Jurnal Pengabdian Nusantara

Vol. 4, No. 4, Agustus 2026, pp. 231~237
ISSN: 2987-2413
http://kampungjurnal.org/index.php/JPN/index

Slope Stability Analysis of the Southern Pit in Block F Using the Morgenstern-Price and Spencer Methods at PT. Garda Tujuh Buana TBK

Andi Afif Farhan *, Abdul Salam Munir, Muhammad Idris Juradi
Mining Engineering Study Program, Faculty of Industrial Technology, Universitas Muslim Indonesia
Jalan Urip Sumoharjo KM 5, Kecamatan Panakkukang, Kota Makassar, Indonesia

Article Info

Article history:

Received July 11, 2026
Revised July 23, 2026
Accepted August 28, 2026

Keywords:

Slope Stability, Factor of Safety, Morgenstern–Price, Spencer, Slide2, Coal Mine

ABSTRACT

This study aims to analyze the stability of an open-pit coal mine slope at the Southern Pit, Block F, PT Garda Tujuh Buana Tbk, located in Bulungan Regency, North Kalimantan Province. The multi-bench mining system forms a 95 m high slope with an overall slope angle of 35°, consisting of soil, claystone, sandstone, siltstone, and coal layers. Slope stability analysis was conducted under static conditions using the Limit Equilibrium Method (LEM) through Slide2 software, applying the Morgenstern–Price and Spencer methods. The geotechnical input parameters were obtained from laboratory testing of 51 material samples. The analysis results showed deterministic Factors of Safety (FoS) of 1.239 using the Morgenstern–Price method and 1.241 using the Spencer method, with a very small difference of 0.002. Probabilistic analysis resulted in a Probability of Failure (PF) of 0.000% and a Reliability Index (RI) greater than 4.8 for both methods, indicating that the risk of slope failure under current static conditions is very low. The identified critical slip surface extends from the crest to the toe of the slope, indicating an overall slope failure mechanism. Based on the Decree of the Minister of Energy and Mineral Resources Number 1827 K/30/MEM/2018, the minimum FoS criterion for an overall slope is 1.30. Although the slope is currently considered stable because the FoS is greater than 1.0, the FoS values below the required safety criterion place the slope in the critical or marginally stable category. Slope management strategies are therefore recommended, including periodic FoS evaluation, regular geotechnical monitoring, groundwater level monitoring, and adjustment of slope geometry according to the design to prevent potential slope failures in the future.

Corresponding Author:

Andi Afif Farhan
Universitas Muslim Indonesia
Email: andiafiffarhan@gmail.com

INTRODUCTION

PT Garda Tujuh Buana Tbk is a coal mining company in Indonesia located on Bunyu Island, Bulungan Regency, North Kalimantan Province. The company employs an open-pit mining method in its mining operations. Open-pit mining generally creates slopes within the mining area that require stability analysis to prevent geotechnical failures. In open-pit mining, slope stability analysis is necessary for slopes formed through excavation or material placement to ensure the safety of the design (Bria & Isjudarto, 2015). Slope stability analysis aims to determine the Factor of Safety (FoS), which provides information regarding whether a slope is stable or unstable. In addition to potentially causing substantial material losses to the company, slope failures can disrupt mining operations. Therefore, geotechnical investigations are essential to minimize such risks (Ma'rief et al., 2022).

In general, the geotechnical conditions at PT Garda Tujuh Buana, particularly in the Southern Pit, Block F, indicate that the slope is relatively safe but has a critical level of stability. However, the characteristics of the slope-forming materials and the existing slope geometry may still pose a potential risk of geotechnical failure, particularly slope instability. Such failures may result in landslides that could compromise occupational safety and disrupt production operations. Based on the aforementioned conditions, slope stability analysis needs to be conducted at PT Garda Tujuh Buana, specifically in the Southern Pit, Block F, to identify the slope safety conditions and prevent potential slope failures. Slope stability can be assessed by evaluating the Factor of Safety to provide appropriate recommendations for improving slope stability in Block F, Southern Pit. This study employs the Morgenstern–Price and Spencer methods to analyze slope stability. The results obtained from both methods are used to determine the Factor of Safety (FoS) and evaluate potential slope failure mechanisms at the Southern Pit, Block F, PT Garda Tujuh Buana Tbk.

