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Characteristics of Geological Conditions on Safety Factor (FK) of Open-Pit Slope and Landslide Mitigation at the Green Pit Location of Nickel Mining at PT. IFISHDECO Tb

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Abstract: The research location is within the IUP area of PT. IFISHDECO Tbk (122.168°–122.204° E and 4.371°–4.404° S), Tinanggea, South Konawe Regency, Southeast Sulawesi Province. This study aims to analyze the Safety Factor (SF) values of the slopes and the probability of landslide potential at the green pit mining slopes, as well as the landslide hazard mitigation map. The data used include engineering geological characteristics, topographic measurements obtained via total station, aerial photographs (drone), and rock mechanics sample test results. The SF analysis applied is the Simplified Bishop method with Mohr-Coulomb analysis, processed using Slide ver.6 software, along with landslide hazard potential maps and landslide hazard mitigation maps based on the Ministry of Energy and Mineral Resources of the Republic of Indonesia Decree (KEPMEN ESDM RI) No. 1827 K/30/MEM/2018.The research results are derived from slope stability analysis at the green pit mining site based on the static Safety Factor (SF) according to the rules of KEPMEN ESDM RI No. 1827 K/30/MEM/2018, which are as follows: (1) Single Slope Type: SF 0.91 - 1.26 (Unstable – Balanced), (2) Inter-ramp Slope Type: SF 1.15 - 1.25 (Balanced), (3) Overall Slope Type: SF 1.31 – 1.37 (Stable). The probability of soil movement (landslide) potential is 10 – 25%, with a medium severity landslide category. The medium severity landslide category applies when there are consequences such as serious human injuries, damage to facilities and infrastructure from 25% to 50%, production stoppages of more than 12 hours but less than 24 hours, buried reserves that can still be recovered, and environmental damage within the scope of the IUP area.The landslide hazard potential map is divided into three severity categories: low landslide severity, medium landslide severity, and high landslide severity. The landslide hazard mitigation map for the green pit open-pit mining site provides information on potential hazard zones covering an area of 0.33 hectares at the pit slope, safe zones covering 2 hectares outside mining activities, evacuation routes with distances ranging from 68 m to 267 m to the safe zone, and worker assembly points (muster points) equipped with emergency response facilities such as first-aid supplies, transportation means, mobilization facilities, and communication equipment, all of which are part of the mining safety management system.

Keyword: Geological Condition Characteristics, Slope Safety Factor, Landslide Mitigation, Mohr-Coulomb,PT IFISHDECO Tbk

INTRODUCTION

PT IFISHDECO Tbk is a nickel mining company located in Tinanggea, South Konawe Regency, Southeast Sulawesi Province. The laterite nickel mining activities at PT IFISHDECO Tbk are carried out in accordance with the characteristics of the ore deposit, which is generally exposed on the surface, especially in hill and slope areas. Therefore, an open-pit mining system is chosen as the most suitable mining method (Nur Hakim, 2005). In open-pit mining, the overburden layers must be stripped first to access the ore. The stripping of the overburden to obtain the ore is followed by the formation of slope geometry, which results in the creation of slopes with varying angles and heights, leading to a redistribution of stresses due to the disruption of the stress distribution in the existing natural slopes. One of the consequences of this new stress distribution is slippage (land movement) along steps, which is a natural property of slopes seeking a new equilibrium by reducing the load they bear (Papua Dorus Rumsowek et al., 2019).

The stability of slopes, whether natural, man-made, or embankment slopes, is influenced by several factors that can be simply expressed as resisting forces and driving forces responsible for the stability of the slope. When the resisting forces (against landslides) are greater than the driving forces, the slope will be stable (safe). However, if the resisting forces become smaller than the driving forces, the slope becomes unstable and a landslide will occur. If the Safety Factor (SF) value of a slope is >1.0 (Resisting forces > Driving forces), the slope is considered stable. However, if SF <1.0 (Resisting forces < Driving forces), the slope is unstable, and a landslide may occur (Arif, 2016). Landslides on slopes are caused by several factors, including the physical and mechanical properties of the rocks, as well as groundwater conditions. Therefore, an accurate slope stability analysis is necessary. The slope's stability can be measured by calculating the Safety Factor (SF) value (I. Pangestu et al., 2023). Based on the Indonesian Ministry of Energy and Mineral Resources Decree (KEPMEN ESDM RI) No. 1827 K/30/MEM/2018, the overall slope must have an SF >1.20 to be considered stable or safe.

Hoek and Brown (1980) define engineering geological characteristics in the context of rock strength and stability, focusing on fractures and the orientation of weak planes. These characteristics are crucial for understanding how rocks can bear loads and maintain stability, particularly in environments susceptible to high stress or seismic activity. Engineering geological characteristics of landslides refer to the properties and behavior of geological materials, especially soil or rock, which influence the potential for and mechanisms of landslides (Karnawati, 2005).KEPMEN ESDM RI No. 1827/K/30 MEM/2018, regarding Guidelines for the Implementation of Mining Engineering Principles (Page 75), in landslide disaster mitigation at open-pit mining areas, is one of the efforts to reduce the risk of material, economic, and worker safety losses. The strategic steps for landslide disaster mitigation in open-pit mining include slope geometry measurement, movement criteria, methods and schedules for monitoring slope movement, follow-up actions based on monitoring results, landslide hazard maps based on slope condition assessments, and landslide hazard mitigation maps, including safety factor values and landslide probability.This study aims to analyze the Safety Factor (SF) value of the slopes and the probability of landslide potential at the green pit mining slopes, as well as to create a landslide hazard mitigation map based on the geological condition characteristics.

