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THE APPLICATION OF FAILURE METHOD PROBABILITY FOR ANALYZING IN PIT DUMP STABILITY AT WEST BLOCK 'X' PIT PT BERAU COAL - EAST KALIMANTAN

APLIKASI PROBABILITAS LONGSOR UNTUK MENGANALISIS KESTABILAN TIMBUNAN IN-PIT DI PIT WEST BLOK 'X' – PT BERAU COAL, KALIMANTAN TIMUR

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ABSTRACT

West Block 'X' pit is one of the coal mining locations operated by the Lati Mine Operation – PT Berau Coal. Administratively, the Lati Mine is located as part of Berau Regency – East Kalimantan. The study area is located at the north side of the concession, in a syncline fold structure zone. The disposal design in this area needs to special attention from slope stability aspect due it is located on the wing of a mega syncline with a certain slope and constituent of unconsolidated materials. The pit design needs to be stable. The purpose of this study is to determine the level of stability of the in-pit dump by analyzing the current in-pit dump stability based on the value of the safety factor (FS) and the probability of failure (PoF). The method used in this study is a probabilistic analysis of slope stability based on the Morgenstern-Price method to obtain the value of the safety factor and the probability of failure. The study results show that the slope is in the safe category (stable slope) in the range of PoF values 0 – 1%, marginal slope 1 – 12%, and unstable slope above 12%. Based on such as results, it is necessary to modify the slope geometry categorized as unstable to carry out mine operation safely underneath the toe of slope.

Keywords: In-pit, probabilistic, probability of failure, safety factor, syncline.

ABSTRAK

PIT West Blok 'X' merupakan salah satu lokasi penambangan batubara yang dioperasikan oleh Tambang Lati – PT Berau Coal. Secara administratif, tambang ini termasuk ke dalam wilayah Kabupaten Berau – Provinsi Kalimantan Timur. Area studi berada di sisi utara konsesi yang terletak pada zona struktur sinklin. Desain lereng timbunan di area ini perlu mendapat perhatian khusus dari aspek stabilitas lereng karena ditempatkan di atas sayap sinklin dengan kemiringan tertentu dan material penyusunnya bersifat lepas sehingga diperlukan design lereng tambang yang stabil. Tujuan dilakukannya penelitian ini adalah utnuk mengetahui tingkat stabilitas timbunan in pit *dengan menganalisis kondisi lereng disposal berdasarkan nilai faktor keamanan (FK) dan probabilitas kelongsoran (PK). Metode yang digunakan dalam penelitian ini adalah analisis probabilitas kestabilan lereng berdasarkan metode Morgernstern-Price untuk mendapatkan nilai faktor keamanan lereng serta probabilitas kelongsoran. Hasil analisis menunjukkan bahwa lereng berkategori aman* (stable slope) *pada kisaran nilai PK 0 – 1 %, marginal slope 1 – 12 % dan lereng tidak stabil (*unstable slope*) di atas 12%. Berdasarkan hasil tersebut, diperlukan modifikasi geometri lereng yang dikategorikan tidak stabil sehingga kegiatan operasional di bawah kaki lereng dapat dilakukan dengan aman.*

Kata kunci: faktor keamanan, in pit, probabilistik, probabilitas kelongsoran, sinklin.

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INTRODUCTION

Open-pit mining systems require an area to dump or store materials resulting from digging soil or cover rocks. Kristyanto, Muslim, and Zakaria (2018) define this area as a disposal or dumping area. The disposal area is composed of loose materials that are stockpiled and vary in terms of density. It can affect the stability of the slope, so it needs an appropriate mine planning in this area to keep it in a stable condition (Prasetyo, Hariyanto, and Cahyadi, 2011). In addition, the stability of the slope can also be influenced by the physical and mechanical properties of the rocks, groundwater conditions, characterization of rock mass, structures in rocks, and geometry of slopes (Kramadibrata *et al.*, 2012). The number of factors that affect the stability of the slope in the disposal area resulting from the safety factor (FS) is not enough to provide a safe theoretical design for a slope (Azizi and Handayani, 2011). This is because the value factor of safety cannot capture the uncertainty resulting from the calculation. These aspects of reality will affect the results of the analysis (Zoorabadi, Canbulat and Ruest, 2016). Another alternative to the FS approach to reduce this uncertainty is to use a probabilistic method to calculate the probability of the failure (Azizi, Marwanza, and Ghifari, 2019). In such a method, the value of a safety factor is a random variable that has a function attributed to treatment parameters such as average value and standard deviation. The estimated probability of failure (PoF) is obtained by combining the distribution in the deterministic model used in calculating the FS (Azizi and Handayani, 2011). The probability of failure can be an alternative in assessing the stability of open pit slopes and becomes an essential tool in decision making (Azizi *et al.*, 2014).

West Block 'X' pit is one of the pit locations at the Lati Mine Operation of PT Berau Coal at East Kalimantan. The low wall area in this pit is used as a disposal area to dump an overburden from the excavation. The research focuses on optimizing coal reserve from previous mining activity in accordance to strip mine ratio (SR) consideration and coal deposit towards down-dip until the final pit slope design. The probabilistic analysis of slope stability aims to determine the uncertainty factor of the data variability. Thus, the optimum pit slope design parameter be applied with no significant pit wall failure that impacted safety and the entire mine operation activities.

