DESIGNING A GEOMETRY OF LOWWALL SLOPE IN COAL MINING USING THE LIMIT-EQUILIBRIUM METHOD AT THE WORKING AREA OF PT. PETROSEA TBK, TARAKAN BASIN, NORTH KALIMANTAN, INDONESIA

Aldo Fauzan[1], Dicky Muslim[1], Cipta Endyana[1], Diki Wandani[2], David Feby Fiverno[2] and Rieza Rachmat Putra[2]
[1]Faculty of Geological Engineering Universitas Padjadjaran 45363, Indonesia
[2] PT. Petrosea TBK
Corresponding author: aldo20001@mail.unpad.ac.id

ABSTRACT

Mining, which involves extracting minerals and utilizing natural resources, requires careful planning to ensure feasibility and safety. A critical aspect of open pit mine design is slope stability, influenced by geological characteristics, slope topography, and groundwater conditions. Slope stability analysis, using methods such as the Limit Equilibrium Method (LEM), which has been popular for decades for its convenience, evaluates the potential for slope failure and provides geometric slope design recommendations to reduce risk, improve operational efficiency, and ensure environmental sustainability. The research was conducted at PT Petrosea Tbk, with the mine site in Sebakis Village, Sebuku Subdistrict, Nunukan Regency, North Kalimantan, PT X region. The research object is a lowwall slope that requires stability analysis to prevent landslides. The slope safety criteria are based on the Minister of Energy and Mineral Resources Decree No. 1827 K/30/MEM/2018 guidelines, specifically 1.1. To perform the analysis, laboratory test data is required, including rock physical property tests and rock shear strength tests to obtain material property values. This data was then analysed using Rocscience Slide2 software by comparing three methods: Bishop, Janbu, and Morgenstern-Price. The analysis was conducted based on the actual conditions of each slope cut geometry. If the obtained safety factor does not meet the criteria of the Minister of Energy and Mineral Resources Decree No. 1827 K/30/MEM/2018, then designing a geometry of lowwall slope is required. The geometric slope design used on the lowwall slope includes creating benches to flatten the slope level, and installing drain holes to decrease the ground water level.

Keywords: Slope Stability, Mining, Coal, Limit-Equilibrium Method, Tarakan Basin

INTRODUCTION

Mining involves the extraction of mining materials and the utilization of natural resources for processing according to market demand, increasing economic value. Careful mine design planning is required to maintain compliance with the feasibility evaluation, especially in open-pit mines affected by slope stability. Slope stability, which is important for safety and production efficiency, is affected by geology, topography, groundwater conditions, weather and human activities. Factors such as earthquakes, rainfall, vegetation and soil conditions can make slopes prone to landslides (Abramson, Lee, Sharma, & Boyce, 2002).

Slope stability analysis requires data on the physical and mechanical properties of the soil and slope geometry, considering earthquake conditions, climate, and rock type. The Boundary Equilibrium Method is often used in geotechnics to evaluate potential slope failures and design mitigation measures.

Slope stability analysis research in coal mining is important to understand geological properties, perform geometry engineering, minimize the risk of failure, improve operational efficiency, and maintain environmental sustainability. The research entitled "Slope Geometry Engineering in Coal Mining Using the Limit-Equilibrium Method in the Tarakan Basin, work area of PT Petrosea Tbk, North Kalimantan" aims to support the sustainability of activities in the mining area.

E-ISSN : 2579 – 3136

RESEARCH METHOD

The analytical method used in the research involves analysing the characteristics of the lithology in the study area, specifically on the coal mining slope. The numerical method calculates the slope stability factor using the Limit Equilibrium Method (LEM) based on the Morgenstern-Price, Janbu, and Bishop methods with the Mohr-Coulomb approach using Rocscience Slide2 software. Comparison of safety factor values from different slope stability analysis methods is an important step to obtain more accurate and reliable results, and ensure safety in design and construction (Oktori, 2019). This method simulates the slope by dividing it into driving forces and resisting forces, with a slip surface acting on the slope. The Safety Factor (Fs) is then determined from the ratio of the driving forces to the resisting forces. Subsequently, the determination of slope design recommendations is carried out by inputting the parameter property values obtained from the back analysis. In this case, the calculation of the Safety Factor (Fs) uses the Mohr-Coulomb failure criterion and the General Limit Equilibrium Method.

Subsequently, slope design recommendations are determined by inputting the parameter property values obtained from the back analysis. In this case, the Safety Factor (Fs) calculation uses the Mohr-Coulomb failure criterion and the General Limit Equilibrium Method by Bishop, Janbu, and Morgenstern-Price.

Two slope design recommendations were simulated: modifying the slope geometry and simulating the lowering of the groundwater table. Modifying the slope geometry can be done by adding benches to the slope. The groundwater table simulation involves the installation of drain holes on the slope (Arief, 2016).

Approach Method

Bishop Method

The simplified bishop method is one of the methods in arc avalanches that uses the wedge principle in determining the safety factor of a mass of material that has the potential to landslide. this method satisfies force equilibrium in the vertical direction and moment equilibrium at the center point of the collapse circle. shear forces between wedges are ignored. to calculate the value of the safety factor can use this equation (Metriani, Anaperta, & Saldy, 2019) :

$$FK = \frac{\left(\Sigma X/\left(1+\frac{Y}{F}\right)\right)}{(\Sigma Z+Q)}$$

Janbu Method

The Janbu Method is one of the methods used in slope stability analysis. This method depicts the slope as a series of vertical segments estimated to slide separately or interact with neighbouring segments. This approach allows for modelling slope deformations in greater detail than other methods. The Janbu method also considers the uniform distribution of shear forces along the potential slip surface, aiding in understanding the overall behaviour of the analysed slope (E & Alva N., 2014).

The basic formula for calculating the factor of safety (FS) in this method is:

$$FS = \frac{\sum\left(c'\Delta l + (W\cos\alpha - u\Delta l)\tan\phi'\right) + T}{\sum W\sin\alpha + V}$$

Morgenstern-Price Method

The Morgenstern-Price method incorporates resisting forces (moment equilibrium) and driving forces (force equilibrium). It considers normal and shear interslice forces for interslice forces. The Morgenstern-Price method is the most meticulous and accurate in slope stability analysis as it accounts for all equilibrium aspects and interslice forces (Malkawi et al., 2000). This method simplifies assumptions to illustrate the relationship between shear forces around the slice and normal forces.

