

Slope Stability Analysis of the Mahakam Monthly Pit Highwall Design at PT Arta Bumi Sakti Insani BaraPerkasa Site East Kalimantan

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ABSTRACT

PT Arta Bumi Sakti operates within the mining sector, focusing on the Insani Baraperkasa. A major challenge in open-pit mining in this area is maintaining the stability of highwall slopes, particularly in the 2025 Mahakam monthly pit design. This study aims to evaluate slope stability in the highwall region using the Limit Equilibrium Method through the Bishop Simplified, Janbu Simplified, Morgenstern Price, and Spencer. Geotechnical parameters were obtained from laboratory tests and interpretations of geotechnical drilling data, including unit weight, cohesion, internal friction angle, UCS, and GSI. Software was used to analyze the slope and calculate safety factors while considering groundwater levels, earthquake loads, and ground pressure across two representative cross-sections. The results show that both cross-sections have safety factor values exceeding the minimum threshold established by the Ministry of Energy and Mineral Resources Regulation No. 1827 K/30/MEM/2018, namely, $FS > 1.1$ and $PoF < 20\%$. Thus, mining activities in this period can be conducted safely. In addition, the Spencer Method, which simultaneously satisfies stability in terms of force and momentum, provides stable results, this can be used as the basis that the Spencer can be used as the main method in the analysis of slope stability in the location.

INTRODUCTION

Slope stability is a crucial aspect in open pit mining. The stability of a slope is greatly influenced by a combination of internal and external factors. Internal factors are cohesion, deep shear angle, constituent material, density, porosity, and discontinuity (Xiong, 2022). Meanwhile, external factors include rainfall conditions, water infiltration, seismic activities, and human activities such as passing or hoarding (Wang, 2021; jia, 2024). The slope stability analysis limit equilibrium method has been used and developed since 1930, the fundamental difference in the use of this method is the application of the forces used in analyzing slope stability. In 2025, PT Arta Bumi Sakti plans to cut back or mine the highwall slope area. No geological structures have been found in this area, but it has heterogeneous constituent layers. In addition, mining activities are currently being carried out at the foot of the slope, which means that this area is an active slope (dynamic slope). In this case, periodic analysis and the use of appropriate methods are required to ensure that the results obtained are accurate, guarantee the sustainability of mining activities, and prevent mining accidents.

Previous research shows that the limit equilibrium method is widely applied in analyzing slope stability. For example, the janbu simplified method (Ma'rief, et al. 2022) to analyze the stability of coal mine slopes by considering the value of properties and the limit equilibrium

method (Edy, et al.2025) are used to design slopes in posing out pit dumps where the potential for avalanches to occur is an arc avalanche. The advantage of previous research is the application of the limit equilibrium method and the use of software to determine the value of safety factors and slope POF, but some still have limitations in the use of existing methods in the limit equilibrium method and the use of methods specific to field conditions.

Based on these factors, the highwall slope stability research was carried out using various methods in the limit equilibrium method (Janbu simplified, Bishop simplified, Spencer, and Morgenstern-Price). Existing research generally only uses one of the methods so that the potential results produced may not reflect the true value in the field.

Slope stability analysis of high cliffs was conducted using Slide 6.0 software. This analysis utilized geotechnical parameters, including specific gravity, cohesion, depth angle of repose, UCS, GSI, intact rock, soil pressure, earthquake load, and groundwater level. The use of these parameters is expected to produce accurate slope safety factor values that are consistent with field conditions. The results of this study are expected to serve as a reference for PT Arta Bumi Sakti in selecting slope stability analysis methods based on comparisons between methods, particularly in highwall areas, so that the results obtained are accurate and in accordance with actual field conditions, enabling safe and sustainable mining operations.

RESEARCH METHODS

This study took place in the highwall region of PT Arta Bumi Sakti, situated in Batuan Village, Loa Janan District, Kutai Kartanegara Regency, East Kalimantan Province. The study of highwall slope stability employs both primary and secondary data. The primary data used is the actual layer appearance in the field. This is used because there are significant discrepancies between the existing borehole log data and the actual conditions in the field. This is why the thickness of the actual constituent material is used as primary data. In addition, secondary data obtained from the company was also used, namely the mine location map, slope geometry including height, width, and single slope angle, as well as the physical and mechanical properties of the rock, including cohesion, specific gravity, internal angle of repose, UCS, GSI, μ , seismic vibration, and ground pressure. The slope geometry was obtained based on the results of studies that had been conducted. The physical and mechanical properties were obtained based on laboratory tests and mapping of the surrounding area that had been carried out. The secondary data became the basis for modeling and analyzing the stability of the highwall slope with the help of slide software. Verification and validation were carried out to ensure the suitability of the data, including that the results obtained were completely accurate. This was done by conducting repeated analysis tests and using different methods.