METHOD

This study was conducted through three main stages: the preliminary stage, data collection, and data processing. The preliminary stage involved administrative preparation and a literature review to establish a theoretical framework relevant to slope stability analysis. The data collection stage integrated both primary and secondary data. Primary data were obtained directly from the field, including slope geometry measurements using a total station at the crest, mid-slope, and toe points, as well as direct lithological observations of rock outcrops, which were verified against the company's borehole log data. In addition, groundwater levels were monitored through the installation of piezometers to obtain accurate hydrogeological parameters. Secondary data consisted of company technical documents and laboratory test results from 51 samples, including unit weight, cohesion, and internal friction angle from five rock units: soil, claystone, sandstone, coal, and siltstone. These data were used as supporting parameters in the analysis.

During the data processing stage, field measurements of slope geometry were converted into two-dimensional cross-sections to represent the actual conditions of the Southern Pit, Block F. The geotechnical parameters obtained from laboratory testing were then statistically analyzed using Microsoft Excel to determine the mean, minimum, maximum, and standard deviation values as representations of the material characteristics. All data were subsequently integrated into Slide2 software for slope stability modeling. Slope stability analysis was performed using the Spencer and Morgenstern–Price methods to calculate the Factor of Safety (FoS) and identify the critical slip surface as an indicator of slope stability in the study area.

ISSN: 2654-8127

RESULTS AND DISCUSSION

Slope Stability Analysis of the Southern Pit, Block F

Slope stability analysis was conducted to evaluate the ability of the Southern Pit, Block F, slope to maintain equilibrium against the forces acting under static conditions. The slope model was developed based on the actual cross-sectional geometry and the geotechnical parameters of each rock layer obtained from laboratory testing, assuming static conditions without considering dynamic loads or other external loads. All parameters were processed using Slide2 software based on the Limit Equilibrium Method (LEM), employing the Morgenstern–Price and Spencer methods. These methods were selected because both satisfy force and moment equilibrium simultaneously, making them suitable for analyzing complex and layered slope geometries such as those encountered in the study area.

The results of the analysis using the Morgenstern–Price method are presented in Figure 1. The deterministic Factor of Safety (FoS) obtained was 1.239, with a Probability of Failure (PF) of 0.000%. The Reliability Index (RI) was 4.902 for the normal distribution and 5.552 for the lognormal distribution.