The morgenstern-price method uses the same assumptions as the generalized limit equilibrium method, namely that there is a relationship between the shear force between slices and the normal force between slices which can be expressed by the following equation :

$$X = \lambda\, f(x)\, E$$

In the Morgenstern & Price method, the calculation of the factor of safety is performed using the equilibrium conditions of the forces and moments of each slice (Kadang, Trides, & Devy, 2019).

Criteria Used for Safe Slope

E-ISSN : 2579 – 3136

The criteria for slope design to achieve a safe safety factor in the upcoming slope design will used the limit-equilibrium method by Bishop, Janbu, and Morgenstern, and will be based on the guidelines outlined in Ministerial Regulation ESDM Number 1827 K/30/MEM/2018. The construction of mine slopes entails specific criteria that must be adhered to and met by various mining companies, as follows:

Table 1. The Safety Factor Value and Landslide Probability of The Mining Slope (KEPMEN ESDM No. 1827 K/30/MEM/2018)

Slope Type	***Consequences of Failure/CoF***	**Acceptance Criteria**		
		Safety Factor (Fs) Statis (Min)	Safety Factor (Fs) Dinamis (Min)	Probability of Failure *(max) PoF (Fs≤1)*
Single Slope	Low to High	1,1	None	25-50%
Inter-ramp	Low	1,15-1,2	1	25%
	Middle	1,2-1,3	1	20%
	High	1,2-1,3	1,1	10%
Overall Slope	Low	1,2-1,3	1	15-20%
	Middle	1,3	1,05	10%
	High	1,3-1,5	1,1	5%

RESULT AND DISCUSSION

Condition of The Research Area

The study area is located in the pit of PT.X, a coal mine operated with open pit mining technology using excavator trucks. Mining at the study site is self-managed. The study focused on the lowwall section of the coal mine project, where cross-sections were drawn as Section B. A lowwall is a slope that slopes in the same direction as the seam, while a highwall is a slope that slopes opposite to the seam, and both are present in all three cross-sections.

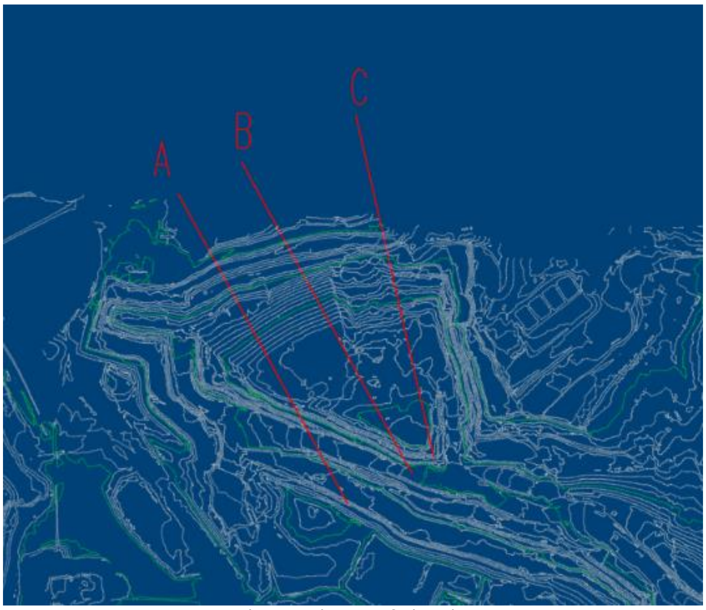


Figure 2. The Aerial View of The Slope Section

Slope Geometry of The Research Area

For slope stability analysis, it is necessary to measure the geometry of the waste dump slope, which is then used as a geometry cross-section profile in the analysis using software. The material in the coal mining area consists of.

Of soil, clay, siltstone, sandstone, and seam or coal. Slope geometry measurements were made by making incisions against the topography, which resulted in three incisions as follows (Figure 3)

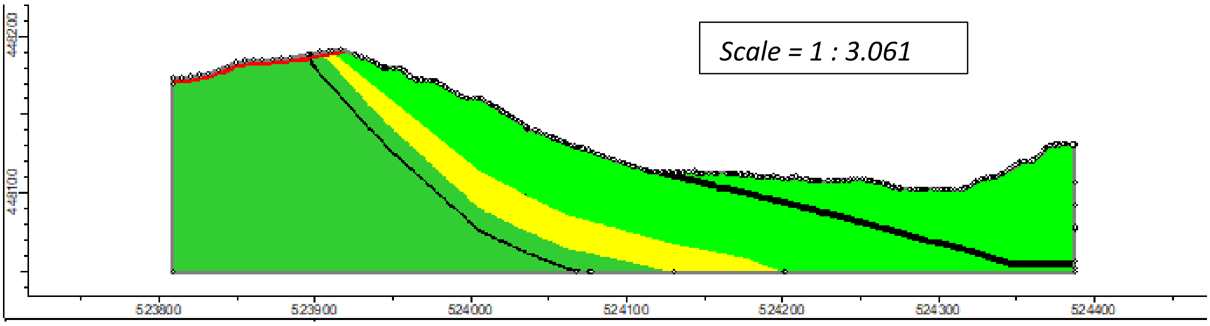


Figure 3. Profile of Slope Geometry of Section B

Material Properties Laboratory Test Results

In section ga, the slope comprises bedrock layers with a specific stratigraphic pattern. The uppermost layer is clay, as a result of the direct shear strength test, with a saturated unit weight of 16.5 kN/m³, cohesion of 39.72 kPa, and an internal friction angle of 28.44°. Beneath this is a 5-7 meters thick coal seam layer, with a saturated unit weight of 9.26 kN/m³, cohesion of 95 kPa, and an internal friction angle of 34.52°. Below the coal seam is another clay layer with the same properties as the one above. Next is a sandstone layer with a saturated unit weight of 24 kN/m³, cohesion of 36.78 kPa, and an internal friction angle of 28.83°. Beneath this is a siltstone layer interbedded with coal; the siltstone has a saturated unit weight of 18.15 kN/m³, cohesion of 38 kPa, and an internal friction angle of 28.6°, while the coal shares the same characteristics as the previous coal seam. This is followed by another sandstone layer, also 5-7 meters thick, with the same properties as the previous sandstone, and another siltstone layer with the same characteristics as the previous one.

Table 2. Slope Material Properties in Lowwall Slope Geometry Simulation

Material	Unit Weight (kN/m³)	Sat. Unit Weight (kN/m³)	Cohesion (kPa)	Phi (deg)
Coal	9.26	12.77	95	34.52
Clay	16.5	24.4	39.72	28.44
Siltstone	15.3	18.15	38	28.6
Soil	10.4	15.4	28.34	24.42
Sandstone	22.2	24	36.78	28.83

Ground Water Condition

The first parameter affecting slope stability is the groundwater level at the research site. This is due to the role of groundwater in adding moisture, which increases the weight and load on the slope. When material is saturated with groundwater, its shear strength decreases because of the pore water pressure within the material (Rai, 1995). In this study, the groundwater level (GWL) is

E-ISSN : 2579 – 3136

assumed to be fully saturated. This approach is used because actual GWL data at the research site is unavailable, so the worst-case scenario is applied to optimize the analysis results (Braja, 2021).

