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ANALYSIS OF THE EFFECT GROUNDWATER LEVEL FLUCTUATION ON SLOPE STABILITY IN THE COAL MINING PLAN

ANALISIS PENGARUH FLUKTUASI MUKA AIR TANAH TERHADAP STABILITAS LERENG RENCANA PENAMBANGAN BATUBARA

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ABSTRACT

Based on geotechnical drilling activities carried out in the PT Battoman Coal mining plan area, it is known that the slope material is dominated by claystone. According to Chen (1975), claystone can be expansive when exposed to water, disrupting slope stability. The presence of the Sungai Putih tributary in the mining plan area can also affect slope stability. This research aims to analyze the influence of groundwater level fluctuations on slope stability in the PT Battoman Coal mining plan area based on actual conditions as a result of the research. Ground water level observations and measurements were conducted using the Casagrande piezometer method and observation wells in the high wall area. Slope stability analysis was carried out using the software Rocscience Slide V.6 using the Morgenstern Price method and the Mohr-Coulomb failure type by simulating slopes in actual conditions, the results of the highest and lowest groundwater measurements in the period September to October 2023, namely 4,26 meters and 28,45 meters from the ground surface. The analysis was carried out in pseudo-static conditions using mining area seismicity factors based on the Indonesian Seismic Zone Map according to the Ministry of PUPR in 2017. Overall slope area high walls in cross sections A-A' and B-B' are included in the critical to stable category with FK values between 0,901 to 1,782. Recommendation of overall slope designed by Kepmen ESDM 1827K/MEM/2018 so that it is obtained overall slope which is stable in saturated conditions with FK values between 1,176 to 1,245.

Keywords: slope stability, ground water level, observation well, morgenstern price, casagrande piezometer

ABSTRAK

Berdasarkan kegiatan pengeboran geoteknik yang dilakukan pada area rencana penambangan PT Battoman Coal diketahui bahwa material penyusun lereng didominasi oleh batulempung. Dimana menurut Chen (1975) batulempung dapat bersifat ekspansif apabila terkena air yang akan menyebabkan terganggunya stabilitas lereng. Keberadaan aliran anak Sungai Putih pada area rencana penambangan juga dapat mempengaruhi stabilitas lereng. Tujuan dilakukannya penelitian ini adalah untuk menganalisis pengaruh fluktuasi muka air tanah terhadap stabilitas lereng pada area rencana penambangan PT Battoman Coal berdasarkan kondisi aktual hasil penelitian. Pengamatan dan pengukuran air tanah dilakukan dengan metode *piezometer casagrande* dan *observation well* pada area *highwall*. Analisis stabilitas lereng dilakukan menggunakan software Rocscience Slide V.6 dengan metode Morgenstern Price dan tipe keruntuhan Mohr-Coulomb dengan mensimulasikan lereng pada kondisi aktual hasil pengukuran air tanah tertinggi dan terendah pada periode bulan September hingga Oktober 2023 yakni 4,26 meter dan 28,45 meter dari permukaan tanah. Analisis dilakukan pada kondisi pseudostatik dengan menggunakan faktor kegempaan area penambangan berdasarkan Peta Zona Kegempaan Indonesia menurut Kementerian PUPR tahun 2017. Stabilitas *overall slope area high wall* pada penampang A-A’ dan B-B’ termasuk dalam kategori kritis hingga stabil dengan nilai FK antara 0,901 sampai 1,782. Rekomendasi *overall slope* dirancang sesuai dengan Kepmen ESDM 1827K tahun 2018 sehingga didapatkan *overall slope* yang stabil pada kondisi jenuh dengan nilai FK antara 1,176 sampai 1,245.

Kata kunci: stabilitas lereng, kondisi muka air tanah, *observation well, morgenstern price, piezometer casagrande*

INTRODUCTION

PT Battoman Coal is located in Bandar Jaya Village, Sekayu District, Musi Banyuasin Regency, South Sumatra with an IUP area of 12,670 Ha. PT Battoman Coal is in the exploration stage of geotechnical drilling. The purpose of geotechnical drilling is to obtain drill-log data [1]. Rock samples from geotechnical drilling are subjected to physical properties tests, compressive strength tests, and shear strength tests to obtain geotechnical parameters for slope stability analysis.

