
B	Rendah (Stabil)	• Investigasi lokasi menyeluruh • Pengujian indeks laboratorium terbatas • Analisis stabilitas dasar diperlukan • Pembatasan konstruksi terbatas • Pemantauan visual dan instrumental rutin	61–80
C	Sedang (Stabil Jangka Pendek)	• Investigasi lokasi mendetail • Sampel utuh mungkin diperlukan • Pengujian laboratorium mendetail termasuk kekuatan geser dan uji ketahanan • Analisis stabilitas mendetail diperlukan, termasuk studi parametrik • Pembatasan konstruksi sedang • Pemantauan instrumental mendetail diperlukan	41–60
D	Tinggi (Tidak Stabil)	• Investigasi lokasi mendetail dan bertahap • Pengambilan sampel utuh kemungkinan besar diperlukan • Analisis stabilitas mendetail diperlukan, termasuk studi parametrik dan evaluasi penuh terhadap alternatif • Pembatasan konstruksi yang ketat • Pemantauan instrumental yang mendetail dan berkelanjutan diperlukan	<40

According to studies by [5], [8], the combination of quantitative and qualitative methods in slope stability analysis provides strong cross-validation and effectively captures the variability of parameters influencing stability. Validation is conducted by comparing the results of FoS and DSR values with visual monitoring data and the slope deformation history at the study site. This integrated approach is recommended for areas with complex geotechnical conditions or where numerical data is limited.

IV. RESULT AND DISCUSSION

A. Slope Stability Analysis Using The Dump Slope Rating (DSR) Method

The Dump Slope Rating (DSR) method is used as an empirical approach to assess slope stability based on physical and geometric parameters commonly found in mine waste dump slopes. DSR takes into account several parameters such as slope height, slope angle, number of benches, cohesion, internal friction angle, and drainage condition — each assigned a score based on the classification developed by [6].

In this study, the DSR method was applied to all four slope cross-sections (A–A', B–B', C–C', and D–D') to obtain a qualitative yet practical overview of slope stability conditions in the field. The assessment was based on actual data from geometric observations, slope conditions, and geotechnical test results.

1) Cross-section A-A'

Cross-section A–A' obtained a total DSR score of 59. Based on the classification developed by [6], this score falls into Category C, which is defined as short-term stable. This means the slope has sufficient stability for a limited period but may experience disturbances or instability if monitoring or improvements are not carried out. This score is derived from the combination of the following parameters: dump height of 58.64 meters (15 points), slope angle of 11.6° (30 points), number of benches more than four (10 points), groundwater condition >40% of slope height (-5 points), cohesion of 38.04 kPa (6 points), and internal friction angle of 16.16° (3 points). Although the slope geometry is considered good, the low internal friction angle and the influence of groundwater significantly reduce the total score.

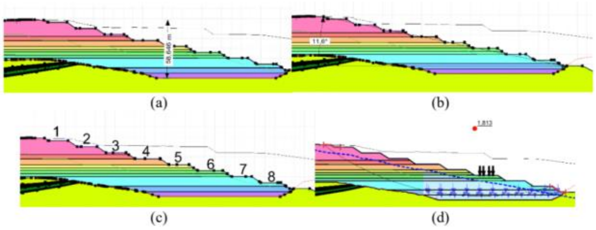

Figure 2. Visualization of Cross-Section A–A' Parameter Measurements: (a) Dump Height, (b) Slope Angle, (c) Number of Benches, and (d) Ground Water Condition.

Table 5. DSR Assessment Results for Cross-Section A–A'

Parameter	Ratings	Description
Dump height (m)	15	58,64
Slope angle (°)	30	11,60
No of Benches	10	8
Condition of groundwater	-5	<40%
Cohesion (kPa)	6	38,04
Friction angle (°)	3	16,16
Total Ratings	**59**	**Short-term Stable**

2) Cross-section B-B'

Cross-section B–B' also obtained a DSR score of 59, placing it in Category C or short-term stable. This indicates that the slope stability is still acceptable for a limited period but may deteriorate if regular evaluation and monitoring are not conducted. The contributing parameters are the same as those in cross-section A–A': dump height of 57.4 meters (15 points), slope angle of 9.73° (30 points), number of benches more than four (10 points), groundwater condition >40% of slope height (-5 points), cohesion of 38.04 kPa (6 points), and internal friction angle of 16.16° (3 points). The consistency of these results reinforces the conclusion that this slope requires attention, particularly regarding groundwater conditions and shear strength characteristics, to improve stability.

