



Slope Stability Analysis in the Mining Area of PT Indocement Tungal Prakarsa Tbk. Block X, Palimanan Quarry, Cirebon Plant Unit

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Abstract

Open-pit limestone mining alters slope geometry and rock mass conditions, potentially reducing slope stability and increasing operational safety risks. Therefore, geotechnical evaluation is essential to ensure safe and sustainable mining activities. This study aimed to analyze the Factor of Safety (FoS) and slope stability of Quarry Palimanan Block X at PT Indocement Tungal Prakarsa Tbk., Cirebon Plant Unit, and to validate the numerical analysis by comparing it with manual calculations using the Bishop method. A quantitative approach was employed based on the Limit Equilibrium Method (LEM) using the Bishop Simplified Method. Slope stability analysis was performed using Rocscience Slide v6.0 with input parameters including slope geometry, cohesion, internal friction angle, and unit weight obtained from field observations and company geotechnical data. The results showed that the FoS of Cross-Section A was 2.070 using Rocscience Slide v6.0 and 2.0724 using manual calculations, while Cross-Section B yielded FoS values of 2.709 and 2.7129, respectively. The difference between the two methods was less than 0.15%, indicating excellent consistency and high reliability of the numerical model. All FoS values exceeded the minimum stability criterion, indicating that both slopes were in a very stable condition with a low risk of failure. These findings demonstrate that Rocscience Slide v6.0 combined with the Bishop Simplified Method provides a reliable approach for evaluating slope stability in open-pit limestone mining.

Keywords: Slope Stability, Safety Factor, Bishop Simplified Method, Rocscience Slide v6.0, Limestone Quarry

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INTRODUCTION

Limestone mining activities in open-pit mines cause changes in slope geometry and rock mass conditions that have the potential to affect their stability. This condition needs to be controlled because slope failure can disrupt the sustainability of mining operations, cause economic losses, and increase risks to worker safety. Therefore, the evaluation of slope stability is one of the important aspects in the

implementation of *Good Mining Practice* (GMP). The level of slope stability is generally assessed using the *Factor of Safety* (FK), which is a parameter that shows the slope's ability to withstand avalanche driving forces based on geometric conditions, rock characteristics, groundwater levels, and the influence of external loads such as blasting vibrations.

Evaluation of the rock strength parameters and geotechnical behavior was performed using the generalized failure criterion framework [1].

PT Indocement Tungal Prakarsa Tbk. is one of the largest cement producers in Indonesia that operates the Palimanan Plant Unit, Cirebon Regency, as the main supplier of limestone raw materials. Mining activities at the Palimanan Quarry are carried out in a sustainable manner through the stages of blasting, excavation, and material transportation, causing changes in the slope geometry along with the development of the mining front. Based on the results of the 2025 operational evaluation, the slope at the Palimanan Quarry Block X shows indications of rock mass movement that is still within safe monitoring limits. Although it has not yet developed into a slope failure, it suggests that periodic geotechnical evaluations are still required to ensure slope stability remains in place to meet operational safety requirements.

Various studies have proven that Safety Factor analysis is an effective approach in evaluating the stability of mine slopes. Pure *et al.* reported that the change in slope geometry in the granodiorite mine was able to increase the value of the Safety Factor from 1.248 to 1.604 so that the slope conditions became safer [2]. Fanani *et al.* showed that the analysis using the Bishop and Janbu methods through the Slide v6.0 software resulted in a Safety Factor value above the safe limit on the sirtu mining slope so that the existing slope geometry is still viable to maintain [3]. Amen Research *et al.* showed that andesite slopes with steep slopes had a Safety Factor value under safe conditions, but increased after changes in slope geometry design [4]. Pangathousands and Retongga obtained a Safety Factor value of 4.775 through the *Rock Mass Rating* (CMR), *Slope Mass Rating* (SMR), and Rocscience Slide analysis, which shows that slope conditions are very stable [5]. Meanwhile, Rachmansyah and Aprilia stated that geological structure, discontinuity field, and lithological characteristics are the dominant factors that control the type of rock avalanche [6]. On the other hand, Rudiansyah *et al.* proving that the comparison between manual calculations and numerical modeling is able to improve the reliability of slope stability

evaluations and produce a more comprehensive basis of analysis [7].

