Stability Analysis of Planned Disposal Slope Using Bishop Method at PT. XYZ

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ABSTRACT:

Mine disposal is a critical facility that requires a stable slope design to ensure operational safety and the sustainability of mining activities. This study aims to analyze the stability of the planned mine disposal design at PT. XYZ, South Sumatra, and to evaluate the necessity of design improvement through a resloping approach. The initial disposal design applied a slope angle of 35°. The slope stability analysis results indicate that, at several locations, this slope angle produced factor of safety (FoS) values below the required stability criteria, classifying the disposal slopes as unstable.

As a mitigation measure against slope failure risks, the slope geometry was modified by reducing the slope angle to 20°. The evaluation results demonstrate that the implementation of resloping significantly increased the FoS values to meet the disposal slope stability criteria. Therefore, a disposal slope design with a 20° inclination is recommended as a safer alternative for implementation at PT. XYZ to enhance operational safety and reduce the potential for slope failure.

Keywords: Mine Disposal, Slope Stability, Factor of Safety, Resloping, Mining Geotechnics.

INTRODUCTION

PT. XYZ is one of the coal mining companies operating in South Sumatra Province using an open-pit mining system. In open-pit mining activities, safe and optimal mine design planning is a critical factor that directly affects occupational safety, operational efficiency, and the sustainability of mining operations. One of the key components of mine design planning is the disposal design, which serves as a dumping area for overburden (OB) materials generated from mining activities.

Mine disposal facilities are designed to accommodate large volumes of waste material; therefore, the stability of disposal slopes must be carefully planned and evaluated. Slope failure at disposal areas may result in serious consequences in terms of safety, operational disruptions, and environmental impacts. Consequently, each disposal design plan must undergo a geotechnical analysis to ensure that the proposed slope geometry yields factor of safety (FoS) values that satisfy the required slope stability criteria.

In relation to the planned development of a new disposal area, PT. XYZ prepared an initial disposal slope geometry and requested a slope stability evaluation through geotechnical analysis. This analysis aims to assess whether the proposed design produces acceptable FoS values or still presents potential instability. In this study, slope stability analysis was conducted using the Slide software with the Bishop method, which is one of the widely applied limit equilibrium methods for slope stability assessment. The results of this analysis are expected to provide an overview of the stability level of the disposal design and to serve as a basis for recommending design improvements to enhance the safety and reliability of the mine disposal facility.

Research Objectives

This research aims to:

- Analyze the stability of mine disposal slopes in the initial design planned by PT. XYZ using geotechnical analysis.

- Determine the factor of safety (FoS) values of the disposal slopes generated from the initial design as a basis for assessing slope stability.

- Evaluate the safety level of the disposal design against potential slope failure based on the required slope stability criteria.

- Analyze the effect of slope geometry modification (resloping) on the improvement of the factor of safety of the disposal slopes.

- Provide recommendations for a safer disposal slope design based on the results of slope stability analysis using the Slide software with the Bishop method.

LITERATURE REVIEW

Slope Stability

Slope stability is one of the most common issues encountered in mining construction engineering. Disturbances to slope stability can affect worker safety, cause environmental damage, damage mining equipment, reduce production intensity, and disrupt mining operations [1]. Therefore, slope stability analysis is essential to prevent failures caused by landslide hazards.

Slope stability in mining activities is influenced by several factors, including local geological conditions, the overall geometry of the slope, external factors such as vibrations from blasting activities or operating mechanical equipment, and the excavation techniques used in slope formation. A commonly used approach to express the stability of a mining slope is through the factor of safety (FoS). This factor represents the ratio between resisting forces that maintain slope stability and driving forces that induce slope failure.

The data required for a basic calculation of the factor of safety (FoS) include:

1. Slope geometry data, which are primarily required to construct slope cross-sections, including slope angle, slope height, and haul road or berm width.

2. Soil and rock mechanical properties, including:
   a. Internal friction angle (φ)
   b. Cohesion (c)
   c. Water content (ω)
   d. Rock density

3. External factors, including:
   a. Vibrations resulting from blasting activities
   b. Loads from operating mechanical equipment

Methods of Slope Stability Analysis

One of the methods developed to analyze slope stability is the Limit Equilibrium Method (LEM). The limit equilibrium method evaluates the balance between resisting forces and driving forces acting on a slope. Slope stability analysis is expressed in terms of the factor of safety. This method presents fundamental principles for designing stable natural or artificial slopes, identifies potential failure mechanisms, and determines the factor

of safety for specific geotechnical conditions. In the limit equilibrium method, slope stability conditions are expressed using a factor of safety index. The factor of safety is calculated using force equilibrium, moment equilibrium, or a combination of both approaches ([2]).

Several calculation methods are included within the limit equilibrium framework, such as the Bishop Simplified method and the Janbu Simplified method. The analysis is performed by dividing the soil mass along the potential failure surface into slices; therefore, these approaches are also referred to as the method of slices[3]

Bishop Simplified Method

The Bishop Simplified method is widely used in slope stability analysis due to its simplicity, computational efficiency, and ability to produce sufficiently accurate factor of safety results ([4]). In this method, the normal forces at the base of each slice are determined from vertical force equilibrium. The method is applied to automatically search for critical circular failure surfaces in order to obtain the minimum factor of safety.

