LANDSLIDE PROBABILITY IN THE EAST ASAM DUMP IN PIT AREA OF PT ARUTMIN INDONESIA CONCESSION AREA ASAMASAM MINE, SOUTH KALIMANTAN

PROBABILITAS LONGSOR TIMBUNAN DI AREA IN PIT DUMP ASAM TIMUR DAERAH KONSESI PT ARUTMIN INDONESIA TAMBANG ASAMASAM, KALIMANTAN SELATAN

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ABSTRACT

Open pit mining involves excavation of soil and overburden, which requires a well-planned disposal area to maintain stockpile stability. This is achieved through an analysis of soil bearing capacity and slope stability. The research was conducted at the ASTIM In Pit Dump (IPD) using actual materials. Data were obtained from direct shear tests and physical properties tests, then statistically analyzed to determine the average value, standard deviation, and minimum and maximum relative values. These data were subsquetly input into geotechnical software to perform a slope stability analysis under pessimistic conditions, including water-saturated slopes with a horizontal seismicity coefficient of 0.045. The simulation results did not meet the stability criteria, yielding a safety factor of 0.647. Therefore, engineering design modifications were necessary, including widening the slope angle to 7.61°, consisting of six steps with a level height of 5 meters, a width of 30 meters, and a slope angle of 25°. This redesign resulted in a safety factor (SF) of 1.254 which meets slope stability criteria based on Bowles (1989) and a probability of failure (PoF) of 4.1%, in accordance with the Decree of the Minister of Energy and Mineral Resources No. 1827 K/30/MEM/2018.

Keywords: disposal area, slope stability, slope failure probability, slope stability simulation.

ABSTRAK

Penambangan terbuka melibatkan penggalian tanah dan lapisan penutup yang membutuhkan area pembuangan yang dirancang dengan baik untuk menjaga kestabilan timbunan melalui analisis daya dukung tanah dan kestabilan lereng. Penelitian ini dilakukan di In Pit Dump (IPD) ASTIM menggunakan material aktual dengan data diperoleh dari uji geser langsung dan uji sifat fisik, kemudian dianalisis secara statistik untuk menghitung nilai rata-rata, standar deviasi, serta nilai relatif minimum dan maksimum. Data tersebut kemudian dimasukkan ke dalam perangkat lunak geoteknik untuk dilakukan analisis kestabilan lereng pada kondisi pesimis, yaitu lereng jenuh air dengan koefisien kegempaan horisontal sebesar 0,045. Hasil simulasi menunjukkan bahwa lereng tidak memenuhi kriteria kestabilan, dengan nilai faktor keamanan sebesar 0,647. Oleh karena itu, perlu dilakukan rekayasa desain dengan memperlebar sudut lereng menjadi 7,61° yang terdiri atas 6 undakan dengan tinggi jenjang 5 meter, lebar 30 meter, dan sudut 25°. Desain ini menghasilkan faktor keamanan (FK) sebesar 1,254 yang memenuhi kriteria kestabilan lereng berdasarkan Bowles (1989) dan probabilitas keruntuhan (PK) 4,1% sesuai dengan Kepmen ESDM No. 1827 K/30/MEM/2018.

Kata kunci: area pembuangan, kestabilan lereng, probabilitas kelongsoran, simulasi kestabilan lereng.

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INTRODUCTION

Coal mining is generally performed by either surface or underground mining. Surface mining involves removing overburden material including vegetation and topsoil from the site and then disposing of all overburden material simultaneously in a nearby hollow area or plain known as a disposal area or waste dump (Singh and Narzary, 2021). Disposal areas are divided into two types: in-pit dumps and out-pit dumps. In-pit dump (IPD) is a dumping of overburden material inside the pit, whether the pit is still active or inactive, while out-pit dump (OPD) is a dumping of overburden material outside the pit area (Marit, Nurhakim and Saismana, 2022).

Under natural undisturbed conditions, soil or the stability of mining embankment slopes is one of the important factors for the safe production of open pit mines. As a combined product of geological processing and artificial backfilling, the stability of mining embankment slopes is mainly affected by the mechanical properties of the foundation, the shape of the slope, and the properties of the dumped material (Jiang *et al.*, 2022).

To maintain slope stability, it is necessary to pay attention to various aspects so that the embankment slope does not collapse from internal and external factors. These factors are morphology, vegetation, weathering or erosion, seismicity, and climate (rainy weather) which can affect the condition of the slope constituent materials due to changes in the groundwater table (Arif, 2016).

Determination of slope stability can no longer be based solely on the value of the factor of safety, especially after several cases were found where slopes with a safety factor that meets the standard still experience landslides, while others with a low safety factor remain stable (Wiradani and Heriyadi, 2018). Therefore, the probability of landslide method was developed, which evaluates the probability of landslide occurrence based on statistical analysis of a number of calculations. Since the Minister of Energy and Mineral Resources Decree No. 1827/2018 was issued, this method has become a mandatory standard in slope stability assessment in Indonesia (Arifadillah, Zakaria and Sophian, 2021).

METHODOLOGY

This research was conducted by analyzing slope stability through several research steps, including data collection, data processing, data analysis, and slope stability analysis simulation. Data collection includes soil sampling for laboratory analysis, slope cross-section profiling from topographic data, and field studies.

Laboratory tests were conducted to determine the physical and mechanical properties of the materials, particularly those to be used in slope stability analysis, including cohesion, internal friction angle, and unit weight. Physical property tests aimed to assess the characteristics and lithology types of the slope materials, such as moisture content, plasticity index, grain size, and specific gravity. Meanwhile, laboratory tests to obtain the values of cohesion and internal friction angle were performed using the direct shear test.