Seismic Vibration Coefficient

In this simulation, the slope design considerations include factors that can render the slope's safety factor unsafe, such as the earthquake vibration coefficient. PT. Petrosea has set the earthquake vibration coefficient at 0.05 as a standard to adhere to. The coefficient pertains to horizontal vibrations, as this type of vibration significantly impacts the potential for landslides on the mining slope.

Slope Stability Analysis of The Research Area

This study analyzed slope stability by calculating the Safety Factor (Fs) for a cross-sections, considering the impact of potential seismic vibrations during mining operations. The analysis also considered the properties of the materials used in the mining area and the groundwater level conditions, which can stress the materials and affect slope safety. The position of the mining openings was determined based on the Minister of Energy and Mineral Resources Decree No. 1827 K/30/MEM/2018, representing all overburden layers in pit X.

The slope geometry design simulation was conducted on section A with the initial approach of constructing benches. This slope design aimed to enhance the Fs value since the current condition indicates unsafety. The benching is illustrated in light green with clay material (Figure 7.)

Per KEPMEN ESDM No. 1827 K/30/MEM/2018, the safety factor value is a benchmark for slope geometry design simulations. A slope is considered safe if the SF value is 1.1 or higher. The slope is deemed unsafe if the Fs value is 1.1 or lower.

The stability simulation of the lowwall slope was carried out using Rocscience Slide2 software to determine the SF value, taking into account the actual slope conditions. If the simulation indicated the slope was unsafe, further slope design simulations were performed under two scenarios: adding benches to the slope and lowering the groundwater level.

These slope design simulations took into account factors that could affect the slope's safety factor, as previously discussed. The analysis utilized three limit equilibrium methods: Bishop, Janbu, and Morgenstern-Price. These methods were selected due to the high likelihood of circular slip failures in the lowwall slope, making them the recommended approaches.

Limit-Equilibrium Method (LEM)

The stability analysis of the lowwall slope under actual conditions was conducted using the limit-equilibrium method (LEM) with a Mohr-Coulomb approach. This method involves analyzing the slope with Rocscience Slide2 software, employing the Bishop, Janbu, and Morgenstern-Price methods. In this slope design simulation, the overall slope angles for each section are as follows: Section A has an overall slope angle of 20°, while Sections B and C each have an overall slope angle of 21°.

A. Bishop Method

The actual condition of the slope at section A shows a slip surface with a safety factor (Fs) value of 0.922 (Figure 4), indicating that the slope is unsafe as the Fs value is ≤ 1.1. This is due to insufficient resisting forces, necessitating slope geometry slope design to achieve an Fs value ≥ 1.1.

E-ISSN : 2579 – 3136

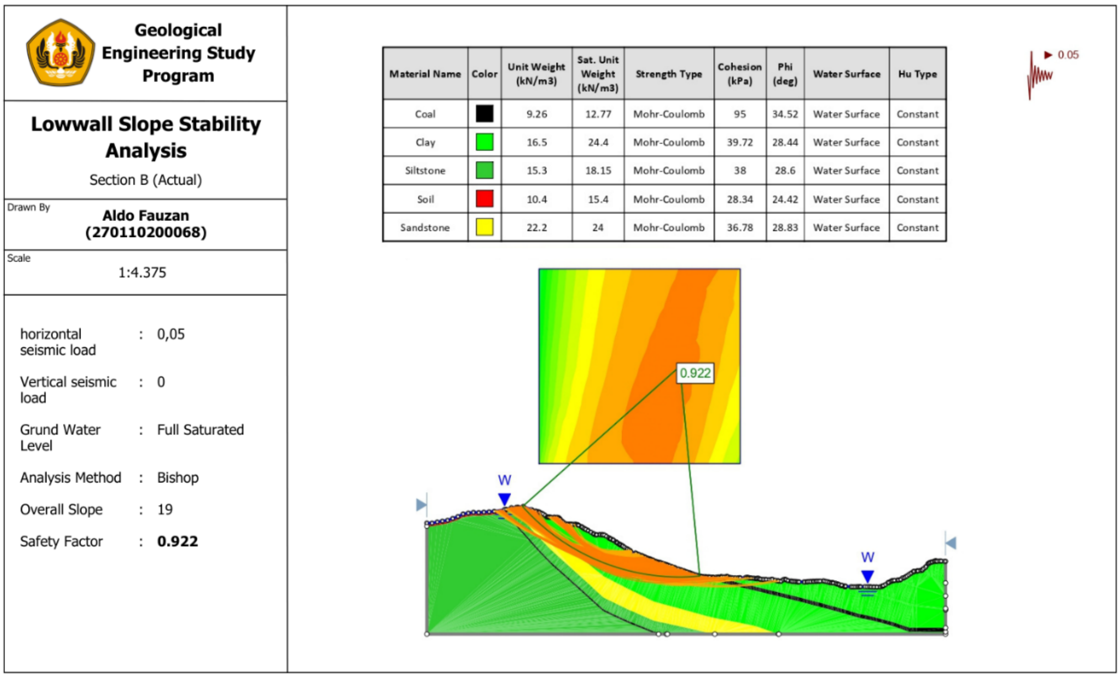


Figure 4. The Actual Condition of Lowwall Slope at Section B Using Bishop Method

B. Janbu Method

The current state of the slope at section A demonstrates a slip surface with a safety factor (Fs) value of 0.863 (Figure 4.7), indicating that the slope is in an unsafe condition as the obtained Fs value is ≤ 1.1. This is due to insufficient restraining forces, necessitating slope geometry slope design to achieve an Fs value of ≥ 1.1.

