



Geotechnical Assessment of Slope Stability in Laterite Nickel Mining Operations in Laeya District, South Konawe Regency

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ABSTRACT

The laterite nickel mining activities in Laeya District, South Konawe Regency, Southeast Sulawesi, are prone to landslides, requiring a stability analysis to ensure safety and production continuity. This study aims to analyze the physical and mechanical properties of slope materials, actual slope geometry, and determine the safety factor (SF) using the Bishop method with Slide software. The research methods include literature review, field observation, primary data collection (slope dimensions and soil samples), and secondary data from the company. Geometric data were processed using Global Mapper, ArcGIS, and Surpac, while physical-mechanical properties were obtained through laboratory tests. The results show that Sop soil has a density of 18.48 kN/m³, cohesion of 7.98 kPa, and internal friction angle of 22.42°; Limonite has a density of 19.30 kN/m³, cohesion of 12.32 kPa, and internal friction angle of 24.99°; while Saprolite has a density of 16.69 kN/m³, cohesion of 14.83 kPa, and internal friction angle of 26.47°. The actual slope geometry consists of three benches with a total height of 12.8 m and an overall angle of 33°. The Bishop method analysis using Slide V.6.0 software shows an overall SF of 1.802 with a landslide probability of 0.000%, indicating the slope is stable according to the ESDM Ministerial Decree No. 1827 K/30/MEM/2018, which requires a minimum SF of 1.3 for low-risk conditions. Thus, the slope at Pit Nursery is safe from landslide hazards, ensuring that mining activities can continue optimally and sustainably.

INTRODUCTION

Mining comprises a series of activities related to the management and exploitation of mineral resources, including exploration, feasibility studies, mine construction, extraction, processing, transportation, and post-mining reclamation (Cheng & Hou, 2025). In surface mining, particularly open-pit operations, these activities inevitably modify the original topography and create man-made slopes whose stability must be carefully evaluated to prevent geotechnical hazards and ensure safe, continuous production (Liu et al., 2024). Recent studies emphasize that open-pit slope stability is a dynamic problem that should integrate empirical classification, geomechanical analysis, and real-time monitoring systems (Roux et al., 2025).

Nickel laterite deposits have become increasingly important due to their role in stainless steel production and the rapidly growing battery industry (Mudd, 2010). Indonesia hosts some of the world's largest lateritic nickel resources, and several open-pit mines in Sulawesi have been developed to meet rising global demand (Ngasang, Rahayu, & Ramadhani, 2023). Case studies on laterite nickel open pits show that slope stability is strongly controlled by the contrasting geotechnical properties of limonite and saprolite horizons, which often behave more like soil than rock and are highly sensitive to weathering and hydrological conditions (Purwanto & Abadi, 2024).

Open-pit mining operations progressively deepen the pit and steepen slope geometries, altering the in situ stress field and potentially driving slopes toward new equilibrium states (Chen et al., 2025). If driving forces exceed the shear resistance of slope-forming materials, instabilities and landslides may





occur (Nizametdinov et al., 2025). Recent open access studies have demonstrated that combining geological surveys, laboratory testing, and numerical simulations provides a robust framework for calculating the factor of safety and deformation characteristics of mine slopes (Krisnanto & Rahardjo, 2021).

In tropical mining regions, slope stability is further complicated by intense weathering processes that progressively reduce material strength (Liu et al., 2024). High rainfall and groundwater fluctuations can significantly reduce effective stress by increasing pore-water pressure within slope materials (Li et al., 2024). Rainfall-induced infiltration and seasonal wet-dry cycles are widely recognized as major triggering factors for both shallow and deep-seated slope failures in open-pit mines (Zhuzhe, 2025).

To manage slope instability risks, various mitigation measures such as slope geometry optimization, drainage improvement, and structural reinforcement can be implemented (Wu et al., 2024). Recent research indicates that appropriate stabilization techniques can maintain acceptable safety levels while optimizing mine economics (Francisco et al., 2024). In addition, stabilization strategies for closed or transitioning open-pit mines demonstrate the importance of long-term slope safety assessment (Zhang et al., 2025).