Slope stability analysis aims to analyze the stability conditions of artificial slopes (excavated slopes and embankment slopes) during mining activities, as well as on natural slopes. Slope stability will change over time due to the influence of the rainy season and dry season which change the groundwater level [2]. One of the important factors that influences slope stability is the presence of groundwater.

One of the factors that influence groundwater conditions on slopes is the type of material that makes up the slope. Based on the results of geotechnical drilling, it is known that the slope material is dominated by mudstone. Mudstone is generally dominated by the mineral montmorillonite which causes expansive properties in the rock because it has a larger surface area and easily absorbs large amounts of water [3]. So based on this, it is necessary to carry out activities to determine the condition and existence of groundwater at the research location.

The presence of groundwater will cause lifting forces (uplit force) and reduce the rock mass that makes up the slope [4]. The higher the groundwater level, the load on the slope will increase and at the same time, the strength of the rock will decrease which results in decreased slope stability and allows landslides to occur on the slope. Groundwater level (MAT) is influenced by rainfall. Changes in groundwater level when rainfall is high and rainfall is low are called groundwater level fluctuations [5]. To determine changes in groundwater levels, MAT monitoring is carried out using the piezometer method and observation well at the research location.

A piezometer is a tool used to measure groundwater level and pore water pressure. The most commonly used type of piezometer is the Casagrande piezometer [6]. Whereas observation well is the term given to a drill hole that has been constructed in such a way that groundwater at certain or overall levels can enter it and its fluctuations can be observed. The results of groundwater monitoring are then used as a reference in calculating slope stability at an observation location.

Before this research was carried out, there were several studies regarding the influence of groundwater levels on slope stability has been carried out. Research by Meliza (2021) regarding the influence of groundwater levels on slope stability carried out in high wall and low wall areas shows that the more saturated the groundwater conditions are, the lower the slope stability conditions. In this research, an effort was made to redesign the geometry of the slope by sloping the angle of the slope so that a safe safety factor value was obtained according to the safety factor value standard by Minister of Energy and Mineral Resources Decree 1827K of 2018. Meanwhile, research by Vickyla (2019) regarding the influence of groundwater on slope stability shows that the addition of Groundwater in the pores of soil and/or rock will increase the unit weight of the material and increase the load on the slope. Based on the analysis and simulations carried out, show that the value of the safety factor will be higher as groundwater conditions decrease.

Slope stability analysis at PT Battoman Coal was carried out on the design overall slope area high wall on cross-sections A-A' and cross-sections B-B' which were carried out under pseudo-static conditions and considering the actual groundwater level conditions based on measurements in the field. This analysis was carried out to determine the effect of groundwater level fluctuations on the stability of the mine slope so that slope stability and geometry can be determined overall slope which is safe for PT Battoman Coal. Slope stability conditions are said to be safe if they have the minimum FK value, namely FK ≥ 1.1 in pseudo-static conditions by KEPMEN ESDM 1827K/MEM/2018 [7].

RESEARCH METHODS

The research was conducted for 5 months, from September 15 2023 to February 9, 2024. Administratively, PT Battoman Coal is located in Bandar Jaya Village, Musi Banyuasin Regency, South Sumatra. The research location can be reached approximately 4 hours by road from the city of Palembang. Research activities are carried out in several stages starting from research preparation, data collection, data processing in the laboratory, data processing, data evaluation and analysis, and preparing the final report. The research method used to solve the problems in this research is by combining theory, previous research results related to the title being studied, as well as primary data and secondary data obtained from the field when conducting research.

Study of literature

This stage was carried out by searching for and studying library materials related to slope stability analysis, safety factors, groundwater level conditions in the research area, and the influence of groundwater levels on slope stability. Literature studies can be done by reading books, journals, articles, reports, and other relevant sources.

Research data
The data required in this research is primary data and secondary data. The data required is as follows.

1. Primary Data
   Primary data is data obtained from direct observation and data collection in the field. Primary data obtained in the research is as follows.
   a. Height and groundwater level data were obtained from groundwater level measurements using a Casagrande piezometer installed in a geotechnical drilling hole at point GT-01 in the PT Battoman Coal mining plan area with the help of a water level meter.
   b. The local stratigraphy of PT Battoman Coal was obtained from geotechnical drilling data carried out at two research location points. The drilling carried out is full coring with length rods 1,5 m.
   c. Geological Strength Index (GSI) data obtained from geotechnical drilling activities.
   d. Dry weight data (γ_d) and wet unit weight (γ_w) obtained from testing the physical properties of the material. Compressive strength data (σ_c) was obtained from the compressive strength test. 47 tests were carried out on sample taken in geotechnical drilling activities.