A key requirement for applying the Bishop Simplified method is the accuracy and reliability of the input data. The parameters used in the analysis must represent actual field conditions. Strength parameters and groundwater data must be derived from appropriate site investigations, as these parameters significantly influence the calculated factor of safety. The pore water pressure ratio plays an important role in determining slope stability, as it directly affects the resulting factor of safety values.

$$r_u = \frac{u_b}{w} = \frac{u}{\gamma h}$$

Where:

- r_u = Pore Water Pressure Ratio

- γ = Unit Weight of Soil (kN/m²)

- u = Pore Water Pressure (kN/m²)

- h = Average Slice Height (m)

- b = Width of the i-th Slice (m)

From a mathematical standpoint, this method can be expressed as follows:

$$FK = \frac{\sum_{i=1}^{i=n}[c.b_i + (W_i - u.b)\tan\phi']\left(\frac{1}{\cos\alpha\,(1 + \tan\phi' \times \tan\alpha)\,/\,FK}\right)}{\sum_{i=1}^{i=n} W_i \sin\alpha}.$$

FK = Factor of Safety

α = Inclination angle of the i-th slice (°)

c = Effective soil cohesion (kN/m²)

b = Width of the i-th slice (m)

W_i = Weight of the i-th soil slice (kN)

Φ' = Effective internal friction angle (°)

U_i = Pore water pressure of the i-th slice (kN/m²)

The value of FK in the above equation appears on both the left-hand side and the right-hand side. Therefore, to calculate the magnitude of the factor of safety, a trial-and-error method must be used by assuming an initial value of the factor of safety.

Relationship between the Slope Safety Factor (FK) and Slope Stability

Slope failure in mining operations generally occurs along a specific surface known as the slip surface. Slope stability depends on the driving forces and resisting forces acting along this slip surface.

The resisting force is the force that counteracts and prevents slope failure, whereas the driving force is the force that causes slope failure to occur. The ratio between the resisting forces and the driving forces acting on the soil mass is referred to as the safety factor (FK) of the mining slope.

Systematically, the safety factor of a slope can be expressed by the following equation:

$$Faktor\ Keamanan = \frac{Gaya\ Penahan}{gaya\ Penggerak}$$

$$Faktor\ Keamanan = \frac{\tau}{S}$$

The basic concept of the relationship between the forces acting to obtain the factor of safety value for a slope slice is as follows:
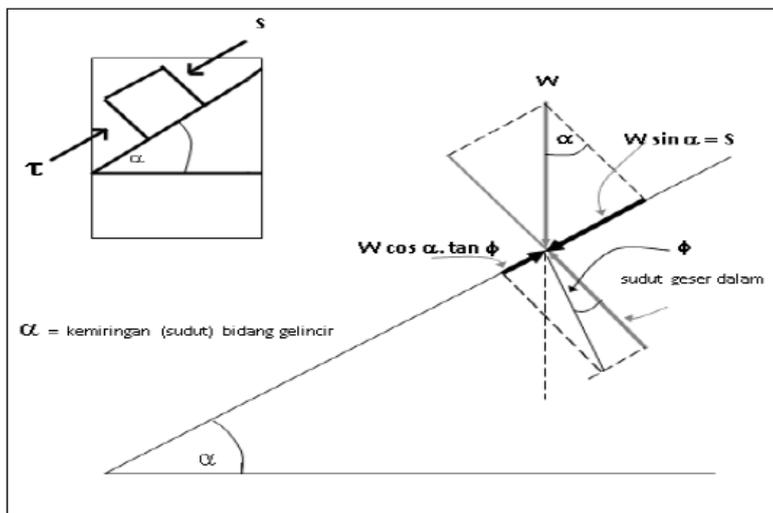
Gambar 2.1 Gaya yang Bekerja Pada Lereng

Mathematically, the factor of safety equation presented above can be formulated as follows:

$$\tau = W\cos\alpha\,.\tan\varphi + c\,L$$

$$S = W\sin\alpha$$

Description:

τ = Resisting forces

S = Driving forces

L = Length of the slip surface

W = Total weight of the slice

c = Cohesion

α = Inclination angle of the slip surface

φ = Internal friction angle

Limit Equilibrium Method

The Limit Equilibrium Method has been used for several decades to safely design geotechnical structures [5] The Simplified Bishop Method is one of the most commonly used limit equilibrium methods for analyzing slope stability [6]. Although the Bishop method is considered less rigorous in slope stability analysis because it does not account for horizontal force equilibrium, this method is relatively simple and practical to apply. In many cases, it produces results with acceptable accuracy [4]

DISCUSSION

Results of Physical Properties Testing

Physical properties testing was conducted to determine the physical properties of the lithology in the study area. The physical properties data used in this study are obtained from tests carried out **by** PT XYZ**,** as presented in the table below.