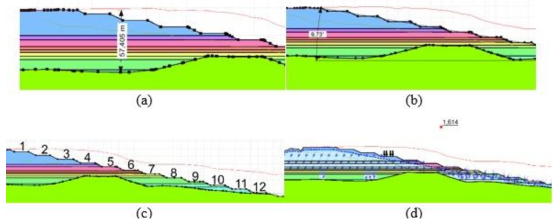

Figure 3. Visualization of Cross-Section B–B' Parameter Measurements: (a) Dump Height, (b) Slope Angle, (c) Number of Benches, and (d) Ground Water Condition.

Table 6. DSR Assessment Results for Cross-Section B–B'

Parameter	Ratings	Description
Dump height (m)	15	57,40
Slope angle (°)	30	9,73
No of Benches	10	12
Condition of groundwater	-5	<40%
Cohesion (kPa)	6	38,04
Friction angle (°)	3	16,16
Total Ratings	**59**	**Short-term Stable**

3) Cross-section C-C'

Cross-section C–C' also achieved a DSR score of 59, which falls into Category C or short-term stable. This means that the slope stability is still adequate for a specific period, but may deteriorate if regular evaluation and monitoring are not carried out. The parameters influencing this score are similar to those of cross-section A–A', with the following details: dump height of 67.62 meters (15 points), slope angle of 12.7° (30 points), number of benches more than four (10 points), groundwater condition exceeding 40% of the slope height (-5 points), cohesion of 38.04 kPa (6 points), and internal friction angle of 16.16° (3 points). These consistent results emphasize the need for special attention to groundwater conditions and slope shear strength to maintain or improve stability in this area.

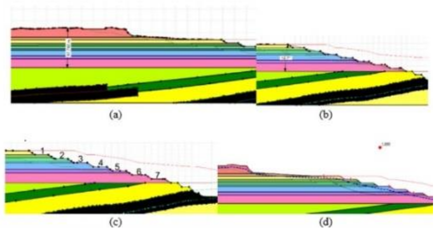

Figure 4. Visualization of Cross-Section C–C' Parameter Measurements: (a) Dump Height, (b) Slope Angle, (c) Number of Benches, and (d) Ground Water Condition

Table 7. DSR Assessment Results for Cross-Section C–C'

Parameter	Ratings	Description
Dump height (m)	15	67,62
Slope angle (°)	30	12,70
No of Benches	10	7,00
Condition of groundwater	-5	<40%
Cohesion (kPa)	6	38,04
Friction angle (°)	3	16,16
Total Ratings	**59**	**Short-term Stable**

4) Penampang D-D'

Cross-section D–D' obtained a DSR score of 64, which is categorized as Category B (Stable) based on the DSR system. This indicates that the slope is considered stable for the medium to long term. The score was supported by the following geotechnical parameters: dump height of 72.04 meters (15 points), a relatively gentle slope angle of 10.44° (30 points), five benches (10 points), groundwater condition at 32.9% of the slope height or equivalent to 23.69 meters (0 points), cohesion of 38.04 kPa (6 points), and internal friction angle of 16.16° (3 points).

The very gentle slope angle and relatively good cohesion value are the main factors supporting the stability. However, the relatively high groundwater condition does not contribute additional points to the score. Overall, the conditions in this cross-section support slope stability, provided that routine monitoring is maintained—especially of groundwater fluctuations and periodic checks of the material's physical properties..

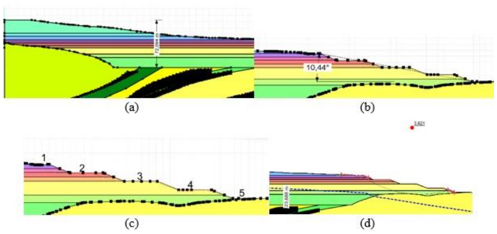

Figure 5. Visualization of Cross-Section D–D' Parameter Measurements: (a) Dump Height, (b) Slope Angle, (c) Number of Benches, and (d) Ground Water Condition

Table 8. DSR Assessment Results for Cross-Section D–D'