Advances in deformation monitoring technologies, including UAV photogrammetry, satellite InSAR, and integrated multi-sensor systems, have significantly enhanced the ability to detect slope movements at early stages (Yiğit & Senol, 2025). Integrated monitoring combined with numerical modeling enables early warning systems and adaptive slope design in open-pit mining operations (Cheng & Hou, 2025).

In nickel laterite mining areas similar to the Nursery Pit in Southeast Sulawesi, previous studies highlight the necessity of conducting detailed slope stability analyses before and during mining operations (Ngasang et al., 2023). When such assessments are not performed, the risk of slope failure increases, potentially leading to work accidents, production disruptions, and environmental impacts (Purwanto & Abadi, 2024). Therefore, a comprehensive slope stability analysis is required to determine the factor of safety and develop effective mitigation strategies to ensure safe and sustainable mining operations (Chen et al., 2025).

RESEARCH METHODS

Research Method

This research employs observational and experimental methods, involving data collection through direct observation and measurement at the research site and in the laboratory. These methods aim to obtain the actual conditions of slope geometry and the characteristics of the materials constituting the slope, which serve as the basis for slope stability analysis.

Research Stages

1. Literature Review
This stage aims to examine concepts, parameters, and methods of slope stability analysis based on relevant scientific journals and previous studies.
2. Field Observations
Field observations were conducted to assess the condition of the slope and the surrounding environment, as well as to document the actual conditions at the research site.
3. Data Collection





The data collected included:

- Primary data, consisting of slope geometry (height and slope angle) and the physical and mechanical properties of soil and rock, such as unit weight, cohesion, and internal friction angle.
- Secondary data, including rainfall records, maps of mining permit areas, and regional geological maps.

Data Processing and Analysis

Topographic data were processed to obtain slope profiles and geometric characteristics. Subsequently, the physical and mechanical properties of the soil were used as input parameters for slope stability modeling using geotechnical software based on the limit equilibrium method to determine the factor of safety (FoS)..

RESULTS AND DISCUSSION

Results

This research was conducted at the Nursery Pit located in Laeya District, South Konawe Regency, Southeast Sulawesi Province. The data used in this study consisted of secondary data, including the physical and mechanical properties of the materials as well as slope geometry data.

Physical and Mechanical Properties of Materials

The physical and mechanical properties of the materials were obtained from existing geotechnical, hydrological, and hydrogeological analyses. These properties include unit weight, cohesion, and internal friction angle. The values of the physical and mechanical properties of the materials used in this study are presented in the following table:

Table 1. Material Properties

| Materials | Unit Weight (Densitas Jenuh) (kN/m ³) | Kohesi (kPa) | Sudut Geser Dalam (°) |
|-----------|--|------------------|--------------------------|
| Topsoil | 18.48 | 7.98 | 22.42 |
| Limonite | 19.30 | 12.32 | 24.99 |
| Saprolite | 16.69 | 14.83 | 26.47 |

Slope Geometry

The actual slope geometry, including the width, height, and angle of each bench on the Nursery pit slope, was obtained from updated topographic data.

Table 2. Slope Geometry

| Bench | Materials | Width (m) | Height (m) | Angle of slope (°) | Overall Slope Height (m) | Overall Slope (°) |
|---------|-----------|--------------|---------------|-----------------------|-----------------------------|----------------------|
| Bench 1 | Top Soil | 3.0 | 2.7 | 52 | 7.8 | 33° |
| Bench 2 | Limonit | 3.0 | 2.6 | 53 | | |
| Bench 3 | Saprolit | 3.0 | 2.5 | 55 | | |

Single Slope Stability Analysis

The results of the single slope stability analysis using Slide software modeling are shown in the following table:

Table 3. Single Slope Stability Analysis

| Bench | Safety Factor (SF) | Probability (Pf) | Information |
|-------|--------------------|------------------|-------------|
|-------|--------------------|------------------|-------------|





| | | | |
|---------|-------|--------|--------|
| Bench 1 | 2.562 | 0.000% | Stable |
| Bench 2 | 2.289 | 0.000% | Stable |
| Bench 3 | 2.923 | 0.000% | Stable |