This study was conducted to analyze the probability of failure used as a parameter for assessing the slope conditions. Similar research has been conducted by Pramuditya *et al.* (2013), Wiradani and Heriyadi (2018), Masagus *et al.* (2017), which includes analyzing the probability of failure and determining acceptable criteria value on mine slopes. It hopes that the results can be obtained reliable to be used as an important aspect in risk assessment and/or evaluation to achieve safe and optimum mining operations.

METHOD

Data Acquisition

Research area is divided into three segments that represent the entire site condition respectively, in particular, the current in-pit dump body as built. Standard penetration test (SPT) drilling has been executed to define the disposal profile and strength of the material that passes through a cross-section are correlated, resulting in a slope model. In this study, mohr-coulomb failure criteria were used as the basis for calculating slope stability analysis with the required parameters of cohesion, internal friction angle, and unit weight. These parameters are derived from the correlation of N-SPT values resulting from SPT drilling.

The SPT testing procedure can be described in SNI 4153, 2008 as follows:

- Standard sampling tool has a length of 46 cm which is then inserted into the drill hole. Next, the device is pounded until it enters the ground, and the number of pounded is recorded with the unit of blows;
- Hammer weighs 63.5 kg was dropped freely as high as 76 cm to punch sampler to go into the ground. Each drop is 15 cm and the number of collisions is recorded until there are 3 points required punches to include the entire length of the sampler into the ground;
- The collision value used is the number of the last two collisions or commonly called the N-SPT.

The purpose of the SPT test is to determine the relative density of the soil layers from soil sampling with tubes so that the soil type and thickness of each soil layer are known and obtain data on soil penetration resistance qualitatively.

In determining the soil type, soil classification is used to obtain a cursory description of the soil properties. One of the classifications commonly used is the Unified Soil Classification System (USCS) as seen in Table 1. Cohesive soils are fine, low-strength, easily deformable soils that tend to adhere to particles. Soils are classified as cohesive if the amount of particulate matter (silt and clay material) exceeds 50% by weight (Mitchell and Soga 2005). Examples of cohesive soils include sandy clay, silty clay, clayey silt, and organic clay (Gautam, 2018). Cohesive soils usually have material particles that pass a 200 mesh sieve more than 50%. Non-cohesive soils are mineral soils that exhibit granular properties in which the grains remain separate from each other and do not form clumps or are held together in grain aggregates (Keaton, 2018). In the soil classification systems used by soil scientists, non-cohesive soils may include sandy loam, sand, and silt particles that are not plastic or sticky. Non-cohesive soils usually have more than 50% of the material particles retained by a 200 mesh sieve.

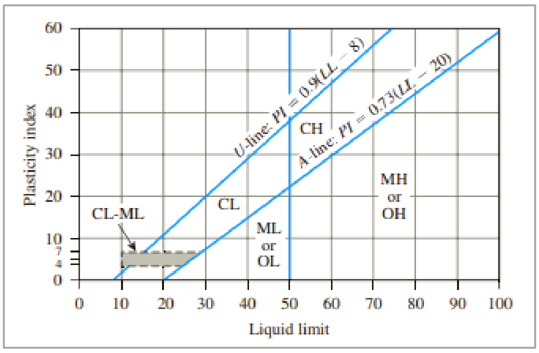
Table 1. Unified soil classification system

Criteria for assigning group symbols				Group Symbol
Coarse-grained soils More than 50% retained on No.200 sieve	Gravels More than 50% of coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines	$C_u \geq 4$ and $1 \leq C_c \leq 3^c$	GW
			$C_u < 4$ and/or $C_c < 1$ or $C_c > 3^c$	GP
		Gravels with Fines More than 12% fines	PI < 4 or plots below "A" line (Figure 1)	GM
			PI > 7 and plots on or above "A" line (Figure 1)	GC
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5% fines	$C_u \geq 6$ and $1 \leq C_c \leq 3^c$	SW
			$C_u < 6$ and/or $C_c < 1$ or $C_c > 3^c$	SP
		Sands with Fines More than 12% fines	PI < 4 or plots below "A" line (Figure 1)	SM
			PI > 7 and plots on or above "A" line (Figure 1)	SC
Fine-grained soils 50% or more passes No. 200 sieve	Silts and clays Liquid limit less than 50	Inorganic	PI > 7 and plots on or above "A" line (Figure 1)	CL
			PI < 4 or plots below "A" line (Figure 1)	ML
		Organic	$\frac{\text{liquid limit-oven dried}}{\text{liquid limit-not dried}} < 0.75$; see Figure 5.3; OL zone	OL
	Silts and clays Liquid limit 50 or more	Inorganic	PI plots on or above "A" line (Figure 1)	CH
			PI plots below "A" line (Figure 1)	MH
		Organic	$\frac{\text{liquid limit-oven dried}}{\text{liquid limit-not dried}} < 0.75$; see Figure 1; OH zone	OH
Highly organic soils	Primarily organic matter, dark in color, and organic odor			Pt

Gravels with 5 to 12% fine require dual symbols: GW-GM, GW-GC, GP-GM, GP-GC.
Sands with 5 to 12% fines require dual symbols: SW-SM, SW-SC, SP-SM, SP-SC.

$C_u = \frac{D_{60}}{D_{10}}$; $C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$

If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 1, use dual symbol GC-GM or SC-SM.
If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 1, use dual symbol CL-ML.
Source: Das and Sobhan (2018)



Source: Das and Sobhan (2018)

Figure 1. Plasticity chart

Kumar, Bhargava, and Choudhury (2016) tested the N-SPT value using the number random generation method. The test results get the best estimation curve for N-SPT correlation to cohesion values based on the following equations:

$C = -2.2049 + 6.484\ N$ (cohesive soils).....(1)
$C = -16.5 + 2.15\ N$ (non cohesive soils)....(2)

Where, C = cohesion (kPa), N = N SPT (blows).