Parameter	Ratings	Description
Dump height (m)	15	67,62
Slope angle (°)	30	12,70
No of Benches	10	7,00
Condition of groundwater	0	32,9% (23,69 m)
Cohesion (kPa)	6	38,04
Friction angle (°)	3	16,16
Total Ratings	**64**	**Stable**

Table 9. Recapitulation of Dump Slope Rating (DSR) Results by Cross-Section

Cross-section	DSR Rating	Stability Category
A–A'	59	Short-term Stable
B–B'	59	Short-term Stable
C–C'	59	Short-term Stable
D–D'	64	Stable

Table 4 shows that the DSR scores exhibit a consistent pattern with the Factor of Safety (FoS) values obtained through the Limit Equilibrium Method. Cross-section B–B', which has a DSR score of 63, falls into the moderately stable category and also recorded the lowest FoS value (1.614). This condition indicates that the slope in that sector requires special attention, both in terms of geometric design and drainage system, as stated by [1], [20].

On the other hand, cross-section D–D' obtained the highest DSR score of 64 and is classified as stable. This score aligns with the FoS analysis results, which also show the highest value. This consistency demonstrates that DSR can be used as a quick and effective preliminary assessment method, especially when available geotechnical data is limited. This is supported by findings from[14], [15], which recommend integrating numerical and empirical approaches in the technical design of open-pit mine slopes.

B. Slope Stability Analysis Using The Morgenstern-Price Method

Slope stability analysis was conducted using the limit equilibrium method on four cross-sections representing critical sectors in Pit X. These cross-sections were selected considering variations in slope geometry, elevation, and relative position to the former disposal area. Input parameters used in the calculations were obtained from laboratory tests and variogram modeling, which depict the spatial distribution of cohesion, internal friction angle, and material density. The analysis was performed under static conditions and also simulated extreme rainfall events that occurred in 2023, thus representing worst-case scenarios that could potentially affect slope stability.

1) Cross-section A-A'

Stability analysis of Cross-section A–A' using the Morgenstern-Price method shows a Factor of Safety (FoS) value of 1.51, which is above the minimum stability threshold according to KEPMEN ESDM Number 1827 K/30/MEM/2018 (FoS ≥ 1.25). This slope consists of overburden material BLU–BLG with a unit weight of 16–17 kN/m³, cohesion of 22–41 kPa, and internal friction angle of 11°–21°. The slip surface pattern is rotational, with a relatively low landslide risk, although the potential increases during the rainy season. Therefore, it is recommended to improve the drainage system to minimize water accumulation and maintain slope stability.

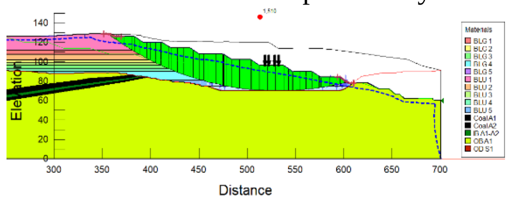

Figure 6. Cross-section A–A'

2) Cross-section B-B'

Cross-section B–B' has a Factor of Safety (FoS) value of 1.54, which is above the minimum stability threshold according to KEPMEN ESDM Number 1827 K/30/MEM/2018 (FoS ≥ 1.25). The slope geometry is relatively steep with a disposal height of 57.40 m and a slope angle of 9.73°. This slope consists of BLG–BLU material with a cohesion of 38.04 kPa and an internal friction angle of 16.16°. The slip surface pattern is rotational, with a relatively low landslide risk, although the potential increases during the rainy season. Mitigation measures are recommended, including optimizing the drainage system to reduce water accumulation on the slope.

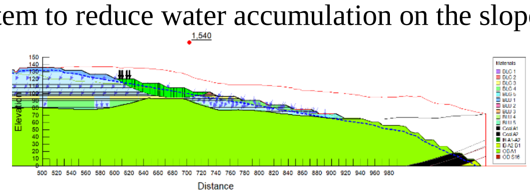

Figure 7. Cross-section B–B'

3) Cross-section C-C'

Cross-section C–C' shows a Factor of Safety (FoS) value of 1.517, which remains above the minimum stability limit according to KEPMEN ESDM Number 1827 K/30/MEM/2018 (FoS ≥ 1.25). This slope has a height of 67.62 m with a slope angle of 12.70°, and the groundwater level is less than 40% of the slope height. The geotechnical parameters include cohesion of 38.04 kPa and an internal friction angle of 16.16°, with the dominant material being BLG–BLU. The slip surface tends to be translational, with a relatively low landslide risk. To maintain long-term stability, improvement and optimization of the drainage system are recommended.