METHOD

The research location is within the IUP area of PT. IFISHDECO Tbk (122.168°–122.204° E and 4.371°–4.404° S), Tinanggea, South Konawe Regency, Southeast Sulawesi

Province (Figure 1). The research area covers 2 hectares and is located in the North Block, specifically in the green pit sub-block

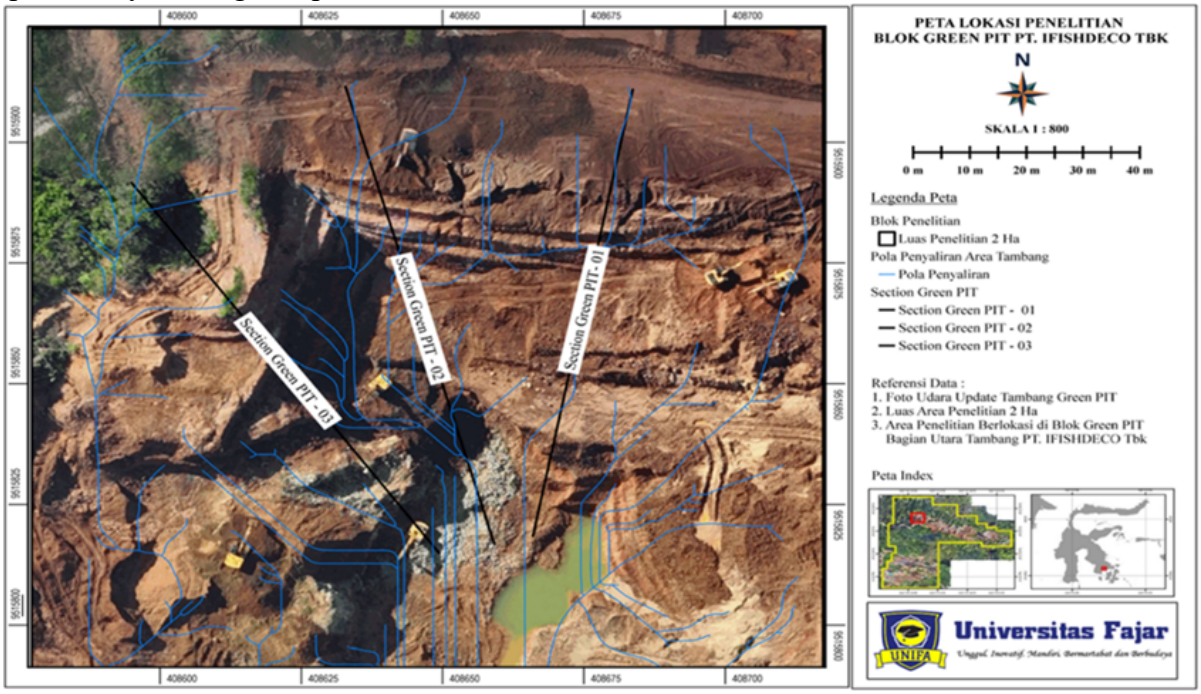


Figure 1. Research location of the green pit area in the North Block of PT. IFISHDECO Tbk (Source: Researcher, 2024).

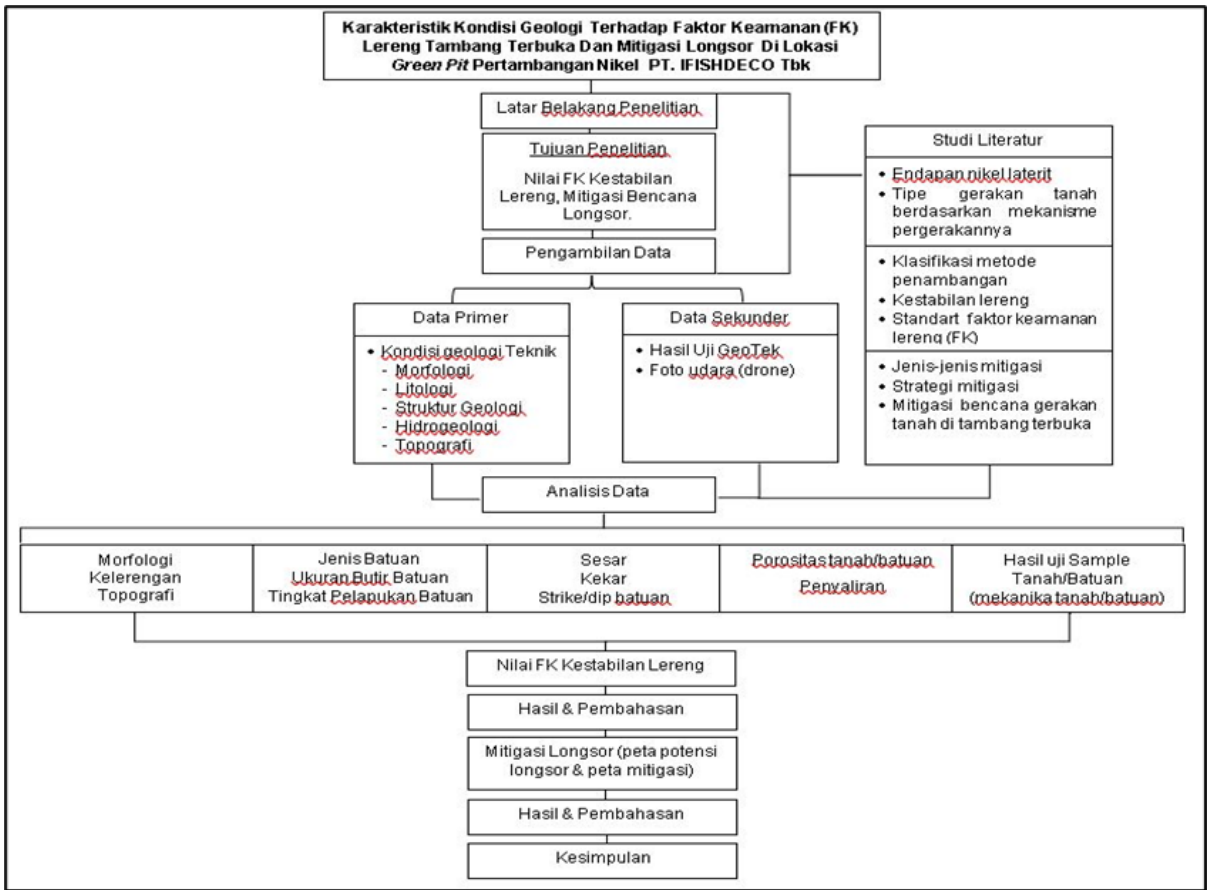


Figure 2. Research Flowchart (Source: Researcher, 2024)

The research method used is a quantitative and observational method. This study involves the collection of numerical data from measurements, analysis of variables, and observation of data without manipulating the existing variables.

