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Analysis of the Influence of Groundwater Level on Slope Stability at Highwall PT. X, South Kalimantan

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Abstract. Mine slope design is an important part of mining operations because it is used to determine the balance between mine economy and operational safety. In the mine slope design there will also be a groundwater level design, the groundwater level is one of the triggers for a slide to occur. Therefore, this study aims to determine the effect of the groundwater level on the stability of the highwall slope cross section A-A' as well as to determine the factor of safety value and probability of slope failure under various conditions of high groundwater levels. This research method uses quantitative methods because there are numerical data that will be used to calculate the value of slope stability. Slope stability analysis uses the "morgenstern-price" boundary equilibrium and the "monte-carlo" landslide probability. From the research results it is known that the higher the groundwater level, the lower the safety factor value because the presence of groundwater can reduce slope stability causing a decrease in soil shear strength due to increased pore water pressure. In addition, the weight of the material will increase due to the presence of groundwater, which causes the driving force on the slope to also increase. In addition, the movement of air in the soil can cause seepage forces which can affect slope stability. The lowest safety factor value is at the groundwater level 100% of the overall slope height, in conditions of 100% of the overall slope height, the deterministic safety factor value is 1.337, the mean safety factor is 1.358, and 0% hazard susceptibility.

Keywords: groundwater level, safety factor, limit equilibrium, probability of failure

1. Introduction

Slopes are inclined surfaces that connect two areas at different elevations. They can form naturally or be constructed by humans. Designing mine slopes is a crucial part of mining operations because it's used to determine the balance between mining cost-effectiveness and operational safety [1]. In designing mine slopes, the design of the groundwater level height is essential, as it's one of the triggers for slope failure due to increased material weight and decreased shear strength of the slope constituents [2]. Mining activities, such as excavating a slope, lead to significant changes in the forces acting on the slope, potentially disturbing its stability and causing possible landslides.

PT. X is a company involved in coal mining located in the Tanah Laut Regency, Panyipatan District, South Kalimantan Province, planning to employ an open-pit mining system that seen in Figure 1. PT. X has designed the highwall slope geometry of the mine until completion.

Changes in the groundwater level height are considered to assess the most critical slope conditions. As this height affects slope stability, a graph is created to illustrate the relationship between the groundwater level height, the safety factor, and the probability of landslides [3,4]. This graph helps determine how changes in the groundwater level height influence the safety factor and the likelihood of landslides. Therefore, analyzing the influence of the groundwater level height on slope stability is essential to understand its impact on the safety factor and the probability of landslides.

Figure 1. Location of PT. X, where the research was conducted

2. Research Methodology

The research method used is a quantitative method. This method is chosen due to the presence of numerical data that will be used to calculate the slope stability values [5]. The study uses various data, including primary and secondary data. Primary data is obtained from direct testing in the laboratory, involving testing the physical and mechanical properties of rocks, which include tests for physical properties, direct shear testing, and uniaxial compressive strength testing. From the laboratory testing conducted, values for cohesion, internal friction angle, dry and saturated unit weight, and uniaxial compressive strength are obtained. The data resulting from the laboratory tests are used as input parameters in conducting slope stability analysis. Secondary data is obtained from the geotechnical department of PT. X. The secondary data used in this analysis includes slope design, slope sections, borehole lithology, and slope types.