The slope stability analysis calculation uses the safety factor value as a reference for determining whether the slope is stable or not. The factor of safety (SF) value is the ratio between the driving force and the retaining force acting on the slope body (Hoek and Bray, 1981).

$$SF=\frac{\Sigma \text{ Resisting Forces}}{\Sigma \text{ Driving Forces}} \qquad (1)$$

In conducting the simulations, this study utilized geotechnical software, and the design of stable slopes refers to the factor of safety requirements outlined in the slope classification based on the factor of safety values according to Bowles (1989) (Table 1).

The calculation of slope stability is carried out by the limit equilibrium method with the approach of balancing the forces and moments of each slice. If the forces that play a role in the slope are in perfect balance then the slope is considered stable. However, the slope is considered unstable if the balance of forces in the slope is not achieved (Azarafza *et al.*, 2021). In slope material collapse, the limit equilibrium method calculates the shear stress and resistance on the sliding surface using the Mohr-coulomb criterion due to the critical combination of shear stress and normal stress (Das and Sobhan, 2022).

Table 1. Slope criteria based on safety factor value (Bowles, 1989)

Safety Factor Value	Landslide Occurence / Intensity
SF < 1.07	Landslides occur frequently (Unstable slopes)
SF= 1.07 - 1.25	Landslides have occurred (Critical slope)
SF > 1.25	Landslides have occurred (Slope stable)

$$SF=\frac{\sum(c.\ L\tan\phi+W\cos\alpha)}{\sum(W\sin\alpha)} \quad \text{.................................(2)}$$

Where:
C : Cohesion
ϕ : Internal friction angle
l : Length of Slip Surface
W : Weight of soil mass

The limit equilibrium method assumes that the shape of the sliding surface must be determined and known in advance. To simplify the calculation, the sliding surface is usually assumed to be a circular arc, and the slope geometry of the sliding surface is divided into several slices (Arif, 2016).

This study used Bishop's method, which is a slope stability analysis that ignores the friction force between wedges and assumes that the normal force is sufficient to represent the interaction between wedges, and assumes that the force on the sides of the wedge has zero resultant in the vertical direction (Bishop, 1955). This method is very suitable for use in analyzing circular sliding surfaces and the results of the calculations carried out are simple and accurate enough to calculate the value of the factor of safety (Aulia, Zakaria and Shopian, 2019). The forces acting on each landslide slice are as follows.

$$SF=\frac{\sum_{i=1}^{n}(C^{*}L_i\sec\alpha_i+W_i^{*}\cos\alpha_i\tan\theta)}{\sum_{i=1}^{n}\left(W_i^{*}\sin\alpha_i+Kh\left(\frac{L_i}{R}\right)\right)} \quad \text{......................(3)}$$

Where:
SF : Safety factor
Ci : Cohesion at the i-th slice
Li : Length of the slip plane at the i-th wedge
Wi : Weight of the i-th slice
R : The radius of the landslide circle

Slope stability analysis usually uses a deterministic approach, but this method is limited because of the uncertainty in the factor of safety due to the variability of slope materials and measurements (Arif, 2016). The probability approach is used to accommodate this variation and calculate the avalanche probability (PoF) based on the restraining and driving forces as random variables. PoF is obtained from the ratio of the SF < 1 distribution area to the total probability distribution area (Arif, 2016).

$$PoF=\frac{N-M}{N}\ X\ 100\% \quad \text{......................................(4)}$$

Where:
PoF : Probability of failure
(N-M) : Number of values that do not meet the SF>1 assumption
M : Number of values that meet the SF>1 assumption
N : Number of tests performance

The probability of landslide in this study uses the Monte Carlo method because it is simple, flexible in combining probability distributions, minimal interpretation, and able to form correlations between variables (Arifadillah, Zakaria and Sophian, 2021). The results of the probability calculation refer to the Decree of the Minister of Energy and Mineral Resources No. 1827/2018 (Table 2) (Menteri Energi dan Sumber Daya Mineral, 2018).

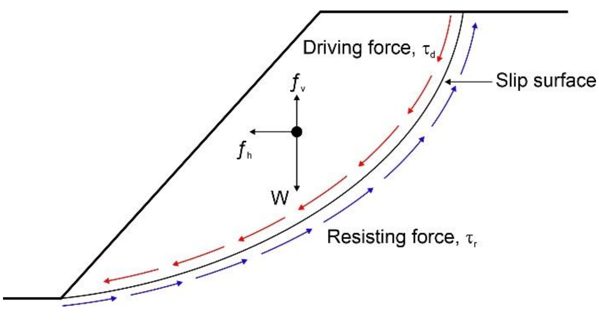

Figure 1. Forces that work on slopes (Zhang, 2015)

Table 2. Safety factor and landslide probability in mining areas (Menteri Energi dan Sumber Daya Mineral, 2018)

Slope Type	Landslide Severity	Acceptable Criteria		
		Static Safety Factor (SF) (min)	Dynamic Safety Factor (SF) (min)	Landslide Probability (max) (SF ≤ 1)
Single Slope	Low - High	1.1	None	25 – 50%
Inter – ramp	Low	1.15 – 1.2	1.0	25%
	Moderate	1.2 – 1.3	1.0	20%
	High	1.2 – 1.3	1.1	10%
Overall Slope	Low	1.2 – 1.3	1.0	15 – 20%
	Moderate	1.3	1.05	10%
	High	1.3 – 1.5	1.1	5%