Data Type and Data Collection Techniques

To facilitate the analysis, data directly related to the research location is required. The data sources come from direct field observations, secondary data from the company and related agencies, as well as literature studies (Hedianto et al., 2023).

a). Primary Data is research data obtained directly from its source:

1. Open-pit area of the North Block, green pit sub-block.
2. Topographic ground survey using updated total station equipment.
3. Updated aerial photographs.
4. Geological structure measurements (strike/dip).
5. Slope angle measurements of the actual green pit mining area.
6. Local geological mapping at a 1:1000 scale.

b). Secondary Data is data obtained indirectly through intermediary sources. This generally consists of literature, satellite/aerial documentation, and reliable data processing results:

1. Literature study on land movement/landslides.
2. Results of Geotechnical Laboratory tests (rock mechanics).

Data Analysis

The data analysis technique in this research is based on engineering geological conditions, where the details of the data and the target objectives to be achieved are as follows:

a). Safety Factor (SF) for the stability of the mining slope at the green pit, using the Bishop Simplified method (Ma'rief et al., 2022), with the following data:

1. Geomorphological Analysis: Landforms, slope, and topography.
2. Lithological Analysis: Description of rock types, grain shape, weathering.
3. Geological Structure Analysis: Fracture measurements and strike/dip.
4. Hydrogeological Analysis:Water table, rock porosity, drainage patterns.
5. Geotechnical Analysis: Results from rock/soil sample tests.

This analysis is optimized using engineering software tools such as Global Mapper V.23, Slide 2D, and Leapfrog Geo.

b). Mitigation efforts in the green pit mining area involve creating a hazard potential and landslide mitigation map based on the Safety Factor analysis of the pit slopes, in accordance with the provisions of the Ministry of Energy and Mineral Resources Decree (KEPMEN ESDM) No. 1827 K/30/MEM/2018.

RESULTS AND DISCUSSION

The research results consist of geological mapping, which involves the systematic observation and recording of geological elements visible in the research object.

Engineering Geological Characteristics of the Green Pit

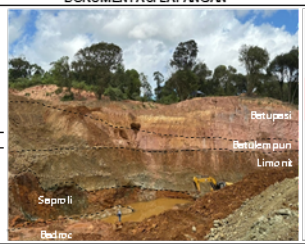
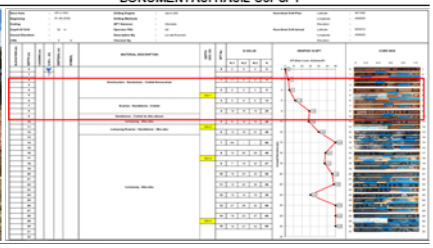
The analysis of the engineering geological characteristics in the green pit area is carried out using three engineering components:

1. Geological identification, 2. Macroscopic description, 3. Results of rock sample tests, including physical and mechanical properties (Table 1) (Ilham Jaya Saputra Iman, 2022)

Table 1. Engineering Geological Characteristics of the Green Pit Area (Source: Author, 2024)

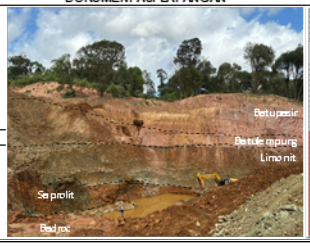
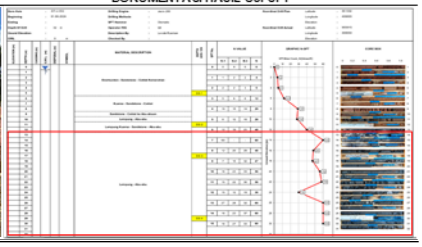
KARAKTERISTIK GEOLOGI TEKNIK

TEBAL (M)	IDENTIFIKASI GEOLOGI	DESKRIPSI MEGASKOPIS	ID - GEOTEK	PENGUJIAN SAMPLE BATU SIFAT FISIK DAN MEKANIK	HASIL LABORATORIUM
	PROFILE BATUPASIR	SINGKAPAN BATUAN			
± 10	G.1 Warna	Kuning - Kecoklatan	PEMBORAN GT- 002	F.1 Berat Volume Kering (kN /m³)	16.7
	G.2 Tekstur	Kasar, Rounded, Sortasi Baik, Kemas Terbuka		F.2 Berat Volume Basah (kN /m³)	17.7
	G.3 Struktur	Berlapis dengan gradasi ukuran halus		F.3 Berat Jenis *(Density)* (kg/m³)	2.65
	G.4 Mineral	Kuarsa		F.4 Porositas (n) (%)	0.42
	G.5 Tingkat Pelapukan	Sedang (dari tingkat oksidasi pada batuan)		F.5 Permeabilitas (") / Ru	Medium / 0.2
	G.6 Tingkat Kompaksi	Rapuh (mudah dihancurkan)		F.6 Derajat Kejenuhan (Sr) (%)	36.38
	G.7 Jenis Batuan	Sedimen klastik		M.1 UCS (Kg / cm²)	5,8
	G.8 Kedudukan Batuan	N 70 ° E / 15° *(Strike/Dip)*		M.2 Triaxial *(Cohesion,c)* (kPa)	10.671
				M.3 Sudut Geser *(friction angle, ϕ)* (deg)	26.65

KONDISI BENTANG ALAM		DOKUMENTASI LAPANGAN	DOKUMENTASI HASIL UJI SPT
Morfologi	Perbukitan Bergelombang		
Kelerengan (Topografi)	10°- 35°		
Struktur Geologi	Sesar Geser Sinistral		
Hidrogeologi	Muka Air Tanah 4 m		
Kondisi Air Tanah	Rembesan dan Basah		
Tataguna Lahan Awal	Lahan Semak -Hutan		
Tataguna Lahan Aktual	Tambang Terbuka		
Kemiringan Tambang	45°		
KEKUATAN BATUAN SECARA ALAMIA			
Rock Mass Rating (Bobot)	-		
Rock Quality Disgnation (%)	-		
Geological Strength Index (%)	-		
Easting	408622		
Northing	9515858		
Elevasi (m)	109		

