INDONESIAN MINING JOURNAL Vol. 25, No. 1, April 2022 : 1 - 11

GEOTECHNICAL STUDY FOR ANALYZING SLOPE STABILITY BETWEEN TWO MINING PIT BOUNDARY

STUDI GEOTEKNIK UNTUK MENGANALISIS STABILITAS LERENG ANTARA DUA BATAS PIT PENAMBANGAN

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ABSTRACT

This paper is a new concept to increase the safety and mining conservation on PT-X and PT-Y with no boundary gap between the two areas. To optimize coal recovery as a basis of supporting conservation, the two companies needed to adjust coal production in terms of avoiding technical problems at the mining time process due to the rock structure and coal seam at the border were the same. PT-X plans to produce 2 million tons of coal, but the government only approved 1 million tons, while PT-Y still approved 2 million tons. This paper discusses the instability of mining in border locations due to the differences of coal production. The applied methodology is conducting geotechnical modeling by considering statistical aspects of data distribution and the probability of failure. Based on the results of geotechnical modeling by numerical methods on the basis of 2D and 3D for the difference in the production level of 1 million tons in all cross-sections, the FK value is 0.992 - 1.248 with a probability of failure (PI) of 5.40 - 48.00%. Results of modeling analysis show that both single and overall slopes are at a critical level and are not safe. If this difference is narrowed by increasing PT-X's coal production by 1.5 million tons, the border location's mining conditions will stabilize. Therefore, it is necessary to propose to the government for PT-X's coal production to be added by at least 500.000 tons so that the production process of each company runs safely.

Keywords: production, pit boundary, slope stability, numerical modeling.

ABSTRAK

Makalah ini merupakan konsep baru untuk meningkatkan keselamatan dan konservasi pertambangan di PT-X dan PT-Y tanpa adanya celah batas antara kedua wilayah tersebut. Untuk mengoptimalkan perolehan batubara sebagai dasar pendukung konservasi, kedua perusahaan perlu menyesuaikan produksi batubara untuk menghindari masalah teknis pada saat penambangan karena struktur batuan dan lapisan batubara di perbatasan sama. PT-X berencana memproduksi 2 juta ton batu bara, namun pemerintah hanya menyetujui 1 juta ton, sedangkan PT-Y masih disetujui 2 juta ton. Makalah ini membahas ketidakstabilan penambangan di lokasi perbatasan akibat perbedaan produksi batubara tersebut. Metodologi yang digunakan adalah melakukan pemodelan geoteknik dengan mempertimbangkan aspek statistic dari distribusi data dan kemungkinan runtuh (probability of failure). Berdasarkan hasil pemodelan geoteknik menggunakan metode numerik berbasis 2D dan 3D, untuk selisih tingkat produksi 1 juta ton pada semua penampang didapatkan nilai FK sebesar 0.992 - 1.248 dengan probabilitas kegagalan (PI) sebesar 5.40 - 48.00%. Hasil analisis pemodelan menunjukkan bahwa baik lereng tunggal maupun lereng keseluruhan berada pada level kritis dan tidak aman. Jika selisih ini dipersempit dengan meningkatkan produksi batu bara PT-X sebesar 1.5 juta ton, maka kondisi tambang di lokasi perbatasan akan stabil. Oleh karena itu, perlu diusulkan kepada pemerintah agar setidaknya produksi batu bara PT-X ditambah lagi 500.000 ton agar proses produksi masing-masing perusahaan berjalan aman.

Kata kunci: produksi, batas pit, stabilitas lereng, pemodelan numerik.

Received: 06 February 2022, first revision: 27 May 2022, second revision: 29 May 2022, accepted: 10 June 2022.
DOI: 10.30556/imj.Vol25.No1.2022.1279