RESULT AND DISCUSSION

Lithology Research Area Conditions

The study area is included in the Warukin Formation based on the Geological Map of Banjarmasin Sheet (Figure 2) (Sikumbang and Heryanto, 1994). The Warukin Formation consists of a mixture of quartz sandstone and claystone, interspersed with shale, coal and limestone. Local carbonaceous sandstones and mudstones contain iron concretions. This unit was deposited in a littoral to paralis environment with a thickness of 1250 meters. This formation contains fossils of *Miogypsina sp.*, *Cycloclypeus sp.*, and *Lepidocyclina cf. sumatrensis* of Early Miocene - Middle Miocene age and overlies the Berai Formation. Based on the field and laboratory analyses, the lithology of the slope in the study area consists of soil, predominantly clay with a reddish-brown color. The slope material is classified as high-plasticity clay (CH) according to the Unified Soil Classification System (USCS), identified based on the grain size of the slope material, which is dominated by clay. The clay in the disposal area is weathered material from the claystone found in Pit 'X', originating from the Muara Enim Formation.

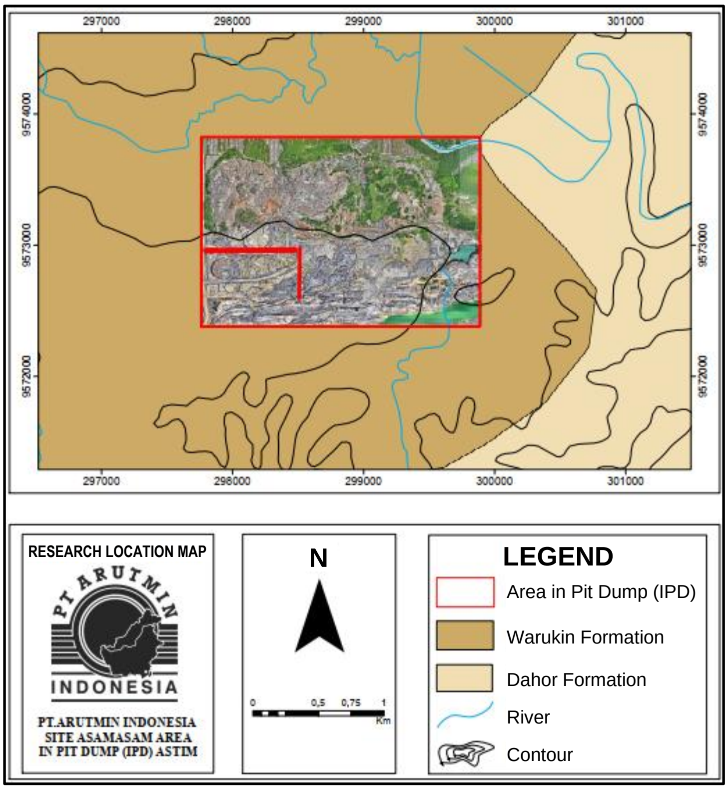

Figure 2. Geological map research area

Engineering Geology Research Area

The research was conducted at the Asamasam site, PT Arutmin Indonesia, South Kalimantan, a mine area planned to accommodate 23,287,687 bcm of overburden from the Astim Pit. 13 Dynamic Cone Penetrometer (DCP) test points were conducted at IPD ASTIM (Figure 3) for soil sampling which will then be subjected to laboratory testing to determine the characteristics of the actual backfill material.

Actual Disposal Material Conditions

The mechanical properties of the actual disposal material were identified through direct shear laboratory testing, which yielded cohesion and internal friction angle values (Table 3). In calculating the factor of safety for the disposal area, the cohesion and internal friction angle values used are those obtained under residual conditions, while the unit weight values used correspond to saturated conditions. This approach takes into account the reduced shear strength of the material at residual conditions, which represents the strength after significant deformation has occurred. At the same time, the saturated unit weight simulates the potential increase in load due to water infiltration, thus capturing a realistic worst-case scenario for stability analysis. Together, these values provide a conservative estimate of the factor of safety, ensuring that stability considerations address material degradation and stress increases due to saturation (Jiang *et al.*, 2022). This refers to the Decree of the Minister of Energy and Mineral Resources No. 1827 K/30/MEM/2018 (Menteri Energi dan Sumber Daya Mineral, 2018) concerning Guidelines for the Implementation of Good Mining Engineering Practices related to the calculation of safety factors in the disposal area using the angle of internal friction and residual cohesion.

Figure 3. Disposal area condition IPD ASTIM

Table 3. Actual disposal material properties IPD ASTIM (Laboratorium of Geotech PT. Arutmin Indonesia)

Material Name Disposal	Colour	Material Strength	Unit Weight (kN/m^3)	Cohesion (KPa)	Internal Friction Angle (°)
OB A1		Very Soft	17.36	12.99	14.91
OB A2		Firm	17.12	10.29	8.1
OB A3		Stiff	17.42	11.49	11.15
OB A4		Very Stiff	17.55	13.51	15.56
OB A5		Hard	17.82	19.6	29.67
Bedrock		Impermeable	-	-	-

Statistical Analysis of Actual Disposal Material Properties

Landslide probability analysis of slopes is performed based on random variables that serve as constraints as well as data validation in determining values such as fill weight, angle of inner shear (SGD), and cohesion obtained from laboratory testing. Statistical analysis is required to provide a strong basis for representing the variability of material properties that can provide more accurate results than deterministic approaches. Statistical analysis is performed to obtain statistical data in the form of distribution type, mean, standard deviation, relative minimum value, and relative maximum value for each material property (Table 4).