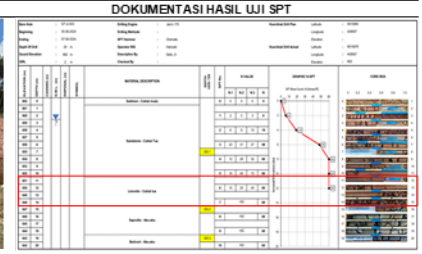
KARAKTERISTIK GEOLOGI TEKNIK

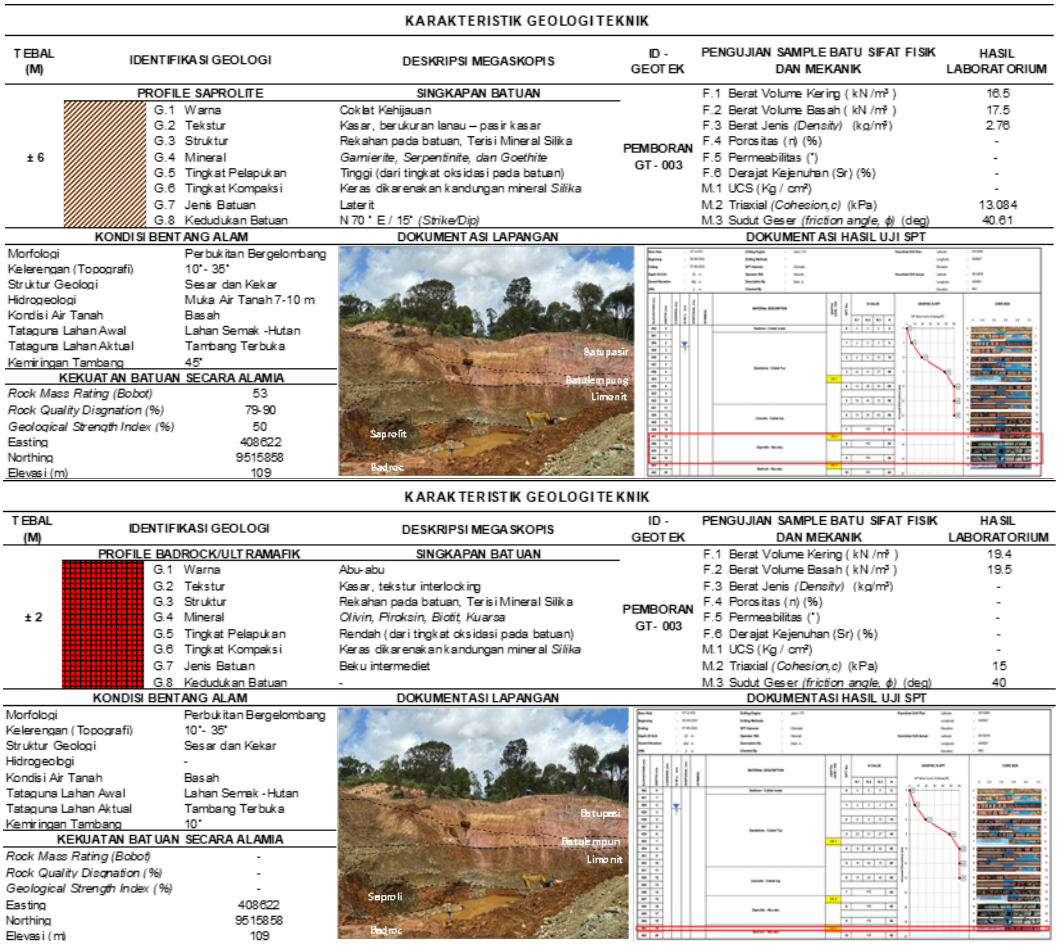
TEBAL (M)	IDENTIFIKASI GEOLOGI	DESKRIPSI MEGASKOPIS	ID - GEOTEK	PENGUJIAN SAMPLE BATU SIFAT FISIK DAN MEKANIK	HASIL LABORATORIUM
	PROFILE BATULEMPUNG	SINGKAPAN BATUAN			
± 5	G.1 Warna	Abu-Abu & Kecoklatan	PEMBORAN GT- 002	F.1 Berat Volume Kering (kN /m³)	16.8
	G.2 Tekstur	Halus, Clay, Elastis, Licin, Lengket		F.2 Berat Volume Basah (kN /m³)	17.7
	G.3 Struktur	Berlapis dengan sisipan string karbon warna hitam		F.3 Berat Jenis *(Density)* (kg/m³)	2.73
	G.4 Mineral	-		F.4 Porositas (n) (%)	0.50
	G.5 Tingkat Pelapukan	Sedang (dari tingkat oksidasi pada batuan)		F.5 Permeabilitas (") / Ru	Very Low /0.2
	G.6 Tingkat Kompaksi	Rapuh (mudah dihancurkan)		F.6 Derajat Kejenuhan (Sr) (%)	69.33
	G.7 Jenis Batuan	Sedimen klastik		M.1 UCS (Kg / cm²)	5,8
	G.8 Kedudukan Batuan	N 70 ° E / 15° *(Strike/Dip)*		M.2 Triaxial *(Cohesion,c)* (kPa)	30.859
				M.3 Sudut Geser *(friction angle, ϕ)* (deg)	13.03

KONDISI BENTANG ALAM		DOKUMENTASI LAPANGAN	DOKUMENTASI HASIL UJI SPT
Morfologi	Perbukitan Bergelombang		
Kelerengan (Topografi)	10°- 35°		
Struktur Geologi	Sesar Geser Sinistral		
Hidrogeologi	Muka Air Tanah 7 m		
Kondisi Air Tanah	Rembesan dan Basah		
Tataguna Lahan Awal	Lahan Semak -Hutan		
Tataguna Lahan Aktual	Tambang Terbuka		
Kemiringan Tambang	68°		
KEKUATAN BATUAN SECARA ALAMIA			
Rock Mass Rating (Bobot)	-		
Rock Quality Disgnation (%)	-		
Geological Strength Index (%)	-		
Easting	408622		
Northing	9515858		
Elevasi (m)	109		