INTRODUCTION

One of the conservation efforts in the Decree of the Indonesian Minister of Energy and Mineral Resources of Indonesia No. 1827K/ 30/MEM/2018 is to optimize mining at the mining concession border. The government recommends mining cooperation between the two concession holders at the border. Still, there are several reasons for not conducting mining cooperation at the border, including the timing and sequence of not concurrent mining and production targets are much different. The pit geometry parameters are not uniform which technically will not be safe to be mine (Lubis, 2020). PT-X borders its area with PT-Y without gaps (corridor). This case allows for mining cooperation. Based on optimizing coal recovery as a basis for supporting conservation and approval of the Directorate General of Mineral and Coal of the Ministry of Energy and Mineral Resources of Indonesia, the two companies have agreed to adjust plans to mutually take reserves at the border location. The adjustment of the mining sequence at the border location is carried out to avoid technical problems during mining because the rock structure and coal seam are generally the same. This means that overburden stripping and coal mining must be carried out simultaneously. The problem is the coal production of PT-X was only approved by the Directorate General of Mineral and Coal of the Ministry of Energy and Mineral Resources of Indonesia only 1 million tons due to administrative reasons. Whereas PT-Y was 2 million tons in the same year. If PT-X mines by 1 million tons per year, the stripping ratio will be high at 16.07 because it can only mine in the high wall section and the potential for slope instability is higher. But if synchronized by PT-Y mines following the mining sequence plan that has been mutually agreed upon, technically, there is no difference in the dimensions of the slopes in the low wall area so it can prevent the higher loads on the low wall, moreover that the down-dip conditions are lead to PT-X concession as illustrated in Figure 1-A and the cross-section in Figure 1-B.

According to the Decree of the Minister of Energy and Mineral Resources No. 1827 K/30/MEM of 2018 in Attachment II Point 4 regarding technology utilization, engineering capability, design and development, and application of technology, no. 4 concerning slope surface mining states, “if geological conditions are found that have not been identified in previous geotechnical studies, then take (a) safeguard measures against slopes; (b) increase the intensity of monitoring of slope movement; (c) ensure slope stability and follow-up on monitoring results, and (d) make further geotechnical studies that the mining Inspector can check from time to time” (Kementerian Energi dan Sumber Daya Mineral, 2018). Based on the regulation, it is necessary to study and analyze the slope stability on this problem with all considerations: technical. Economic, environmental, and the safety work issues (Fleurisson, 2012).

This paper is a new concept to improve mining conservation using geotechnical simulation and modeling while increasing the acquisition of coal reserves at the concession border of the two companies. This paper discusses the impact of PT-X and PT-Y's coal production imbalance which causes unsynchronized mining sequences around the border. This difference greatly affects the geotechnical stability around the location. The revision of the planned increase in coal production by PT-X from 1 million tons to 1.5 million tons with an overburden of 22.9 million BCM at SR 14.9 is needed to offset PT-Y's mining activities around the boundary where the company has been permitted to Mining of 2 million tonnes with an overburden of 27.8 million tonnes at SR 14.5. The increase in PT-X's coal production can at least adjust the mining sequence around the border so that geotechnical instability at the border between the two companies can be avoided. This study aims to explain the difference in slope safety on the working surface of the mine at PT-X around the border location at production levels of 1 million tons and 1.5 million tons. It is hoped that in addition to achieving a better level of mine safety, the backfilling process (in-pit dump) can also be more efficient, and the conservation of coal natural resources can be more optimal. Likewise, the handling of dumping material can be completed immediately to accelerate the regrading-reshaping and revegetation processes.