Nilai min, max, dan average uji sifat fisik perLitology

Lithology	Nilai	∂nat, Gr/cm³	∂Jenuh, Gr/cm³	∂Kering, Gr/cm³
Claystone	min	1,74	1,82	1,34
	max	1,93	1,98	1,57
	Average	1,86	1,90	1,47
Siltstone	min	1,90	1,93	1,52
	max	1,99	2,06	1,71
	Average	1,94	1,98	1,58
Sandstone	min	1,51	1,64	1,05
	max	2,48	2,52	2,25
	Average	1,92	1,96	1,53
Coal	min	1,20	1,21	0,71
	max	1,26	1,28	0,83
	Average	1,22	1,23	0,78

**Results of Mechanical Properties Testing**

Mechanical properties testing was conducted to obtain the values of the internal friction angle and cohesion, which were subsequently used as material input parameters in slope stability analysis. The results of the rock mechanical properties tests were obtained from laboratory testing conducted by **PT. XYZ** and are presented in the table below.

Litology	Cohesi (Kpa), Residual			Sudut Geser Dalam (º), Residual		
	Min	Max	Average	Min	Max	Average
Claystone	11.8	84.6	38.84	6.11	22.15	13.66

Siltstone	20.6	82.9	40.88	13.87	28.9	21.93
Sandstone	4.9	115.4	41.73	8.47	23.8	17.4
Coal	16.1	113.8	67.87	6.67	30.9	19.9

Research Layout Map

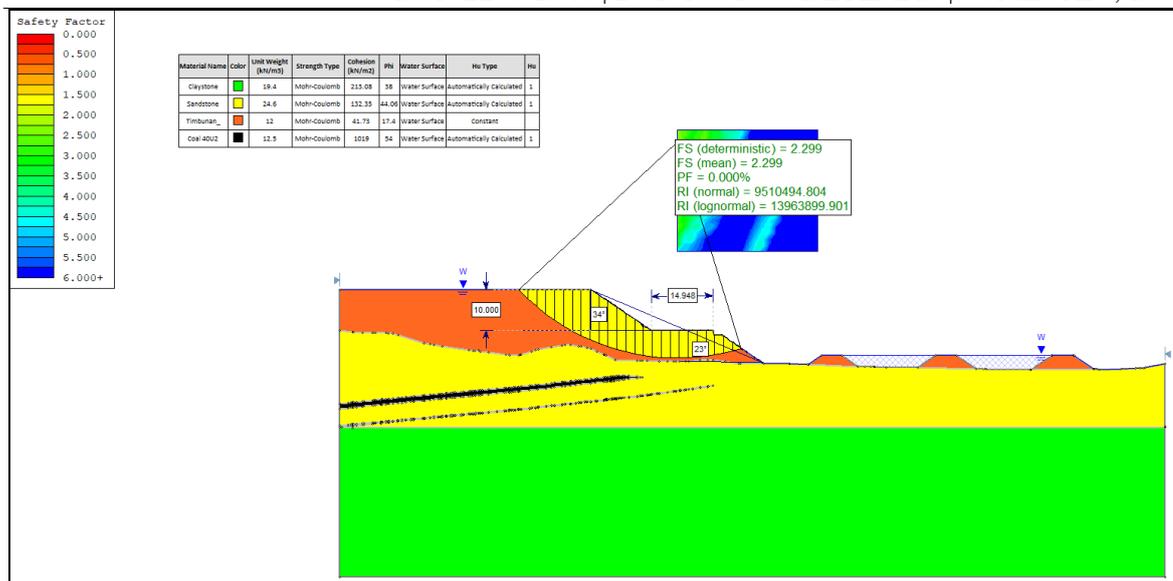The geotechnical analysis was conducted on Sections A–E, as shown in the figure below.
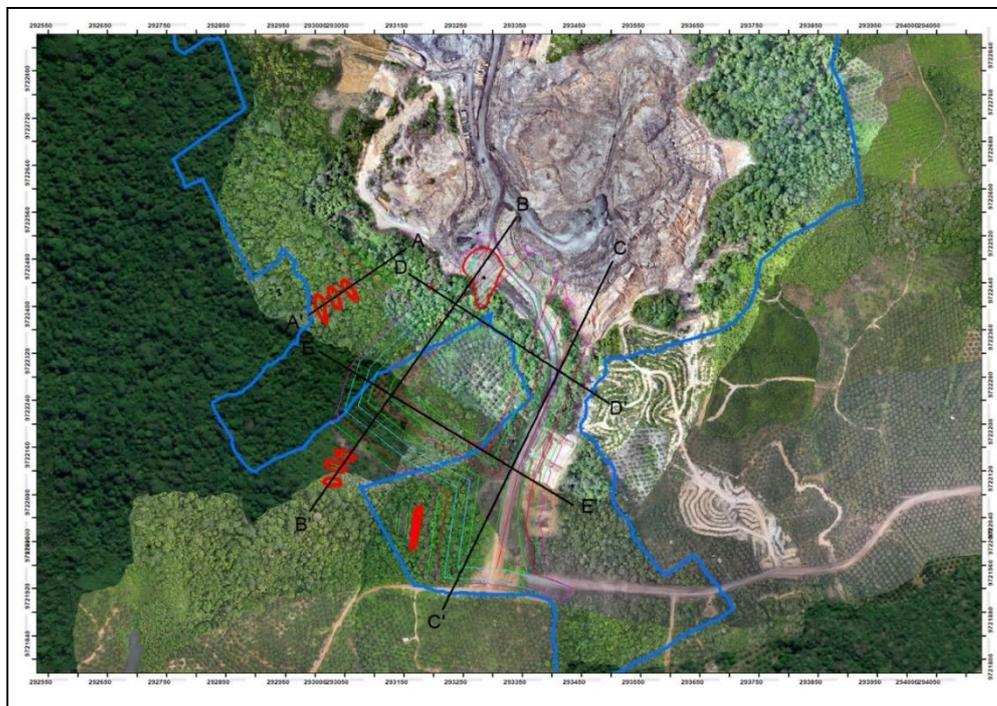
Factor of Safety Analysis