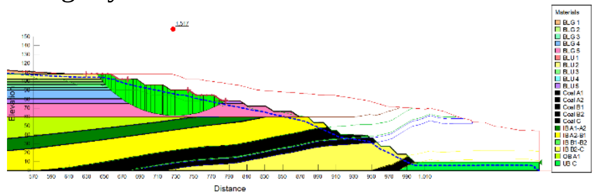

Figure 8. Cross-section C–C'

4) Cross-section D-D'

Cross-section D–D' has the highest Factor of Safety (FoS) value of 3.62, which is well above the minimum stability threshold according to KEPMEN ESDM Number 1827 K/30/MEM/2018 (FoS ≥ 1.25). The relatively low groundwater level supports the overall slope stability. The slip surface pattern is rotational, with a very low risk of failure.

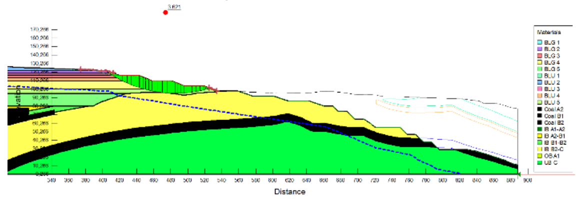

Figure 9. Cross-section D–D'

Table 10. Factor of Safety (FoS) Values by Cross-Section

Cross-section	FoS Value	Stability Category
A–A'	1,51	Stable
B–B'	1,54	Stable
C–C'	1,517	Stable
D–D'	3,621	Stable

The analysis results show that the FoS values vary among the cross-sections, depending on the groundwater conditions. Cross-section A–A' has the lowest FoS value (1.51), which is closest to the ideal stability threshold and indicates potential instability, especially under rainfall or additional loading conditions. This aligns with studies by [15], [18], which state that slope angle and drainage conditions are the main factors contributing to FoS reduction in open pit mine slopes.

Conversely, cross-section D–D' has the highest FoS value (3.62), with groundwater levels lower than those in the other cross-sections. This condition supports the findings by [14], which state that slopes with strong parameters and optimal geometry yield FoS values well above the minimum threshold.

V. CLOSURE

A. *Conclusion*

This study was conducted to evaluate the slope stability at Pit X using a combined approach of analytical methods (Limit Equilibrium Method using Morgenstern-Price) and the empirical classification method Dump Slope Rating (DSR). The stability analysis results show that the Factor of Safety (FoS) values for cross-sections A–A', B–B', and C–C' range between 1.51 and 1.54, approaching the minimum stability threshold based on KEPMEN ESDM No. 1827 K/30/MEM/2018 (FoS ≥ 1.25). Cross-section A–A' has the lowest FoS value at 1.51, followed by cross-sections C–C' (1.517) and B–B' (1.54). Meanwhile, cross-section D–D' has the highest FoS of 3.62, indicating a very stable condition. The assessment results using the DSR method also support these findings, where cross-sections with FoS values near the minimum threshold obtained lower DSR scores compared to more stable cross-sections. The combined approach of analytical and empirical methods has proven to be complementary and effective as a technical basis for evaluating slope geometry design in disposal areas with heterogeneous geotechnical conditions.

B. *Recommendation*

Based on the research findings, several technical recommendations can be made to support slope stability at Pit X:

1. Conduct regular monitoring of slope conditions in sectors A–A', B–B', and C–C', which have FoS values close to the minimum threshold, with a focus on groundwater conditions, especially during the rainy season or extreme rainfall events.
2. Improve and optimize surface and subsurface drainage systems to reduce pore water pressure that can affect the FoS value.
3. Continue using the DSR method as a rapid field evaluation tool to prioritize monitoring and remediation areas.
4. It is recommended to conduct further studies, including dynamic condition simulations (e.g., seismic loads or heavy equipment vibrations) and probabilistic analyses to account for geotechnical data uncertainties in the field.

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