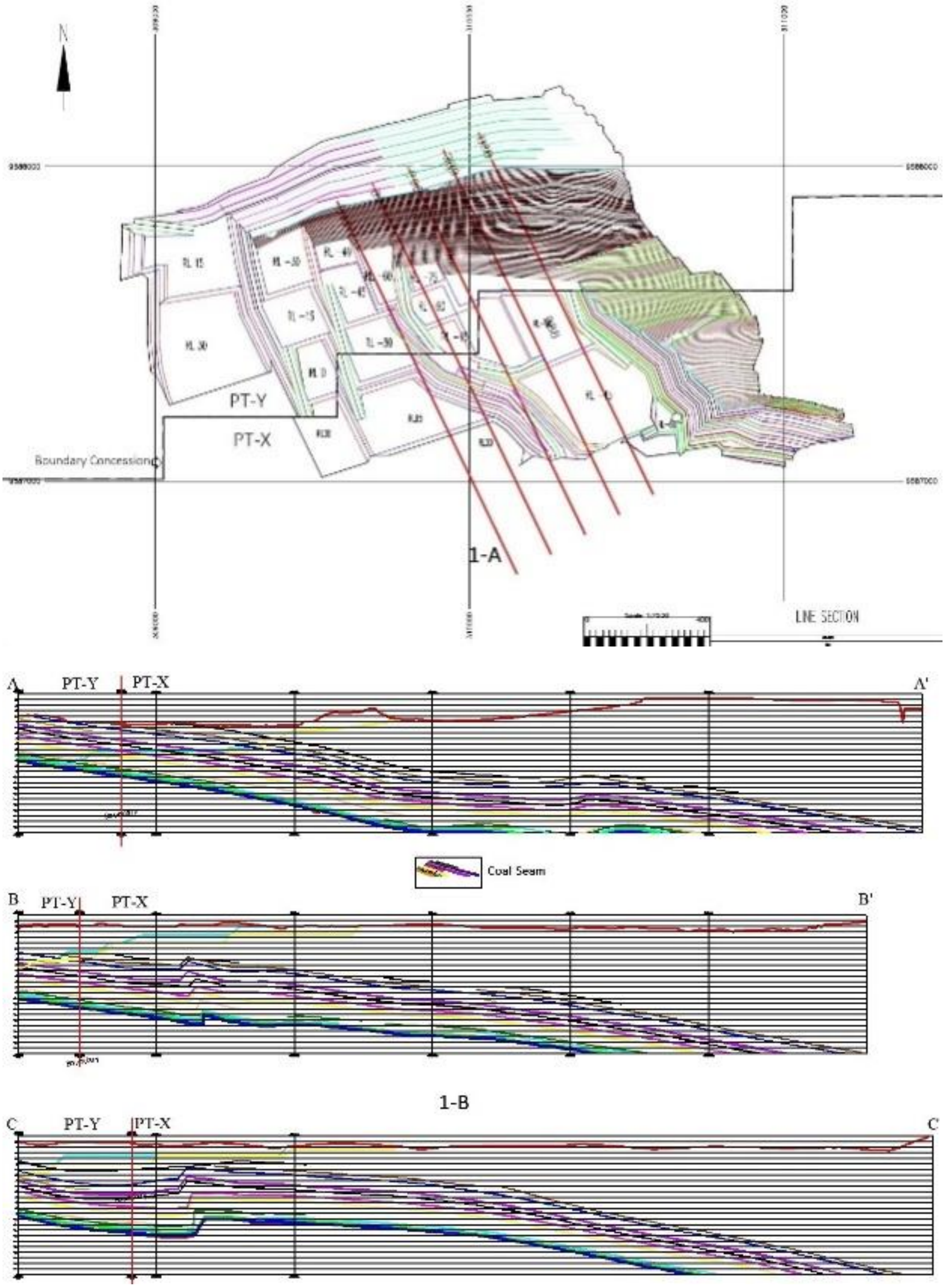


Figure 1. Pit condition on the boundary concession (1-A) and sections A-A’, B-B’, and C-C’(1-B)

METHOD

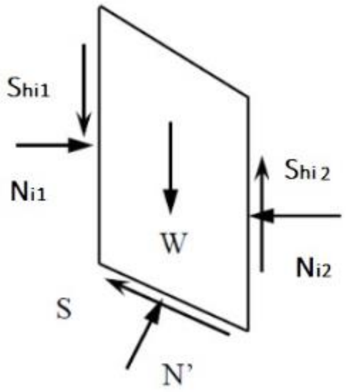
This study obtained the data sources from the results of laboratory tests originating samples in that the border of two concessions that are in sections A-A'; B-B'; C-C' and 88-92, then accomplish the numerical modeling based on 2D limit equilibrium (LE) and 3D finite element (FE) method with several stages. The two methods are widely used because the value of the safety factor and the failure prediction are generally appropriate and consistent (Berisavljevic *et al.*, 2015; Burman *et al.*, 2015; Kanda and Stacey, 2016; Koca and Koca, 2020; Renani and Martin, 2020). The LE method has long time ago developed by researchers in solving slope stability analysis (Liu, Shao and Li, 2015) which was originally developed from analytical concepts using the principle of balance of forces with various approaches (Das, 2013).

To solve the calculation of the failure mechanism by the LE method, several assumptions and equilibrium equations are needed as a reference in determining the safety factor value. The LE method has undergone many developments and computational technology development. This method has been developed for a long time and the ordinary method of slices (OMS) was the first LE method initially developed by Fellenius (Utili and Crosta, 2015). However, it is rarely applied nowadays because the calculation of the safety factor requires a lot of simplification, so this method is less accurate. Generally, the calculation results of the safety factor show a low value from the design aspect, it becomes less economical.