2. Secondary Data
   Secondary data is a literature study obtained by citing literature and attachments from the bibliography, related agencies, and related literature as well as company data or archives that support research work. The required secondary data consists of:
   a. Rock parameters (mi)
   b. Material disturbing factors (d)
   c. Location map of PT Battoman Coal
   d. Regional geological map
   e. Geotechnical drilling location map
   f. Groundwater flow direction map
   g. Regional earthquake acceleration data

Processing and analysis of data
Data processing in this research was carried out using the Rocscience Slide V.6 and Roclab 1.0 programs. Roclab 1.0 is software to determine the strength of the rock mass in the form of cohesion (c) and internal friction angle (ϕ). Rocscience Slide V.6 is software analysis of the stability of a slope by calculating slope strength based on geotechnical parameters. The data processed in this research is primary data. The processing stages, data analysis and summary of solving this problem are as follows.

1. Compressive data (σ_c), rock parameters (mi), disturbing factors (d), Geological Strength Index (GSI), and wet unit weight (γ_w), were entered into Roclab V.1 software to obtain the cohesion (c) and internal friction angle (ϕ) values.
2. Elevation and groundwater level data based on measurements observation well what has been done are then input into ArcGIS to get a groundwater distribution map. Calculate pore water pressure based on the results of subtracting the depth elevation of the tool which is subtracted from the ground water level elevation. Analyze groundwater distribution and pore water pressure. Modeling groundwater level conditions at cross sections A-A' and B-B' based on deep piezometer measurements software Rocscience Slide V.6.
3. Highwall slope stability analysis using the Morgenstern-Price method with Mohr-Coulomb failure type was carried out with the assistance software Rocscience Slide V.6. The data used in the analysis are cohesion (c), internal shear angle (ϕ), and dry content weight (γ_d) and wet unit weight (γ_W).
4. Slope stability analysis of high walls in pseudo-static conditions, is carried out using the regional earthquake acceleration coefficient based on the Indonesian seismic zone map by the Ministry of PUPR in 2017. The analysis is carried out using the vertical seismicity coefficient and the horizontal seismicity coefficient.

The stages of the research can be seen in detail in the following figure (Figure 1).

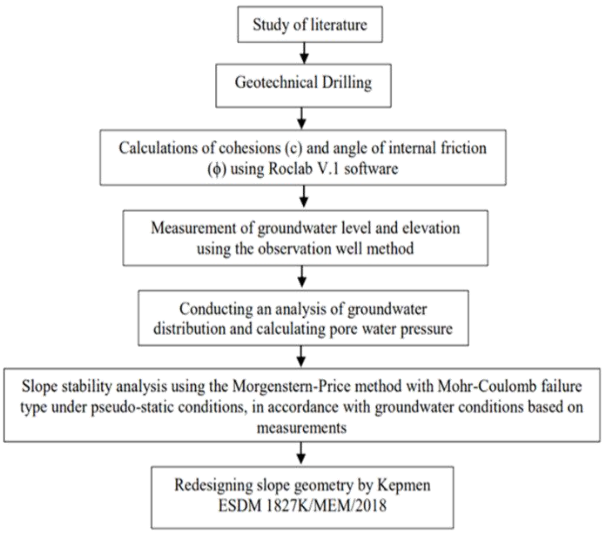

Figure 1. Research flowchart

RESULTS AND DISCUSSION

Local Geological Conditions of PT Battoman Coal
Geotechnical drilling activities were carried out at 4 points spread across the PT Battoman Coal mining plan area. Based on the drilling results, it is known that the lithologies found in the research area are mudstone, siltstone, sandstone, carbonaceous rock, and coal. Based on geotechnical drilling data, two cross-sections were obtained which depict the local stratigraphy of PT Battoman Coal. Cross-section A-A' describes the rock condition of the area around GT-01 and Cross-section B-

B' describes the rock condition of the area around GT-03. These two cross-sections will be used as a slope stability analysis model using the software Rocscience Slide V.6.

1. Cross-section A-A'
   Cross section A-A' is the correlation between GT-01 and the surrounding drilling points. Based on the cross-section A-A' is known dip of 13 degrees which leads to the southwest with coal getting thicker towards the surface. The lithology of the A-A' section is dominated by mudstone. The coal contained in the cross section consists of: seams K, J. I, H, GU, and GL (Figure 2).