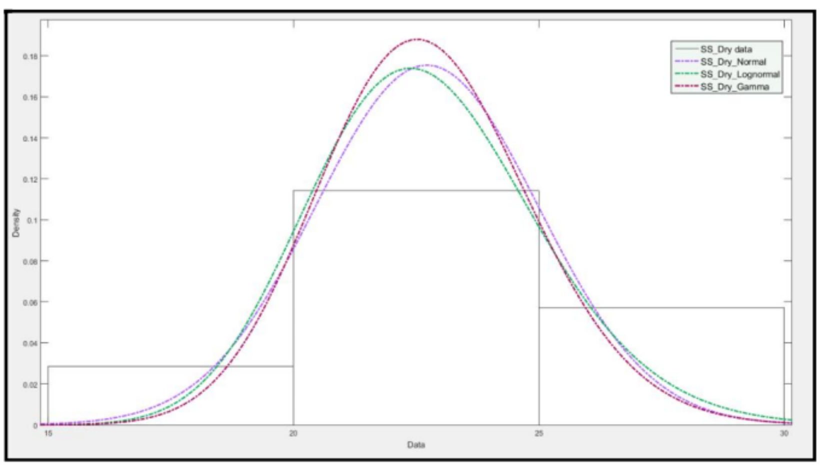

Figure 2. Example of a fitting test for sandstone material

The test results data will undergo a fitting test to obtain the best distribution that will be used as input parameters during the stability analysis, seen in figure 2. An example of the fitting test process can be seen in Figure 1. After the fitting test process for all materials has been completed, the next step is to design the mine slope in accordance with the section lines. Subsequently, slope analysis is performed uses Slide2, which is licensed software that adopts the finite element method from Rocscience Inc. to determine the values of the safety factor and the probability of landslides, as depicted in Figure 3.

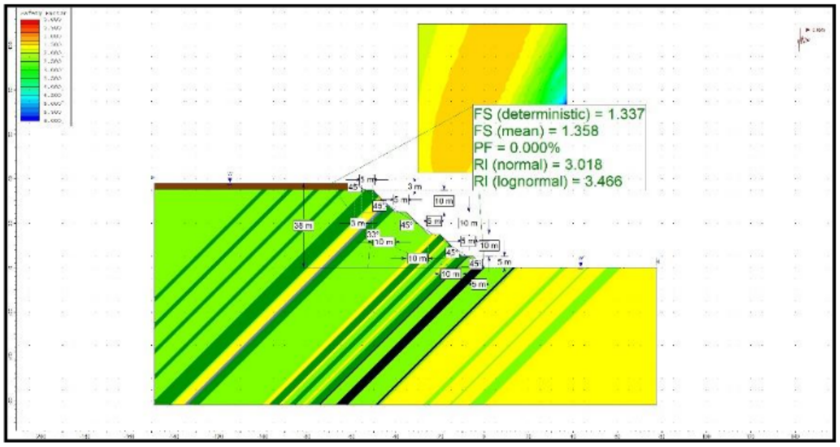

Figure 3. Example of an overall highwall slope analysis for cross section A-A'

The safety factor is calculated using the limit equilibrium method "Morgenstern-Price," while the probability of landslides is determined using the "Monte Carlo" method [6,7].

2.1 *Morgenstern Price*

The Morgenstern-Price method uses the same assumptions as the general limit equilibrium method, which implies a relationship between the shear forces between slices and the normal forces between slices, expressed by equation below [8].

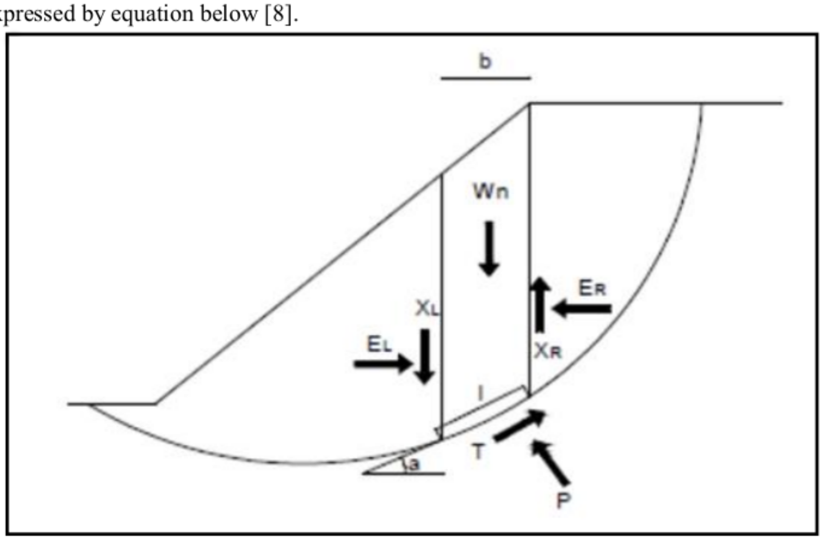

Figure 4. Forces acting on each slice

$$X = \lambda f(x) E \quad (1)$$

In the equation above, it shows that X is the shear force around the slice, λ is lambda, f(x) is the function of normal force, and E is the modulus of elasticity. The function f(x) has several functions that can be used, as depicted in Figure 4.