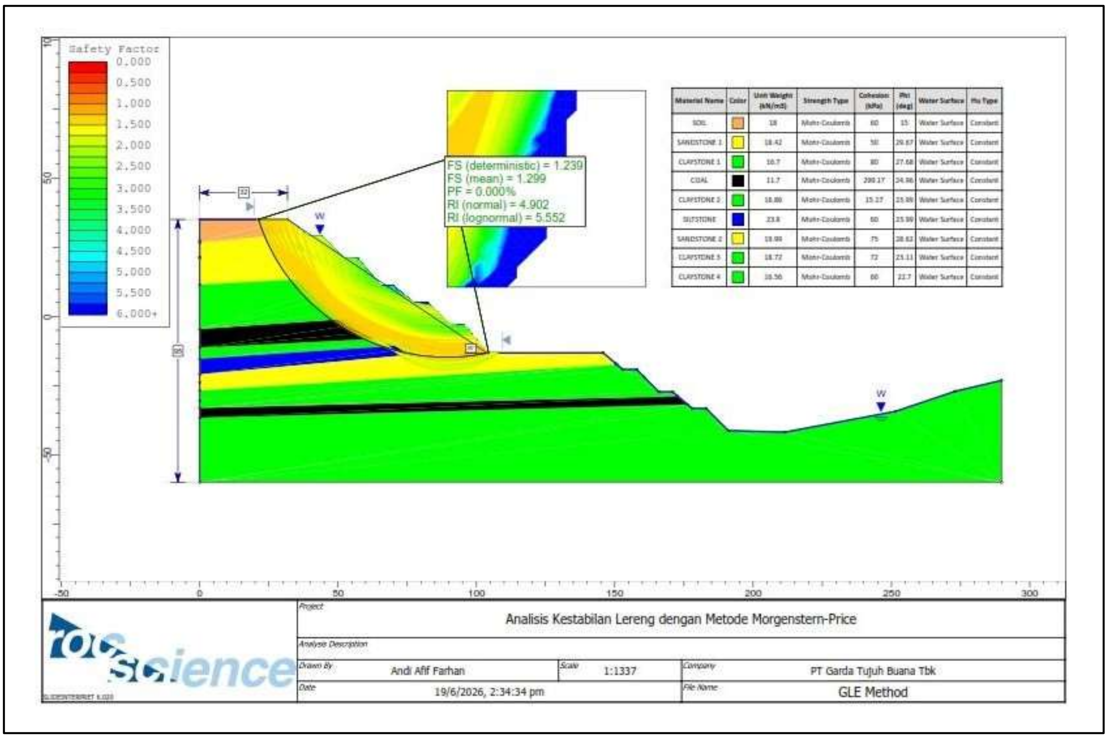

Figure 1. Slope stability analysis results using the Morgenstern–Price method

The results of the analysis using the Spencer method are presented in Figure 2. The deterministic Factor of Safety (FoS) obtained was 1.241, with a Probability of Failure (PF) of 0.000%. The Reliability Index (RI) was 4.802 for the normal distribution and 5.431 for the lognormal distribution.

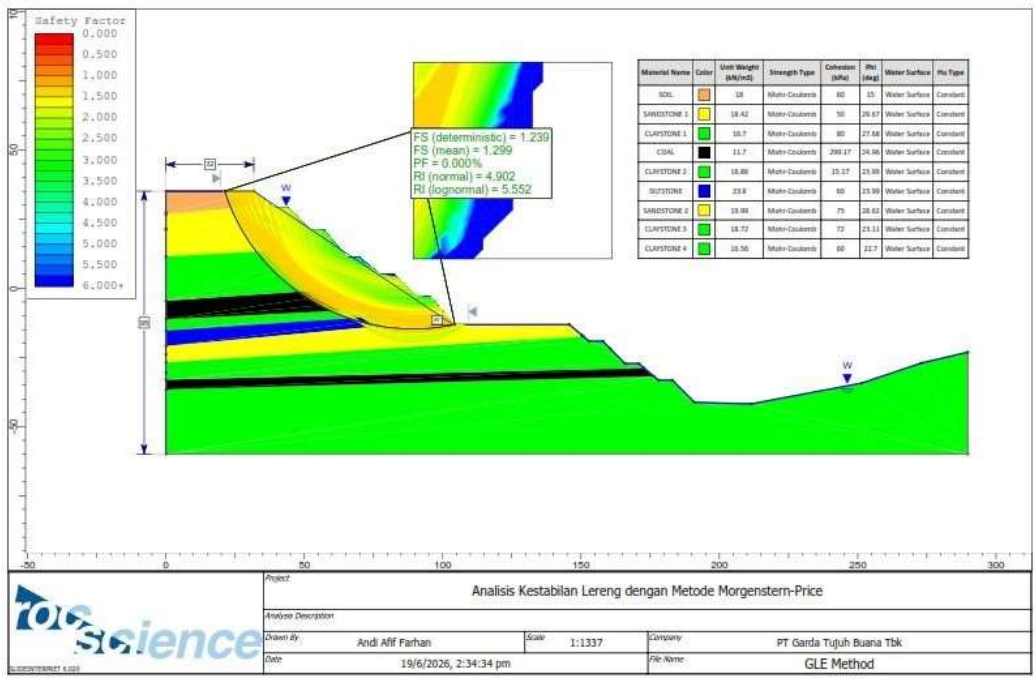

Figure 2. Slope stability analysis results using the Spencer method

The difference in the FoS values between the two methods was only 0.002 (approximately 0.16%), while the Probability of Failure (PF) for both methods was 0.000%. Both methods also produced critical slip surfaces at relatively similar locations, originating from the slope crest and intersecting the soil, sandstone, claystone, siltstone, and coal layers before emerging at the slope toe, with a rotational failure mechanism. This agreement indicates that the differences in assumptions regarding the distribution of interslice forces—parallel interslice forces in the Spencer method and a more flexible force distribution function in the Morgenstern–Price method—did not significantly affect the final results of this model. Slope geometry and the shear strength parameters of the materials were more influential in determining the location of the slip surface and the magnitude of the FoS than the choice of calculation method.