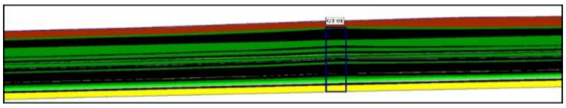

Figure 2. Cross-section A-A' at drilling point GT-01

2. Cross-section B-B'
   Cross-section B-B' is the correlation between GT-03 and the surrounding drilling points. Based on the cross section B-B' is known dip of 13 degrees which leads to the southwest with coal getting thicker towards the surface. The lithology of the B-B' section is dominated by mudstone, sandstone and siltstone. The coal contained in the cross-section consists of seams H, GU, GL, and F (Figure 3).

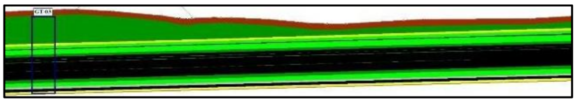

Figure 3. Cross-section B-B' at drilling point GT-03

Physical Properties of Materials
Physical property data in the form of unit weight is obtained from physical property tests in the laboratory. Slope stability analysis using the Morgenstern-Price method using assistance software Rocscience Slide V.6 only dry unit weight data (γ_d) and wet unit weight (γ_w) (Table 1).

Table 1. Physical properties of PT Battoman Coal materials

No	Material	Natural Unit Weight (γ_n) (KN/m^3)	Wet Unit Weight (γ_w) (KN/m^3)	Dry Unit Weight (γ_d) (KN/m^3)
1	Soil	17.98	18.57	14.38
2	Claystone	17.49	18.05	13.47
3	Siltstone	17.15	17.81	13.02
4	Sandstone	17.64	18.20	13.40
5	Coal	12.48	12.76	7.21
6	Carbonaceous Siltstone	18.42	18.86	14.57
7	Carbonaceous Claystone	17.85	18.93	15.11

Mechanical Properties of Materials
Cohesion data and internal shear angles are obtained from the input values of compressive strength, mi, disturbing factors (d), unit weight, and GSI using the software Roclab 1.0. Cohesion data and internal friction angle (ϕ) probabilistic statistical analysis was carried out to obtain the average cohesion and shear angle data for each lithology (Table 2).

Table 2. Mechanical properties of PT Battoman Coal material

No	Lithology	Cohesion (c)	Internal Shear Angle (ϕ)
1	Soil	56.80	13.69
2	Claystone	68.23	15.19
3	Siltstone	84.47	19.10
4	Sandstone	97.19	22.83
5	Coal	78.47	21.03
6	Carbonaceous Siltstone	75.00	16.42
7	Carbonaceous Claystone	53.20	19.97

Regional Earthquake Acceleration
Based on the Indonesian earthquake zoning map by the PUPR Ministry, the acceleration of the earthquake in Bandar Jaya Village, Musi Banyuasin was 0,05-0,1 g (Figure 4).

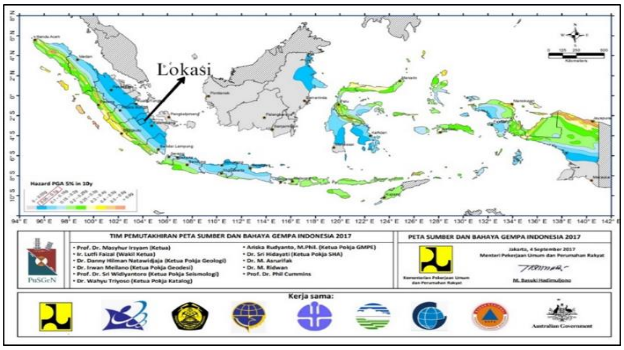

Figure 4. Research location on the Indonesian earthquake zoning map

According to the California Department of Mines and Geology (1997), the use of horizontal coefficients in soil

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and rock slope stability analysis uses 50% of the PGA design value (Peak Ground Acceleration) [8], so that PT Battoman Coal's horizontal earthquake acceleration coefficient is 0.025 g while the vertical earthquake acceleration coefficient is 0.05 g. The earthquake acceleration coefficient is used in the analysis to determine slope stability conditions in critical conditions.