Although these studies have examined slope stability under various geological conditions and analysis methods, studies on limestone slopes at Quarry Palimanan Block X of PT Indocement Tungal Prakarsa Tbk. are still limited. In addition, previous research has generally focused on evaluating slope design or using numerical methods without directly validating the results of software simulations and manual calculations on actual slope conditions. This condition shows that there is still a need for research that can evaluate the reliability of numerical analysis results through comparison with manual calculations at the research site.

The novelty of this study lies in the direct validation and comparative reliability assessment between numerical modeling using Rocscience Slide v6.0 and manual calculations using the Simplified Bishop Method under actual slope conditions, specifically addressing the complex heterogeneous rock-clay interface in Block X, Palimanan Quarry. Furthermore, this research contributes to establishing a validated geotechnical benchmark and operational safety guidelines for long-term slope stability management in active limestone open-pit mining.

Based on this description, this study aims to analyze the value of Safety Factors and slope stability level at the Palimanan Quarry Block X of PT Indocement Tungal Prakarsa Tbk. Cirebon Plant Unit uses the Bishop method through the Rocscience Slide v6.0 software, and validates the simulation results by comparing them with the manual calculation of the Bishop method on representative slope sections.

METHOD

The research was carried out at Quarry Palimanan Block X, PT Indocement Tungal Prakarsa Tbk. Cirebon Plant Unit, West Java, with a research area of about 30 ha. This location is an open-pit limestone mine area that undergoes continuous slope geometry changes due to mining activities so that it requires an

evaluation of slope stability as part of operational safety control.



Figure 1. Research Area Location of Block X, Palimanan Quarry

The research uses a quantitative approach with the *Limit Equilibrium Method* through the *Bishop Simplified Method*. Numerical slope modeling alongside slope failure risk assessment were conducted by utilizing limit equilibrium analysis approaches [8].

The analysis was carried out using the Rocscience Slide v6.0 software to obtain the value of the Safety Factor (SF) on the actual slope. The results of the software modeling are then validated through manual calculation of the Bishop method on representative slope sections so that the consistency level of the analysis results can be evaluated.

The research data consists of primary data and secondary data. Primary data was obtained through field observation which included slope geometry measurements, namely slope height, slope angle, *bench width*, and documentation of actual slope conditions. Secondary data was obtained from PT Indocement Tunggul Prakarsa Tbk., including data on the physical and mechanical properties of rocks in the form of cohesion (c), internal friction angle (ϕ), and unit weight (γ), as well as mine maps, slope designs, and geotechnical reports that support the analysis process.



Figure 2. Research Method Flow Chart

The research stage begins with a literature study to identify concepts, analysis methods, and results of previous research related to slope stability. Furthermore, field data and geotechnical data are collected and verified so that all parameters used meet modeling needs. The slope geometry parameters and mechanical properties of the rocks are then fed into Rocscience Slide v6.0 to build a slope model according to actual conditions.

The stability analysis was carried out using the *Bishop Simplified Method*, which is a boundary equilibrium method that assumes a circular *failure surface* with the avalanche mass divided into several vertical slices. The Safety Factor value is calculated based on the balance between the holding force and the driving force on each slice through the iteration process until a convergent value is obtained. The general equation of the Bishop method is stated as follows.