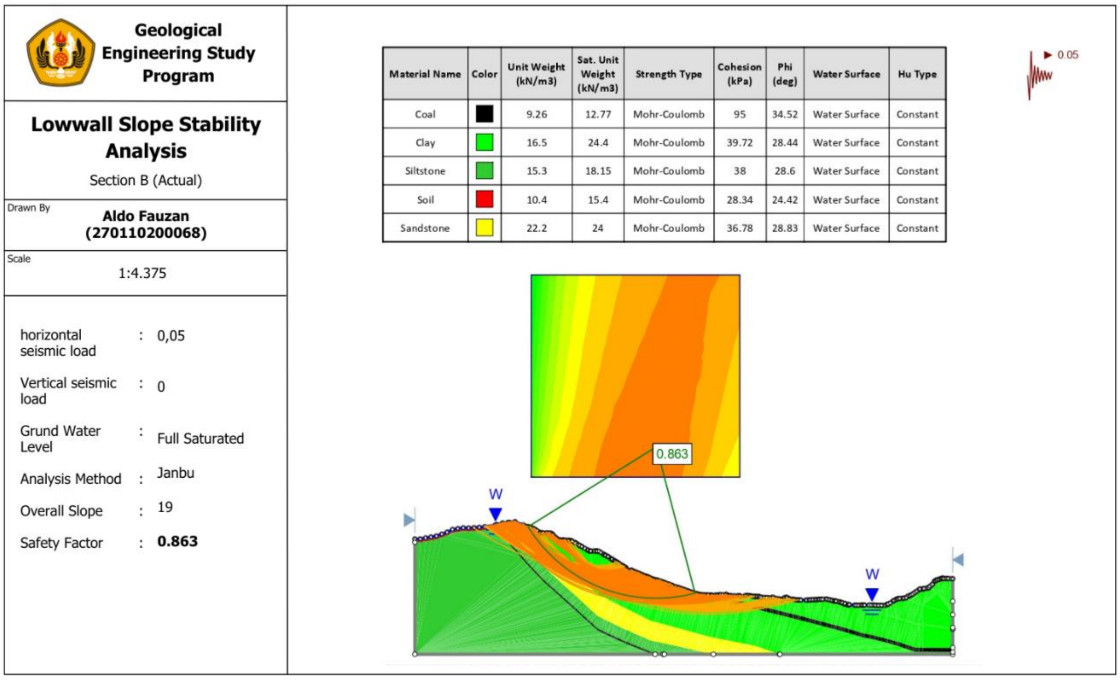


Figure 5. The Actual Condition of Lowwall Slope at Section B Using Janbu Method

C. Morgenstern-Price Method

The current state of the slope at section A displays a slip surface with a safety factor (Fs) value of 0.924 (Figure 6.), indicating that the slope is in an unsafe condition as the obtained Fs value is ≤ 1.1. This is attributed to insufficient restraining forces, necessitating slope geometry slope design to achieve an Fs value of ≥ 1.1.

E-ISSN : 2579 – 3136

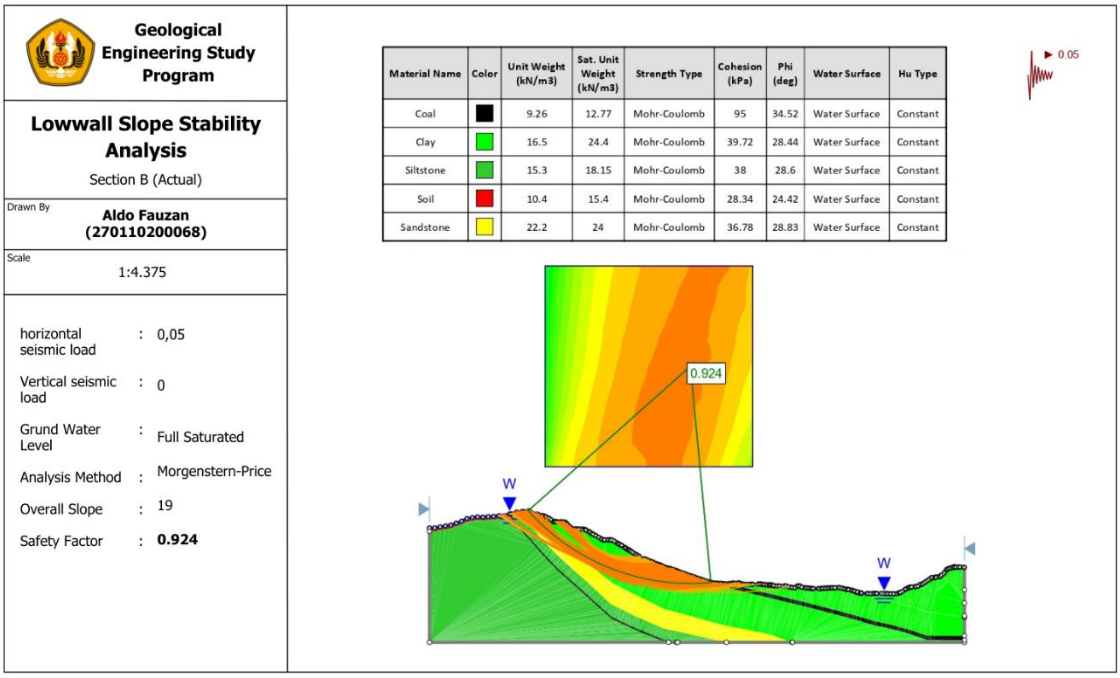
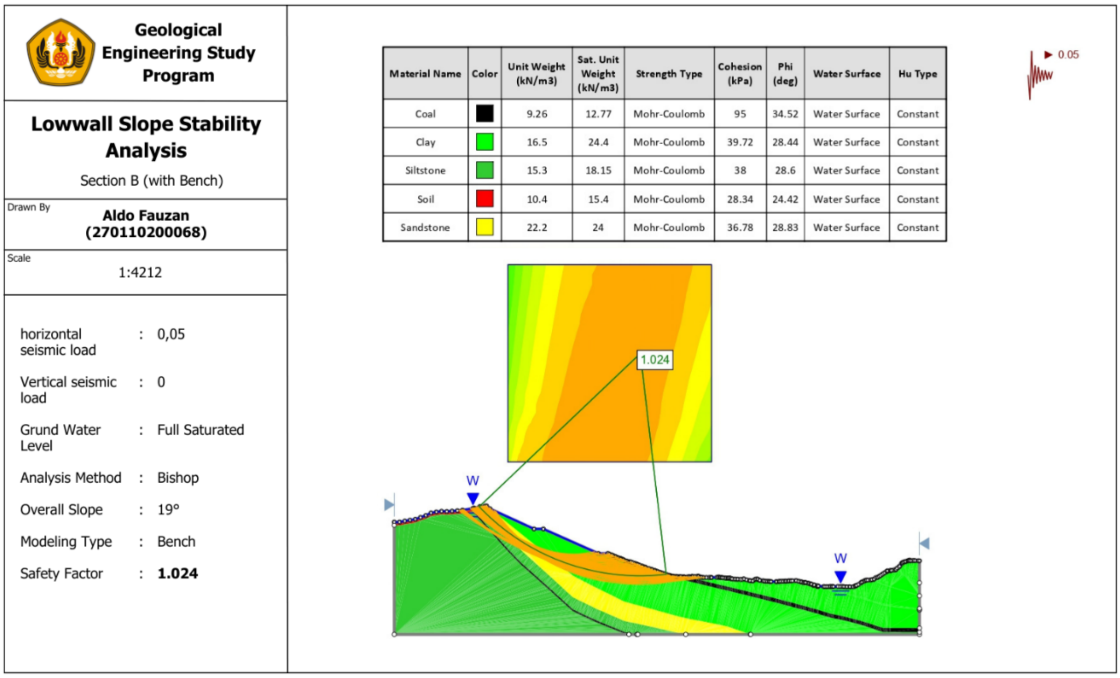