To analyze slope stability and ensure safe slope conditions, slope design modeling was carried out to determine the Factor of Safety (FoS) using Rocscience Slide v6 software, as shown in the figure below. The analysis employed the Bishop method, incorporating material definition data based on the results of the mechanical properties testing described above.
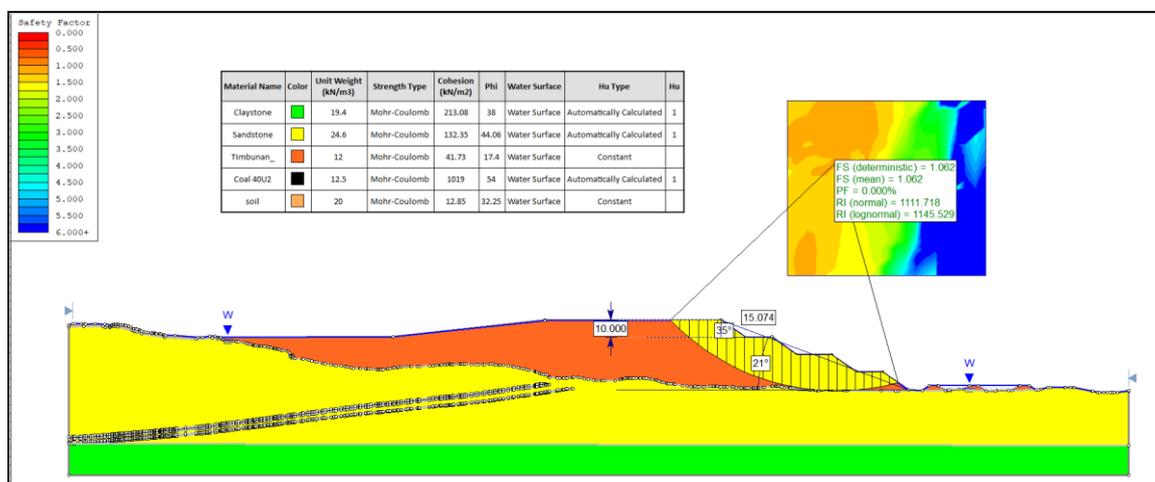
Section A–A'

Based on the geotechnical analysis of the disposal design plan for Pit 6 at Section A–A', a Factor of Safety (FoS) value of 2.29 was obtained. According to the Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia No. 1827 of 2018, the Factor of Safety for waste dumps shall be calculated using residual cohesion and residual internal friction angle values, with a minimum FoS of **1.5**. Therefore, Section A–A' can be classified as stable.