The type of distribution used in this landslide probability analysis are using normal and lognormal distribution which is determined based on the smallest AD and largest P values (Table 5) from the results of Goodness of Fit (GoF) test results using the Anderson-Darling method on each material properties

The initial design of the disposal slope uses the average value of the five actual embankment material conditions (Table 6). Determination of the type of distribution on the material constituent of this slope using uniform because the distribution of data is too much, all material properties values are used, namely from the smallest to the largest value will be included in the calculation of the probability of landslide.

Table 4. Statistical data of actual disposal material properties of IPD ASTIM (Laboratorium of geotech PT. Arutmin Indonesia)

Material Name Disposal	N	Parameter	Mean	Standard Deviation	Relative Minimum	Relative Maximum
OB A3	11	Unit weight	17.42	0.31876	0.36	0.53
		Cohession	11.49	0.43065	0.77	0.68
		Internal Friction Angle	11.15	1.51003	2.05	3.50
OB A4	17	Unit weight	17.55	0.46662	1.27	0.89
		Cohession	13.39	0.87993	1.34	1.39
		Internal Friction Angle	15.56	1.71058	2.48	2.94
OB A5	15	Unit weight	17.82	0.72423	0.85	1.11
		Cohession	19.6	4.71311	8.98	11.7
		Internal Friction Angle	29.67	10.90860	20.81	27.08

Table 5. Material properties distribution type determination (Statistical analysis on Minitab19)

Material	Parameter	Distribution Type	AD	P
OB A3	Unit weight	Normal	0.559	0.114
		Lognormal	0.548	0.120
	Cohession	Normal	0.147	0.950
		Lognormal	0.146	0.951
	Internal Friction Angle	Normal	0.389	0.321
		Lognormal	0.269	0.604
OB A4	Unit weight	Normal	0.718	0.743
		Lognormal	0.743	0.042
	Cohession	Normal	0.148	0.956
		Lognormal	0.159	0.937
	Internal Friction Angle	Normal	0.201	0.856
		Lognormal	0.191	0.882
OB A5	Unit weight	Normal	0.499	0.177
		Lognormal	0.485	0.193
	Cohession	Normal	0.342	0.443
		Lognormal	0.307	0.523
	Internal Friction Angle	Normal	0.345	0.434
		Lognormal	0.516	0.160

Table 6. Material properties of embankment slope (Statistical analysis on Minitab 19)

Parameter	Mean	Relative Minimum	Relative Maximum
Unit weight	17.45	0.33	0.37
Kohesi	12.99	2.92	6.61
Sudut Geser Dalam	14.45	6.31	15.26

Disposal Slope Design Stability Analysis

In analysing the stability of the disposal slope in the ASTIM IPD area (Figure 4), a cross section was drawn in each section, where in the western part of the study it is represented by cross section A (Figure 5), in the southern part it is represented by cross section B (Figure 6), and in the northern and eastern parts it is represented by cross section C (Figure 7). This is done because the layers below have different characteristics and the thickness of the formed layer resulting from the ASTIM PIT disposal in the southern part of the ASTIM IPD.

The cross-section already represents the bedrock boundary marked with a black line, the topography of the last mining that was done before marked with a blue line, and the initial design of the disposal slope marked with a red line.

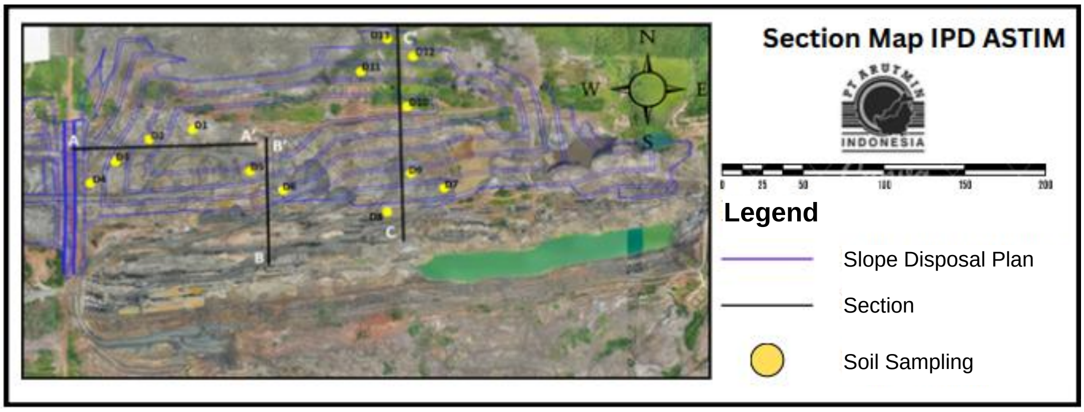

Figure 4. Section disposal area

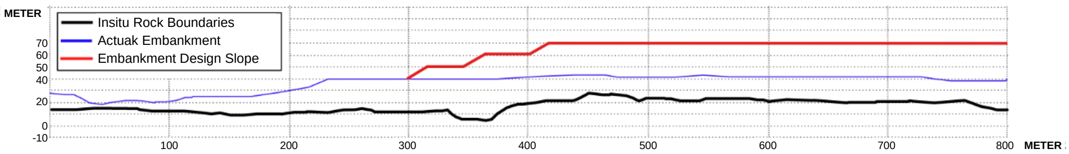

Figure 5. Design of embankment Slope A – A’