With the formula:

$$SF = \frac{\sum[(c \cdot \Delta x + W \tan \phi) \cdot \frac{1}{m_\alpha}]}{\sum W \cdot \sin \alpha}$$

With $m = \cos \alpha + \frac{\sin \alpha \cdot \tan \phi}{SF}$, where:

- SF = Factor of Safety
- c = Cohesion (kN/m²)
- ϕ = Internal friction angle (°)
- W = Slice weight (kN/m)
- Δx = Slice width (m)
- α = Base inclination angle (°)
- m_α = Bishop correction factor

To determine the Factor of Safety, this study implemented the simplified Bishop formulation, an established technique extensively applied in slope stability evaluations for open-pit limestone mining [9].

The Safety Factor values obtained from Rocscience Slide v6.0 are then compared with the results of manual calculations of the Bishop method on the same slope section. The comparison is used to evaluate the consistency of the analysis results as well as verify the reliability of the numerical modeling. Based on the Safety Factor values obtained, the slope condition is then evaluated to determine its level of stability and identify the need for geometry improvement if necessary.

RESULTS AND DISCUSSION

Geological Conditions of Engineering and Characteristics of Slope Materials

The results of field observations show that the Palimanan Quarry Block X area is composed of limestone and massive clay-rich limestone. In general, rocks have a massive, compact, and relatively hard character with gray to brownish colors due to the surface weathering process. The rock layer develops with a slope of about 45° and a thickness that varies between 1–40 m. At the foot of the slope, overhauled materials were found which indicated a weathering process and the release of material from the upper slope.

The engineering properties of weathered rock layers exert a primary influence on controlling slope vulnerability and calculating safety margins [10].

Technical geological studies show the presence of clay layer insertions between long rocks that have the potential to become weak zones. Clay

material has lower plastic properties and shear strength than massive limestone. This condition is a factor controlling the stability of the slope because the contact field between the limestone layer and the clay layer has the potential to develop into a slip field, especially when there is an increase in moisture content due to rainwater infiltration. Similar phenomena have been widely reported on layered rock slopes, where the presence of layers with low shear strength is the preferential path for avalanches [2].

Based on standard laboratory testing such as the direct shear test the geotechnical parameters of the test results show that Massive Limestone has a cohesion of 594.5 kPa and a shear angle of 26.09°, while Alternating Limestone Clay has a cohesion of only 125 kPa and a shear angle of 22°. These differences in values indicate that the clay layer has a much lower shear resistance capacity than massive limestone. Therefore, although the rocks that make up the slope are dominated by relatively strong limestone, the presence of clay layers remains a critical factor that determines the position of potential landslide fields.

Analysis of Shear Slope Stability A

The results of the analysis on Cross-Section A show that the slope has a total height of 63 m with 13 levels (bench) and an overall slope angle of 14.14°. Based on simulations using the Bishop method on the Slide v6.0 software, a security factor value of 2.070 was obtained. This value shows that the holding force on the slope is still greater than the driving force so that the slope condition is relatively stable.

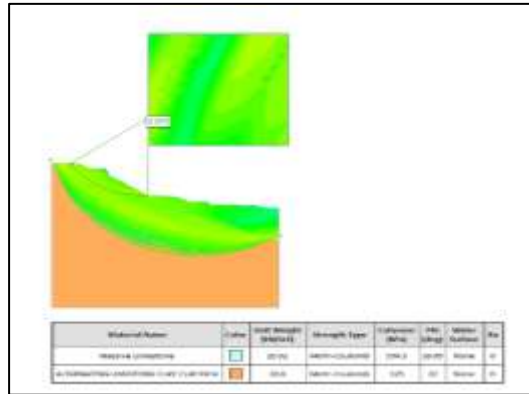


Figure 3. Slide Analysis Results of Slope Cross-Section A, Block X, Palimanan Quarry

The critical slip field produced by the model shows that avalanche potential develops in the Alternating Limestone Clay layer. This shows that the slope failure mechanism is not

controlled by massive limestone that has high strength, but rather by a clay layer that has lower shear strength parameters. These findings are in line with the concept of slope mechanics which states that avalanches generally develop in zones with the smallest cohesion values and shear angles [3].