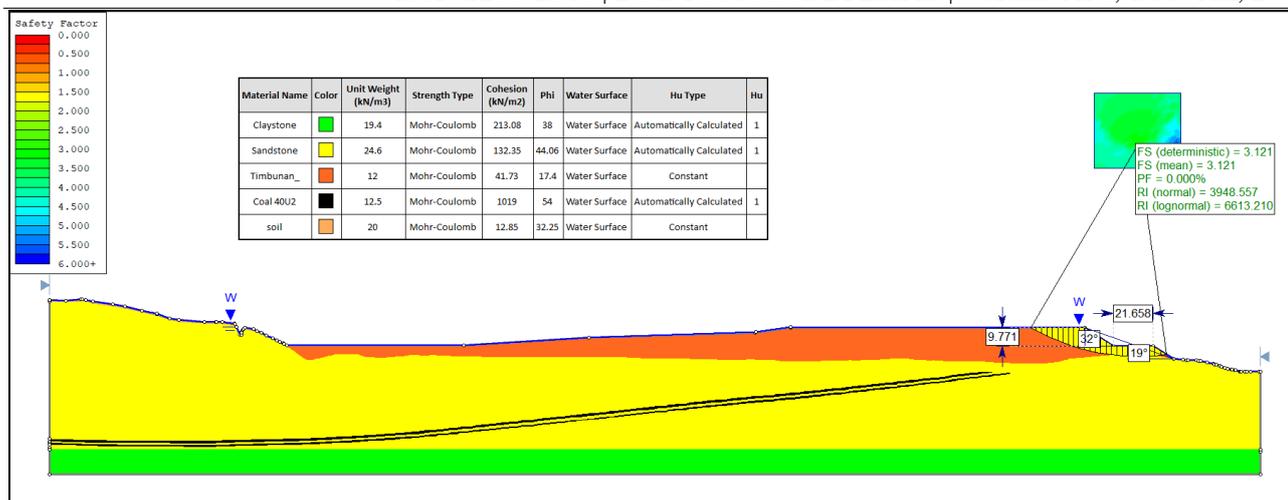| Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kN/m2)	Phi	Water Surface	Hu Type	Hu
Claystone	🟩	19.4	Mohr-Coulomb	213.08	38	Water Surface	Automatically Calculated	1
Sandstone	🟨	24.6	Mohr-Coulomb	132.35	44.06	Water Surface	Automatically Calculated	1
Timbunan_	🟧	12	Mohr-Coulomb	41.73	17.4	Water Surface	Constant	
Coal 40U2	⬛	12.5	Mohr-Coulomb	1019	54	Water Surface	Automatically Calculated	1

Section B–B'

Based on the geotechnical analysis conducted at Section B–B', a Factor of Safety (FoS) value of **1.062** was obtained. This indicates that Section B–B' is **unstable**. Therefore, **resloping** is required to improve the stability of Section B–B'.

Section C–C'

Based on the geotechnical analysis of Section C–C', a factor of safety (FK) value of **3.1** was obtained, indicating that Section C–C' is considered **stable**.
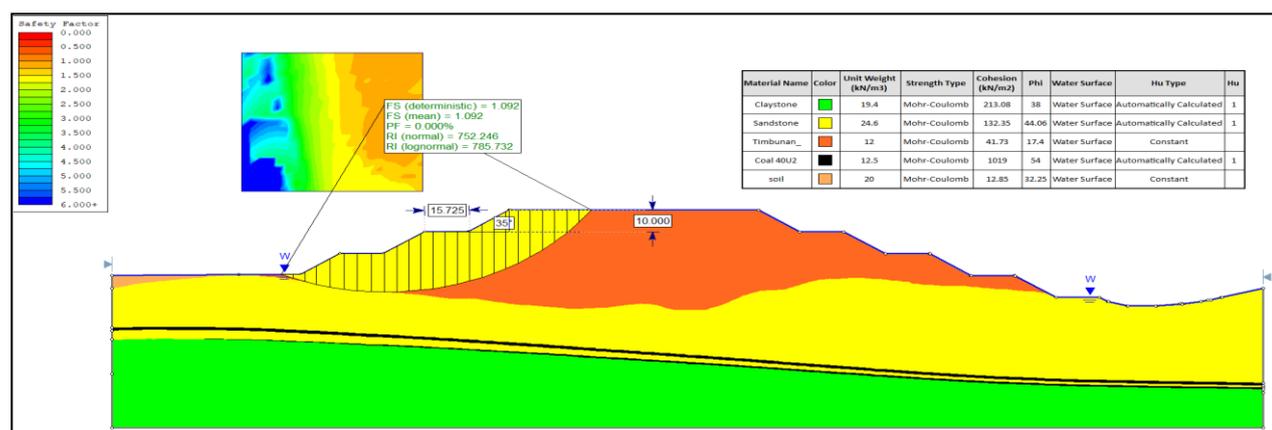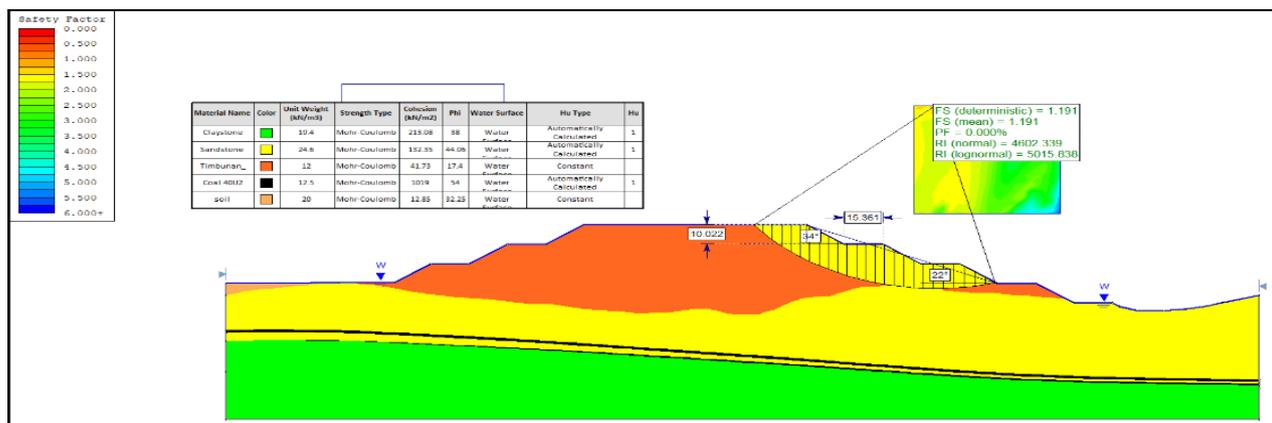
| Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kN/m2)	Phi	Water Surface	Hu Type	Hu
Claystone	🟩	19.4	Mohr-Coulomb	213.08	38	Water Surface	Automatically Calculated	1
Sandstone	🟨	24.6	Mohr-Coulomb	132.35	44.06	Water Surface	Automatically Calculated	1
Timbunan_	🟧	12	Mohr-Coulomb	41.73	17.4	Water Surface	Constant	
Coal 40U2	⬛	12.5	Mohr-Coulomb	1019	54	Water Surface	Automatically Calculated	1