2.2 Monte Carlo Method

The Monte Carlo method is a technique commonly used in probability analysis. This approach is highly useful for solving problems involving random variables. In addition to being straightforward, this method offers high flexibility in combining various probability distributions without requiring extensive interpretation. Furthermore, this method easily models correlations between the variables involved (Hammah et al., 2009).

$$PL = \frac{N-M}{M} \quad (2)$$

In the equation above, it shows that PL is the probability of a landslide, N is the total number of data, and M is the number of accepted data.

3. Results and Discussion

3.1. Research Parameters

The geotechnical laboratory testing involves various examinations, such as testing the physical and mechanical properties of rocks. The mechanical properties testing includes direct shear testing and uniaxial compressive strength testing, aimed at determining the cohesion and internal friction angle of the rock, as well as the overall compressive strength of the rock [9]. Additionally, the physical properties testing aims to determine the dry and saturated unit weight. All this data is gathered based on the lithology type of the rocks being studied. Presented in Table 1 are the data resulting from the geotechnical laboratory tests, categorized according to the rock lithology types.

Table 1. Parameters of the rock material testing in the geotechnical laboratory

Sample Code	Density (kN/m^3)		Friction Angle (°)	Cohesion (kPa)	UCS (MPa)
	γdry	γsat			
SO1A	14.05	17.84	30.02	44.41	0.03
CS1B	18.45	21.30	28.94	56.10	0.32
CS1A	14.00	18.35	41.05	50.05	0.20
SL1A	24.82	25.50	32.01	67.95	8.91
SS1A	20.04	22.19	20.53	45.15	0.44
SS1B	22.40	23.65	36.06	87.21	2.71
MI1D	19.66	21.52	31.89	94.83	0.33
SS1A	19.55	20.25	40.16	55.30	7.20

3.2. Highwall Slope Design

The Highwall slope design for cross-section A-A' comprises an overall slope geometry of 38.04 meters and an overall slope inclination of 33°, consisting of five individual slopes with a slope angle of 45°. The individual slope heights are 3, 5, and 10 meters, with a 5-meter berm. The geometry of the highwall slope for cross-section A-A' can be seen in Figure 5, the lithology of the rock constituting the highwall slope is depicted in Figure 6, and the highwall slope design can be observed in Figure 7.

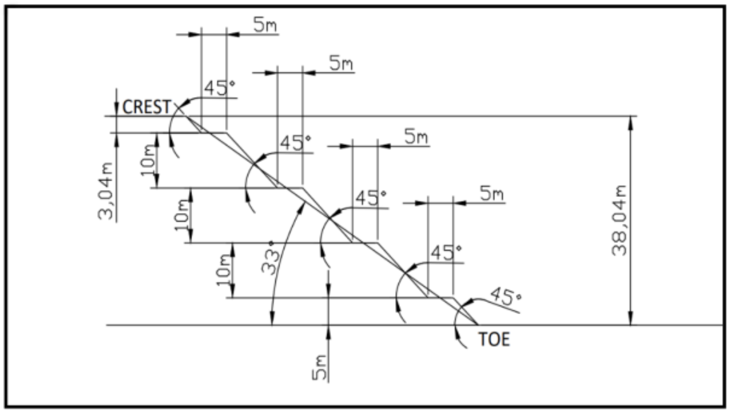

Figure 5. Design of highwall slope geometry A-A'

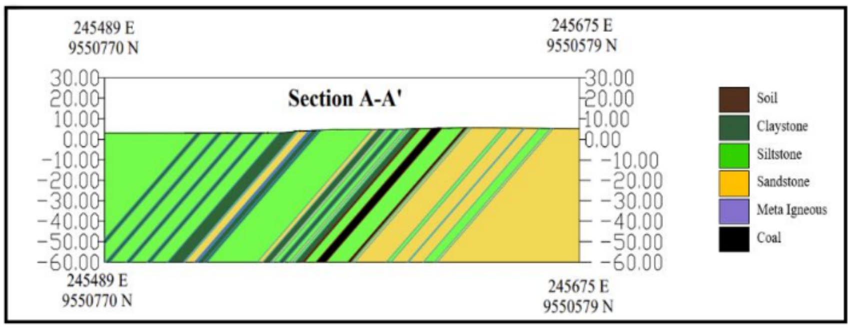

Figure 6. Lithology of the rock on highwall slope A-A'