This method by Bishop (Utili and Crosta, 2015) was refined by including the normal interslice force so that the accuracy of the safety factor calculation was increased, which was called the Simplified Bishop's Method (Zhu, 2008; Ji *et al.*, 2020). This method considers normal interslice forces but ignores interslice shear forces (Abramson *et al.*, 2002). In 1967, Spencer improved this method by including force and moment equilibrium (Utili and Crosta, 2015). Spencer's method is not only able to predict circular failure but also non-circular failure (Agam *et al.*, 2016). Another method that can predict non-circular failure is "Janbu's Simplified Method" developed by Janbu then refined for some special cases with Janbu's generalized method (Cheng *et al.*, 2013; Utili and Crosta, 2015; Ky, Martinez and Chhun, 2018; Wang *et al.*, 2019; Kumar, Kayet and Pathak, 2021). Morgenstern and Price improved Spencer's method by assuming the slope of the resultant interslice force to vary based on the portion of an arbitrary mathematical function. This method allows one to determine different types of interslice force functions (Pandit, Jignesh and Amol, 2013; Kumar, Kayet and Pathak, 2021). According to this method, the slope of the interslice force can vary with an arbitrary function:

$$f(x) = \frac{S_{hi}}{\lambda N_i}$$

Where f(x) is interslice force function which changes continuously along the surface of the slip plane; S_{hi} is interslice shear forces; N_i is interslice normal forces; and λ is scale factor of the assumed function. The relationship for the basic normal force (N) and the interslice force (N_i, S_{hi}) is the same as that given by Janbu and Spencer as shown in Figure 2.



Note: $S_{hi1\&2}$ is interslice shear forces; Ni is interslice normal forces; S is shear force of the slip plane; N' is an effective base normal force.

Figure 2. Forces considered in Morgenstern-Price Method

For a given force function, the interslice force is calculated by an iterative procedure until the equilibrium is obtained. The Spencer, Janbu and Morgenstern-Price method requires computer software to perform calculations, because the process of calculating the moment and force equilibrium must be satisfied for each slice and requires repeated iterations for a number of assumptions of the factor of safety and the slope of the interslice force.

The use of the LE method has been applied in several commercial computer programs, but unfortunately in this method there is no information on deformation that occurs along the slip plane. This condition occurs because this modeling is based on the soil mass model which is generally divided into wedges as a rigid solid material so that the effect on the yield is much higher than that of the case.

The most flexible method used is finite element method. Modeling in this method is almost similar to the boundary element but such the method requires discretization of soil or rock mass elements. One of the advantages of this method is that there is no need for assumptions or speculation about the location of the center of the critical slip plane. This is reflected by the solution in the form of identifying which part of the slope has reached the failure condition. Generally progressive collapse can be modeled in this method.

Finite element approach conceptually depends on the stress-strain relationship and stress distribution. Currently, the FE approach is growing rapidly, and the development of computing technology with two primary methods: the strength reduction and the limit strength method (Krabbenhoft and Lyamin, 2015). However, the LE method is widely used because it is simple and in many cases, still proven accurate. While the FE requires modeling with complicated iteration (Memon, 2018; Ayob *et al.*, 2019). The stages consisted of creating the models, model simulation, meshing, the input of material and operational data, modeling in situ loads and stresses, boundary conditions, and model validation.

Slope stability analysis aims to determine the condition of the slope stability of the mine opening that this analysis will create following the mining plan (pit plan). The stability of a slope or a mine opening slope depends on five main factors, namely; slope geometry which includes the depth and slope of the slope angle, rock mass strength, general orientation or direction, and general slope of the weak plane structure (discontinuity) of the rock mass to the orientation of the mine opening slope, groundwater conditions (especially water level) in the rock mass of the slope. and the presence of external loads acting on the slope model in the form of static and dynamic loads (vibration).

Creating the Models

With advances in computational technology and the development of geomechanical calculations, numerical modeling methods have made it possible to understand complex geotechnical problems (Hussain *et al.*, 2018; Schweiger *et al.*, 2019; Khan and Wang, 2021). Numerical calculations can mathematically solve a pattern of relationships between variables or parameters described in the form of functions. The approach used in the numerical method is a mathematical analysis approach. The rationale is not far from the basis of analytical thinking. It's just that the use of graphics and calculation techniques in the numerical method makes it easier to analyze. Given that the algorithm developed in the numerical method is an approximation algorithm, the term iteration will appear in the algorithm, namely the repetition of the calculation process. In academic research and engineering practice, the numerical approaches of continuum modeling and discontinuous modeling have gained wide popularity (Fish and Belytschko, 2007; Moses *et al.*, 2020). The parameters and variables used in this research are data from the geomechanics laboratory test results, the dimensions of the slope, the shape of the pit, which is adjusted to the final low wall model of the pit belonging to PT-X under study. The modeling of geotechnics has been done by simulation with the variation of different pit depths and geological conditions based on 2D and 3D models.