Figure 6. The Actual Condition of Lowwall Slope at Section B Using Morgenstern-Price Method

Geometry Design Recommendation

A. Geometry Recommendation with Bench

The slope geometry engineering simulation was carried out on incision B with the first approach, which is to create steps. The purpose of this engineering is to increase the Fs value because the Fs value in the current condition shows insecurity. The engineering with steps is shown in light green color with clay material in (Figure 7.).



E-ISSN : 2579 – 3136

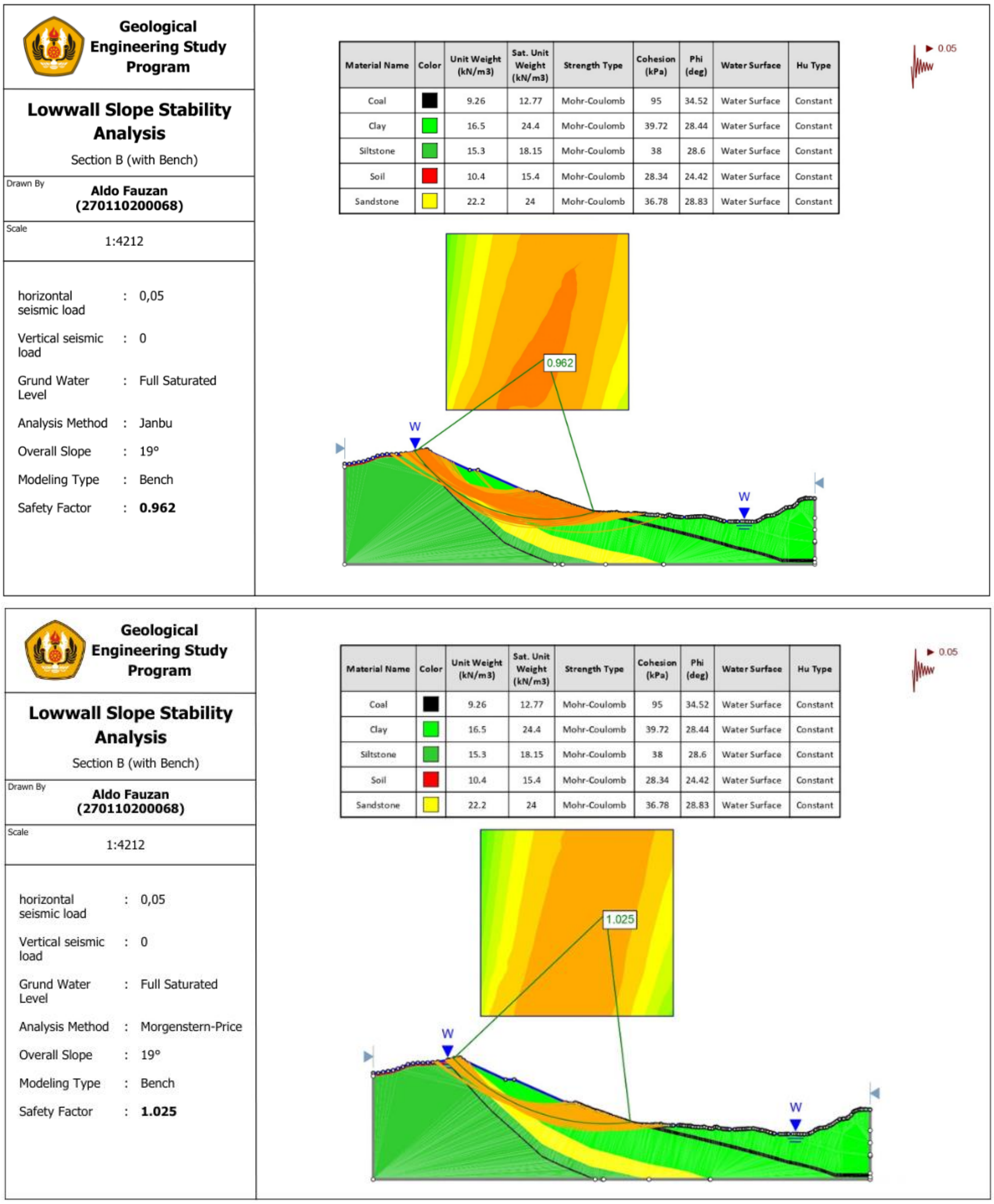
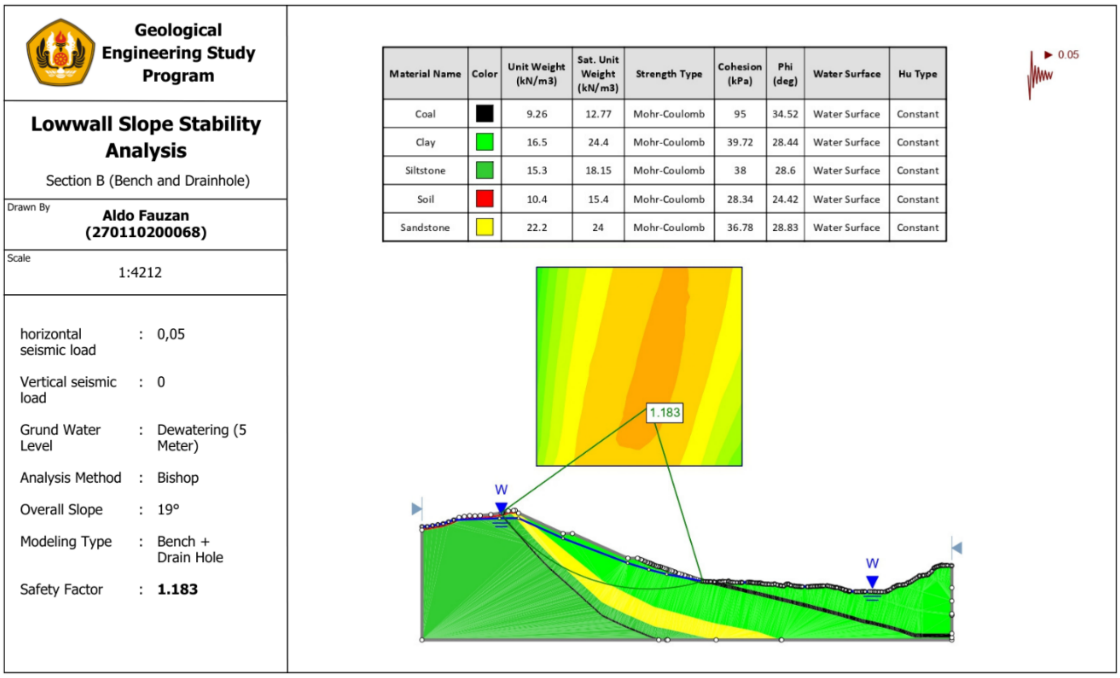