PT Battoman Coal Groundwater Condition based on Observation Well

An observation well is a drilled well specifically designed to monitor groundwater levels and water quality in the aquifer at a certain depth. Through MAT monitoring with this method, groundwater distribution at the research location can be determined. In this research observation well carried out at 22 points of former exploration wells spread throughout the PT Battoman Coal mining plan area. Groundwater level measurement activities were also accompanied by mapping and measuring hydrological conditions which were carried out at 5 points consisting of 3 community wells and 2 tributaries.

Data from groundwater measurements and observations in the research area shows that groundwater conditions are getting closer to the surface in the southeastern area of PT Battoman Coal's mining plan. The depth of groundwater in the southern area is between 14,8 meters-37,7 meters. Based on groundwater measurements and monitoring, groundwater mapping was then carried out to obtain the distribution of groundwater at the research location. Based on MAT measurement data, it shows that groundwater at the research location is getting higher towards the southeast of the PT Battoman Coal mining plan area.

It is known that the southeast area has a groundwater level that is quite close to the surface, adjacent to the White River tributary, and is the GT-01 drilling point. Where GT-01 is dominated by clay stone which based on laboratory test results has a high porosity value of 51,98% and a permeability of 6,84 x 10^{-7} cm/s. Based on this, it is known that the characteristics of clay rock at the research location have high porosity and low permeability, so that the rock can hold large amounts of water but is difficult to drain. Claystone is expansive where the rock can absorb water and expands when exposed to water, conversely when the water decreases this material will shrink and cause slope stability to be disturbed. The existence of this tributary allows water to enter the rock pores which are then retained in the rocks that make up the slope so that groundwater conditions are higher in the southeast area of PT Battoman Coal's mining plan (Figure 5).

Ground Water Level Conditions based on Piezometer

Monitoring groundwater conditions using a piezometer big house which is placed in a former geotechnical drilling hole. The Casagrande piezometer was installed at an elevation of 14,65 meters and a depth of 52,80 meters, which was carried out in September and October. Based on measurements, it is known that pore water pressure at the research location continues to increase (Figure 6). Pore water pressure is calculated as the difference between the water surface elevation in the pipe and the elevation of the piezometer tip which is measured manually using a dipmeter measuring instrument which will sound when the tip of the rod touches the water [9].

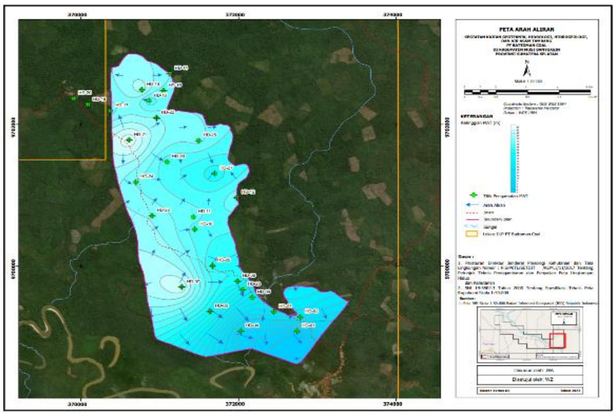

Figure 5. Map of groundwater level distribution based on monitoring methods observation well at PT Battoman Coal

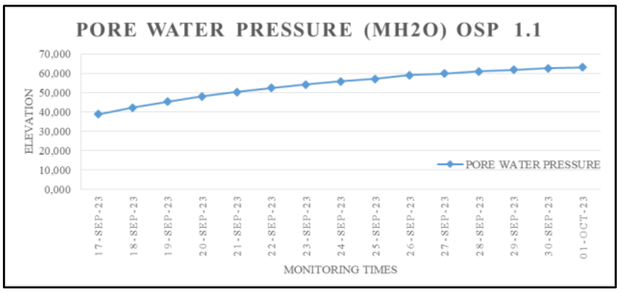

Figure 6. Graph of pore water pressure against Casagrande piezometer measurement time

The graph above shows that pore water pressure at the research location has increased quite significantly. Observations were carried out over 15 days on the GT-01 drilling test well. The increase in pore water pressure is indicated by the increase in groundwater level at the research location which ranges from 1,73 meters every day. This is caused by the presence of clay rock which dominates the mining plan area. Where it is known that the clay rock at the research location has a high porosity value (51,98%) and low permeability (6.84 x 10^{-7} cm/s) which causes water to enter and be trapped in the rock which causes the underlying material to become saturated. water. The existence of the White River tributary is also one of the factors that causes groundwater to enter the constituent rocks. The condition of the material which has high porosity allows for water infiltration from the White River tributary into the rock through the pores and causes the groundwater level to rise. This also correlates with the results of the observation well where groundwater has increased to the southeast of the planned mining area which is also the location for groundwater monitoring using a Casagrande piezometer.