Simulation

The model was conducted using Slide 2D and Ansys 3D software. Each command used to construct the model is stored in the input file. The main input parameters for the 2D model are density (unit weight). strength type, cohesion, and internal friction angle. Meanwhile, for the 3D model, besides the parameters required in the 2D model, other parameters such as Young modulus, Poisson's ratio, bulk modulus, tensile strength, compressive strength, residual cohesion, and residual internal friction angle are also needed. Model aspects such as geometry, material properties, mesh size, contact conditions, and load conditions are defined as parameters created at the beginning of data input. The formation of the model is done repeatedly and takes a long time. All aspects of the model consisting of the material, element formulation, mesh, and boundary conditions are adjusted to the area conditions and slope geometry being analyzed. All data in this model have been prepared according to the model's needs. By doing several simulations on the variation of the amount of coal production resulting in changes in the dimensions of the slopes, it will be possible to know the value of the safety factor of these slopes. This study uses the Mohr-Coulomb shear failure criteria to determine whether the slope is stable or not on overburden, inter burden, coal, and bedrock layers (below the coal seam).

Discretization and Meshing

The basic concept of finite elements is to discretize or divide a structure into a finite number of smaller parts, then carry out a combined review of these small elements. T This finite element method aims to obtain a numerical approximation value so that the calculation of the forces or stress-strain in these small parts calculation can complete one by one with the help of computations.

Inputting Data

After that, inputting geotechnical data such as physical and mechanical properties of rock for all layers that form the slope, all rock layer materials that make up the model are based on the characterization of the rock mass as a result of laboratory tests. The geotechnical data is taken from the average value of the laboratory test results from the site around the pit. Generally, the rocks on the research location are claystone, sandstone, mudstone, and coal. The geomechanics tests carried out consisted of physical and mechanical properties such as density, porosity, void ratio, UCS (uniaxial compressive strength), direct shear, and triaxial tests. Tables 1, 2, and 3 are input parameters representing each section of the pit site analyzed. Figure 3 is the research flow chart starting from the preparation of materials and equipment to the conclusion of this research.

Table 1. Physical properties of the rocks

No	Lithology	W_n (gr)	W_s (gr)	W_o (gr)	W_w (gr)	ρ_n (gr/cm^3)	ρ_d (gr/cm^3)	ρ_s (gr/cm^3)	w %	S %	n %	e
1	Carb. Claystone	61.90	32.40	59.60	62.90	2.03	1.95	2.06	3.86	69.70	10.82	0.12
2	Mudstone	72.25	39.35	70.40	74.05	2.09	2.03	2.14	2.64	51.21	10.51	0.12
3	Coal	68.10	21.50	65.60	69.90	1.41	1.36	1.44	3.81	58.14	8.88	0.10
4	Sandstone	72.83	45.57	70.20	75.57	2.43	2.34	2.52	3.79	54.26	17.71	0.22

Description: W_n = Normal weight; W_s = weight of solids; W_o = weight of optimum; W_w = weight of water;
ρ_n = normal density; ρ_d = dry density; ρ_s = saturated density; W = normal water content;
S = saturated water content; n = porosity; e = void ratio

Table 2. Average mechanical properties using Direct Shear test

No	Lithology	σ_{normal} (MPa)	τ (MPa)		C (MPa)		Internal friction Angle (°)	
			Residual 1	Residual 2	Residual 1	Residual 2	Residual 1	Residual 2
1	Claystone	0.122	0.730	0.243	0.58	0.19	48.5	25.2
		0.260	0.844	0.324				
		0.351	0.995	0.351				
2	Mudstone	0.083	0.472	0.208	0.4	0.175	42.4	27
		0.169	0.552	0.276				
		0.277	0.648	0.312				
3	Coal	0.117	0.409	0.234	0.32	0.16	39.4	18.3
		0.227	0.511	0.227				
		0.371	0.619	0.309				
4	Sandstone	0.125	0.580	0.228	0.447	0.203	47.27	22.2
		0.244	0.712	0.305				
		0.374	0.850	0.331				