The consistency of the model with field conditions is supported by several observations obtained during the study. The overall slope geometry used in the model, consisting of a 95 m slope height, 35 m upper bench width, and 35° overall slope angle, was consistent with direct field measurements. The lithological sequence interpreted from the borehole log also corresponded to the material layering represented in the model cross-section, namely soil, sandstone, claystone, coal, and siltstone. In addition, visual observations conducted in the field during the study did not indicate the presence of tension cracks or excessive stress manifestations on the slope surface, which qualitatively corresponds with the FoS values obtained from the analysis, which remained above one. However, this validation is qualitative and does not yet include slope movement monitoring using geotechnical instrumentation or back-analysis based on historical slope failures. Therefore, the analysis results should be considered a representation of the slope conditions at the time of data collection and should be supported by continued monitoring.

Based on Decree of the Minister of Energy and Mineral Resources Number 1827 K/30/MEM/2018, the recommended minimum FoS for an overall open-pit mining slope under static conditions is 1.30. The FoS values obtained in this study, 1.239 and 1.241, remain below this threshold, indicating that the Southern Pit, Block F slope falls into the critical (marginally stable) category. Although slope failure has not occurred because the FoS values remain above one, the safety margin is relatively small, making the slope vulnerable to changes in field conditions, such as mining progression, increased pore-water pressure during the rainy season, or weathering of materials around the crest. This condition requires control of the slope geometry according to the design, effective drainage management, and regular geotechnical monitoring to ensure that the FoS does not decrease below the acceptable safety limit during mining operations.

ISSN: 2654-8127

Strategy for Analyzing Potential Slope Failures

The identification of potential slope failures in this study was based on the Factor of Safety (FoS) obtained from the Slide2 analysis, with reference to the threshold specified in Decree of the Minister of Energy and Mineral Resources Number 1827 K/30/MEM/2018 as the primary criterion for determining slope stability status. To strengthen the interpretation of the FoS values, probabilistic analysis results, including the Probability of Failure (PF) and Reliability Index (RI), as well as the location and mechanism of the critical slip surface and the field validation results presented in Subsection 4.2, were also considered as supporting evidence. These parameters were used to explain how the critical condition indicated by the FoS values may manifest in the actual slope conditions of the Southern Pit, Block F.

The deterministic FoS values obtained from the analysis, namely 1.239 using the Morgenstern–Price method and 1.241 using the Spencer method, were below the recommended minimum value of 1.30 for an overall slope under static conditions. Therefore, the slope was classified as critical (marginally stable). The PF value of 0.000% obtained from both methods indicates that none of the parameter combinations generated during the probabilistic simulations resulted in an FoS below one. Meanwhile, RI values greater than 4 for the normal distribution and 5 for the lognormal distribution indicate a relatively large distance between the mean model condition and the failure condition. These results indicate that the risk of slope failure under the current static conditions is relatively low, despite the relatively narrow safety margin indicated by the FoS values.

The critical slip surfaces identified by both methods developed from the crest toward the toe of the slope and intersected nearly all of the constituent layers, namely soil, sandstone, claystone, siltstone, and coal. This indicates an overall slope failure mechanism rather than a failure confined to a single bench. Consequently, if slope conditions deteriorate, the potentially affected area would not be limited to one bench but could involve the entire slope body, with potential impacts extending to mine access roads and working areas around the slope toe. This condition is further supported by the field validation results presented in Subsection 4.2, in which the modeled geometry was consistent with actual field measurements, the lithological sequence in the model corresponded to the borehole log data, and visual field observations did not indicate tension cracks or excessive stress manifestations on the slope surface.

