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SIMULATION OF SLOPE CUTTING STAGES USING PLAXIS 2D (CASE STUDY: RD 24 PT. BARA TABANG, INDONESIA)

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ABSTRACT

Proper slope cutting planning is crucial to minimize the risk of landslides in infrastructure development projects located on slopes. The potential for landslides is triggered by the weight of the soil mass, external loads, and groundwater infiltration. The Plaxis 2D application is generally widely used by geotechnical planners, but most perform slope cutting in one stage at a time. Therefore, on this occasion, a study will be conducted that focuses on a gradual cutting method based on variations in cutting direction on slope stability in a humid tropical soil environment that is vulnerable to weather changes. This study was located on the slope of RD 24, PT. Bara Tabang, Kutai Kartanegara, East Kalimantan. Soil parameters for the Mohr-Coulomb model in Plaxis 2D were obtained from the N-SPT correlation table and laboratory results, which identified the presence of five clay layers with consistencies ranging from very soft to hard. This simulation was divided into 14 cutting phases. The top-down method was planned to be 2,5 m high, while the bottom-up method was with a slope angle of < 45°, where both methods were proven stable because they obtained SF values > 2 under normal and rainy conditions. The top-down method is the most effective recommendation because the work begins by reducing the soil thrust on the slope. The staged calculation also provides a basis for identifying critical temporary conditions, so unstable excavation phases can be anticipated before field implementation.

Keywords:
Dry Conditions, Plaxis 2D, Rainy Conditions, Safety Factor, Slope Cutting

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INTRODUCTION

Sloping topography is one of the main challenges in infrastructure planning because it has the potential for landslides due to the weight of the soil mass itself, groundwater infiltration, and external loads from outside the slope [1]. Therefore, proper slope cutting planning is necessary to maintain slope stability during the construction process. With the development of geotechnical technology, the use of the Plaxis 2D application is used to model soil behavior, simulate earth pressure, and slope deformation before the cutting process is carried out. Previous studies generally carried out slope cutting in one stage at a time, while the influence of the direction and stages of cutting on slope stability has not been studied in depth, especially in the characteristics of tropical soils that are humid and vulnerable to weather changes. Therefore, this study aims to analyze slope stability based on simulations of cutting stages with top-down and bottom-up methods using the Plaxis 2D application under normal conditions and during rain, by paying attention to the safety factor values obtained.

Stage-by-stage slope cutting calculation provides important benefits because excavation is a path-dependent process in which each removal phase changes the slope geometry, releases confining stress, and redistributes stress and pore-water pressure. The calculation therefore supports the selection of cutting direction, equipment sequence, and preventive measures before construction. If the calculation is not conducted, the excavation sequence may rely only on empirical judgment, so temporary critical conditions, excessive deformation, progressive failure, or rainfall-triggered instability may not be detected during field implementation [11], [12].

METHODOLOGY

This research is located on the slopes of RD 24, precisely in the area of PT. Bara Tabang, Tabang District, Kutai Kartanegara Regency, East Kalimantan Province, which can be seen in Figure 1.

Figure 1 Research Location

The research began with a literature review of relevant previous studies. Secondary data collected included Standard Penetration Test (SPT) data, laboratory results, slope geometry drawings (as seen in Figure 2), and rainfall data obtained from the Kalimantan Meteorology, Climatology, and Geophysics Agency (BMKG) for water infiltration rate analysis. Soil mechanical parameters were obtained through the correlation of N-SPT values with reference to Lambe and Whitman [2]. Specifically, the relationship between N-SPT and clay soil consistency refers to Terzaghi & Peck [3], whereas for sandy soil refer to Meyerhof [4]. The value of the soil elastic modulus and Poisson's ratio is determined based on the type of soil according to Bowles [5]. Soil stratification is modeled by grouping similar physical characteristics of soil layers and N-SPT values to determine layer boundaries in the model [6]. The soil geometry and stratification were then modeled in Plaxis 2D to simulate the slope cutting sequence from top to bottom and from bottom to top. Afterward, slope stability analysis was performed under normal and rainy conditions, taking into account the factor of safety.