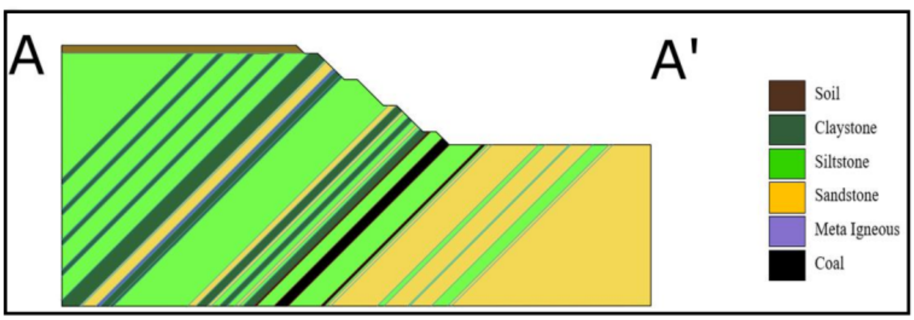

Figure 7. Design of highwall slope A-A'

3.3. Groundwater Level Design

The groundwater level is designed for every 10% increase in the overall highwall slope height on cross-section A-A', which has a height of 38.04 meters. The groundwater level (GWL) height model can be seen in Figure 8.

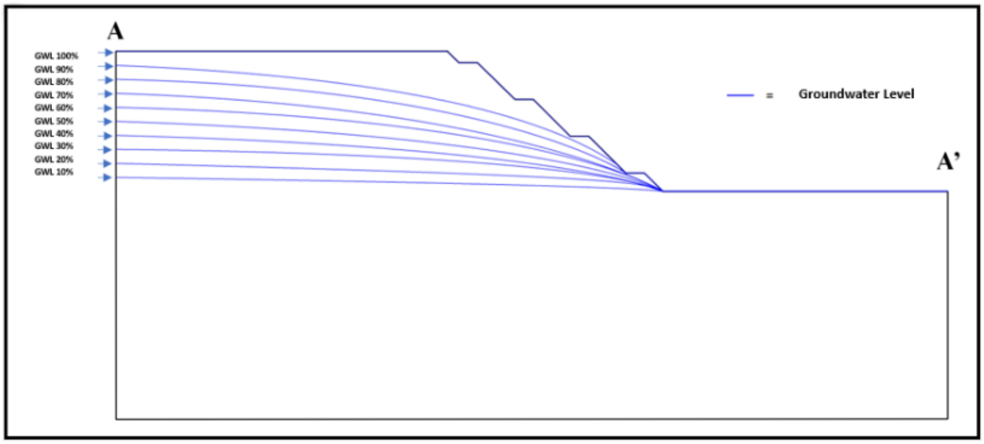

Figure 8. Groundwater level height model for cross-section A-A'

3.4. Analysis of the Influence of Groundwater Level on Slope Stability

The analysis of the influence of the groundwater level on slope stability focuses solely on the highwall slope section A-A'. The groundwater level has a significant impact on the safety factor and the probability of landslides. The presence of groundwater can reduce slope stability by causing a decrease in soil shear strength due to increased pore water pressure. Additionally, the material weight increases due to the presence of groundwater, which adds to the driving force on the slope. Furthermore, water movement in the soil can generate seepage forces that can affect slope stability.

The groundwater level is designed for every 10% increase in the overall highwall slope height on the A-A' cross-section, which measures 38.04 meters in height which is shown in the Table 2. The analysis results using Slide software indicate that as the groundwater level height increases, the safety factor decreases. This is due to the influence of the groundwater level on the increased unit weight of the material in the slope. The increase in material unit weight leads to an increase in driving forces on the slope, thereby decreasing the safety factor. Additionally, groundwater can reduce the shear strength of the material due to the increased pore pressure.