Manual calculations using the Bishop method with 25 slices yielded a safety factor of 2.0724. The difference in software results is only 0.0024 or 0.12%. This very small deviation shows that the numerical model used is able to accurately represent the calculation of the equilibrium of the limit. The suitability of these results also indicates that the geometric and geotechnical parameters used have been well defined, resulting in a high level of analytical reliability.

Table 1. Results of Cross-Section Calculation A

Slice	Luas (m ²)	Wt (kN)	θ (°)	γ (kN/m ³)	c (kPa)	φ (°)	Sin θ	Cos θ	Bi (m)	ui	tan φ	Wt . Sin θ	Wt . Tan φ	c . Bi	Wt . ui . Bi	Mi	FK Iterasi c . Bi + Wt . tan φ × 1/Mi
1	7.4926	154.348	52	20.6	125	22	0.788	0.616	3.4534	0	0.404	121.828	62.360	431.68	154.348	0.789	642.049
2	21.3868	440.568	49	20.6	125	22	0.755	0.656	3.4534	0	0.404	332.501	178.001	431.68	440.568	0.803	758.903
3	33.7958	696.193	46	20.6	125	22	0.719	0.695	3.4534	0	0.404	500.800	201.280	431.68	696.193	0.835	853.777
4	43.9072	905.724	44	20.6	125	22	0.695	0.719	3.4534	0	0.404	629.169	365.936	431.68	905.724	0.855	932.961
5	47.7215	983.063	41	20.6	125	22	0.656	0.755	3.4534	0	0.404	644.947	397.183	431.68	983.063	0.883	936.939
6	49.4493	1018.656	39	20.6	125	22	0.629	0.777	3.4534	0	0.404	641.061	411.564	431.68	1018.656	0.900	936.955
7	54.4972	1122.642	37	20.6	125	22	0.602	0.799	3.4534	0	0.404	675.623	453.577	431.68	1122.642	0.916	986.328
8	62.8037	1293.756	34	20.6	125	22	0.559	0.829	3.4534	0	0.404	723.459	522.711	431.68	1293.756	0.938	1017.272
9	70.3219	1448.631	32	20.6	125	22	0.530	0.848	3.4534	0	0.404	767.658	585.285	431.68	1448.631	0.951	1068.621
10	77.2127	1590.582	30	20.6	125	22	0.500	0.868	3.4534	0	0.404	795.291	642.637	431.68	1590.582	0.964	1114.875
11	83.3573	1717.160	28	20.6	125	22	0.469	0.883	3.4534	0	0.404	806.158	693.778	431.68	1717.160	0.975	1154.868
12	84.8237	1747.368	26	20.6	125	22	0.438	0.899	3.4534	0	0.404	785.996	705.983	431.68	1747.368	0.984	1155.738
13	66.6820	1373.855	24	20.6	125	22	0.407	0.914	3.4534	0	0.404	558.797	555.074	431.68	1373.855	0.993	993.771
14	60.1036	1238.134	22	20.6	125	22	0.375	0.927	3.4534	0	0.404	463.813	500.239	431.68	1238.134	1.000	931.634
15	57.0949	1176.155	20	20.6	125	22	0.342	0.940	3.4534	0	0.404	402.269	475.197	431.68	1176.155	1.006	901.062
16	53.8267	1108.830	18	20.6	125	22	0.309	0.951	3.4534	0	0.404	342.647	447.996	431.68	1108.830	1.011	869.781
17	50.1216	1032.505	16	20.6	125	22	0.276	0.961	3.4534	0	0.404	284.597	417.159	431.68	1032.505	1.015	836.239
18	45.9884	947.361	14	20.6	125	22	0.242	0.970	3.4534	0	0.404	229.187	382.759	431.68	947.361	1.018	800.415
19	41.4386	853.835	13	20.6	125	22	0.225	0.974	3.4534	0	0.404	192.026	344.891	431.68	853.835	1.018	762.628
20	36.4137	750.122	11	20.6	125	22	0.191	0.982	3.4534	0	0.404	143.130	303.060	431.68	750.122	1.019	721.136
21	30.2675	623.511	9	20.6	125	22	0.156	0.988	3.4534	0	0.404	97.539	251.915	431.68	623.511	1.018	671.356
22	23.5346	484.813	7	20.6	125	22	0.122	0.993	3.4534	0	0.404	59.084	195.877	431.68	484.813	1.016	617.467
23	16.7848	345.767	5	20.6	125	22	0.087	0.996	3.4534	0	0.404	30.136	139.699	431.68	345.767	1.013	563.927
24	10.3460	213.128	3	20.6	125	22	0.052	0.999	3.4534	0	0.404	11.154	86.109	431.68	213.128	1.009	513.245
25	3.5329	72.778	2	20.6	125	22	0.035	0.999	3.4534	0	0.404	2.540	29.404	431.68	72.778	1.006	458.237
TOTAL																	2182.326
FK =																	2.0724