In addition, Kumar, Bhargava and Choudhury (2016) conducted similar tests on the relationship between N-SPT and internal friction angle values by obtaining the best estimation curve based on the following equations:

$\varphi = 7N$ (for $N < 4$) ....(3)
$\varphi = 27.12 + 0{,}2857N$ (for N = 4 - 50)........(4)

where φ = internal friction angle (°)
N = N SPT (blows)

Fitting Test

The Goodness of Fit (GoF) test is a statistical procedure used to assess the distribution of a data set (Romeu, 2003). The value of cohesion and internal friction angle is the tested data. In this study, the GoF test using the Anderson-Darling method is used to compare the empirical distribution function to the theoretical distribution function data to be tested. This method is categorized as part of the statistical, empirical distribution function (EDF). In fitting the distribution, the AD test uses the Cumulative Distribution Function (CDF). It has similarities with the Kolmogorov-Smirnov (KS) test. If a distribution is assumed to be the same, the theoretical distribution will follow the increase in the empirical distribution (Romeu, 2003). The values used as parameters to assess the suitability of the distribution of data in the Anderson-Darling test are AD Score and P-*Value.*

In the AD testing on a data group, if the P-Value value is less than 0.05, the data group is considered not to follow a specific distribution. This AD score becomes a reference in determining the most suitable distribution to represent the data group. Suppose the AD test is carried out for several distributions. In that case, the most appropriate distribution is the distribution with the lowest AD score.

Monte Carlo Simulation

Monte Carlo simulation is a method used to develop uncertainty models. This simulation can produce a set of values (range) and distribution of possible values for each uncertainty factor rather than a single average value (in Read and Stacey, 2009). Monte Carlo simulation requires a threshold (Gibson, 2011) as a calculation reference. The threshold in this study uses a safety factor based on the concept of boundary equilibrium calculation, namely, the slope is safe if the FS>1, and the slope will experience landslides if the FS<1. The probability of failure is determined from each test that meets these assumptions. For the record, the Monte Carlo simulation must meet a certain number of tests to have a normal distribution modeling. The frequency of the test value (n) and the level of confidence of the entire trial must meet the following equation (Gibson, 2011):

$$n=\left(\frac{d}{\alpha}\right)^2\frac{1-p}{p};\alpha=d\sqrt{\frac{1-p}{n.p}} \quad \text{......(5)}$$

Where:
- n = number of simulation;
- d = normal standard deviate estimated from Table 2;
- α = acceptable error in the analysis to assess the probability of failure;
- p = probability of failure.

Gibson (2011) makes a relationship between the standard deviation of normal (d) to the confidence value of the probability test (Table 2).

Table 2. The relationship of the standard deviation of normal (d) to the confidence value

Percentage of Confidence (%)	Standard Deviation of normal (d)
80	1.28
85	1.44
90	1.64
95	1.96
99	2.57

Source: Gibson (2011)

Two issues should be noted with respect to the Equation (5). The number of Monte Carlo simulations required is independent of the variable number, First involved in the problem and Second, since the probability of failure cannot be known in advance, the probability (p) must be estimated using Equation (5). While this may seem like a major drawback to estimating the number of iterations required, it usually allows engineers to estimate the probability of failure required for a particular design.

Determination of Slope Condition

SRK Consulting (2006) (in Read and Stacey, 2009) has made a simple relationship of the probability of failure criteria based on the experience and case studies with the types of failure described in Table 3. The assessment for slope conditions based on the probability of failure and safety factors is represented by Priest & Brown (1983) in Read and Stacey (2009), described in Table 4. In addition, the probability of failure can explain the duration of slope resistance and the condition of the slopes described by Kirsten (1983) in Read and Stacey (2009), indicated by Table 5.

Table 3. Typical FS and PoF acceptance criteria values

Slope scale	Consequences of failure	Acceptance criteria		
		FoS (min) (static))	FoS (min) (dynamic)	PoF (max) P[FoS ≤ 1]
Bench	Low – High	1.1	N/A	25-50%
Inter-ramp	Low	1.15 – 1.2	1	25%
	Medium	1.2	1	20%
	High	1.2 – 1.3	1.1	10%
Overall	Low	1.2 – 1.3	1	15-20%
	Medium	1.3	1.05	5-10%
	High	1.5	1.1	<5%

Source: SRK Cosulting (2006) in Read and Stacey (2009)

Table 4. Interpretation of FS and PoF guidelines

Performance of slope	Interpretation
Satisfies all three criteria	Stable slope
Exceeds minimum mean FoS but violates one or both probabilistic criteria	Operation of slope presents risk that may or may not be acceptable; level of risk can be reduced by comprehensive monitoring program
Falls below minimum mean FoS but satisfies both probabilistic criteria	Marginal slope: minor modifications of slope geometry required to raise mean FoS to satisfactory level
Falls below minimum mean FoS and violates one or both probabilistic criteria	Unstable slope: major modifications of slope geometry required; rock improvement and slope monitoring may be necessary

Source: Priest & Brown (1983) in Read and Stacey (2009)