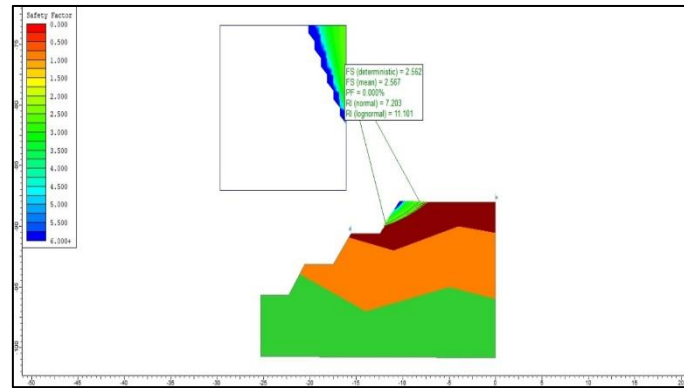


Figure 1. Bench 1 Analysis Results

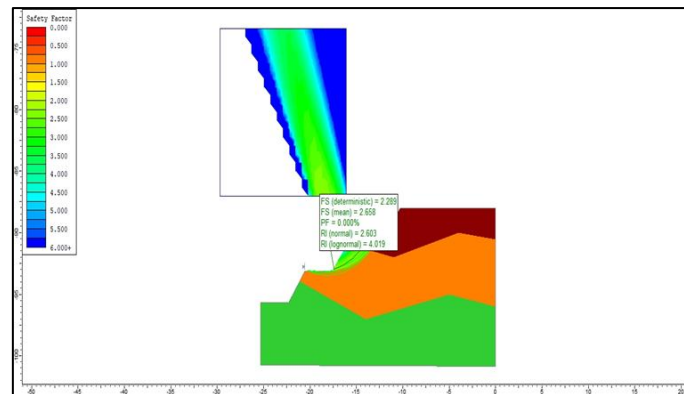


Figure 2. Bench 2 Analysis Results

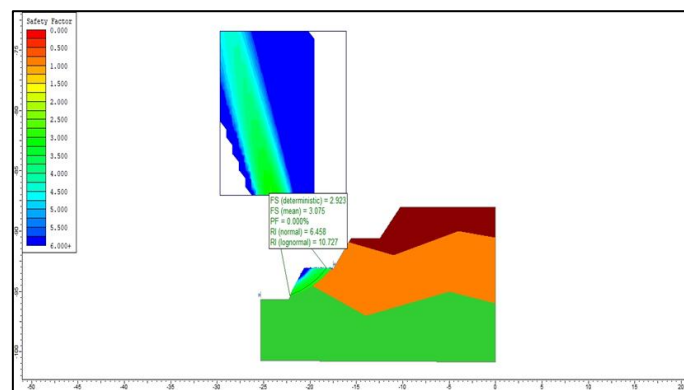


Figure 3. Bench 3 Analysis Results

Analisis Kestabilan Lereng Keseluruhan Pada Pit Nursery

Overall slope stability analysis using Slide software shows that the slope condition is stable, with a Safety Factor (SF) value of 1.802. This value has exceeded the SF slope standard stipulated in ESDM Ministerial Decree No. 1827 K/30/MEM/2018. In addition, the probability of failure (Probability of Failure/PF) or the



possibility of landslides was recorded at 0.000%, which indicates that there is no possibility of landslides on the slope.