The Effect of Ground Water Level Fluctuations on Slope Stability Highwall PT Battoman Coal

The analysis was carried out on cross-sections A-A' and cross-section B-B' using three groundwater conditions, namely dry conditions and conditions based on variations in groundwater measurements in the field, namely 28,45 meters and 4,26 meters from the surface of the planned slope.

Overall slope it's the area high wall The A-A' cross section designed by PT Battoman Coal has a height of 73 meters with an angle of 31 degrees. The analysis was carried out using the Morgenstern Price method with Mohr-Coulomb failure type with software Rocscience Slide V.6. which was carried out in groundwater conditions of 4,26 meters, 28,45 meters, and dry conditions. The analysis was carried out under pseudo-static conditions involving regional seismicity factors [10]. Based on slope analysis high wall at a groundwater depth of 4,26 meters from the slope surface, it is known that the safety factor value is 0,901 (Figure 7).

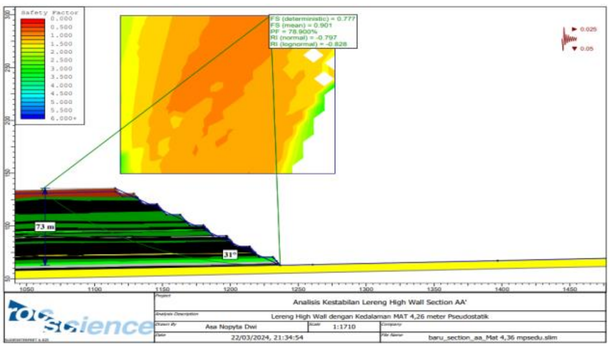

Figure 7. Condition of overall slope stability of the area high wall section A-A' with a groundwater depth of 4,26 meters

Based on an analysis of the high wall slope at a groundwater depth of 28.45 meters, it is known that the safety factor value is 1,303 (Figure 8). Slope analysis in dry conditions was carried out to determine slope stability in the absence of groundwater parameters. Based on slope analysis of high wall in dry conditions it is known that the safety factor value is 1,782 (Figure 9).

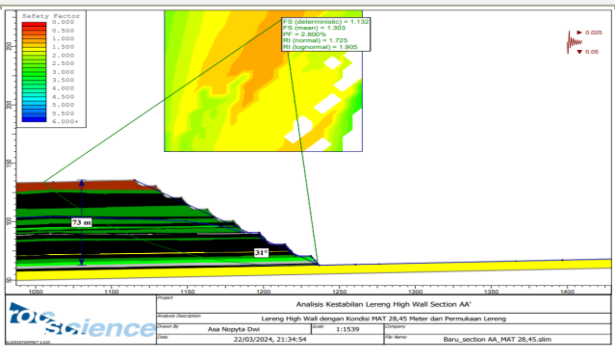

Figure 8. Slope stability conditions high wall cross section A-A' at a groundwater depth of 28,45 meters from the slope surface

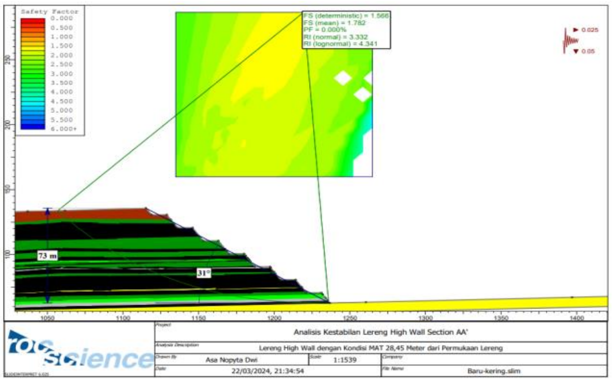

Figure 9. Stability conditions for high wall slopes of section A-A' in dry conditions

Overall slope area high wall The B-B' cross-section at PT Battoman Coal is designed to have a height of 54 meters with an angle of 28 degrees. The angle of each level is 54 degrees. Analysis was carried out under pseudo-static conditions.