Table 5. PoF design acceptance guidelines

PoF (%)	Design criteria			Aspects of natural situation	
	Serviceable life	Public liability	Minimum surveillance required	Frequency of slope failures	Frequency of unstable movements
50-100	None	Public access forbidden	Serves no purpose	Slope failures generally evident	Abundant evidence of creeping valley sides
20-50	Very very short-term	Public access forcibly prevented	Continuous monitoring with intensive sophisticated instruments	Significant number of unstable slopes	Clear evidence of creeping valley sides
10-20	Very short-term	Public access actively prevented	Continuous monitoring with sophisticated instruments	Significant instability evident	Some evidence of slow creeping valley sides
5-10	Short-term	Public access prevented	Continuous monitoring with simple instruments	Odd unstable slope evident	Some evidence of very slow creeping valley sides
1,5-5	Medium-term	Public access discouraged	Conscious superficial monitoring	No ready evidence of unstable slopes	Extremely slow creeping valley sides
0,5-1,5	Long-term	Public access allowed	Incidental superficial monitoring	No unstable slopes evident	No unstable movements evidence
<0,5	Very long-term	Public access free	No monitoring required	Stable slopes	No movements

Source: Kirsten (1983) in Read and Stacey (2009)

RESULTS AND DISCUSSION

N-SPT value correlation

The research area is grouped based on the block-strip mine and considered to previous mining history. As mentioned above, the geotechnical drilling by SPT method to obtain the strength parameter data was allocated at the pit boundary. The cross-sectional line to determine the boundary of the drill point will be used in the analysis. The cross-sectional line comprises three incisions, namely A-A', B-B', and C-C' sections, that pass through the drill holes location (Figure 2). Based on the SPT drilling result, the profile of the slope body at the area of study comprises are disposal material, overburden, mud layer, and coal seam.

The material properties parameters used to define the safety factor in this analysis are cohesion, internal friction angle, and unit weight. The value of properties used is obtained from the results of SPT drilling (Table 6).

Table 6. The results of correlation N-SPT values on the cross-section A-A', B-B', C-C'

Cross-Section	Material	N-SPT	Material Properties	Minimum Value	Maximum Value
A-A'	Cohesive soils	3 – 55	Cohesion (kN/m^2)	17.25	354.44
			Phi (^{o})	21	42.8
	Non cohesive soils	27 – 47	Cohesion (kN/m^2)	41.55	84.55
			Phi (^{o})	34.8	40.5
B-B'	Cohesive soils	4 – 50	Cohesion (kN/m^2)	23.7	321.9
			Phi (^{o})	28.26	41.4
	Non cohesive soils	15 – 38	Cohesion (kN/m^2)	15.7	65.2
			Phi (^{o})	31.4	37.9
C-C'	Cohesive soils	8 – 48	Cohesion (kN/m^2)	49.6	309
			Phi (^{o})	29.4	40.8
	Non cohesive soils	22 – 30	Cohesion (kN/m^2)	30.8	48
			Phi (^{o})	33.4	35.6

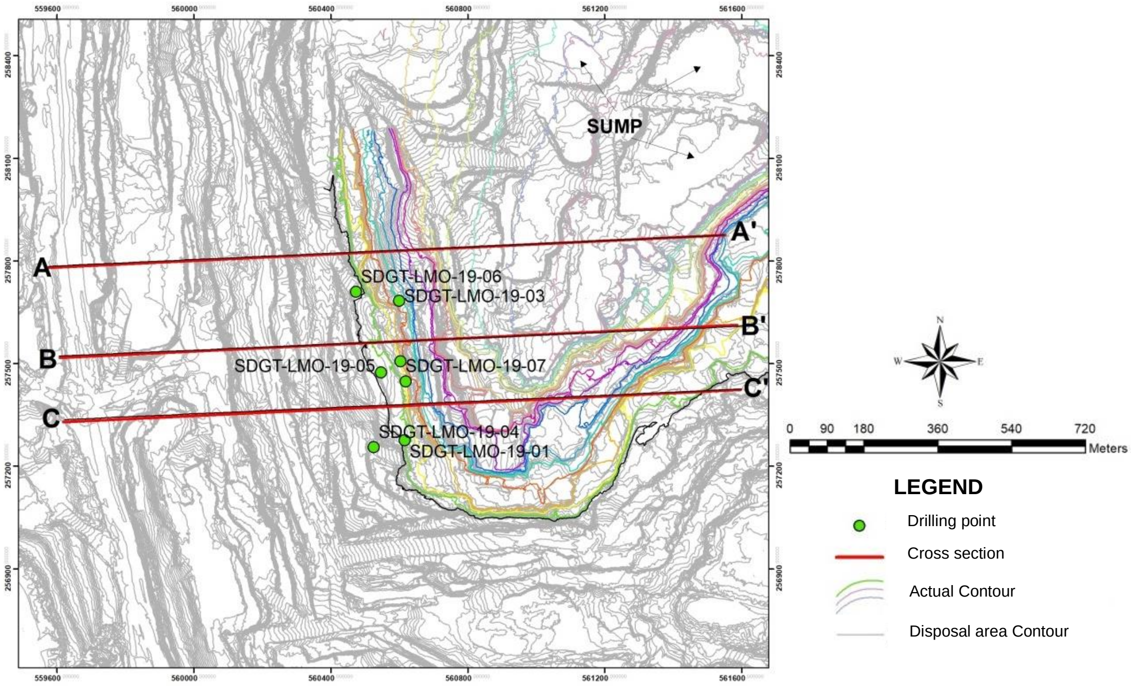


Figure 2. Cross-sectional location for geotechnical modeling and analysis in the study area

Fitting Test

The material properties parameters tested statistically were included in the Mohr-Coulomb criteria, namely cohesion and internal friction angle. All the data were considered random variables. The data have high variations, so it was chosen to be analyzed. They will significantly affect the slope stability analysis to be carried out. The results of the fitting test can be observed in Tables 7, 8, and 9.