KARAKTERISTIK GEOLOGI TEKNIK

TEBAL (M)	IDENTIFIKASI GEOLOGI	DESKRIPSI MEGASKOPIS	ID - GEOTEK	PENGUJIAN SAMPLE BATU SIFAT FISIK DAN MEKANIK	HASIL LABORATORIUM
	PROFILE LIMONITE	SINGKAPAN BATUAN			
± 5	G.1 Warna	Kecoklat Kemerahan	PEMBORAN GT- 003	F.1 Berat Volume Kering (kN /m³)	17.1
	G.2 Tekstur	Halus, Clayed, Licin, Lengket, Padat		F.2 Berat Volume Basah (kN /m³)	17.7
	G.3 Struktur	Berlapis dengan konkresi besi yang padat		F.3 Berat Jenis *(Density)* (kg/m³)	2.72
	G.4 Mineral	*Goetit, Hematit, Mangan dan Silika*		F.4 Porositas (n) (%)	-
	G.5 Tingkat Pelapukan	Tinggi (dari tingkat oksidasi pada batuan)		F.5 Permeabilitas (")	-
	G.6 Tingkat Kompaksi	Keras dikarenakan kandungan mineral *hematit* ting		F.6 Derajat Kejenuhan (Sr) (%)	-
	G.7 Jenis Batuan	Laterit		M.1 UCS (Kg / cm²)	5,4
	G.8 Kedudukan Batuan	N 70 ° E / 15° *(Strike/Dip)*		M.2 Triaxial *(Cohesion,c)* (kPa)	10.641
				M.3 Sudut Geser *(friction angle, ϕ)* (deg)	37.99

KONDISI BENTANG ALAM		DOKUMENTASI LAPANGAN	DOKUMENTASI HASIL UJI SPT
Morfologi	Perbukitan Bergelombang		
Kelerengan (Topografi)	10°- 35°		
Struktur Geologi	Sesar dan Kekar		
Hidrogeologi	Muka Air Tanah 7-10 m		
Kondisi Air Tanah	Basah		
Tataguna Lahan Awal	Lahan Semak -Hutan		
Tataguna Lahan Aktual	Tambang Terbuka		
Kemiringan Tambang	72°		
KEKUATAN BATUAN SECARA ALAMIA			
Rock Mass Rating (Bobot)	53		
Rock Quality Disgnation (%)	79-90		
Geological Strength Index (%)	50		
Easting	408622		
Northing	9515858		
Elevasi (m)	109		



Geotechnical Rock Sample Test Results (GEOTECH)

The rock mechanics for the research area (green pit) were obtained from the geotechnical drilling at points GT-02 and GT-03. The results of the rock mechanics tests are presented in Table 2.

Table 2. Rock Mechanics Properties of the Green Pit (Source: Author, 2024)

No	ID-Geotek	Litology	Profile	Berat Volume Kering (kN /m³	Berat Volume Basah (kN /m³	Kuat Tekan Batu UCS (Kg / cm²)	Triaxial (kPa)	Sudut Geser (deg)	Berat Jenis
1	GT-002	Batupasir		15.3	16.7	5,8	0.9	32.18	2.65
2	GT-002	Batulmepung		16.8	17.7	5,8	30.859	13.03	2.73
3	GT-003	Limonite		17.1	17.7	5,4	10.641	37.99	2.72
4	GT-003	Saprolite		16.5	17.5	-	13.084	40.61	2.76
5	GT-003	Bedrock		19.4	19.5	-	15	40	-

Analysis of Safety Factor (SF) and Landslide Probability of the Green Pit Mining Slope Based on KEPMEN ESDM RI No. 1827 K/30/MEM/2018.

The Safety Factor (SF) value and landslide probability of the mining slope are two critical elements in slope stability analysis (Panangian Manullang, 2020). These two concepts are used to assess whether a mining slope is safe or at risk of landslide movement. The standard KEPMEN ESDM RI No. 1827 K/30/MEM/2024 provides guidelines and standards for calculating SF and landslide probability on mining slopes, which must be followed by mining companies to ensure operational sustainability and safety. The Safety Factor (SF) and landslide probability on the green pit mining slope were calculated using the Bishop Simplified method with Mohr-Coulomb analysis, processed through the Slide ver.6 software.

1. Safety Factor (SF) measures how stable a slope or earth structure is under specific conditions, considering the cohesion strength of the soil, friction angle, and the load acting on the slope. An SF value > 1 indicates that the slope is stable and not at risk of landslide, while an SF value < 1 indicates a potential for landslides (Faridha Aprilia et al., 2014). To calculate the SF on the green pit mining slope, the following parameters are used:

a. Soil cohesion (c), which measures the adhesive strength between soil particles.
b. Internal friction angle (φ), which indicates the soil's resistance to shear movement.
c. Wet soil unit weight (γ), which affects the load acting on the slope.
d. Condition changes (Ru), such as rainfall or load changes due to mining activities.

2. Landslide Probability is determined by using the Probability of Failure (PoF) (Max) (FK < 1) in the severity classification of landslides from different types of mining slopes (Standard KEPMEN ESDM RI No. 1827 K/30/MEM/2024).