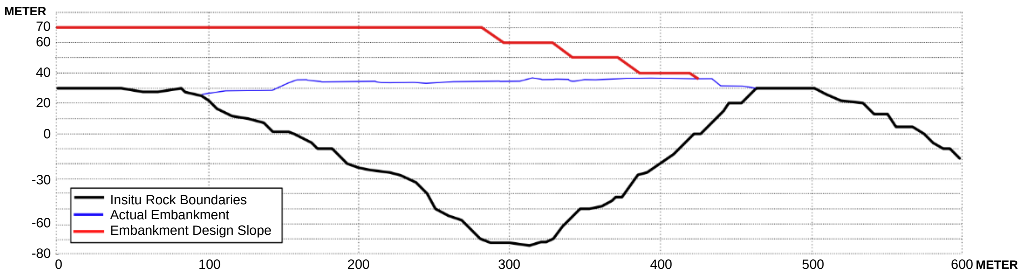

Figure 6. Design of embankment Slope B – B’

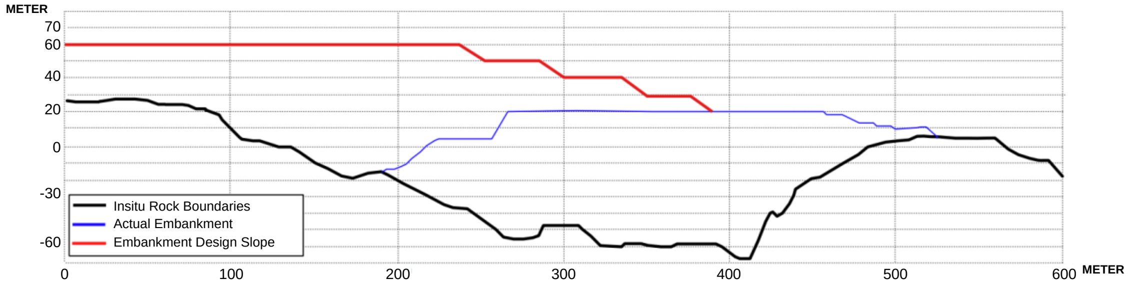

Figure 7. Design of embankment slope C – C’

The early design of the disposal slope has a slope geometry with a slope width of 30 metres, a slope height of 10 metres, and a slope angle of 30 degrees. The results of the preliminary design of the disposal slope geometry resulted in an overall height of the disposal slope of 30 metres and a diverse overall angle of the overall disposal slope, including in section A with 14.2 degrees, section B with 13.16, and section C with 13.9.

Safety Factor and Probability of Failure of Disposal Slope Design

The initial design disposal slope stability analysis uses dynamic conditions due to external influences in the form of seismic waves to the ground surface generated by the magnitude of the earthquake that cannot be avoided (Aulia, Zakaria and Shopian, 2019). This study uses a horizontal coefficient (kh) based on the Peak Ground Acceleration (PGA) value obtained from the Peak Acceleration Map in bedrock (SB) for a 2% exceedance probability in 50 years of 0.1. The PGAm value is obtained from multiplying PGA with an induction factor of 0.9 in the study area so that the PGAm value is 0.596. Furthermore, the value of the horizontal coefficient (kh) in the research area was found to be 50% of the PGAm, resulting in a value of horizontal coefficient (kh) 0.045.

Another factor affecting slope stability is the presence of water in the initial design disposal slope. The initial design disposal slope is assumed to be saturated because the soil on the slope will experience infiltration where the disposal slope soil will absorb water resulting in the material will experience a decrease in shear characteristics due to pore water pressure in the material (Rai, Kramadibrata and Wattimena, 2014).