Section D–D'

Based on the geotechnical analysis of Section D–D', the factor of safety (FK) obtained is 1.191 for the right side and 1.092 for the left side. These values indicate that the disposal slope at Section D–D' is unstable. Therefore, resloping is required for this section.

| Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kN/m2)	Phi	Water Surface	Hu Type	Hu
Claystone		19.4	Mohr-Coulomb	213.08	38	Water Surface	Automatically Calculated	1
Sandstone		24.6	Mohr-Coulomb	132.35	44.06	Water Surface	Automatically Calculated	1
Timbunan_		12	Mohr-Coulomb	41.73	17.4	Water Surface	Constant	
Coal 40U2		12.5	Mohr-Coulomb	1019	54	Water Surface	Automatically Calculated	1

Based on the geotechnical analysis of Section E–E', the factor of safety (FK) obtained is 1.42 for the right side and 1.398 for the left side. These values indicate that the disposal slope at Section E–E' is unstable. Therefore, resloping is required for Section E–E'.
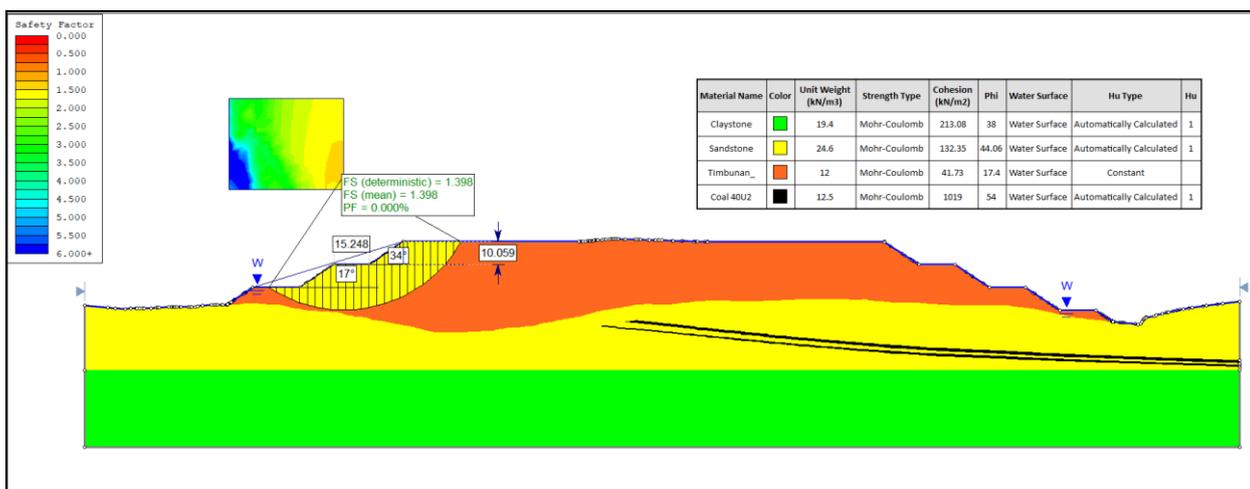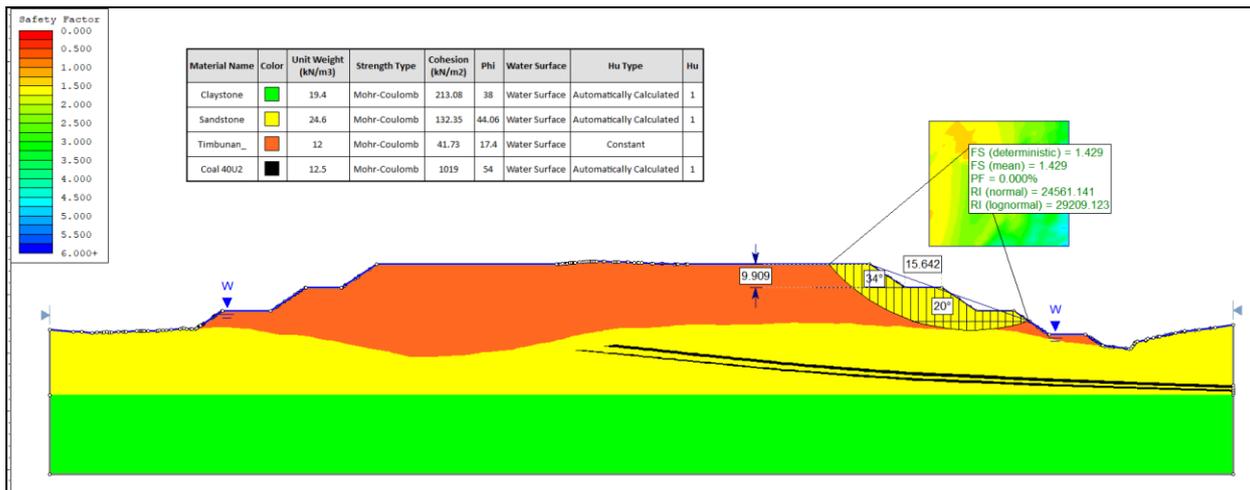