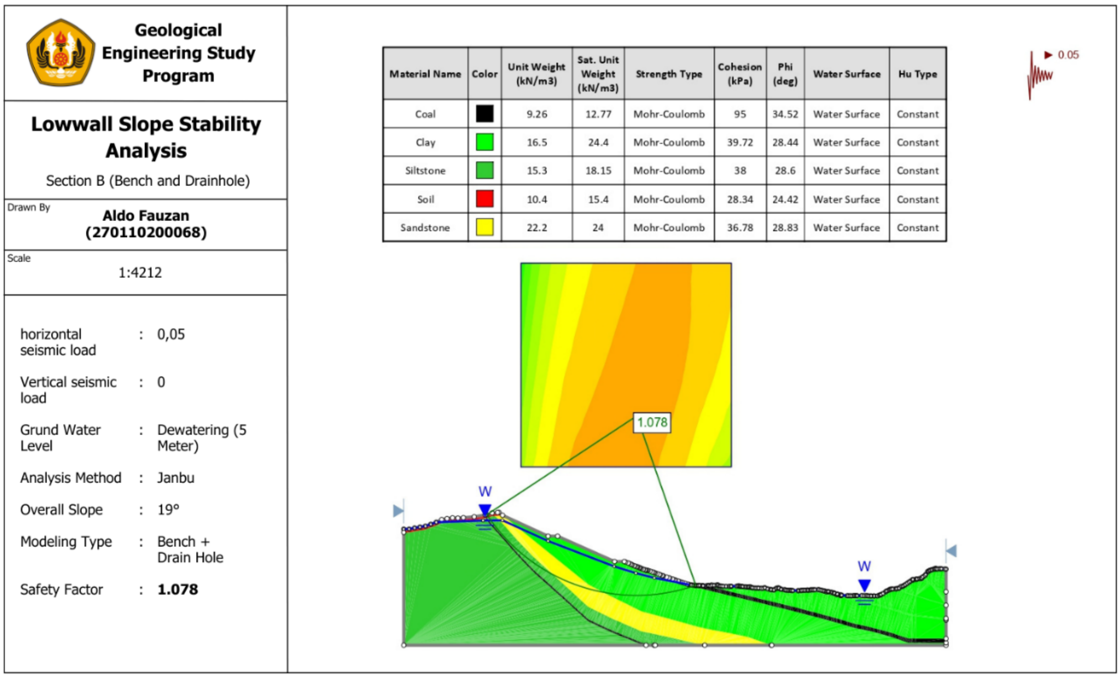
Figure 7. The Analysis Results of Fs for The Geometry Design of Lowwall Slope in Section B Using Bishop Method (Top), Janbu Method (Middle), and Morgenstern-Price (Bottom)

However, after engineering in this condition, the Fs values obtained are 1.024 (Bishop), 0.962 (Janbu), 1.025 (Morgenstern-Price), which still do not meet the safety standards in accordance with the criteria of KEPMEN ESDM Number 1827 K/30/MEM/2018. Therefore, this incision requires additional engineering to increase the Fs value. This condition has not resulted in a safe Fs value because the driving force on the sliding plane is still greater than the restraining force. Thus, other engineering needs to be applied to this incision to achieve a safe Fs value based on KEPMEN ESDM Number 1827 K/30/MEM/2018.

B. Geometry Recommendation with Bench and Drain Hole

This condition greatly affects the Fs value so that it increases, namely 1.183 (Bishop), 1.078 (Janbu), and 1.189 (Morgenstern-Price). Because in the first 5 meters there is one Fs that does not meet the criteria for safe slopes based on KEPMEN ESDM Number 1827 K/30/MEM/2018, the slope stability engineering analysis is continued at the lowering of the groundwater level in the next 5 meters