Table 7. Statistical test results on the A-A' cross-section

No	Material	Material Properties	Distribution Type	Mean	Std. Dev.	Rel. Min	Rel. Max
1	Mudstone	Cohesion	Normal	118.75	13.75	41.15	41.25
		Phi	Normal	24.17	3.2	9.6	9.6
2	S	Cohesion	Lognormal	29.03	19,63	11.78	14.14
		Phi	Normal	26.13	4.461	5.13	2.99
3	F	Cohesion	Normal	46.43	4.585	3.246	3.237
		Phi	Normal	29.26	0.202	0.140	0.145
4	St	Cohesion	Normal	69.12	12.97	19.45	19.451
		Phi	Normal	30.26	0.5714	0.854	0.859
5	Vst	Cohesion	Normal	133.2	24.78	44.628	33.179
		Phi	Normal	33.09	1.092	1.9702	1.458
6	H	Cohesion	Normal	293.3	44.59	68.564	61.115
		Phi	Lognormal	40.133	24.37	3.013	2.7
7	MD	Cohesion	Normal	66.28	19.98	24.73	18.27
		Phi	Normal	38.12	2.655	3.286	2.427

Table 8. Statistical test results on the B-B' cross-section

No	Material	Material Properties	Distribution Type	Mean	Std. Dev.	Rel. Min	Rel. Max
1	Mudstone	Cohesion	Normal	118.75	13.75	41.15	41.25
		Phi	Normal	24.17	3.2	9.6	9.6
2	Sandstone	Cohesion	Normal	121.75	15.58	46.74	46.75
		Phi	Normal	28.63	6.61	19.83	19.83
3	F	Cohesion	Normal	34.11	7.393	10.378	9.0731
		Phi	Normal	28.72	0.325	0.457	0.3999
4	St	Cohesion	Normal	73.66	12.61	17.508	14.911
		Phi	Normal	30.46	0.556	0.768	0.659
5	MD	Cohesion	Normal	39.94	24.6	24.19	25.26
		Phi	Normal	34.62	3.269	3.214	3.356
6	Vst	Cohesion	Gamma	146.965	988.044	51.909	71.286
		Phi	Lognormal	3368	20.446	2.274	3.153
7	H	Cohesion	Lognormal	250.255	153.387	51.456	71.739
		Phi	Lognormal	38.213	23.181	2.236	3.191

Table 9. Statistical test results on the C-C' cross-section

No	Material	Material Properties	Distribution Type	Mean	Std. Dev.	Rel. Min	Rel. Max
1	Mudstone	Phi	Normal	24.17	3.2	9.6	9.6
		Cohesion	Normal	118.75	13.75	41.15	41.25
2	Vst	Phi	Normal	33.23	0.915	1.5388	1.6039
		Cohesion	Normal	136.5	20.77	62.31	62.31
3	MD	Cohesion	Lognormal	38.239	23.563	7.439	9.761
		Phi	Lognormal	34.375	20.857	0.9703	1.3152
4	H	Phi	Lognormal	38.472	23.357	2.4960	2.3608
		Cohesion	Lognormal	255.78	156.91	56.986	53.242
5	St	Phi	Normal	30.66	1.042	1.2544	1.0312
		Cohesion	Normal	78.2	23.65	28.532	23.339
6	Sandstone	Cohesion	Normal	121.75	15.58	46.74	46.75
		Phi	Normal	28.63	6.61	19.83	19.83

Probability Analysis

Slope stability analysis was carried out on the design of the A-A', B-B', and C-C' using Rocscience Slide v.6.0 software. Material characteristics data and material properties that have been statistically tested. The data included in the slope stability analysis using the Morgenstern-Price boundary equilibrium method with the Monte Carlo sampling method. Furthermore, parameters groundwater level and vibration coefficient are added to produce the safety factor's value and the probability of failure in each cross-section.

In this study, the probability of failure reference table was used by SRK Consulting (2006), Priest-brown (1983), and Kirsten (1983) in Read and Stacey (2009) for mine slopes as can be seen in Table 10. From the reference table, the appropriate threshold value is determined for the research area. This research is carried out on the overall slope with the impact of landslides is medium. The landslide effect is adjusted to the activities, equipment, and possible costs needed to repair the slope in the event of a landslide. From these aspects, the maximum PoF threshold is determined, which is 10%, and the FS threshold is 1.05, which means that if the slope stability analysis is obtained for the slope PoF above 10% and the FS value is below 1.05, then the slope can be said to be unstable. A comparison of the failure probability and the resulting safety factor for each section can be seen in Figure 3, while the slope stability of each section are shown in Figure 4 to 6.

In general, the research area is classified as having a high probability of failure and a critical slope safety factor. The area with a low probability of failure and a high slope safety factor due to the geometry of the in-pit dump body is smaller, which is located in the north part of the pit. Therefore the risk of pit wall failure in the area needs to be reduced.