The research method used in this study is a quantitative – descriptive method, where the quantitative method is used on the results of statistical processing of laboratory tests on the physical and mechanical properties of rocks processed using slide 6.0 software to obtain the value of safety factors and avalanche probability values and descriptive methods are used on the results of data processing presented in the form of descriptive and narrative descriptions. The stages of processing highwall slope stability data consist of several steps, including: 1) Collect data from literature studies and literature reviews that support research; 2) Monitor highwall slope areas and assess critical areas based on monthly design; 3) Summarize laboratory test results data and sort data to be used and not used; 4) Analyze the critical highwall slope based on the monitoring results using slide 6.0 software; and 5) Drawing conclusions and suggestions from the results of the value of the safety factor and the probability of the highwall slope failure.

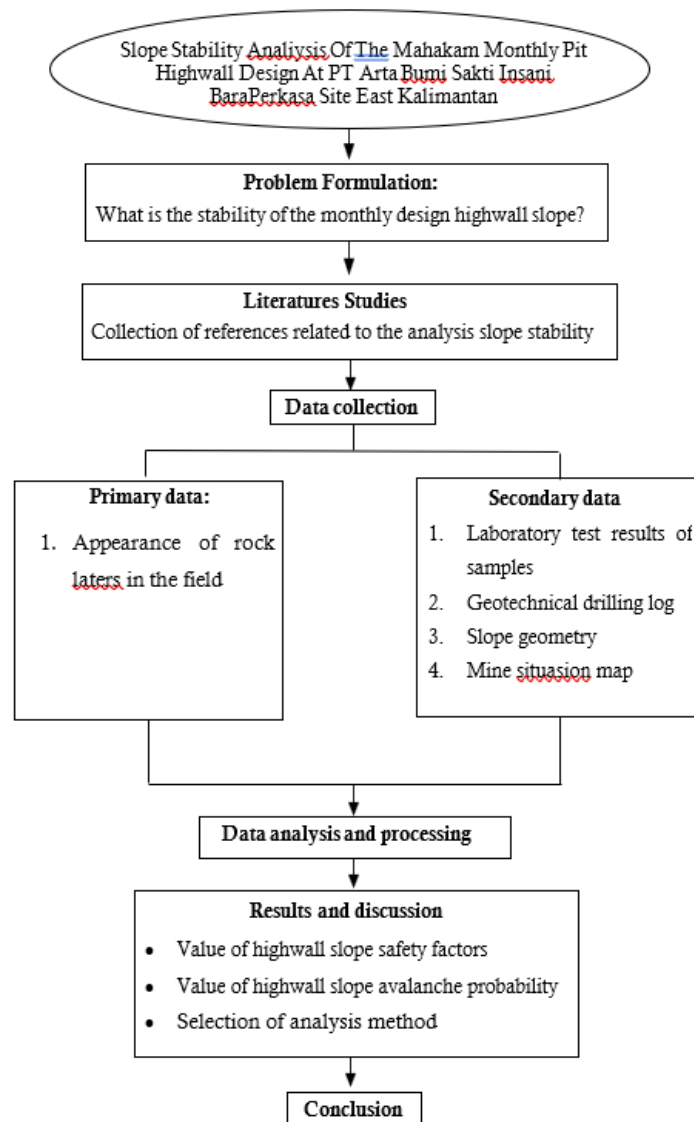


Figure 1. Research Flow Chart

RESULTS AND DISCUSSION

Highwall Slope

The research was conducted on the southeast side of the Mahakam pit which covers the highwall area. In this area, there are 3 layers of coal with each position, namely seam B N114°E/4°, seam C N118°E/6°, and seam D N117°E/4°. The focus of this research is to find the value of slope stability in the highwall area because in 2025 the company will carry out cut back or excavation on the highwall slope. In addition, the highwall area is very close to the coal front at the foot of the highwall slope. The appearance of the highwall slope can be seen in **figure 2**. Below:



Figure 2. Appearance of the highwall slope from the view point

Figure 2 shows the highwall area to be analyzed. It is clear that there is mining activity at the foot of the slope in this area. In addition, the highwall slope has heterogeneous constituent materials ranging from topsoil, siltstone, sandstone, claystone, and coal.