E-ISSN : 2579 – 3136

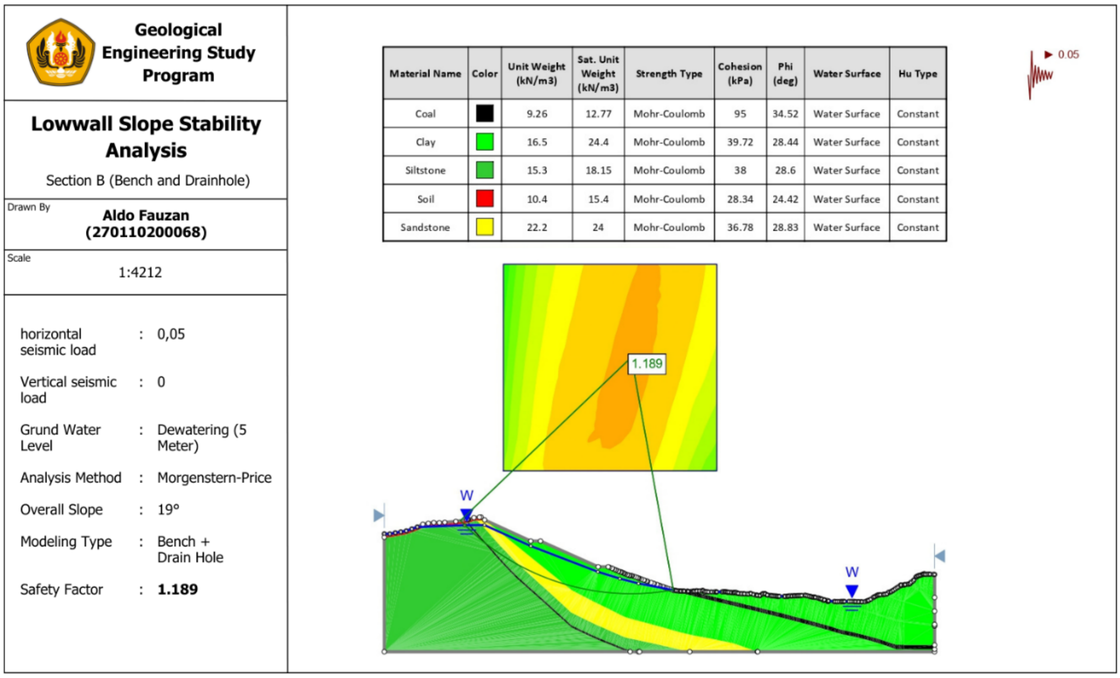
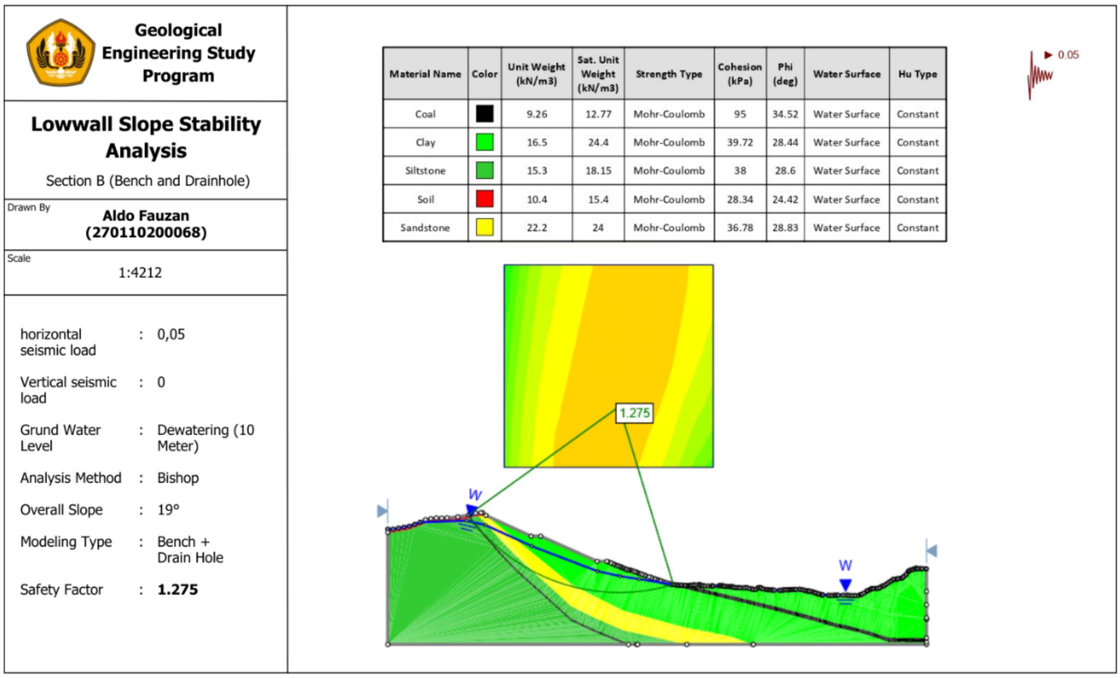


Figure 8. The Analysis Results of Fs for The Geometry Design of Lowwall Slope at Section B with Bench and Drain Hole Installation Using Bishop Method (Top), Janbu Method (Middle), and Morgenstern-Price (Bottom)

After lowering the groundwater level in the second scenario, which is as high as 10 meters, this condition greatly affects the Fs value because it has increased, namely 1.275 (Bishop), 1.166 (Janbu), and 1.286 (Morgenstern-Price), this is a safe value based on the criteria of KEPMEN ESDM Number 1827 K/30/MEM/2018. Therefore, this slope engineering requires a drain hole as shown in (Figure 4.16). Drain holes are used so that the slope is not in a fully saturated state which makes the soil weight increase. This condition has an overall slope value of 19°.