Table 10. Recapitulation of the results of probabilistic analysis

Slope	FS Deterministic	FS Mean	PoF Analysis	PoF with error value
Cross-section A-A'	1.162	1.160	0%	0% - 0.073%
Cross-section B-B'	1.040	1.040	12.2%	10.17% - 12.56%
Cross-section C-C'	1.042	1.042	9.8%	7.95% - 11.64%

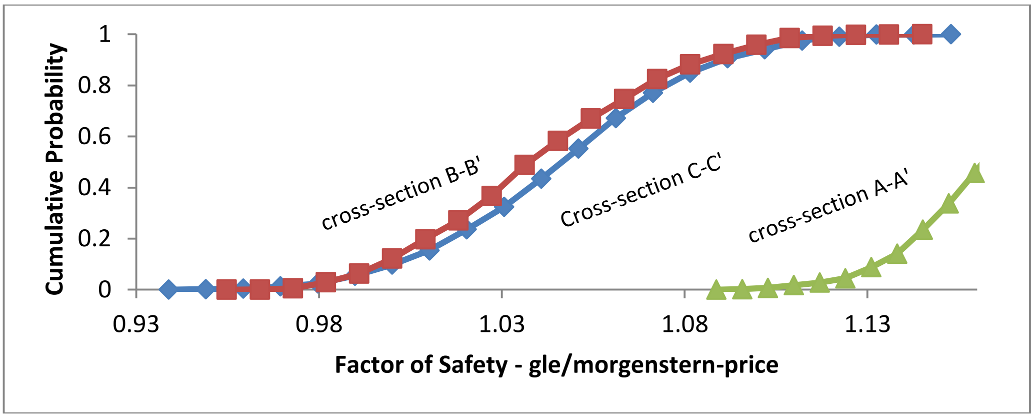


Figure 3. The relationship between the cumulative probability and the value of the factor of safety