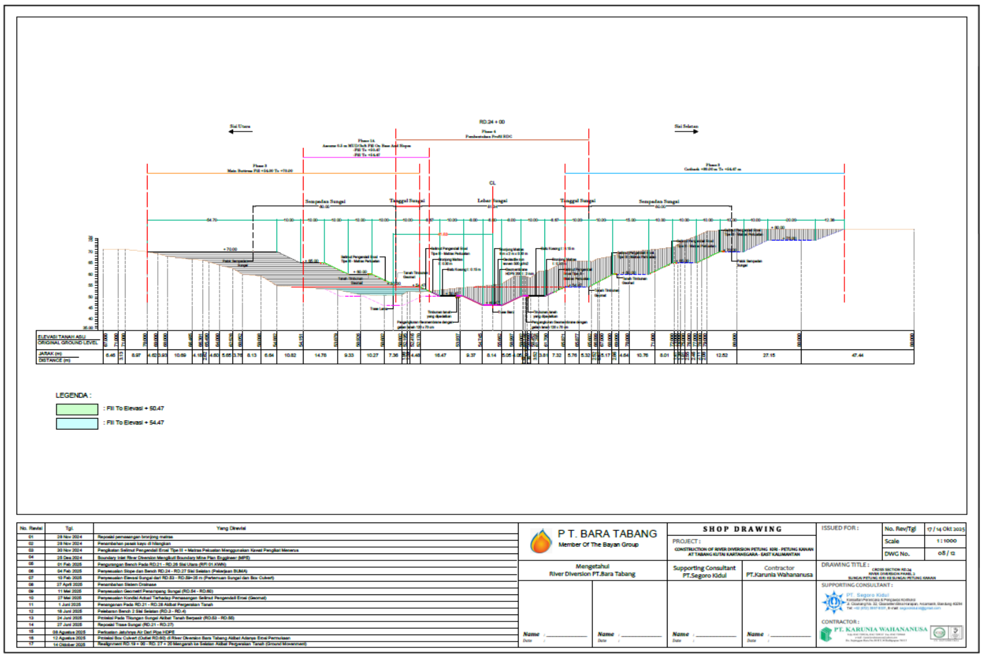


Figure 2 Slope Cross-Section

RESULTS AND DISCUSSION

Determination of Soil Stratification

The results of the investigation to create soil stratification were obtained from the SPT test data at points BH-04, BH-05, BH-06, and BH-06A which can be seen in Table 1. The soil stratification image was created by placing the borehole point according to the elevation of the ground surface at each point, then drawn vertically following the depth of the SPT test results, and finally, connecting the soil layers that have similar types and consistencies as well as similar N-SPT values based on the depth of each layer which can be seen in Figure 3. The soil layer in the slope area that is not passed by the borehole point is determined by assuming the soil layer based on the nearest borehole data.

No. Point	Elevation (m)	Groundwater Level (m)	Depth (m)	N-SPT	Soil Type	Consistency
BH-04	53,041	1,2	0-2	12	Clay	Medium
			2-4	7	Clay	Soft
			4-6	9	Clay	Medium
			6-8	22	Clay	Stiff
			8-10	41	Clay	Stiff
			10-12	53	Clay	Hard
			12-14	47	Clay	Hard
BH-05	50,773	1,55	0-2	3	Clay	Soft

Table 1 Soil Stratification

No. Point	Elevation (m)	Groundwater Level (m)	Depth (m)	N-SPT	Soil Type	Consistency
BH-05	50,773	1,55	2-4	4	Clay	Soft
			4-6	18	Clay	Stiff
			6-8	5	Clay	Soft
			8-10	34	Clay	Hard
			10-12	42	Clay	Hard
			12-14	48	Clay	Hard
BH-06	55,113	1,4	0-2	3	Sandy Clay	Very Soft
			2-4	4	Sandy Clay	Very Soft
			4-6	9	Clay Stone	Medium
			6-8	9	Clay Stone	Medium
			8-10	18	Clay	Stiff
			10-12	22	Clay	Stiff
			12-14	53	Sandy Clay	Hard
			14-16	55	Sandy Clay	Hard
			16-18	47	Sandy Clay	Hard
BH-06A	61,532	1,85	0-2	12	Clay	Medium
			2-4	7	Sandy Clay	Soft
			4-6	10	Clay Stone	Medium
			6-8	7	Clay Stone	Soft
			8-10	15	Sandy Clay	Medium
			10-12	19	Sandy Clay	Stiff
			12-14	29	Sandy Clay	Stiff
			14-16	38	Clay Stone	Hard
			16-18	43	Clay Stone	Hard
			18-20	49	Clay Stone	Hard
			20-22	45	Clay Stone	Hard

Table 1 Soil Stratification (Advanced)