E-ISSN : 2579 – 3136

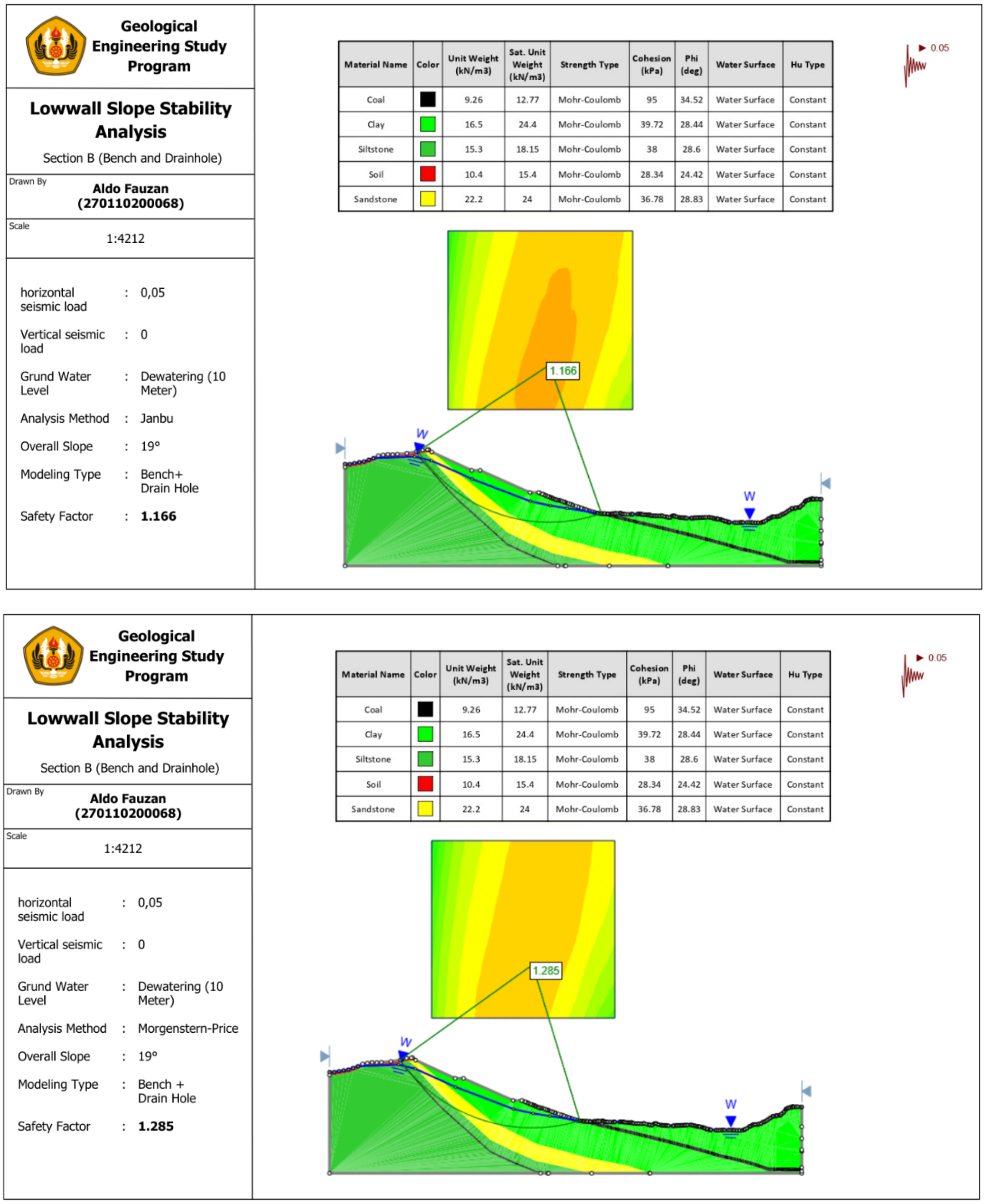


Figure 8. The Analysis Results of Fs for The Geometry Design of Lowwall Slope at Section B with Bench and Drain Hole Installation Using Bishop Method (Top), Janbu Method (Middle), and Morgenstern-Price (Bottom)

CONCLUSION

Based on the research findings and data analysis, several conclusions can be drawn as follows:

1. Core data obtained from the mining slopes at the research site indicates the lithological composition. Materials in the lowwall area consist of clay, siltstone, sandstone, and coal.
2. The physical and mechanical properties of the research area materials were tested by PT.X company, following ASTM standards. Laboratory testing yielded material property values such as bulk density, cohesion, and internal friction angle. These properties consist of both overburden and commodity materials. The commodity material includes coal, while the overburden material

E-ISSN : 2579 – 3136

comprises clay, siltstone, and sandstone lithologies.

3. Based on the analysis results of the actual conditions of each slope geometry cut, the obtained safety factor values do not meet the criteria for safe slopes according to Ministerial Decree No. 1827 K/30/MEM/2018, as the safety factor values obtained are ≤ 1.1 on Bishop, Janbu, which is the most pessimistic, and Morgenstern-Price method. Therefore, geometric slope design is required at each cut to achieve safe slope safety factor values.
4. The geometric slope design used on the lowwall slope includes creating benches and installing drain holes. Based on the analysis results of the geometric slope design simulation, benching at each cut increases Fs, but it is still unsafe. This is because the outermost lithology (clay layer) on the actual slope is not thick enough, limiting the slope's stabilization. Therefore, the required design involves installing drain holes to achieve a safe Fs value.

ACKNOWLEDGEMENT

Upon finalizing this scholarly publication, the writer wishes to extend appreciation to Mr. Nur Khoirullah, S.T., M.T. for helping me to publish this paper, alongside Mr. Diki Wandani, Mr. David Feby Fiverno Sitepu, and Mr. Rieza Rachmat Putra who acted as the technical supervisor at PT. Petrosea TBK.

REFERENCES

Abramson, Lee, Sharma & Boyce (2001): Slope Stability and Stabilization Methods. 2nd Edition. New York: A Wiley-Interscience Publication. Jhon Wiley & Sons, Inc.

Andriyan, Febri, dan Yuliadi (2018): Stabilisasi Optimal Lereng Timbunan Overburden pada Area Disposal PT Insani Baraperkasa tambang Loa Janan, Provinsi Kalimantan Timur dengan Rekayasa Geoteknik. Prosiding Teknik Pertambangan. Vol 4. No2.

Bishop, M. G. (2001): South Sumatra Basin Province, Indonesia: the Lahat/Talang Akar-Cenozoic Total Petroleum System. U.S. Geological Survey, Colorado.

Bowles, J.E. (1989): Sifat-sifat Fisik & Geoteknis Tanah, Erlangga, Jakarta, 562.

De Coster, G. (1974). The Geology of Central and South Sumatra Basin. Proceeding Indonesia Petroleum Association Vol.143, 77-110.

E, T. A., & Alva N., S. (2014, January 1). *Analisis Kestabilan Lereng dengan Metode Janbu*. Retrieved from Jurnal Sipil Statik: file:///C:/Users/ALDO/Downloads/jm_jss,+JSS020103+Thyac+Korah+090211012.pdf

Gafoer, S., Cobrie, T., and Purnomo, J. (1986): Geological map of the Lahat Quadrangle, South Sumatra, scale 1:250.000. Geological Research and Development Centre, Bandung.

Hardiyatmo.H.C. (2007): Mekanika Tanah 2,UGMPress, Yogyakarta

Kadang, E. S., Trides, T., & Devy, S. D. (2019, June 1). *ANALISIS KESTABILAN LERENG LOW WALL PIT 7 SELATAN BLOK AM YANG DIPENGARUHI AIRTANAH DI PT. ALAM JAYA BARA PRATAMA, KECAMATAN LOAKULU, KABUPATEN KUTAI KARTANEGARA, KALIMANTAN TIMUR*. Retrieved from JURNAL TEKNOLOGI MINERAL FT UNMUL: https://e-journals.unmul.ac.id/index.php/TM/article/view/2429/pdf

Kajian Geometri Jalan Tambang Berdasarkan Teori AASHTO dan Kepmen ESDM No 1827 K/30/MEM/2018 Pada Area Pertambangan Menggunakan Data Foto Udara (Studi Kasus : Sanga – Sanga, Kutai Kartanegara, Kalimantan Timur) - ITS Repository. https://repository.its.ac.id/101403/

Metriani, R., Anaperta, M. Y., & Saldy, T. G. (2019, June 1). *Analisis Balik Kestabilan Lereng Dengan Menggunakan Metode Bishop yang disederhanakan Pada Front II Existing Tambang Quarry PT. Semen Padang, Sumatera Barat*. Retrieved from Jurnal Bina Tambang: https://ejournal.unp.ac.id/index.php/mining/article/view/106741/102527

Oktori, A. Y. (2019, January 21). *Analisis Stabilitas Lereng Menggunakan Program Slope/W berdasarkan Metode Morgenstern-Price, Metode Bishop, dan Metode Janbu.* Retrieved from FTSP Usakti: http://repository.trisakti.ac.id/usaktiana/index.php/home/detail/detail_koleksi/4/SKR/penerbit/00000000000000096830/4

E-ISSN : 2579 – 3136