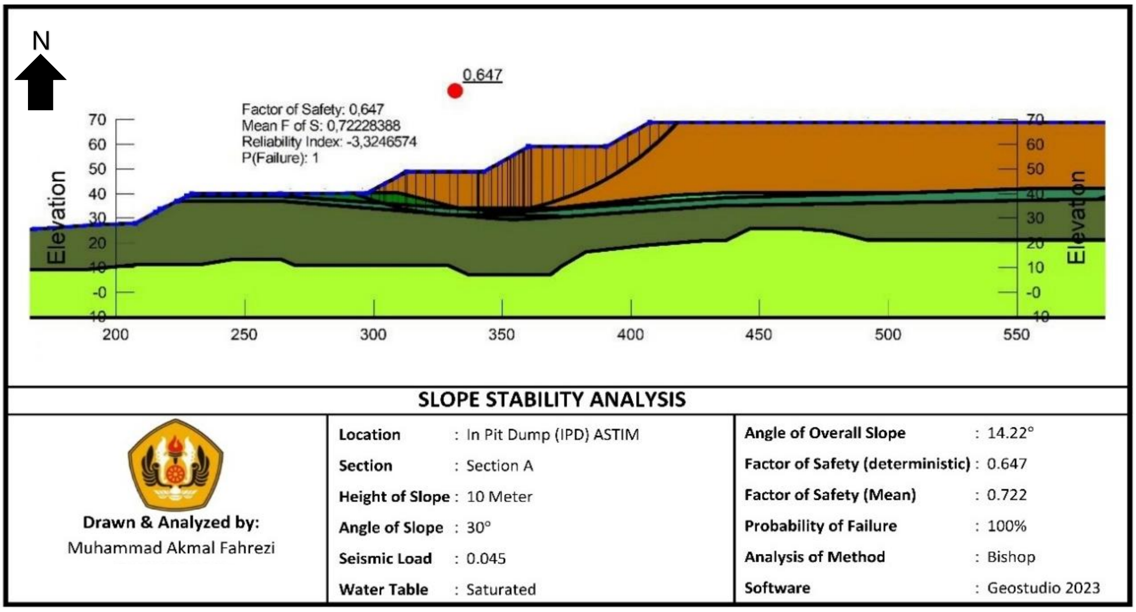

Figure 8. Design slope stability analysis result in dynamic condition

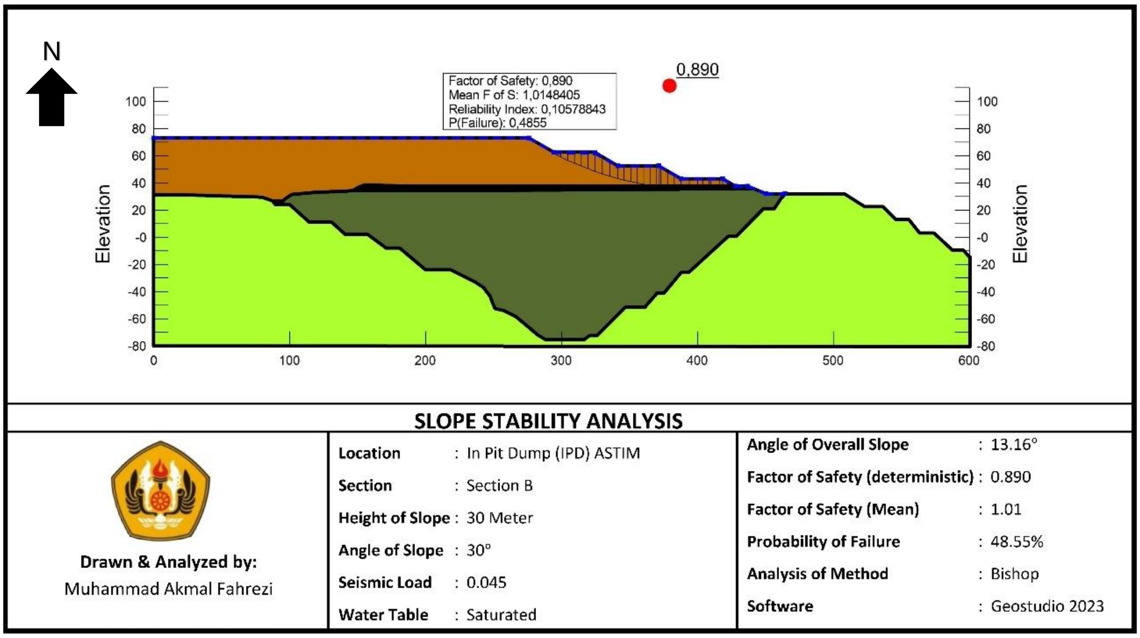

Figure 9. Design slope stability analysis result in dynamic condition

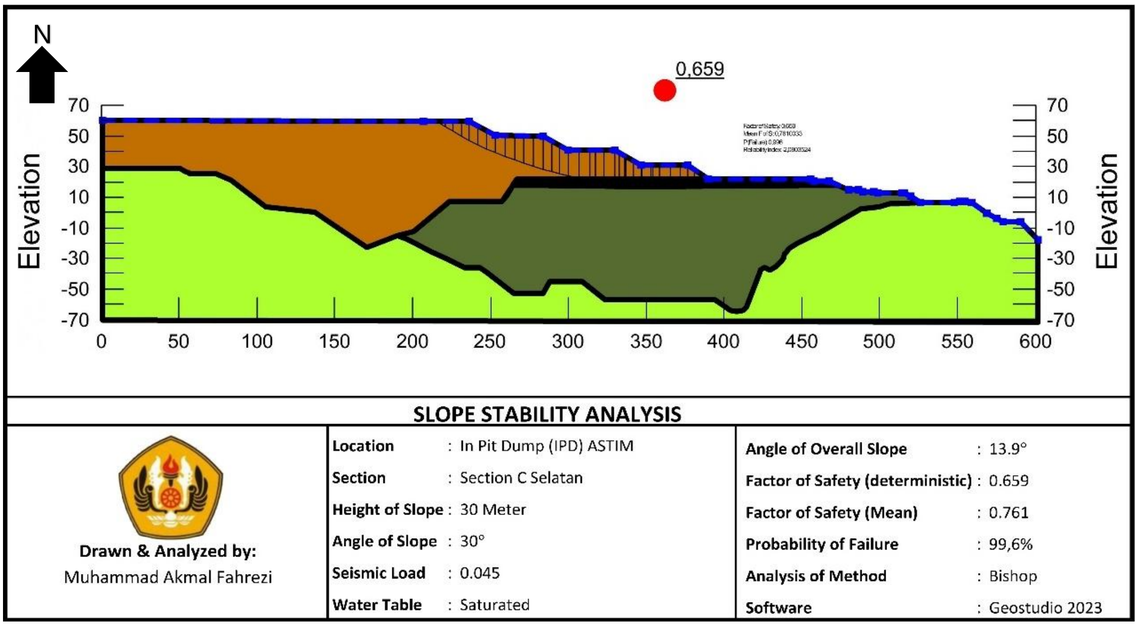

Figure 10. Design slope stability analysis result in dynamic condition

The simulation results of the safety factor on the initial design of the disposal slope resulted in a deterministic safety factor (SF) of 0.647 (Figure 8), an average SF of 0.722 (Figure 9) and a probability of failure (PoF) of 100%. The Safety Factor (SF) value of the initial design of the disposal slope is included in the unstable slope category based on Bowles (1989) and the probability of failure (PoF) value does not meet the criteria based on the Minister of Energy and Mineral Resources Decree No. 1827 K/30/MEM/2018 concerning Guidelines for the Implementation of Good Mining Practices (Menteri Energi dan Sumber Daya Mineral, 2018).