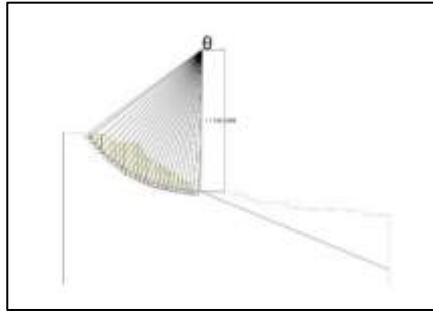


Figure 4. The Slip Surface of Slope Cross-Section A

Analysis of Shear Slope B

Cross-Section B has a slope height of 56.9 m with the same number of levels, namely 13 benches. However, the overall slope angle is more sloping, which is 12.82° . The results of the analysis using Slide v6.0 resulted in a safety factor of 2.709, while the manual calculation gave a value of 2.7129. The difference between the two methods is only 0.0039 or 0.14%.

The value of the safety factor of Cross-Section B is higher than that of Cross-Section A. The difference is mainly influenced by the sloping slope geometry so that the components of the driving force acting along the landslide plane are smaller. In slope stability analysis, a decrease in slope angle in general will increase the ratio between the retaining force to the driving force, resulting in a greater safety factor [4].

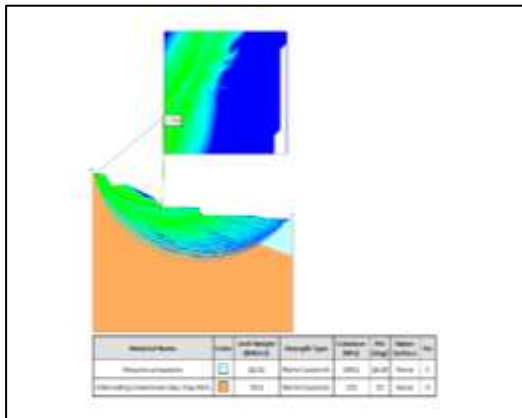


Figure 5. Slide Analysis Results of Slope Cross-Section B, Block X, Palimanan Quarry

Although the lithological conditions of the two sections are relatively similar, the influence of slope geometry has been shown to contribute significantly to improved stability. These results show that slope geometry regulation is still one of the most effective approaches in controlling landslide risk in open-pit mines. Safety factor values that are well above the minimum limit commonly used on the mine slope indicate that Cut B has a better level of stability than Cut A.