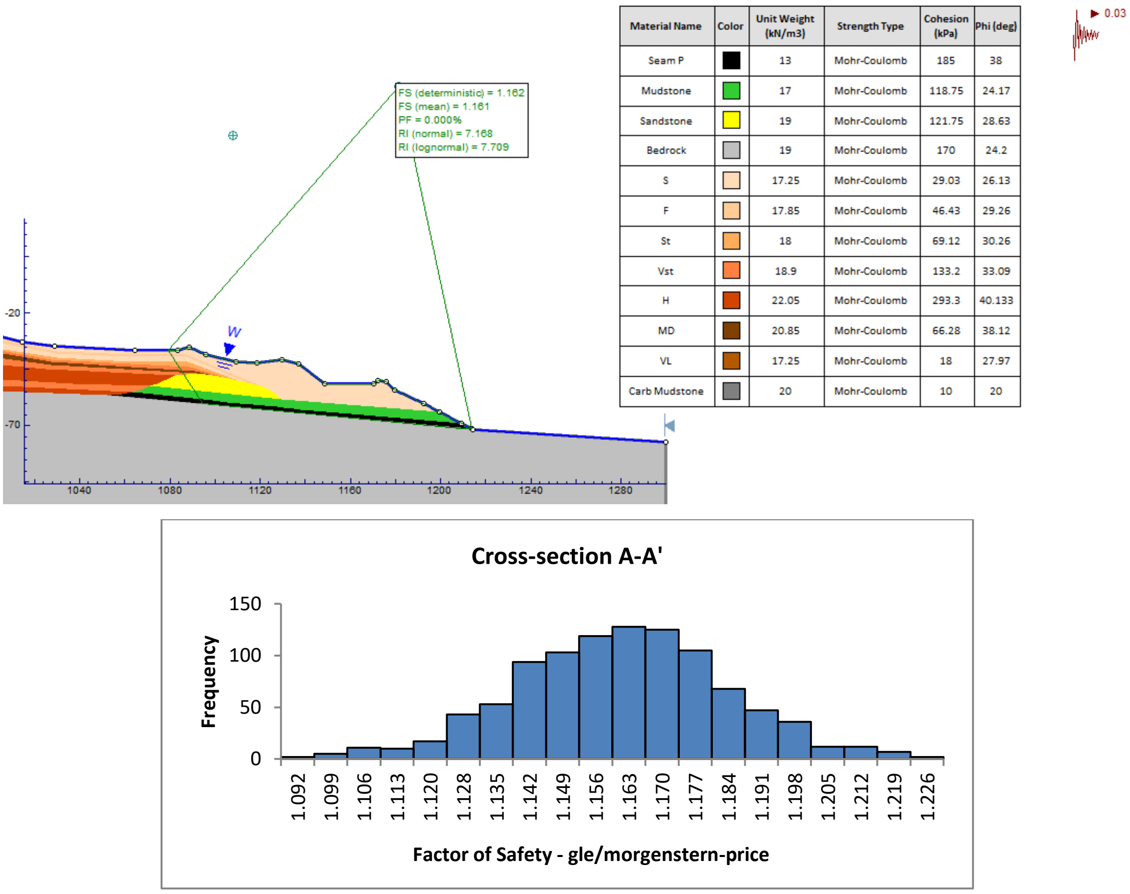
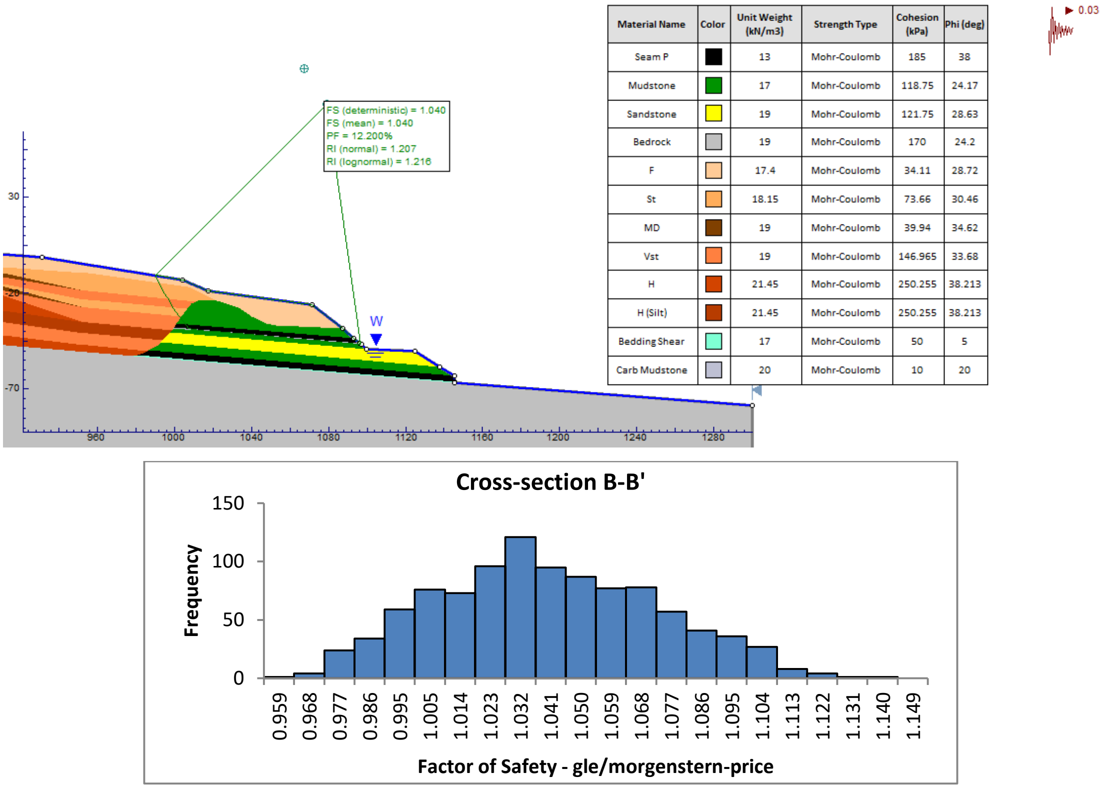
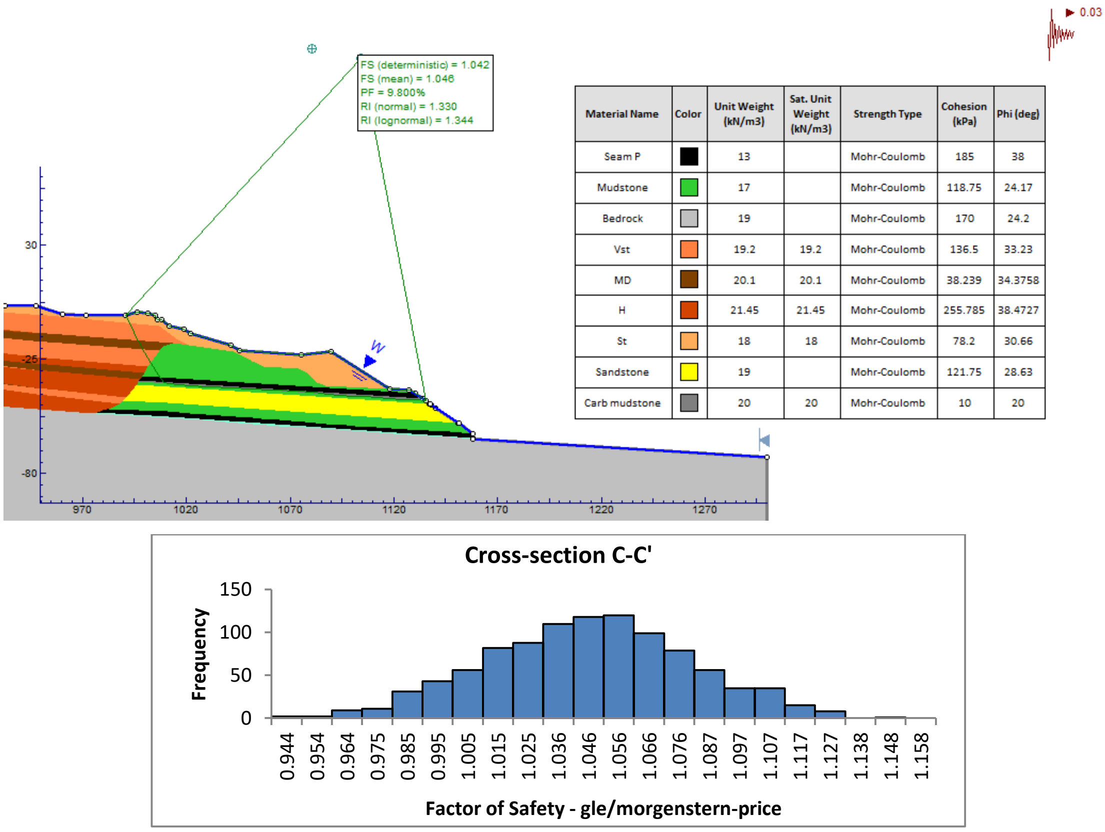


Figure 4. Slope stability analysis using slide software and PoF histogram on A-A' cross-section