Geotechnical Parameters

In the calculation of slope safety factors and probability of failure, several geotechnical parameters are needed. In this study, the geotechnical parameters used are the mechanical and physical properties of the rocks, groundwater level, seismic load, heavy equipment load, and disturbance factors. The mechanical and physical properties used come from the results of laboratory tests that have been carried out by the company. The seismic load used was 0.06 based on the map of the Indonesian earthquake zone where the research location of the East Kalimantan area had small tectonic activity and the heavy equipment load used was 302.8 kPa calculated based on the largest heavy equipment (transportation) used by the company, namely Tonly Tld 90 with a full load overburden capacity of around 60 tons. The nuisance factor is 0.7 because the company uses heavy equipment to provide materials at the mining site. These parameters are entered into the slide 6.0 software as a reference for calculating the value of safety factors and probability of failure. The input parameters in the slide 6.0 software can be seen in **table 1.** below

Table 1. Geotechnical Input Parameters in Software

Material	Unit Weight (natural) (kN/m ³)	Cohesion (kN/m ²)	Friction angle (°)	UCS (Mpa)	D factor
Soil	18,1	11,34	9,1	-	-
Material	Unit Weight (natural) (kN/m ³)	GSI	Intact rock (mi)	UCS (Mpa)	D factor
Sandstone	17,315	47	14	1,152	0,7
Claystone	17,16	58	2	1,669	0,7
Siltstone	18,64	43	5	1,614	0,7
Coal	12,1	83	6	9,791	0,7

Actual Slope Geometry

The analysis of the stability of the highwall slope in the Mahakam monthly pit design was carried out with two main section scenarios, namely the A-A' and B-B' incisions. The modeling was performed utilizing Slide 6.0 software. In **figure 2**. Showing the actual condition of the highwall slope in the Mahakam pit. Generally, a single slope has a level height of 10 m, a slope angle of 40° , and a bench width of 5m. The condition of the constituent rocks looks heterogeneous with the conditions of sandstone, limestone, claystone, and coal inserts. Clearly the geometry of the highwall slope and the modeling of the highwall slope section A-A' and B-B' can be seen in **Figure 3**. and **Figure 4**.

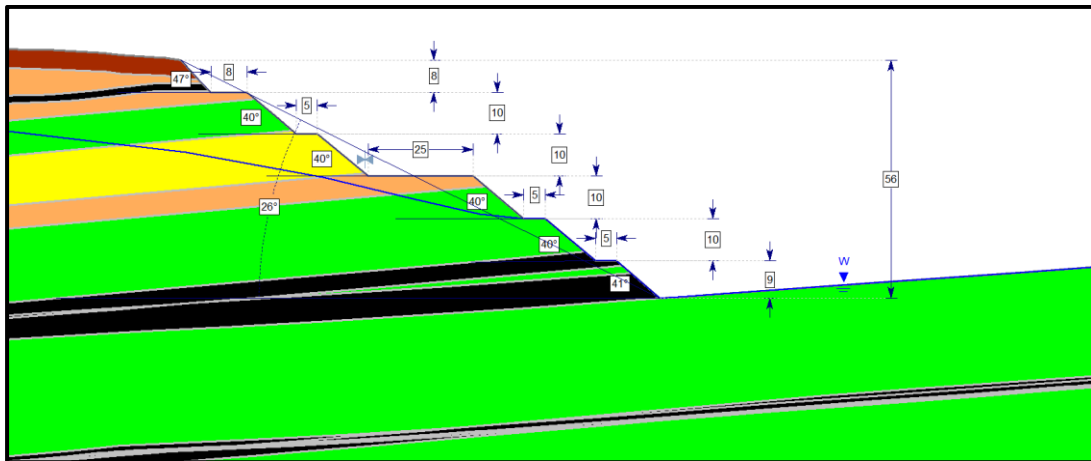


Figure 3. Geometry of the slope of the highwall section A-A'