Table 2. Results of Cross-Section Calculation B

Slice	Luas (m)	Wl (kN)	θ (°)	γ (kN/m ³)	c (kPa)	ϕ (°)	Sin θ	Cos θ	Bl (m)	ul	$\tan \phi$	Wl Sin θ	Wl Tan ϕ	c Bl	Wl ul Bl	Mi	FK Iterasi	(c Bl + Wl tan ϕ) x 1/Mi
1	6.1697	127.096	49	20.6	125	22	0.755	0.656	3.3248	0	0.404	95.920	51.350	415.6	127.096	0.769		607.519
2	17.7468	365.584	47	20.6	125	22	0.731	0.682	3.3248	0	0.404	267.371	147.706	415.6	365.584	0.791		712.077
3	28.2973	582.924	44	20.6	125	22	0.695	0.719	3.3248	0	0.404	404.933	235.517	415.6	582.924	0.823		791.206
4	36.2391	746.525	42	20.6	125	22	0.669	0.743	3.3248	0	0.404	499.523	301.616	415.6	746.525	0.843		850.850
5	30.1437	620.960	40	20.6	125	22	0.643	0.766	3.3248	0	0.404	399.146	250.884	415.6	620.960	0.862		773.263
6	17.9530	369.832	38	20.6	125	22	0.616	0.788	3.3248	0	0.404	227.691	149.422	415.6	369.832	0.880		642.193
7	19.3273	398.142	35	20.6	125	22	0.574	0.819	3.3248	0	0.404	228.365	160.860	415.6	398.142	0.905		637.186
8	26.7993	552.066	33	20.6	125	22	0.545	0.839	3.3248	0	0.404	300.676	223.049	415.6	552.066	0.920		694.260
9	33.7861	695.994	31	20.6	125	22	0.515	0.857	3.3248	0	0.404	358.463	281.200	415.6	695.994	0.934		746.053
10	40.2614	829.385	29	20.6	125	22	0.485	0.875	3.3248	0	0.404	402.094	335.093	415.6	829.385	0.947		792.769
11	46.2396	952.536	27	20.6	125	22	0.454	0.891	3.3248	0	0.404	432.442	384.849	415.6	952.536	0.959		834.918
12	51.7472	1065.992	26	20.6	125	22	0.438	0.899	3.3248	0	0.404	467.300	430.689	415.6	1065.992	0.964		877.735
13	56.2566	1158.865	24	20.6	125	22	0.407	0.914	3.3248	0	0.404	471.353	468.212	415.6	1158.865	0.974	2.789	907.212
14	55.1279	1135.635	22	20.6	125	22	0.375	0.927	3.3248	0	0.404	425.416	458.826	415.6	1135.635	0.983		889.500
15	53.3523	1099.057	20	20.6	125	22	0.342	0.940	3.3248	0	0.404	375.900	444.048	415.6	1099.057	0.991		867.716
16	52.0549	1072.331	18	20.6	125	22	0.309	0.951	3.3248	0	0.404	331.368	433.250	415.6	1072.331	0.997		851.281
17	48.9585	1008.586	16	20.6	125	22	0.276	0.961	3.3248	0	0.404	277.998	407.487	415.6	1008.586	1.002		821.140
18	46.4763	957.412	15	20.6	125	22	0.259	0.966	3.3248	0	0.404	247.796	386.819	415.6	957.412	1.005		798.804
19	43.8435	903.176	13	20.6	125	22	0.225	0.974	3.3248	0	0.404	203.170	364.907	415.6	903.176	1.008		774.374
20	40.8559	841.632	11	20.6	125	22	0.191	0.982	3.3248	0	0.404	160.591	340.041	415.6	841.632	1.010		748.097
21	37.5204	772.920	9	20.6	125	22	0.156	0.988	3.3248	0	0.404	120.911	312.280	415.6	772.920	1.011		719.947
22	33.8428	697.162	8	20.6	125	22	0.139	0.990	3.3248	0	0.404	97.026	281.672	415.6	697.162	1.011		689.688
23	27.4165	564.780	6	20.6	125	22	0.105	0.995	3.3248	0	0.404	59.036	228.186	415.6	564.780	1.010		637.341
24	17.0452	351.131	4	20.6	125	22	0.070	0.998	3.3248	0	0.404	24.494	141.886	415.6	351.131	1.008		553.060
25	5.7550	118.553	3	20.6	125	22	0.052	0.999	3.3248	0	0.404	6.205	47.899	415.6	118.553	1.006		490.535
TOTAL												6885.191	7267.727	10390	17988.256	23.612		18678.703
FK =															2.7129			