Based on the evaluation results, an analysis strategy for identifying potential slope failures in slopes with similar characteristics can be developed by using the FoS as the primary reference and strengthening the assessment through two complementary approaches. First, the FoS obtained from deterministic analysis should be directly compared with the threshold specified in Decree of the Minister of Energy and Mineral Resources Number 1827 K/30/MEM/2018 to rapidly determine the slope stability status. When the evaluation indicates a critical category, as observed in this study, probabilistic analysis involving PF and RI should be conducted as a subsequent step to assess the likelihood of the FoS decreasing below one. This is important because a marginal FoS alone may not adequately describe the actual level of slope failure risk. Second, the mapped location and mechanism of the critical slip surface should be used to determine priority monitoring areas. In the case of the Southern Pit, Block F, the identified overall slope failure pattern indicates that monitoring should cover the entire slope body rather than being limited to a particular bench. This strategy allows slope stability evaluation to be conducted progressively, beginning with the FoS as an initial indicator, followed by probabilistic analysis and critical slip-surface mapping when the FoS falls within the critical category. Thus, potential slope failures can be identified more systematically before appropriate slope management measures are established.

Based on the FoS values classified as critical and supported by PF and RI values indicating a low failure risk under current static conditions, the Southern Pit, Block F slope can be considered stable in the short term but with a narrow safety margin. This condition may change if any of the controlling factors deteriorate, such as mining progression that alters the slope geometry, increased pore-water pressure during the rainy season, or reduced material shear strength due to weathering, particularly within the claystone layer that dominates the cross-section. Therefore, the current slope condition requires continuous monitoring, particularly of changes in slope geometry and hydrogeological conditions, so that any reduction in the FoS can be detected before developing into a potential slope failure.

CONCLUSION

Based on the results of the analysis and discussion of slope stability at the Southern Pit, Block F, PT Garda Tujuh Buana Tbk, using the Morgenstern–Price and Spencer methods, several conclusions can be drawn. The geotechnical conditions and slope geometry of the Southern Pit, Block F indicate that the slope consists of several material units, namely soil, claystone, sandstone, siltstone, and coal, each exhibiting different geotechnical characteristics based on the unit weight, cohesion, and internal friction angle obtained from laboratory testing. The slope geometry forms a multi-bench slope, with relatively continuous rock layers following the slope inclination. The combination of slope geometry and geotechnical characteristics results in an overall slope failure mechanism, indicating that slope stability is governed by the behavior of the entire rock mass rather than by a single bench.

The Factor of Safety (FoS) analysis using Slide2 software showed that the Morgenstern–Price method produced an FoS of 1.239, while the Spencer method produced an FoS of 1.241 under static conditions without considering dynamic loads or other external loads. The difference between the two values was only 0.002, indicating a high degree of consistency between the two methods in evaluating slope stability. Based on these results, the slope remains in an equilibrium condition because the FoS values are greater than one. However, when compared with the criteria recommended in Decree of the Minister of Energy and Mineral Resources Number 1827 K/30/MEM/2018, the FoS values indicate that the slope is in a critical (marginally stable) condition and therefore has a relatively limited safety margin.

Potential slope failure was identified by using the FoS as the primary reference, supported by a Probability of Failure (PF) of 0.000% and a Reliability Index (RI) greater than 4 for both methods. These results indicate that the risk of slope failure under the current static conditions is relatively low, despite the narrow FoS safety margin. The identified critical slip surface extends from the crest to the toe of the slope and intersects nearly all constituent layers, indicating an overall slope failure mechanism that could affect the entire slope body if stability deteriorates. This identification is further supported by field validation, including the consistency between the modeled geometry and actual field measurements, the consistency between the modeled lithology and borehole log data, and the absence of tension cracks or indications of excessive stress on the slope during the study. Based on these findings, a tiered analysis strategy is proposed for identifying potential slope failures in slopes with similar characteristics, beginning with an evaluation of the FoS against the threshold specified in Decree of the Minister of Energy and Mineral Resources Number 1827 K/30/MEM/2018 as the initial indicator, followed by probabilistic analysis when the FoS falls within the critical category, and mapping of the location and mechanism of the critical slip surface to determine priority monitoring areas.