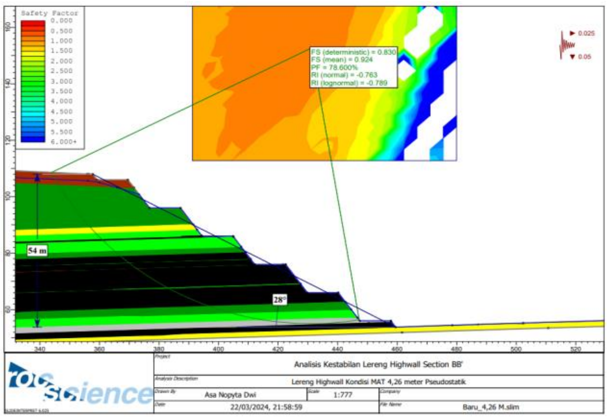

Figure 10. Slope stability conditions high wall cross - section B-B' at a groundwater level of 4.26 meters

Based on slope analysis of high wall in the three groundwater conditions, it is known that the slope stability conditions are in the critical to stable category. Based on analysis carried out at a groundwater depth of 4,26 meters, it is known that the safety factor value for pseudo-static conditions at the B-B' cross section is 0,924 (Figure 10).

Based on an analysis of the high wall slope at a groundwater depth of 28,45 meters, it is known that the safety factor value is 1,323 (Figure 11).

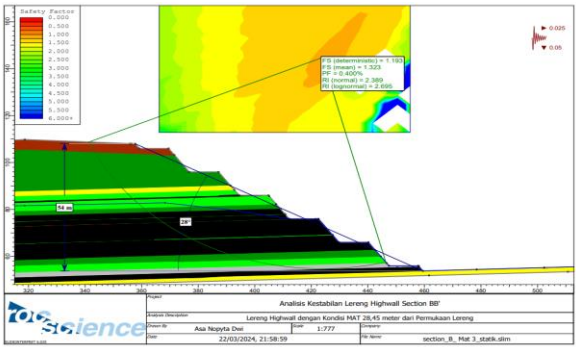

Figure 11. Slope stability conditions high wall cross-section B-B' at a groundwater level of 28,45 meters from the slope surface

Analysis of slope stability on the B-B' section was also carried out in dry conditions. Based on slope analysis of high wall in dry conditions it is known that the safety factor value is 1,738 (Figure 12).

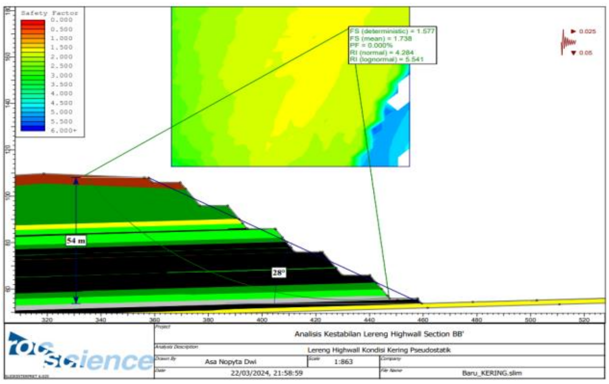

Figure 12. Slope stability conditions high wall cross-section B-B' in dry conditions

Based on the data from the analysis, it is known that the value of the safety factor has an inverse relationship with the condition of the groundwater level. The results of the analysis show that the slope stability of PT Battoman Coal is classified as critical to stable according to KEPMEN ESDM 1827K of 2018. The analysis was carried out at a groundwater level of 4,26 meters from the surface in the cross-section A-A' and BB' showing FK values of 0,901 – 0,924 (FK < 1) which are classified as critical conditions. Meanwhile, when the groundwater level is 28,45 meters and in dry conditions, the FK value is 1,303-1,782, which is included in the stable slope category. The following graph shows the influence of groundwater conditions on the value of the safety factor at PT Battoman Coal (Figure 13).

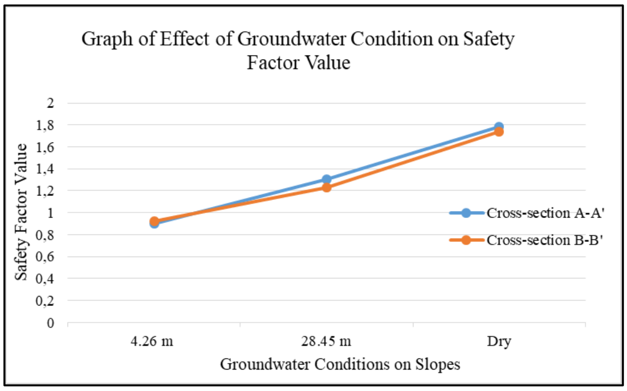

Figure 13. Graph of the influence of ground water conditions on the safety factor value of PT Battoman Coal