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)
Seam P		13	Mohr-Coulomb	185	38
Mudstone		17	Mohr-Coulomb	118.75	24.17
Sandstone		19	Mohr-Coulomb	121.75	28.63
Bedrock		19	Mohr-Coulomb	170	24.2
F		17.4	Mohr-Coulomb	34.11	28.72
St		18.15	Mohr-Coulomb	73.66	30.46
MD		19	Mohr-Coulomb	39.94	34.62
Vst		19	Mohr-Coulomb	146.965	33.68
H		21.45	Mohr-Coulomb	250.255	38.213
H (Silt)		21.45	Mohr-Coulomb	250.255	38.213
Bedding Shear		17	Mohr-Coulomb	50	5
Carb Mudstone		20	Mohr-Coulomb	10	20

Figure 5. Slope stability analysis using slide software and PoF histogram on B-B' cross-section



Material Name	Color	Unit Weight (kN/m3)	Sat. Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)
Seam P		13		Mohr-Coulomb	185	38
Mudstone		17		Mohr-Coulomb	118.75	24.17
Bedrock		19		Mohr-Coulomb	170	24.2
Vst		19.2	19.2	Mohr-Coulomb	136.5	33.23
MD		20.1	20.1	Mohr-Coulomb	38.239	34.3758
H		21.45	21.45	Mohr-Coulomb	255.785	38.4727
St		18	18	Mohr-Coulomb	78.2	30.66
Sandstone		19		Mohr-Coulomb	121.75	28.63
Carb mudstone		20	20	Mohr-Coulomb	10	20

Figure 6. Slope stability analysis using slide software and PoF histogram on C-C' cross-section

Slope Condition

Based on the PoF and FS calculation at the following cross-section as mentioned above, the result has shown that the slope section A-A', the design has classified as a stable condition. The slope design on the B-B' section is classified as an unstable condition. Meanwhile, the C-C' section is classified as a marginal slope condition (Table 11).

Evaluation of the stability of the disposal slope is carried out by considering the material properties parameters that affect the stability of the slopes in the study area based on sensitivity analysis. The analysis results show that the slip planes on the B-B' and C-C' sections are formed through the disposal material to the shally coal layer, which is in contact with the claystone. This causes the material properties parameter that has a significant effect on increasing the probability of failure and decreasing the safety factor, namely the cohesion value of the disposal soil with clay soil type (CL) Stiff density (ST) - very stiff (VST). Clay material in this research area will reduce slope stability which can pose a risk of landslides. Based on Das and Sobhan (2018), if the clay grains in solution are located close to each other, then the diffuse double layer between the grains will cause a repulsive force, and the Van Der Waal forces will produce an attractive force between the clay grains. If the clay particles are dispersed under the influence of the groundwater table, the soil particles will be far apart from each other. This is due to the increase in the distance between the particles so that the repulsive force between the particles will be greater than the attractive force (Van Der Waal force).

CONCLUSION AND SUGGESTION

Conclusion

Based on the results of the study as described above, several conclusions can be summarized as follows:

- The material properties in the research area vary depending on the material and N-SPT blows number. The higher N-SPT blows have represented, the greater the cohesion and friction angle as well. The strength of the material tends to increase follow to the depth too;
- The fitting test used the Goodness of Fit Test Anderson-Darling, where in general, the material properties have a normal distribution type. However, materials with a lognormal distribution are also materials, namely soft clay materials and dense to medium sand materials;
- The disposal area at PIT West Block 'X' has a probability of failure, and various slope safety factors are influenced by the dominance of the material that composes it. From the failure probability, it can be seen that there are unstable slopes with very short resistance times, which can harm mining operations. So urgent treatment is needed with minor modifications of the slope geometry and reduction of soft material to raise the mean FS and PoF to a satisfactory level.

Table 11. Slope condition based on the FS and PoF value

Slope	Acceptance Criteria (SRK Consulting, 2006)		Performance of slope[1] (Priest-brown, 1983)	Serviceable life[2] (Kirsten,1983)
	FS > 1.05	PoF < 10%		
Cross-section A-A'	Yes	Yes	Stable slope: Satisfies FS and PoF criteria	*Very long term* *(*PoF <0,5%)
Cross-section B-B'	No	No	Unstable slope: PoF Falls below minimum mean criteria. FS violates probabilistic criteria	*Very short term* (PoF 10-20%)
Cross-section C-C'	No	Yes	Marginal slope: PoF falls below minimum mean criteria. FS but satisfies probabilistic criteria	*Short term* (PoF 5-10%)

[1]Table 4 Interpretation of FS and PoF guidelines
[2]Table 5 PoF design acceptance guidelines
Source: modifications of SRK Consulting (2006), Priest-brown (1983) and Kirsten (1983) in Read and Stacey (2009)

Suggestion

From this analysis, if the coal mining process in the research area is to be continued, it is necessary to modify the slopes and their constituent materials, especially on the slopes in the B-B' and C-C' cross-sections. Sandstone material must be left with sufficient volume to reduce the probability of failure in the study area. In addition, the reduction of clay material can further reduce the value of the probability of failure in the study area. Suggestions for further research should be conducted a local geological mapping first to determine the lithological characteristics in detail. In addition, it is necessary to study and monitor the condition of the groundwater table (MAT) so that the input data used for slope stability analysis is more representative. The material properties of the original rock data from the results of laboratory tests also need to be added so that the results of the statistical analysis are more representative. A stable slope simulation should be carried out as an evaluation recommendation for repairing slopes that have the potential for landslides.

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