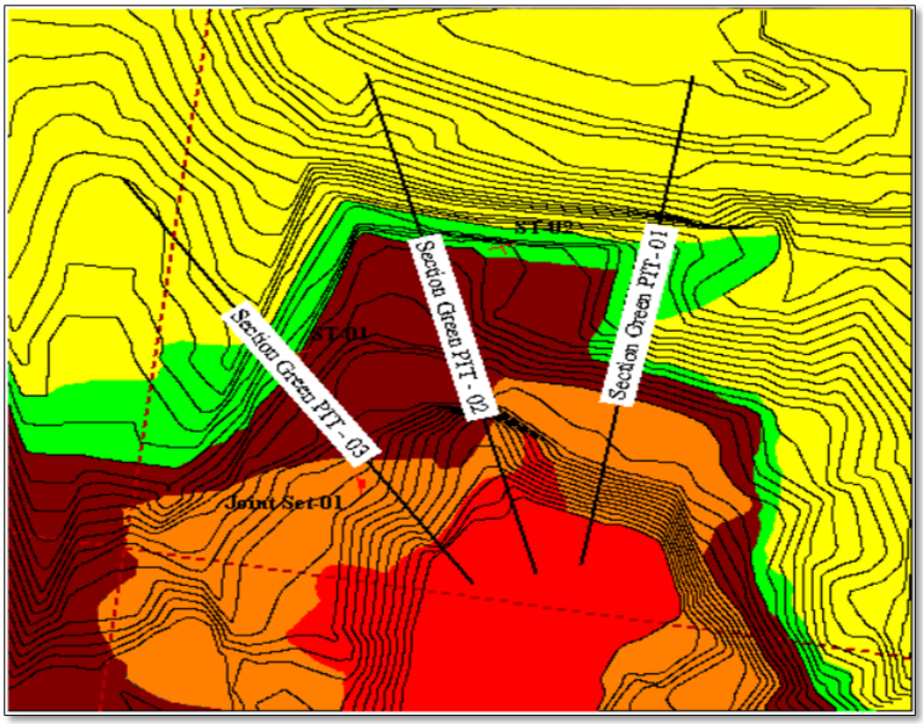


Figure 3. Slope Section Line on the Geological Map (Source: Author, 2024)

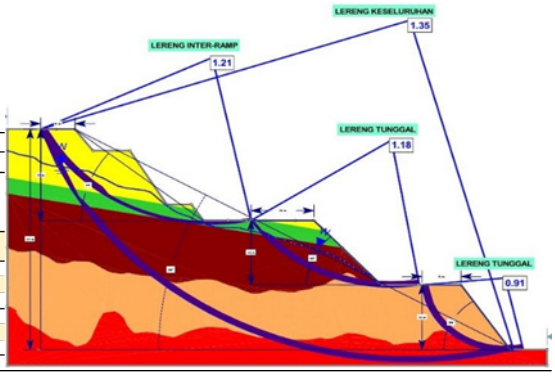
The slope section line of the green pit mine is based on the density of the contour lines of elevation and cuts through the stratigraphic layers of rock from the North to the South, as well as the geological structures. The orientation and spacing between section lines is approximately 40 meters, with a length of about 90 meters. The section is divided into 3 parts, extending from East to West. The purpose of the section is to identify slope stability (Yan Adriansyah et al., 2009). The results of the analysis of the safety factor value for slope section-01

Table 3. FK Value of Green PIT-01 Section

Nilai Faktor Keamanan dan Probabilitas Longsor Lereng Tambang

Jenis Lereng	Keparahan Longsor (*Consequences of Failure / CoF*)	Kriteria dapat diterima (*Acceptance Criteria*)	
		Faktor Keamanan (FK) Statis (Min)	Probabilitas Longsor (*Probability of Failure*) (Maks) *PoF* (FK<1)
Lereng Tunggal	Rendah s.d. Tinggi	1,1	25 - 50 %
Inter-ramp	Rendah	1,15 - 1,2	25%
	Menengah	1,2 - 1,3	20%
	Tinggi	1,2 - 1,3	10%
Lereng Keseluruhan	Rendah	1,2 -1,3	15 - 20 %
	Menengah	1,3	10%
	Tinggi	1,3 - 1,5	5%

Sumber Klasifikasi : KEPMEN ESDM RI Nomor 1827 K /30 / MEM / 2018 (Hal.57)



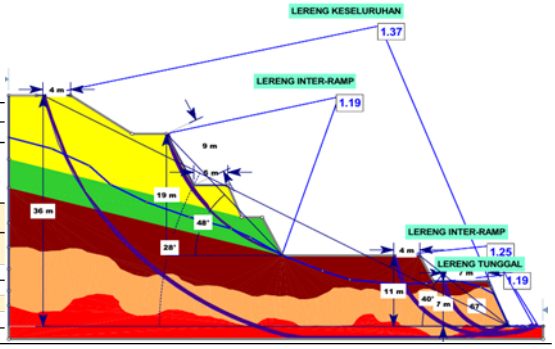
Penampang	Jenis Lereng	Tinggi Bench (m)	Sudut (°)	Lebar Bench (m)	Faktor Kemanan (Statis)	Kondisi Lereng	Batuan/Lapisan	Keparahan Longsor (*CoF*)
Section-01	Lereng Tunggal-01	12	56	6	0.91	Tidak Stabil	Saprolit	Tinggi
	Lereng Tunggal-02	12	47	10	1.18	Seimbang	Limonit	Menengah
	Lereng Inter-Ramp	17	39	6	1.21	Seimbang	Sedimen	Menengah
	Lereng Keseluruhan	41	30	6 - 10	1.35	Stabil	Sedimen -Laterit	Menengah

The results of the analysis of the slope safety factor value of section-02

Tabel 4. FK Value of Green Section Green PIT – 02

Nilai Faktor Keamanan dan Probabilitas Longsor Lereng Tambang			
Jenis Lereng	Keparahan Longsor (*Consequences of Failure / CoF*)	Kriteria dapat diterima (*Acceptance Criteria*)	
		Faktor Keamanan (FK) Statis (Min)	Probabilitas Longsor (*Probability of Failure*) (Maks) *PoF* (FK<1)
Lereng Tunggal	Rendah s.d. Tinggi	1,1	25 - 50 %
Inter-ramp	Rendah	1,15 - 1,2	25%
	Menengah	1,2 - 1,3	20%
	Tinggi	1,2 - 1,3	10%
Lereng Keseluruhan	Rendah	1,2 -1,3	15 - 20 %
	Menengah	1,3	10%
	Tinggi	1,3 - 1,5	5%

Sumber Klasifikasi : KEPMEN ESDM RI Nomor 1827 K / 30 / MEM / 2018 (Hal. 57)

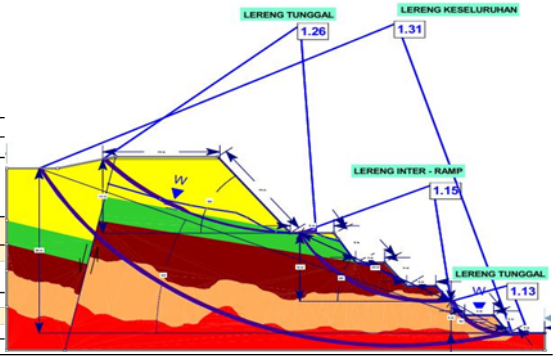


Penampang	Jenis Lereng	Tinggi Bench (m)	Sudut (°)	Lebar Bench (m)	Faktor Kemanan (Statis)	Kondisi Lereng	Batuan/Lapisan	Keparahan Longsor (*CoF*)
Section-02	Lereng Tunggal	7	67	7	1.19	Seimbang	Laterit	Menengah
	Lereng Inter-Ramp - 01	11	40	4 - 7	1.25	Seimbang	Laterit	Menengah
	Lereng Inter-Ramp - 02	19	48	5	1.19	Seimbang	Sedimen	Rendah
	Lereng Keseluruhan	36	28	4 - 7	1.37	Stabil	Sedimen -Laterit	Menengah