Slope Engineering Simulations

To increase the factor of safety (SF) and reduce the landslide probability (PoF), slope engineering is required. The purpose of slope engineering is to reduce risk, prevent landslides, and address negative impacts.

This approach is based on geological studies that include engineering geology, soil mechanics, and hydrogeology (Zakaria, 2011). Single slope simulation is conducted to determine the value of single slope safety factor. This safety factor will be a consideration factor in the formation of the slope as a whole (Arifadillah, Zakaria and Sophian, 2021).

After various simulations based on Table 6. of a single slope with angle variations of 25° and 30° with height variations of 5 metres, 8 metres, and 12 metres, it can be concluded that with a slope angle of 25 degrees, a slope height of 5 metres, and a slope width of 30 metres can represent the entire cross section in IPD ASTIM with a safety factor value that is included in the category of stable slopes according to Bowles (1989) which is 1. 727 with a landslide probability value of 0% which is acceptable by the Decree of the Minister of Energy and Mineral Resources No. 1827 K/30/MEM/2018 on Guidelines for the Implementation of Good Mining Practices (Table 7).

Table 7. Disposal slope engineering safety factor value in dynamic condition

Bench Height	Slope Angle Bench	Safety Factor	Probability of Failure
5 meter	25°	1.727	0%
	30°	1.156	5.80%
8 meter	25°	0.891	5.75%
	30°	0.827	27,35%
12 meter	25°	0.685	8.21%
	30°	0.618	96.55

Disposal Slope Recommendation Design

After several engineering simulations at the slope level scale, changes in slope geometry were obtained from the planned design, namely in section A (Figure 11) with an overall slope angle from 14.22 degrees to 7.61 degrees, Section B (Figure 12) with an overall slope angle from 13.16 degrees to 7.83 degrees, and Section C (Figure 13) with an overall slope angle from 13.9 degrees to 7.98 degrees.

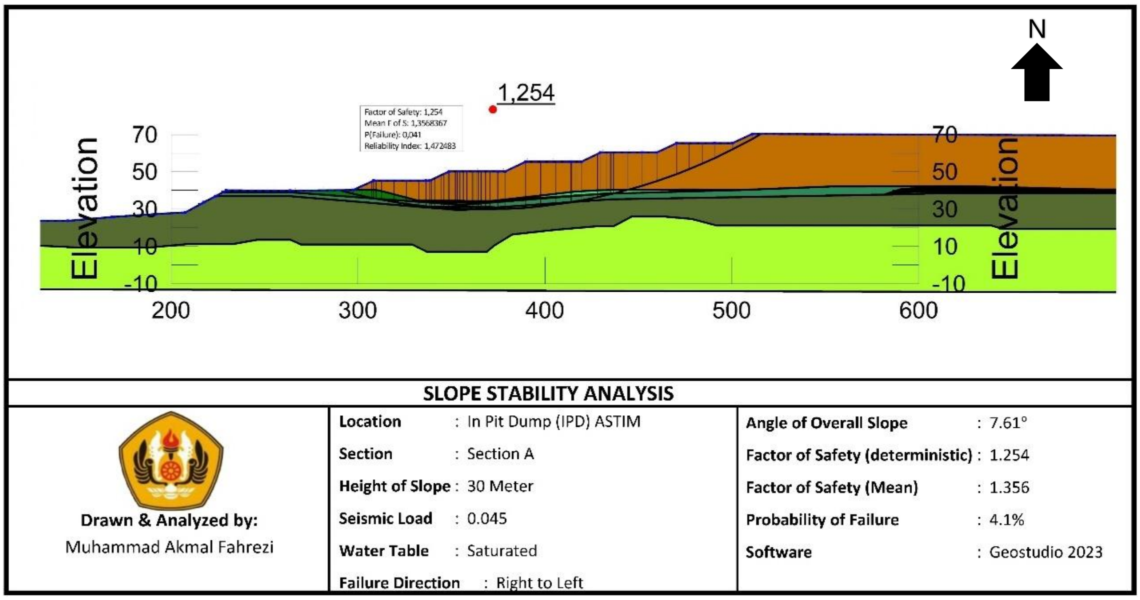

Figure 11. Slope stability analysis result design recommendation in dynamic condition

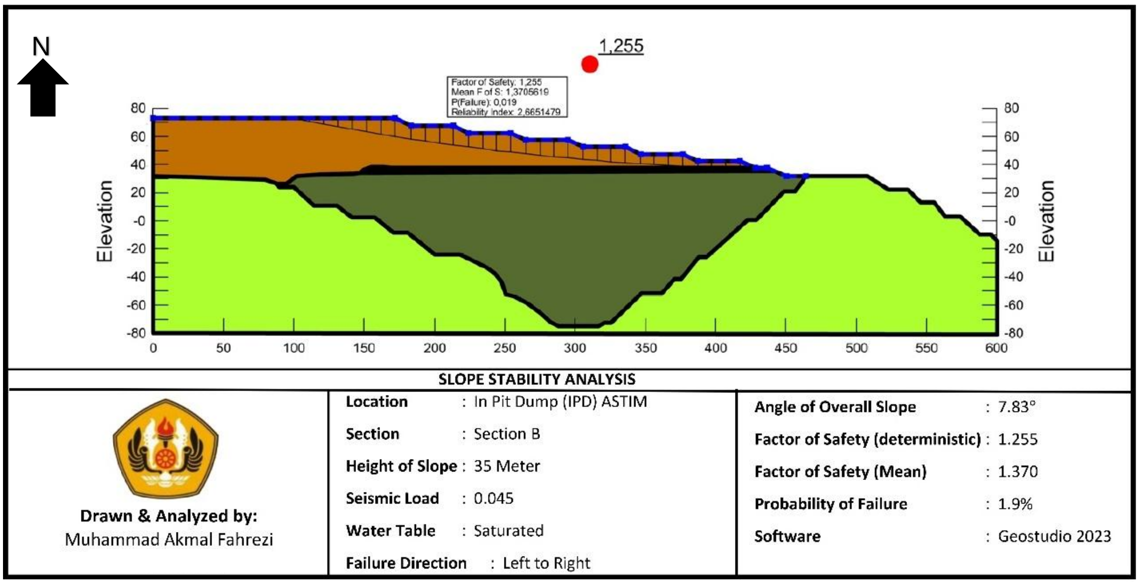

Figure 12. Slope stability analysis result design recommendation in dynamic condition