Results of Back Analysis

Results of Resloping Analysis for Section B–B'

To obtain a stable factor of safety (FK), a change in the slope angle was carried out. The initial slope angle of 35° was modified to 20°. The resulting FK value after resloping **is** 1.509. Therefore, the disposal slope can be considered **s**table.
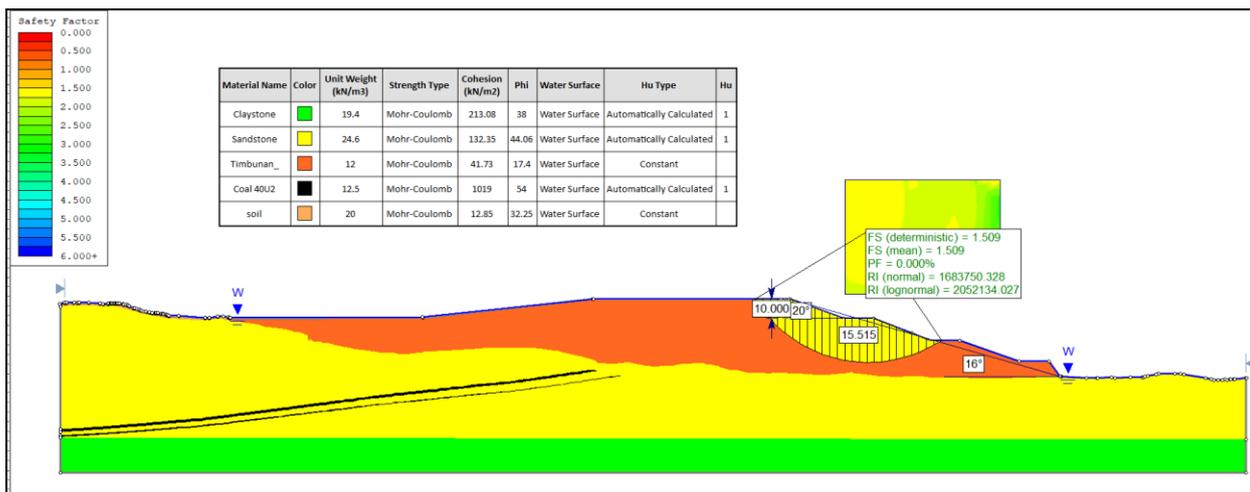
Results of Resloping Analysis for Section D–D'