Table 3. Overall Slope Stability Analysis

| Bench | Safety Factor (SF) | Probability (Pf) | Information |
|---------|--------------------|------------------|-------------|
| Overall | 1.802 | 0.000% | Stable |

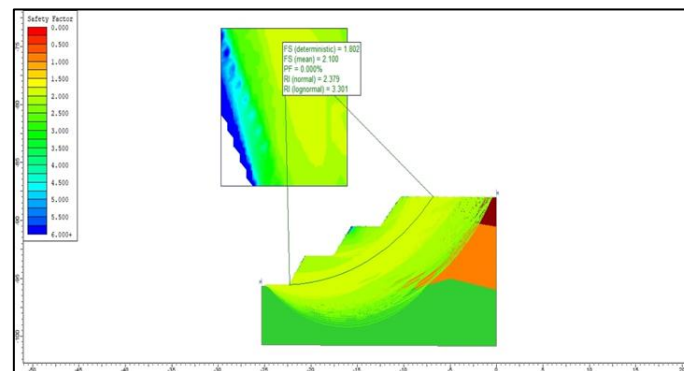


Figure 4. Overall Slope Analysis Results

Discussion

Slope Stability Analysis

Slope stability analysis is performed using the Bishop method, either using the limit equilibrium method or using the Science Slide software. Slope stability analysis requires input data in the form of slope geometric dimensions and material physical-mechanical properties, including unit weight, cohesion, and internal friction angle. Slope geometric data is obtained through a series of topo data updates in ArcGIS software. Physical-mechanical material properties are obtained from laboratory testing results.

Unit weight is an indicator of soil density. The denser a soil, the higher its bulk weight, meaning it is more difficult to transmit water. Cohesion is the shear strength of the soil due to the tensile moments between soil particles. The internal friction angle is the component of the soil shear strength due to interparticle friction. The cohesion and internal friction angle values indicate the potential for a soil mass to experience landslides. The greater the cohesion and internal friction angle values of a soil mass, the greater the stability of the slope composed of that soil mass.

Overall Slope Stability Analysis Modeled Using Slide Software

A slope stability analysis was conducted on the mining pit slope at the Nursery pit using geometric data such as height, bench width, and slope angle. Other supporting data for this slope stability analysis included the physical-mechanical properties of the slope's constituent materials, such as cohesion, internal friction angle, and unit weight. After collecting this data, geometric modeling was performed using Slide Software. The next step was selecting the analysis method, the Bishop method. This method was chosen because it is the most suitable slope analysis method for slopes composed of soil. Physical-mechanical property data was also inputted, and then the analysis was run to determine the SF and PF values of the analyzed slope.

The analysis results indicated that the slope was in a stable condition based on No. 1827 K/30/MEM/2018 concerning Guidelines for the Implementation of Good Mining Engineering Principles with a SF value greater than 1.3, namely 1.802, and a Probability of Failure (PF) of 0.000%, meaning the possibility of



collapse is 0.000%. Input data in the probability of failure calculation is obtained from statistical data on materials from laboratory testing.

Material Sensitivity Analysis

Safety Factor vs Unit Weight

Based on the sensitivity graph, it shows that a material has a high sensitivity to limonite, clay, and saprolite materials or layers. The heavier the material, the higher its SF value. Based on the graph above, it identifies that unit weight is a material property that acts as a driving force, namely the force that causes landslides on a slope. The increase in the unit weight value is inversely proportional to the safety factor value, where the greater the unit weight value, the smaller the safety factor value on a slope.

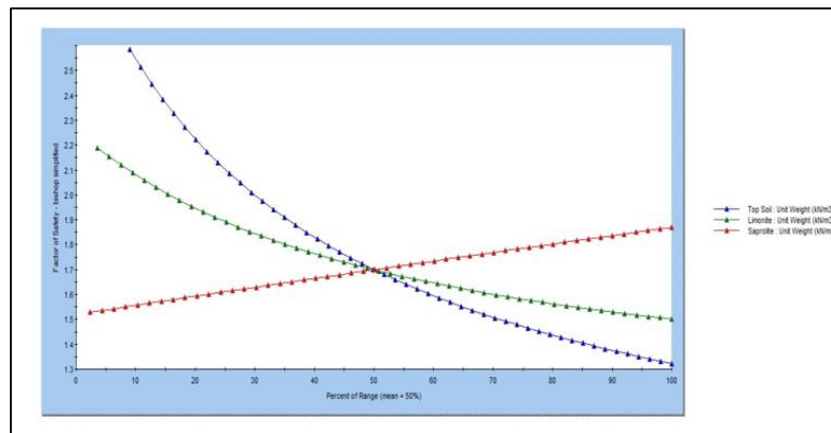


Figure 5. Safety Factor vs Unit Weight

Safety Factor vs Cohesion

Based on material sensitivity, it can be seen that the graph for the cohesion value plays a significant role in calculating the SF value. The graph above can be concluded that the cohesion value and the SF value are directly proportional, meaning that the greater the percentage of the cohesion value, the greater the SF value on a slope and can be said to be safer.