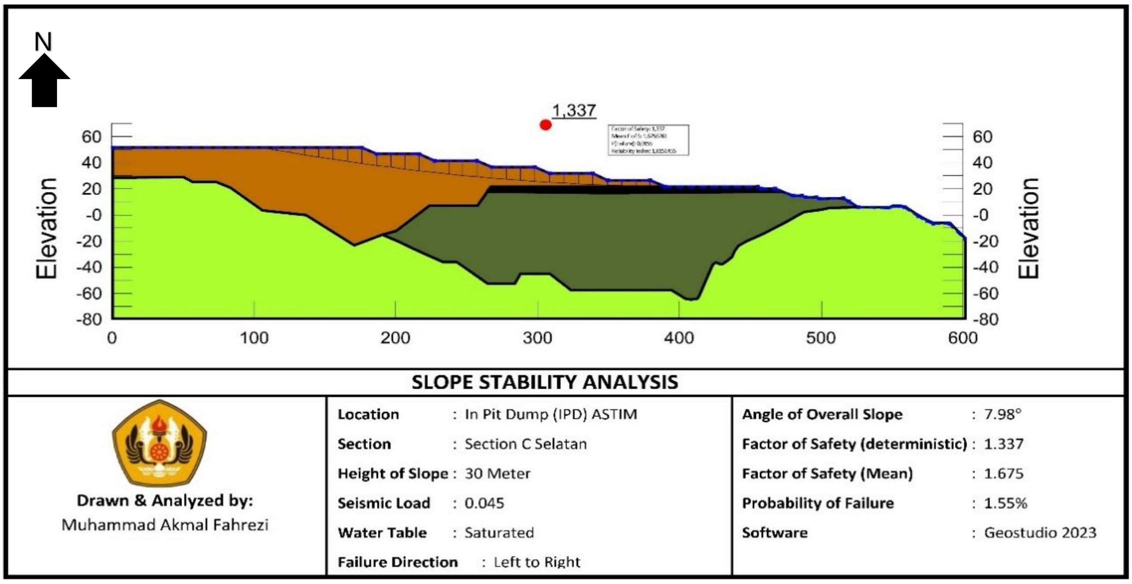

Figure 13. Slope stability analysis result design recommendation in dynamic condition

With the reduction of the overall slope, the safety factor value is included in the stable slope category based on Bowles (1989) and the probability of landslide is acceptable based on the Minister of Energy and Mineral Resources Decree No. 1827 K/30/MEM/2018 on Good Mining Practices. 1827 K/30/MEM/2018 on Guidelines for the Implementation of Good Mining Practices with high landslide severity criteria, namely human casualties, more than three people seriously injured, more than 50% damage to facilities and infrastructure, and environmental damage that impacts outside the IUP area including settlements.

CONCLUSION AND SUGGESTION

Conclusion

- Based on data analysis, it was identified that the actual ASTIM IPD disposal material is not homogeneous and can be categorized into five types: very soft, firm, stiff, very stiff, and hard. Each soil type was subjected to laboratory testing to determine unit weight, cohesion, and inner shear angle values. The lowest unit weight value was found in the firm material at 17.12 kN/m^3, while the highest was in the hard material at 17.82 kN/m^3. Cohesion values ranged from 10.29 kPa (lowest) to 19.6 kPa (highest, in the firm material). The inner shear angle varied from 8.1° in the firm material to 29.67° in the hard material.

- The slope stability analysis using the Bishop method, under saturated MAT conditions and with a horizontal coefficient of 0.045, was conducted on four cross sections of the initial embankment slope design. The original geometry consisted of a single angle height of 10°, a slope width of 30 metres, and a height of 10 metres. The analysis showed that the slope did not meet the safety criteria set by Decree of the Minister of Energy and Mineral Resources No. 1827 K/30/MEM/2018. Therefore, a redesign of the slope geometry is necessary, taking into account the material properties and geometry of the embankment slope.
- Considering the influence of the foundation material beneath the disposal slope on overall stability of the ASTIM IPD, a revised embankment slope geometry with a tier width of 30 meters, tier height of 5 meters, and slope angle of 25° was proposed. This configuration satisfies the required safety standards based on the Safety Factor (SF) and Probability of Failure (PoF), in accordance with the Decree of the Minister of Energy and Mineral Resources No. 1827 K/30/ MEM/2018, as demonstrated in cross section A, B, and C.

Suggestion

It is recommended that a more detailed geotechnical investigation, such as Standard Penetration Test (SPT), be carried out in future research. Although the simulation and analysis results meet the criteria for Probability of Failure as outlined in the Minister of Energy and Mineral Resources Decree No. 1827K/30/MEM/2018 and the slope classification according to Bowles (1989), regular monitoring and supervision are still necessary to assess the actual condition of the embankment slopes.

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