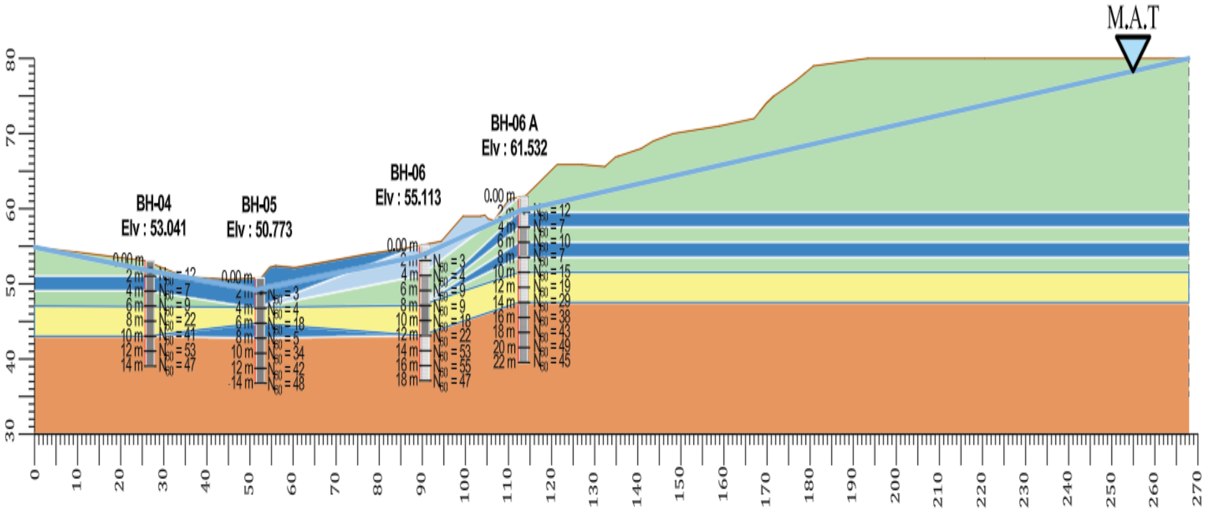


Figure 3 Soil Stratification

Soil Parameters

The soil parameters in this study were obtained using a correlation approach between N-SPT data and laboratory test results. To analyze slopes, soil parameters were input into Plaxis 2D, as shown in Table 2.

	Name	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Unit
Material Model	Model	*Mohr-Coulomb*	*Mohr-Coulomb*	*Mohr-Coulomb*	*Mohr-Coulomb*	*Mohr-Coulomb*	-
Types of Material Behavior	Jenis	*Undrained A*	*Undrained A*	*Undrained A*	*Undrained A*	*Undrained A*	-
Unsaturated Soil Bulk Density	γ_{unsat}	18,00	18,73	19,89	20,27	22,00	kN/m^3
Saturated Soil Unit Weight	γ_{sat}	19,00	19,42	20,11	21,79	22,10	kN/m^3
Modulus Elasticity	E	20000	23333	40000	49286	75000	kN/m^2
Poisson’s Ratio	v	0,4	0,4	0,4	0,4	0,4	-
Cohesion	c	21,25	33,25	54,16	129,38	200,00	kN/m^2
Internal Friction Angle	φ	17,50	22,82	28,34	33,57	39,33	°
Permeability	$K_x = K_y$	0,048	0,048	0,048	0,048	0,048	m/day

Table 2 Soil Parameters

Slope Cutting Simulation Modeling

The slope cutting is planned to be carried out in 14 excavation phases. This simulation modeling was carried out using top-down and bottom-up cutting methods to compare which method is more effective when applied in the field. The top-down cutting at each stage was designed to be 2,5 meters high, considering the reach capacity of heavy equipment, while the bottom-up cutting was carried out considering a slope of <45°. This statement has also been mentioned by Yudha et al. [7] the application of the horizontal method is effective at a depth of 1 to 3 meters, using a maximum permissible slope angle of 30° on soft sandy clay soil, while on medium sandy silt it is <45°. The schematic of the cutting sequence can be seen in Figures 4 and 5.

In this study, staged calculation was used not only to verify the final safety factor, but also to identify the temporary critical phases that may occur during excavation. This is important because a slope that appears stable in its final geometry can still experience a lower safety margin during intermediate cuts; numerical finite-element modelling allows deformation, horizontal displacement, and stress-path changes to be checked for each construction phase [11], [13].