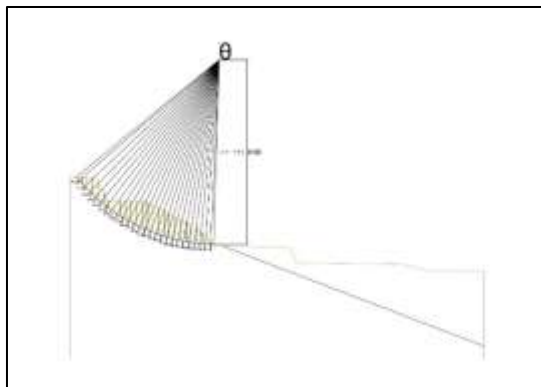


Figure 6. The Slip Surface of Slope Cross-Section B

Comparison of Analysis Results of Cross-Section A and Cross-Section B

A comparison of the results of the two sections showed that the overall value of the safety factor was above 2.0. This condition indicates that the slope is in the stable category and has sufficient safety margins against the potential for landslides. Nonetheless, the existence of an *Alternating Limestone Clay* layer still needs to

be a concern because the entire critical slip field develops on the material.

The analysis also showed that changes in slope geometry had a more dominant influence on the value of safety factors than the difference in slope height alone. Cross-Section B, which has a sloping slope, produces a safety factor of about 30.9% higher than Cross-Section A. These findings confirm that slope geometry optimization is the main factor in maintaining the stability of the mine slope under relatively similar lithological conditions.

In addition, the deviation between the results of manual and software calculations is below 0.15%, which indicates an excellent level of consistency. These results strengthen the validity of the use of Slide v6.0 software as a tool for analyzing slope stability using the Bishop method on the geological conditions of Block X of the Palimanan Quarry.

Table 3. Summary of Comparative Slope Stability Analysis Results

Parameters	Cross-Section A	Cross-Section B
Slope Height (m)	63,0	56,9
Number of Benches	13	13
Average Bench Width (m)	19,20	19,23
Average Bench Height (m)	4,84	4,37
Overall Slope Angle (°)	14,14	12,82
Safety Factor Slide v6.0	2,070	2,709
Manual Safety Factors	2,0724	2,7129
Deviation	0,0024	0,0039
Deviation (%)	0,12	0,14
Slip Plane Controller Material	Alternating Limestone Clay	Alternating Limestone Clay
Stability Interpretation	Stable	Highly Stable

The results showed that both sections met the criteria for safe slope stability based on the Bishop method. The high value of the safety factor indicates that the existing slope geometric design is still able to maintain slope balance in dry conditions. However, the presence of a clay layer that functions as a weak zone still needs to be considered in long-term slope management, especially when there are changes in hydrogeological conditions due to rainfall or continued mining activities.

CONCLUSION

The main outcomes derived from this study confirm that slope stability evaluations for Cross-Section A produced Safety Factor (SF) metrics of 2.070 via computational simulation and 2.0724 through manual determination, while Cross-Section B reached SF values of 2.709 (software) and 2.7129 (manual). Because both cross-sections comfortably surpass the established thresholds for minimum safety (SF

> 1,25) and long-term performance (SF >1,50) per Bowles (1984) criteria, the slope conditions are declared to be highly stable.

Furthermore, cross-referencing the numerical outputs from Rocscience Slide v6.0 against hand calculations based on the Limit Equilibrium Method (Simplified Bishop) revealed exceptional alignment, where marginal variance levels of only 0.12% for Cross-Section A and 0.14% for Cross-Section B demonstrate that digital slope modeling provides valid, high-precision, and scientifically sound results suitable for corporate geotechnical quality assurance.

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