Description: σ_{normal} = Normal stress; τ = shear strength; C = cohesion

Table 3. Average mechanical properties using uniaxial compressive strength test

No	Lithology	F (kN)	σ (MPa)	E (MPa)	u
1	Carbonaceous Claystone	68.00	42.68	7.907.48	0.23
2	Sandstone	42.00	26.64	5.004.51	0.23
3	Mudstone	30.00	18.97	2.858.73	0.22
4	Sandstone	52.00	32.74	6.004.74	0.24
5	Carb. Mudstone - Sandstone	72.00	45.23	6.019.75	0.22
6	Mudstone	14.00	8.82	4.167.18	0.28
7	Sandstone	32.00	20.13	3.718.65	0.23

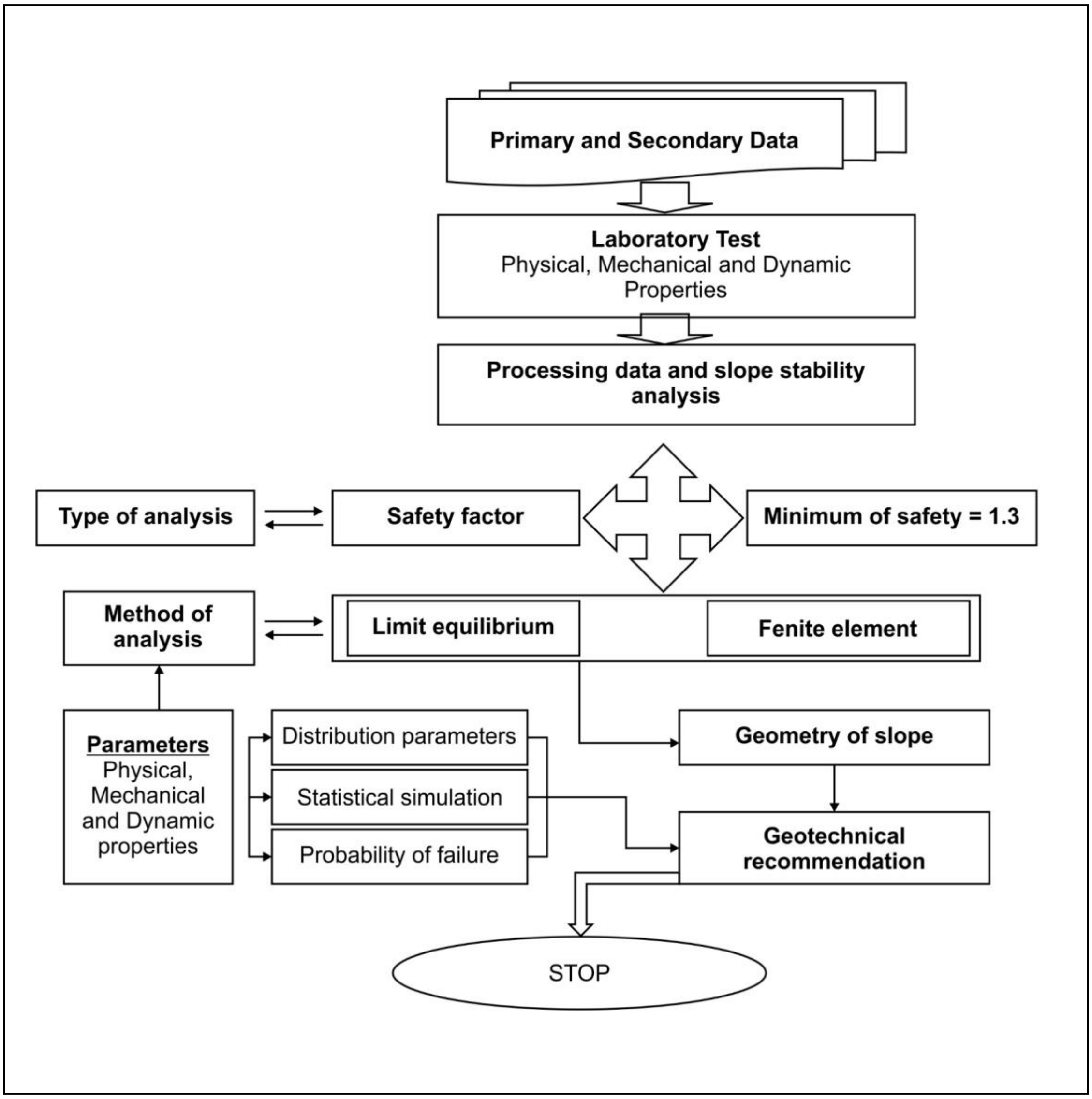


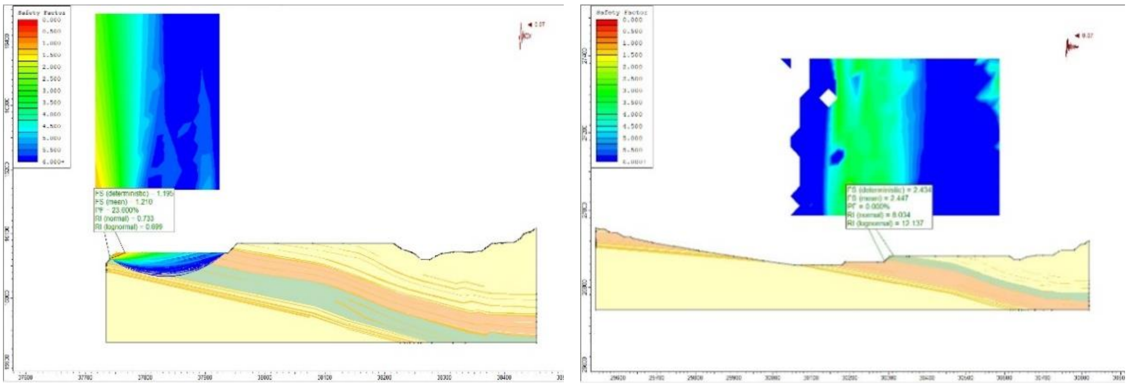
Figure 3. Flowchart of research methodology

RESULTS AND DISCUSSION

By executing the limit equilibrium and finite element programs on all the slope models, it can know the value of the slope safety factor (SF). In the context of the mine opening slope stability analysis, the SF distribution will be used as an indicator to determine the stability of the slope around the mine opening. Theoretically, each element in the slope model is stable if the strength to stress ratio for that element is greater than one (SF > 1).

This condition can also say that a safety factor is a number that describes the magnitude of the rock strength value compared to the stress value acting on each model element, according to the failure criteria