Tabel 5. FK Value of Green Section Green PIT – 03

Nilai Faktor Keamanan dan Probabilitas Longsor Lereng Tambang			
Jenis Lereng	Keparahan Longsor (*Consequences of Failure / CoF*)	Kriteria dapat diterima (*Acceptance Criteria*)	
		Faktor Keamanan (FK) Statis (Min)	Probabilitas Longsor (*Probability of Failure*) (Maks) *PoF* (FK<1)
Lereng Tunggal	Rendah s.d. Tinggi	1,1	25 - 50 %
Inter-ramp	Rendah	1,15 - 1,2	25%
	Menengah	1,2 - 1,3	20%
	Tinggi	1,2 - 1,3	10%
Lereng Keseluruhan	Rendah	1,2 -1,3	15 - 20 %
	Menengah	1,3	10%
	Tinggi	1,3 - 1,5	5%

Sumber Klasifikasi : KEPMEN ESDM RI Nomor 1827 K / 30 / MEM / 2018 (Hal. 57)



Penampang	Jenis Lereng	Tinggi Bench (m)	Sudut (°)	Lebar Bench (m)	Faktor Kemanan (Statis)	Kondisi Lereng	Batuan/Lapisan	Keparahan Longsor (*CoF*)
Section-03	Lereng Tunggal-01	5	34	4	1.13	Seimbang	Saprolit	Menengah
	Lereng Tunggal-02	13	52	16	1.26	Seimbang	Batubpasir	Menengah
	Lereng Inter-Ramp	12	29	4	1.15	Seimbang	Sedimen -Laterit	Rendah
	Lereng Keseluruhan	28	23	4	1.31	Stabil	Sedimen -Laterit	Menengah

The current slope stability conditions of the 3 (three) sections in the green pit mine, based on the engineering geological characteristics data and slope geometry analysis, result in slope conditions ranging from unstable to stable. Referring to the static Safety Factor (SF) of the mining slope as outlined in KEPMEN ESDM RI No. 1827 K/30/MEM/2018, the actual slope conditions are detailed in Table 6 as follows:

Table 6. FK Value and Landslide Probability of Green Pit Mine

Nilai Faktor Keamanan dan Probabilitas Longsor Lereng Tambang *green pit*				
Jenis Lereng	Keparahan Longsor (*Consequences of Failure / CoF*)	Kriteria dapat diterima (*Acceptance Criteria*)		Modifikasi Hasil Analisis
		Faktor Keamanan (FK) Statis (Min)	Probabilitas Longsor (*Probability of Failure*) (Maks) *PoF* (FK<1)	Kondisi Lereng Aktual
Lereng Tunggal	Rendah s.d. Tinggi	0,91-1,26	25 - 50 %	Tidak Stabil - Seimbang
Inter-ramp	Rendah	1,15 - 1,25	25%	Seimbang
Lereng Keseluruhan	Menengah	1,31-1,37	10%	Stabil

Sumber Klasifikasi : KEPMEN ESDM RI Nomor 1827 K / 30 / MEM / 2018 (Hal. 57) dan modifikasi Peneliti, 2024.

Slope

The probability of potential landslide movement (sliding) is 10 – 50%, with a moderate severity category. The moderate landslide severity category occurs when there are consequences such as severe human injury, damage to facilities and infrastructure from 25% to 50%, production stoppage for more than 12 hours but less than 24 hours, reserves being buried but still recoverable, and environmental damage remaining within the scope of the IUP area.

Landslide Mitigation

KEPMEN ESDM RI No. 1827 K/30/MEM/2018 provides comprehensive guidelines for landslide hazard mapping (hazard map) based on assessments of slope conditions and landslide hazard mitigation maps, which should at least include hazard zones, safe zones, muster points, and evacuation routes in case of danger, as part of the mine safety management system.

Landslide Hazard Potential Map Based on Landslide Severity Classification

Landslide severity is classified using slope type parameters and the results of SF analysis, then plotted on a landslide hazard map (hazard map) as shown in Figure 4

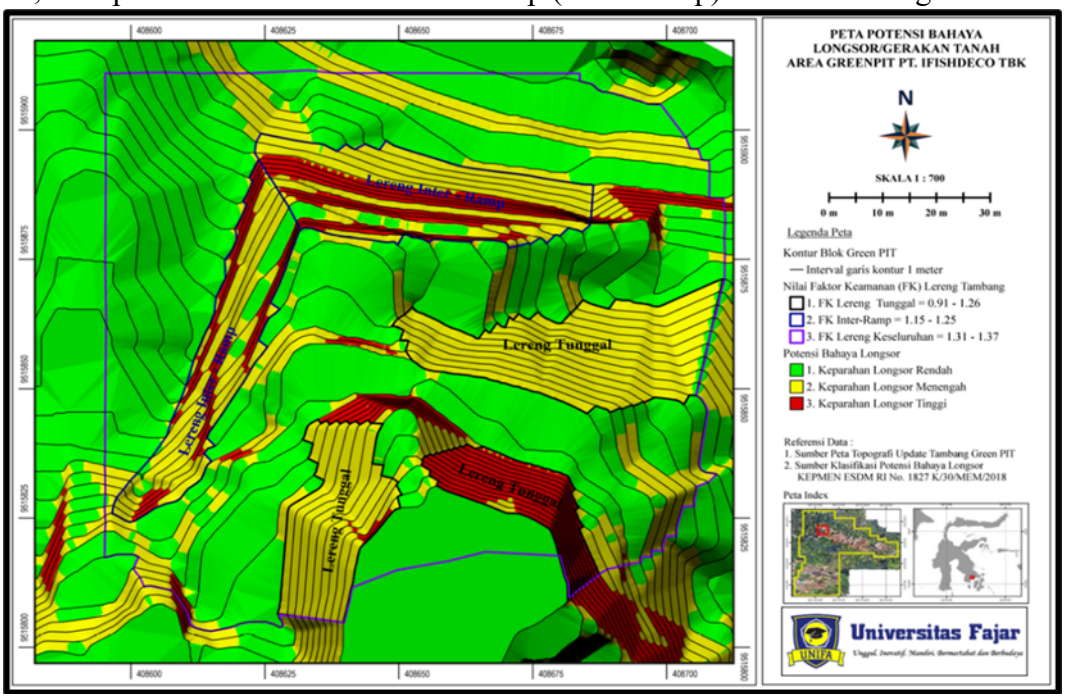


Figure 4. Landslide Hazard Potential Map of the Green Pit Area (Source: Author, 2024)