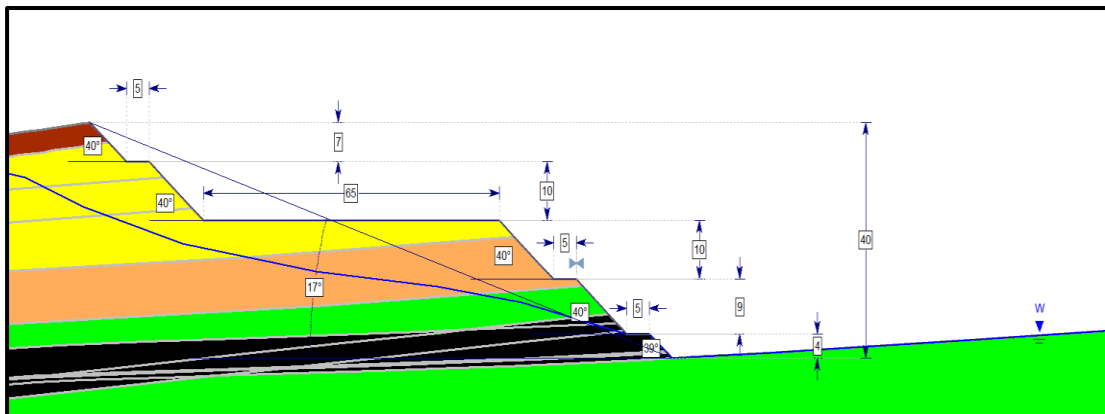


Figure 4. Geometry of the slope of highwall section B-B'

Based on **Figures 3** and **figure 4**, it can be seen that the overall slope height of section A-A' is 56 m, with an angle of 26 degrees, and there are 6 slope levels. Meanwhile, section B-B' has an overall slope height of 40 meters, an angle of 17 degrees, and there are 5 slope levels. In addition, both sections show bench widening, where section A-A' has a bench width of 25 meters, while section B-B' has a bench width of 65 meters.

Slope Stability Analysis

The stability analysis of the highwall slope was carried out using the limit equilibrium method (LIM) using 4 methods, namely janbu simplified, bishop simplified, morgenstern price, and spencer with geotechnical parameters such as cohesion and deep shear angle used for top soil while UCS, GSI, mi, and factor D were for rocks. In addition, the groundwater level of 1/3 slope, dynamic load, and ground pressure are also included. In the A-A' incision, 1 analysis was carried out, namely the overall slope, in the B-B' incision, 2 analyses were carried out, namely the upper

section and lower section, this is because the B-B' incision at elevation 50 has a wide bench. The results of the highwall slope stability analysis can be seen in **figure 5.** and **figure 6.** below:

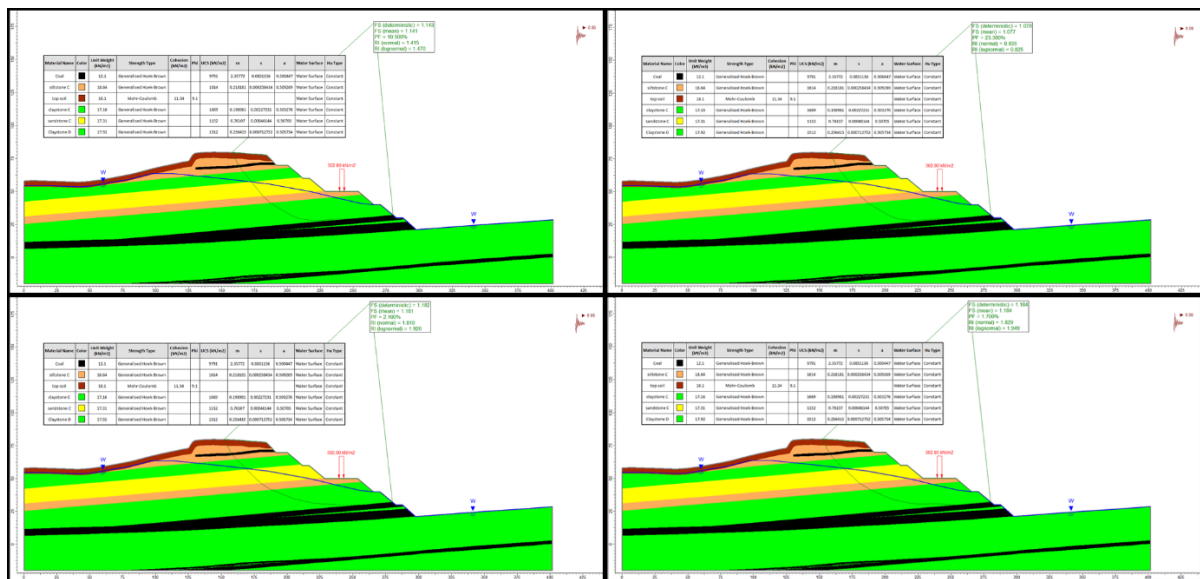


Figure 5. Analysis of the slope stability of the highwall section A-A'