used. Although theoretically, SF>1 means that the slope is in a stable state, in this study, the criteria for assessing slope stability is determined at SF ≥ 1.3. The slope of the mine opening is considered quite stable if the value of the slope safety factor is not less than 1.3. This is taken from the Decree of the Minister of Energy and Mineral Resources No. 1827K of 2018, concerning Guidelines for implementing good mining practices.

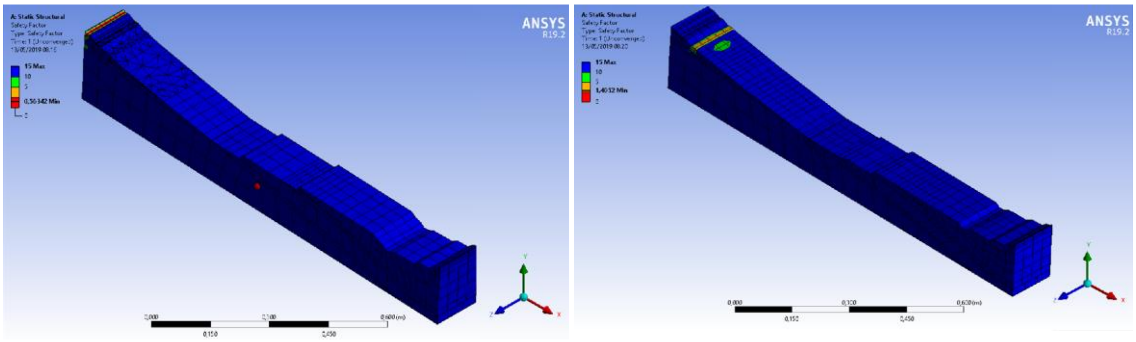
By every model that has been made, the overall slope stability calculation for each cross-section has been calculated by comparing the level of coal production between 1 million tons and 1.5 million tons of coal productions. For example, in sections A-A, a review of slope stability can be seen in Figures 4 and 5. In these figures, an example is shown a review of the overall slope stability conditions of the cross-section using 2D and 3D-based software. The simulation review was carried out using two variables: the overall slope height and the slope angle. Table 4 shows the modeling result of the slope stability simulation on several cross-sections. Figures 4 and 5, respectively, show the comparison between safety factor values when coal production is 1 million tons and 1.5 million tons in 2D and 3D models.