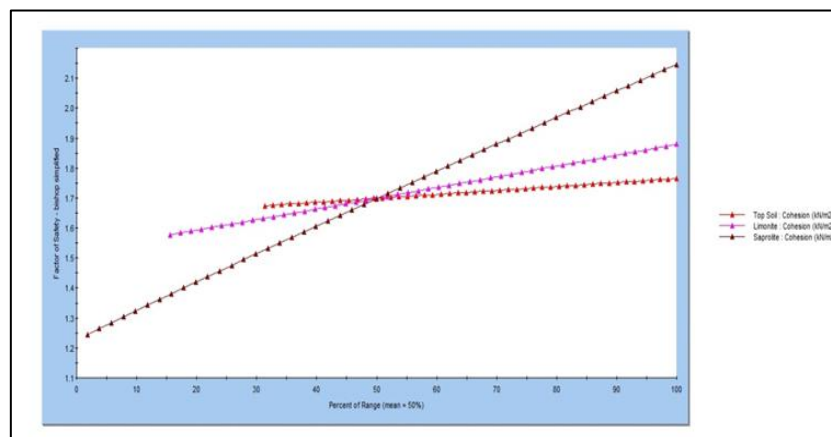


Figure 6. Safety Factor vs Cohesion

Safety Factor vs Friction Angle





The results of the sensitivity analysis indicate that the mechanical properties of the internal friction angle significantly influence changes in the safety factor. The internal friction angle also has a retaining property that functions to stabilize a slope against driving forces. The graph above can be concluded that the internal friction angle is directly proportional to the safety factor value. In other words, the greater the percentage of the internal friction angle, the greater the safety factor value of a slope.

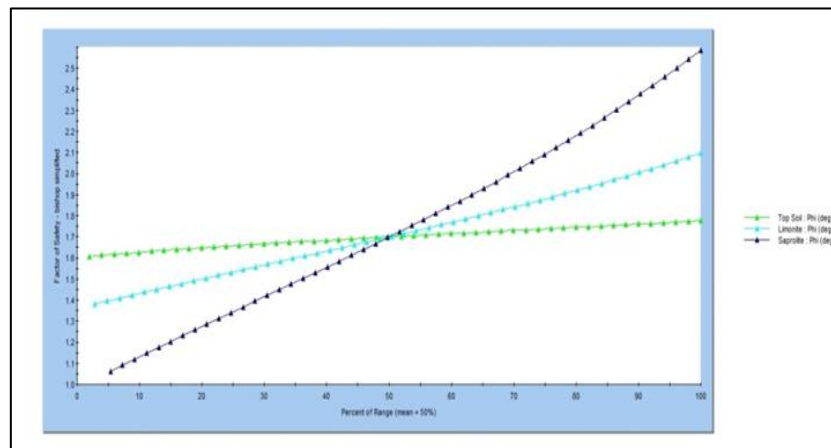


Figure 7. Safety Factor vs Friction Angle

CONCLUSION

Based on the results of processing and analysis of the collected data, it can be concluded that the value of the slope safety factor of the Slide Software modeling for slope 1 with Top Soil material is 2.562, slope 2 with Limonite material has an SF value obtained of 2.289 and slope 3 with Sapolite material has an SF value of 2.923. While for the Overall slope safety factor value using Slide Software modeling is 1.802. In addition, based on the results of the sensitivity analysis, it is known that the input parameters greatly affect the stability of the slope where the greater the load working on the slope, the smaller the slope safety factor value.

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