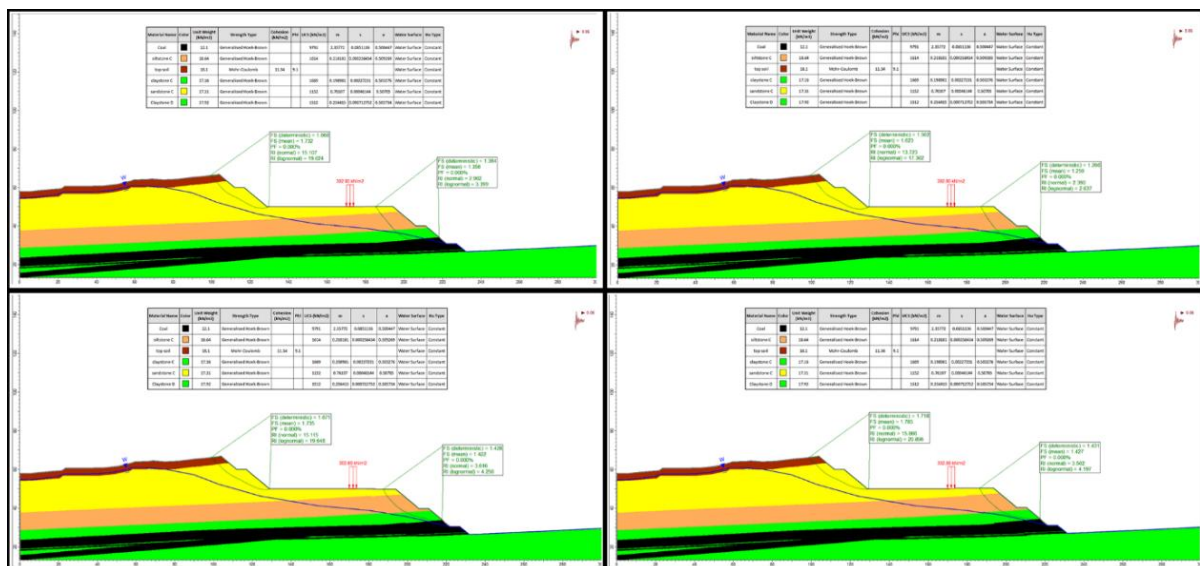


Figure 6. Analysis of the slope stability of the highwall section B-B'

Based on the image above, there are four columns. The top left column shows the analysis using the simplified Bishop method, the top right column shows the simplified Janbu method, the bottom left column shows the Morgenstern Price method, and the bottom right column shows the Spencer method. The result of the highwall slope stability analysis conducted, the safety factor of the highwall slope and the likelihood of failure are determined in the A-A' incision and B-B' incision in both the upper and lower sections. **Table 2** displays the summary of safety factor values and the likelihood of highwall slope failure.

Tabel 2. Highwall slope stability value

Section A-A'							
Method			FK		PoF (%)0		
<i>Bishop simplified</i>			1,143		10,5		
<i>Janbu simplified</i>			1,078		23,3		
<i>Morgenstern Price</i>			1,182		2,1		
<i>Spencer</i>			1,184		1,7		
Section B							
<i>Upper section</i>			<i>Lower section</i>				
Method		FK	PoF (%)	Method		FK	PoF (%)
<i>Bishop simplified</i>		1,668	0	<i>Bishop simplified</i>		1,364	0
<i>Janbu simplified</i>		1,563	0	<i>Janbu simplified</i>		1,266	0
<i>Morgenstern Price</i>		1,672	0	<i>Morgenstern Price</i>		1,428	0
<i>Spencer</i>		1,718	0	<i>Spencer</i>		1,431	0

Based on **table 2.** The value of the safety factor and probability of failure of the highwall slope tends to have entered the safety standard in accordance with the Ministry of Energy and Mineral Resources No. 1827 k/30/MEM/2018, namely the value of FK on the dynamic slope at least ≥ 1.1 . In addition, the results of the analysis showed differences in FK and PoF values between methods. The bishop simplified and janbu simplified methods tend to produce lower values compared to Morgenstern price and spencer. This is in accordance with the way Bishop and Janbu analyze by ignoring the horizontal forces between the slices, while Spencer and Morgenstern price consider forces and moments simultaneously.