Table 2. Influence of GWL height on safety factor (FK) and probability of landslide (PL) for cross-section A-A'

GWL	SF Deterministic	SF*Mean*	PL
0%	2,112	2,123	0%
10%	2,108	2,12	0%
20%	2,079	2,089	0%
30%	2,047	2,067	0%
40%	2,03	2,051	0%
50%	1,982	2,002	0%
60%	1,91	1,944	0%
70%	1,875	1,913	0%
80%	1,76	1,792	0%
90%	1,648	1,679	0%
100%	1,337	1,358	0%

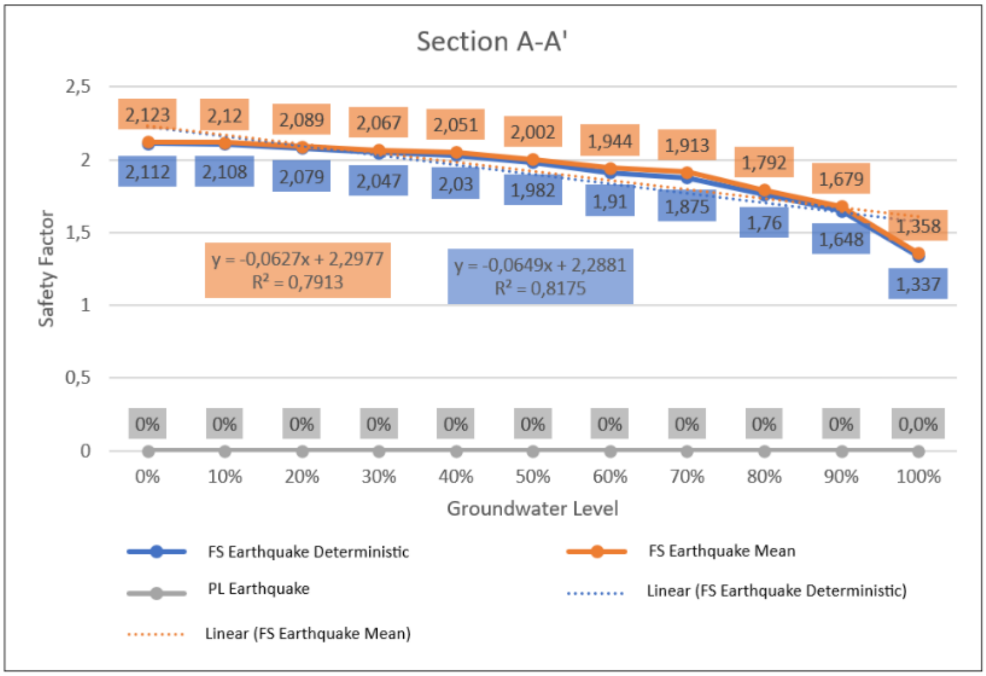

Figure 9. Graph of the influence of GWL on the FK and PK values for cross-section A-A'

From the analysis results conducted, it's been determined that the highwall slope condition in cross-section A-A' remains stable under various groundwater level heights. Figure 9 indicates that as the groundwater level height increases, the safety factor and slope probability values decrease. This is because the higher the groundwater level, the value of the safety factor will decrease because the groundwater level has an effect on increasing the bulk weight of the material on the slope. The increase in the bulk weight of the material causes the driving force on the slope to increase so that the safety factor value will increase. reduced and groundwater can also reduce the shear strength of the material due to increased pore water pressure. The lowest safety factor value is observed at a groundwater level height of 100% of the overall slope height. Refers to the standard permitted by the company for the slope safety factor limit which is 1.3, at this 100% groundwater level height condition can be stated as stable because the deterministic safety factor value is 1.337, the mean safety factor is 1.358, and the landslide probability is 0%.

4. Conclusion

The conclusions drawn from this research are as follows:

1. The higher the groundwater level, the lower the safety factor.
2. Under all groundwater level height conditions, the highwall slope in cross-section A-A' remains stable.
3. At a groundwater level height of 100% of the overall slope height, the deterministic safety factor value is 1.337, the mean safety factor is 1.358, and the landslide probability is 0%.
4. The groundwater level significantly affects the safety factor as the presence of groundwater can reduce slope stability by causing a decrease in soil shear strength due to increased pore water pressure. Moreover, the material weight increases due to the presence of groundwater, adding to the driving force on the slope.

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