REFERENCES

[1] Abdillah, R. A., Purwanto, M. S., & Warnana, D. D. 2017. Analisa Stabilitas Pada Lereng Tambang Terbuka Lapangan “TG”. Disertasi. Institut Teknologi Sepuluh November.
[2] Abramson, L. W., Lee, T. S., Sharma, S., & Boyce, G. M. 2002. Slope Stability and Stabilization Methods. John Wiley & Sons.
[3] Arief, S. 2008. Analisis Kestabilan Lereng dengan Metode Irisan-Irisan, 1–66.
[4] Arif, I. I. 2016. Geoteknik Tambang. Gramedia Pustaka Utama.
[5] Bowles, J. E. 1991. Sifat-Sifat Fisis dan Geoteknis Tanah Edisi. Jakarta: Erlangga.
[6] Bria, K., & Isjudarto, A. 2015. Analisis Kestabilan Lereng Pada Tambang Batubara Terbuka Pit D Selatan PT. Artha Niaga Cakrabuana Job Site CV. Prima Mandiri Desa Dondang Kabupaten Kutai Kartanegara Provinsi Kalimantan Timur. ReTII.
[7] Fadhlurohman, A. F., & Radityo, D. 2025. Analisis Kestabilan Lereng Highwall Tambang Batubara Pit X Pada Kabupaten Balangan, Kalimantan Selatan. Jurnal Ilmiah Geologi PANGEA, 12(2).
[8] Gouw, T. L., & Herman, D. J. 2012. Analisa Kestabilan Lereng Limit Equilibrium vs Finite Element Method. Proceedings HATTI PIT XVI, Indonesia, 16, 1–7.
[9] Hardiyatmo, H. C. 2003. Mekanika Tanah II. Yogyakarta: Gadjah Mada University Press.
[10] Khajehzadeh, M., Taha, M. R., El-Shafie, A., & Eslami, M. 2014. Stability Assessment of Earth Slope Using Modified Particle Swarm Optimization. Journal of the Chinese Institute of Engineers, 37(1), 79–87.
[11] Kusumaningsih, D. A., Saepudin, A., Razak, S., & Haryono, A. F. 2025. Analisis Kestabilan Lereng Tambang Terbuka Batubara untuk Perencanaan Tambang PT BCD Kalimantan Timur. Jurnal Geomine, 13(02), 186–199.
[12] Ma’rief, A. A., Hedianto, N. O., Mahyuni, E. T., & Affan, A. 2022. Analisis Stabilitas Lereng Tambang Batubara dengan Menggunakan Metode Limit Equilibrium pada PT. Kalimantan Prima Nusantara. Jurnal Geocelebes, 6(2), 117–125.
[13] Nugroho, C. P. 2019. Analisis Stabilitas Lereng Gunung Banyak di Kota Batu Dengan Bantuan Perangkat Lunak. Tesis. Universitas Brawijaya.
[14] Parissing, V., Hariyadi, S., Saptono, S., Dwinagara, B., & Koesnaryo, S. 2024. Evaluasi Analisis Kestabilan Lereng Pada Tambang Terbuka Batubara Pit North West PT Anak Tambang Indonesia Job Site PT Adimitra Baratama Nusantara, Kalimantan Timur.
[15] Rocscience. 2022. Slide 2-2D Limit Equilibrium Analysis for Slopes.
[16] Salsabil, K. R., Rachman, A., & Yuliani, T. 2019. Analisis Kestabilan Lereng Tambang Terbuka Menggunakan Metode

ISSN: 2654-8127

Morgenstern-Price dan Spencer untuk Menentukan Faktor Keamanan dan Probabilitas Longsor. Jurnal Geoteknik dan Pertambangan, 8(2), 101–110.

[17] Sukandi, S. 2021. Analisis Stabilitas dan Deformasi Lereng Villa Sekeq Grupuk Dengan Simulasi Numeris. Jurnal Konstruksika, 12(1).

[18] Terzaghi, K. 1950. Mechanics of Landslides in Application of Geology to Engineering Practice (Berkey Volume). New York: Geological Society of America.

[19] Zheng, Y., Tang, X., Zhao, S., Deng, C., & Lei, W. 2009. Strength Reduction and Step-Loading Finite Element Approaches in Geotechnical Engineering. Journal of Rock Mechanics and Geotechnical Engineering, 1(1), 21–30.

[20] Zhu, H., Wu, H., Shu, J., Zhang, Z., Yang, Q., Chen, X., & Zhu, P. 2025. Improved Green–Ampt Model for Evaluating Rainfall Infiltration and Slope Stability. Geotechnical and Geological Engineering, 44(1).