The results of the analysis showed that the bishop simplified and janbu simplified methods were not suitable for use on slopes that have high complexity. This is because both methods analyze in a simple way (low complexity) and the bishop simplified method is more suitable for slipping planes that are generally circular in shape. Therefore, these two methods are suitable for the initial analysis of a slope. The use of the Morgenstern price method is based on this method is very flexible, it can be used for all types of slopes with homogeneous and heterogeneous materials as well as all types of avalanches. In addition, when compared to other boundary equilibrium principle methods, this method is one of the most thorough methods in slope stability analysis. But, this method requires users to select a force distribution that is suitable for field conditions. If the wrong distribution is chosen, the results will not be very accurate.

The spencer method was chosen because it not only considers normal forces, but considers normal forces and moments simultaneously on the entire slice. This makes the Spencer method more accurate than simple methods such as bishop simplified and janbu simplified (Abramson, et al., 2002). In addition, the spencer method assumes that the forces between sections are constant, which means that errors in the selection of methods in the distribution of section forces can be minimized. The resulting safety factor value shows stable and fairly representative results. This can strengthen that the Spencer method can be used as an alternative or validation in slope design planning, especially in complex geotechnical conditions. The differences between each method can be seen in the **table 3** below:

Tabel 3. Different between each method

Method	Type of balance	Assumptions force between slices	Sliding surface	Complexity	Additional information
<i>Bishop simplified</i>	Momen	Shear forces are ignored	Generally circular	Low	Quick analysis
<i>Janbu simplified</i>	Horizontal force	Shear forces are ignored	Circular and non circular	Low	The result tend be smaller
<i>Morgenster-Price</i>	Force + moment	Inter slice force calculated	Circular and non circular	High	Flexible and accurate
<i>Spencer</i>	Force + moment	Unifrom inter slice spacing	Circular and non circular	High	Flexible and accurate

When compared to similar studies, generally the use of one method is sufficient to analyze slope stability. However, the use of these four methods simultaneously will result in a more accurate value of the safety factor because the four methods will correct or compare the results of the analysis between one method and another in the system formed in Slide 6.0.

In addition, the results of this analysis show that the company's February monthly design is still in a stable condition. However, if there is an increase in rainfall, it is likely that FK will decrease due to the layer of material that forms the slope in the form of sandstone with low strength. Therefore, regular monitoring is required.

CONCLUSION

The analysis of the stability of the highwall slope used several parameters such as the characteristics of the physical and mechanical properties of the rock, groundwater level, seismic load, and ground pressure and used 4 methods, namely bishop simplified, janbu simplified, morgenstern price, and spencer. The analysis used two main scenarios, namely the A-A' and B-B' incisions with a single slope geometry of 10 m high, an angle of 40°, and a bench width of 5m. The results of the slope stability analysis in general produced a safety factor value in accordance with the KEPMEN ESDM standard no. 1827 K/30/MEM/2018 for dynamic slopes, which is a minimum of ≥ 1.1 . The results of the analysis show that the bishop simplified and janbu simplified methods are not suitable for use on slopes with complex geotechnics and this method can be used to initially design slopes.

The Morgenstern price method when compared to other boundary equilibrium principle methods, it is one of the most thorough methods in slope stability analysis. The spencer method has a conservative and representative FK value so that it can be used as an alternative or the main validation in slope stability, especially in complex geotechnical conditions. For further research, it can be developed by analyzing how one method affects the results of another method in the slide 6.0 software system. In addition, in the Morgenstern price method there is a method that can be chosen in the application of the force distribution of each slice, this can be further researched regarding the use of each method and the implementation with actual field conditions. Thus, the analysis of the method in this study is expected to be the basis or reference in the selection of methods for analyzing the stability of the slope of the appropriate mine design in the future.

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