The landslide severity zoning on the landslide hazard potential map, based on the analysis results, is as follows:

a. FK < 1.0: High landslide severity potential zone.
b. b.1.0 ≤ FK ≤ 1.3: Moderate landslide severity potential zone.
c. FK > 1.3: Low landslide severity potential zone.
d. Slope Angle: Steep slopes (>45°) have a higher risk.
e. Pore Water Pressure: Mining slopes with high pore water pressure are more prone to landslides.
f. Material Propertie: Clay or weathered rock materials tend to have lower stability.
g. Landslide Hazard Mitigation Map

KEPMEN ESDM RI No. 1827 K/30/MEM/2018 for landslide hazard mitigation in open-pit mines includes determining hazard zones, safe zones, evacuation routes, and muster points, as shown in Figure 5."

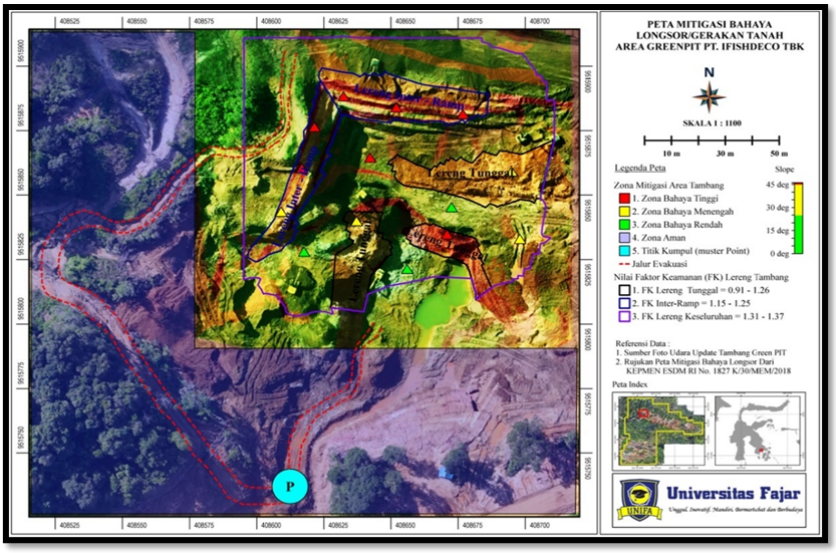


Figure 5. Landslide Hazard Mitigation Map of the Green Pit Area (Source: Author, 2024)

Hazard Zone

The hazard zone in the green pit mining area, which is at potential risk of soil movement (landslide), covers an area of 0.33 hectares, based on slope stability analysis with the following details:

a. Safety Factor (SF) < 1.0: High landslide severity potential.
b. Cracks/faults in the rock form weak zones.
c. Limonite and saprolite layers due to weathering.
d. Water seepage on the slope surface due to rock fractures and high rock porosity, such as sandstone and clay.
e. Steep slopes > 45˚ or areas near geological structures like faults and fractures.

Safe Zone

The safe zone in the green pit mining area covers 2 hectares, which is not susceptible to landslides, even if soil movement occurs in the hazard zone, with the following criteria:

a. Safety Factor (SF) > 1.5 and no mining activities.
b. Located outside potential landslide pathways.
c. No pore water pressure or significant rock fractures.

Evacuation Routes

The evacuation routes in the green pit mining area consist of 2 (two) routes designed to safely move workers from the hazard zone to the safe zone, with the following design criteria:

a. The route is accessible by evacuation vehicles and wide enough for large groups of workers.
b. The route's security does not pass through areas with potential soil movement.
c. The speed of the route is designed to minimize travel time to the safe zone or muster point, with the closest distance being 68 meters and the farthest 267 meters.

Muster Point

The muster point in the green pit mining area is located in a safe area and is accessible to all workers during evacuation. The location criteria are as follows:

a. Located in the safe zone, far from the influence of potential landslides.
b. Has enough capacity to accommodate all workers in the mining area.
c. Close to emergency communication facilities and safety equipment.

CONCLUSION

The results of the slope stability analysis at the green pit mine, based on the Safety Factor (SF) of the slope according to the regulations of the Indonesian Ministry of Energy and Mineral Resources (KEPMEN ESDM RI No. 1827 K/30/MEM/2018), conclude that:

a. Single Slope Type: SF 0.91 – 1.26 (Unstable – Balanced).

b. Inter-ramp Slope Type: SF 1.15 – 1.25 (Balanced).
c. Overall Slope Type : SF 1.31 – 1.37 (Stable).

The probability of soil movement (landslide) is 10 – 25%, with a moderate severity category. The landslide hazard potential map is designed based on the plotting of the severity potential zones from the Safety Factor (SF) assessment and the open-pit slope types, as follows:
a. SF < 1.0: Red zone, with high landslide severity potential.
b. 1.0 ≤ SF ≤ 1.3: Yellow zone, with moderate landslide severity potential.
c. SF > 1.3: Green zone, with low landslide severity potential.

The landslide hazard mitigation map for the open-pit green pit mine provides information on the hazard zone potential, with an area of 0.33 hectares at the mine slope surface, a safe zone covering 2 hectares, evacuation routes ranging from 68 meters to 267 meters, and muster points for workers, equipped with emergency response facilities such as medical supplies, transportation, mobilization facilities, and communication tools, all of which are part of the mining safety management system.

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