To obtain a safe factor of safety (FK), the slope angle was modified. The initial slope angle of **35°** was changed to **20°**. The resulting FK values after resloping are 1.509 for the left side and 1.546 for the right side of the slope. Therefore, the disposal slope can be considered stable.
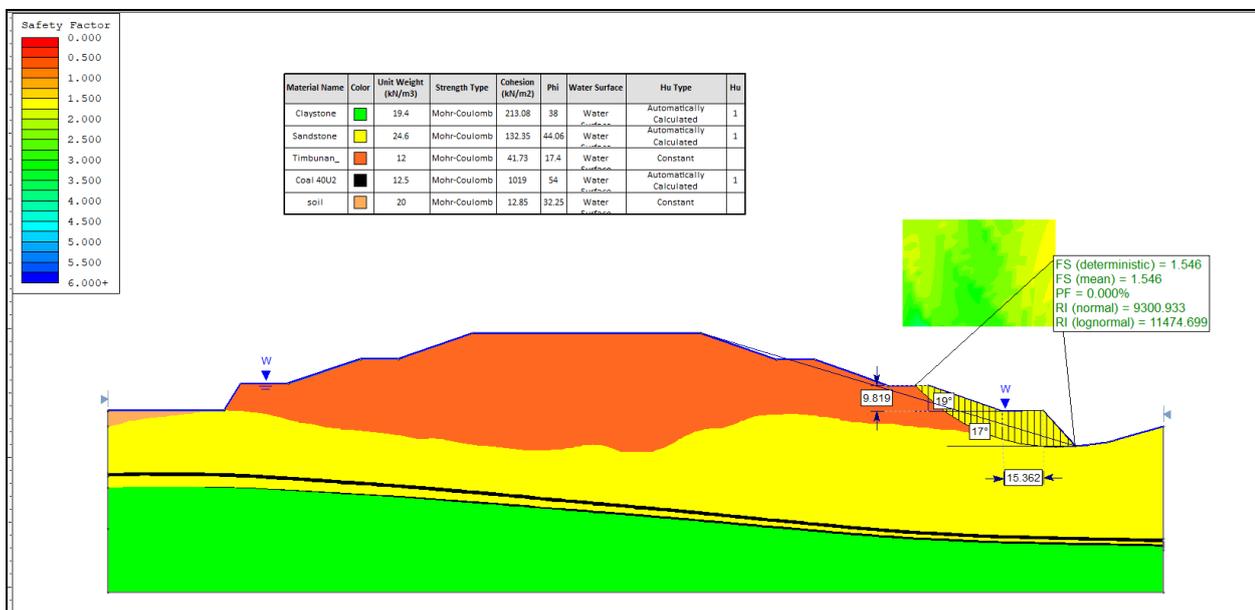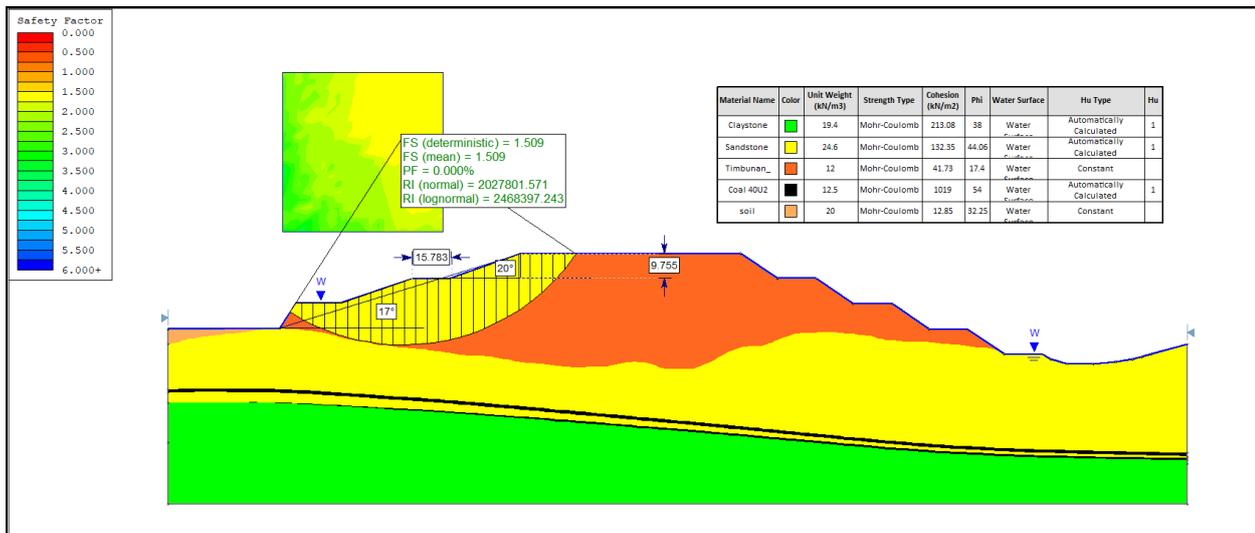
RECOMMENDATIONS

1. For the mudtrap position at Section B–B', it is recommended to provide sufficient spacing so that it is not located too close to the disposal face.

2. For Sections B–B', D–D', and E–E', it is recommended to use a slope angle of 20°, a bench width of 15 meters, and a bench height of 10 meters in order to achieve a factor of safety (FK) greater than 1.5.

3. Sections A–A' and C–C' have stable FK values using the originally planned geometry, with a slope angle of 35°.

CONCLUSION

Based on the results of the slope stability analysis conducted on the planned mine disposal design, it is found that the initial disposal geometry does not yet meet the required factor of safety criteria. This condition indicates a potential slope instability that may increase the risk of slope failure, particularly under long-term

loading conditions and the influence of external factors such as rainfall and the mechanical properties of the disposal material.

Design improvement efforts through the application of the resloping method have proven effective in increasing the disposal slope factor of safety to values exceeding the recommended minimum limit. Modifications to the slope geometry, especially in terms of slope angle and bench height, provide a more stable stress distribution and reduce the driving forces that may lead to slope failure.

Therefore, the implementation of resloping can be recommended as an effective technical solution to enhance the stability of mine disposal slopes. The results of this study emphasize the importance of periodic geotechnical evaluations of disposal designs to ensure operational safety, the sustainability of mining activities, and the mitigation of environmental risks in mining areas.

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