Recommendation Overall Slope High wall

Analysis carried out on slopes high wall cross-section A-A' and B-B' with slope heights of 54-73 meters and corners overall slope 28-31 degrees carried out in dry conditions and the actual conditions of variations in groundwater levels measured from the ground surface show that the slope safety factor is included in the critical to stable category. Based on the analysis carried out, it is known that overall slope cross-section A-A' and cross-section B-B' in saturated groundwater conditions have safety factor values that are classified as critical. Critical slope conditions allow landslides to occur on the slope.

To prevent landslides, geometric recommendations are made overall slope high wall which is safe on cross-section A-A' and cross-section B-B' for PT Battoman Coal. Geometric redesign overall slope area high wall was carried out in saturated groundwater conditions based on piezometer monitoring in the field to obtain safe slope geometry in the most critical and pseudo-static conditions according to Minister of Energy and Mineral Resources Decree 1827K of 2018. The following is the geometry overall slope high wall which is safe to apply to PT Battoman Coal's mining plans (Table 3).

Table 3. Geometry recommendations overall slope high wall PT Battoman Coal

Name	Initial Design Slope						Slope Resulting					
	Overall Slope Geometry		Single Slope Geometry			FK Values	Overall Slope Geometry		Single Slope Geometry			FK Values
	Height (m)	Degree	Height (m)	Width (m)	Degree		Height (m)	Degree	Height (m)	Width (m)	Degree	
High wall Section AA'	73	31	5	12	55	0,901 (Critical)	73	20	5	12	45	1,176 (Stable)
			10	12					8	12		
			10	12					8	12		
			10	12					8	12		
			10	12					8	12		
			10	12					8	12		
			10	12					8	12		
			8	12					8	12		
									8	12		
									4	12		
High wall Section BB'	54	28	2	12	55	0,924 (Critical)	54	20	4	12	45	1,245 (Stable)
			10	12					8	12		
			10	12					8	12		
			10	12					8	12		
			10	12					8	12		
			10	12					8	12		
			2	12					8	12		
									2	12		

CONCLUSION

The geological condition of PT Battoman Coal is composed of claystone, siltstone, sandstone, carbonaceous claystone, carbonaceous siltstone, and coal which has a dip of 13 degrees. Based on physical properties testing, the natural bulk weight of the material (γ_n) at PT Battoman Coal ranges from 12,48-18,42 KN/m3, wet bulk weight (γ_{In}) between 12,76-18,93 KN/m3, and dry bulk weight (γ_d) ranges from 7,21-15,11 KN/m3. Based on calculations that have been carried out, the cohesion value (c) of the PT Battoman Coal slope material ranges from 53,20-97,19 Kpa, and the internal friction angle (ϕ) ranges from 13,69-22,83 degrees.

Groundwater level conditions are based on measurements via observation well. It is known that groundwater at the research location is higher towards the southeast of the PT Battoman Coal mining plan area. Meanwhile, groundwater level conditions are based on piezometer monitoring big house placed in monitoring wells for 15 days, it was found that pore water pressure increased significantly with an average increase in height of 1,73 meters every day.

Stability overall slope area high wall of the A-A' cross-section and the B-B' cross-section are included in the critical to stable category. Based on the analysis carried out in three groundwater conditions, it is known that in groundwater conditions with a depth of 4,26 meters from the surface, the stability of sections A-A' and B-B' are classified as critical with FK values of 0,901 and 0,924 respectively in pseudo-static conditions. Meanwhile, in the MAT condition of 28,45 meters from the surface, it is known that the FK value at cross-section A-A' is 1,303 and at cross-section B-B' is 1,323. The FK value for dry conditions at cross-section A-A' is 1,782 and at cross-section BB is 1,738.

Recommendation overall slope designed by KEPMEN ESDM 1827K of 2018 with FK values ≥ 1,1 to obtain safe slope stability by considering regional seismicity (pseudo-static). Overall slope area high wall The A-A' cross section is designed to have a height of 73 meters with an angle of 20 degrees, based on analysis, the FK value is 1,176. Meanwhile, in cross section B-B', the overall slope area high wall was designed with a height of 54 meters with an angle of 20 degrees which after analysis has an FK value of 1,245.

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