4-A

4-B

Figure 4. Comparison of SF value on the Block 88 with 1 MT (4-A) and 1.5 MT (4-B) coal production in 2D models



5-A

5-B

Figure 5. Comparison of SF value on the Block 88 with 1MT (5-A) and 1.5 MT(5-B) coal production in 3D models

Table 4. Modeling result of the slope stability simulation on several cross-sections

Cross Section	Coal production per year									
	1 MT			1.5 MT			1 MT		1.5 MT	
	2 D						3 D			
	SF	PF (%)	Level	SF	PF (%)	Level	SF	Level	SF	Level
A-A’	1.050	35.20	Critical	1.651	1.30	Safe	0.966	Failure	1.425	Safe
B-B’	1.040	16.10	Critical	1.753	0.60	Safe	1.043	Critical	1.496	Safe
C-C’	0.986	5.40	Failure	2.125	0.00	Safe	0.629	Failure	1.305	Safe
Block 88	1.195	23.60	Critical	2.434	0.00	Safe	0.563	Failure	1.405	Safe
Block 89	1.248	12.70	Critical	1.883	0.30	Safe	0.909	Failure	1.489	Safe
Block 90	1.039	39.10	Critical	1.794	0.60	Safe	1.266	Critical	1.344	Safe
Block 91	0.992	48.00	Failure	1.905	1.00	Safe	1.054	Critical	1.782	Safe
Block 92	1.157	23.10	Critical	2.625	0.00	Safe	0.994	Failure	1.381	Safe

Note: SF = Safety Factor (Deterministic); PF = Probabilistic of Failure; and Level: SF < 1 = Not Safe; SF >=1 and < 1.3 Critical; SF >= 1.3 Safe, based on the Decree of the Indonesian Minister of Energy and Mineral Resources of Indonesia No. 1827 K/ 30/MEM/2018

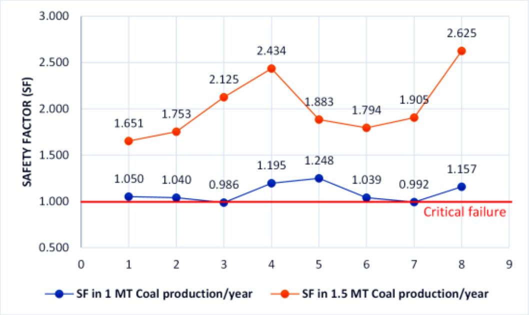


Figure 4. Comparison slope safety factor in 2D Model

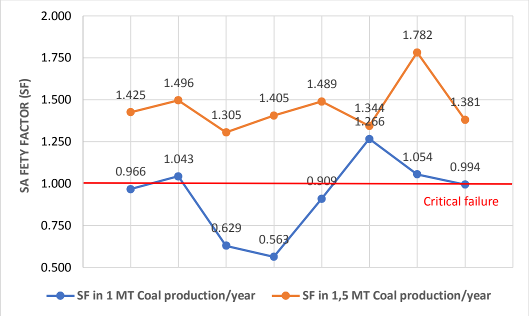


Figure 5. Comparison slope safety factor in 3D Model

CONCLUSION AND SUGGESTION

The significant difference in coal production between PT-X (1 MT/year) and PT-Y (2 MT/year) will lead to unstable mine slopes at the two concession boundaries. From the modeling results for the overall slope in all cross-sections, if PT-X's production is only one million tons, it shows SF < 1.3, even in some locations the SF value is less than 1, such as in the cross-sections of A-A, C-C, Block 88, Block 89, Block 91, and Block 92. Meanwhile, if coal production of PT-X is increased to 1.5 MT/year and PT-Y remains at 2.0 MT/year, the modeling results show a stable or SF > 1.3. Therefore, PT-X has a reason to apply for an increase in the coal production to a 1.5 MT/year level so that mining activities at the border of the two concessions remain stable.

As a recommendation from the author, the open-pit monitoring system must be carried out periodically with a visual observation system or equipment to evaluate slope performance and detect the emergence of unexpected movements, namely by shaping the slope by eliminating the potential for rock fall. PT-X and PT-Y should synchronize their mining according to the mining sequence plan. There are no differences in slope dimensions between the PT-X and the PT-Y areas to prevent higher loads on the low wall, especially the down-dip of the seam that leads to the PT-X.

Considering the boundaries of the mining concession area, such as in Figure 1B, the companies can execute the mining activity from the PT-X direction or the PT-Y direction. Then the mining results are divided proportionally based on the number of reserves of each company and the mining costs that have been incurred. This method is also more efficient because it can minimize the number of remaining reserves.

ACKNOWLEDGEMENT

The author special thanks to Ms. Fathona and Ms. Khairunisa, the internship student who assisted with the modeling and helped to test the samples.

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