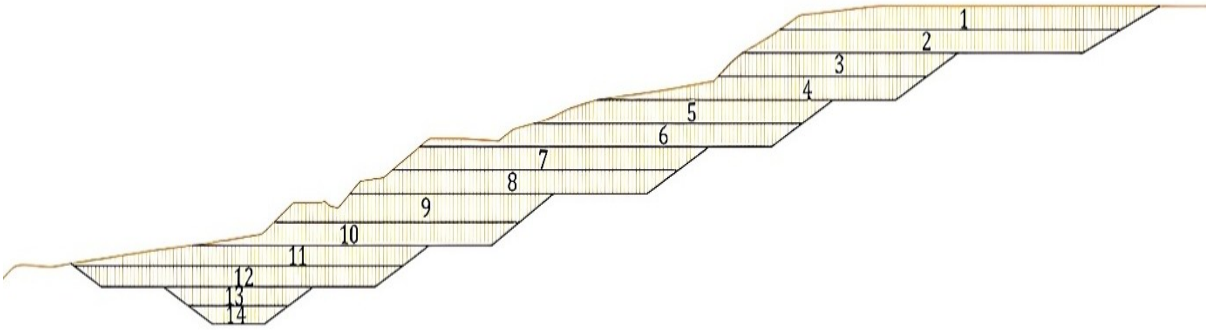


Figure 4 Schematic of Cutting Sequence from Top to Bottom of Slope

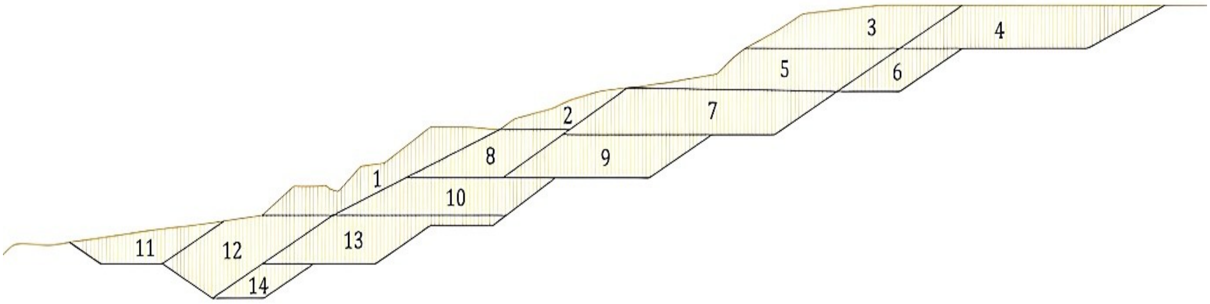
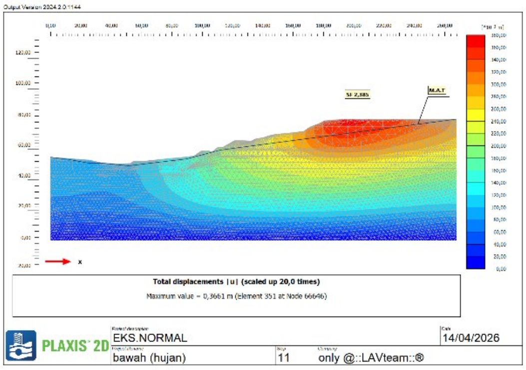


Figure 5 Schematic of Cutting Sequence from Bottom to Top of Slope

Existing Slope Stability Analysis

Before analyzing the slope cutting stages, an existing slope analysis is necessary to determine the slope stability under existing conditions in the field without the influence of geometric changes. Figures 6 and 7 show that the SF value under normal conditions is 2,385, while under rainy conditions it is 2,376. Based on the SF values obtained from the analysis results, the existing slope under normal and rainy conditions has an SF greater than the minimum limit required, which is 1,5 in SNI 8460:2017. [8].



Total displacements |u| (scaled up 20,0 times)
Maximum value = 0,3661 m (Element 351 at Node 66646)

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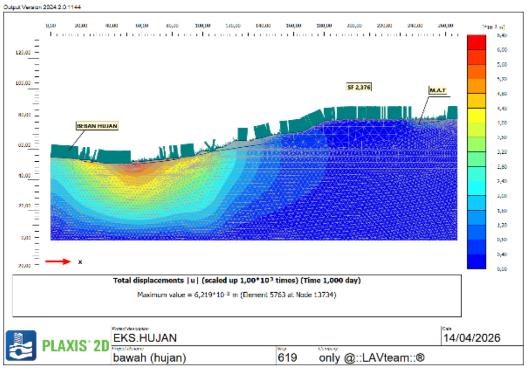
Figure 6 Total Displacement of Existing Conditions under Normal Conditions



Total displacements |u| (scaled up 1,00*10³ times) (Time 1,000 day)
Maximum value = 6,219*10⁻³ m (Element 5763 at Node 13734)

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Figure 7 Total Displacement of Existing Conditions Under Rainy Conditions

Analysis of Slope Cutting Stages Under Normal Conditions

Table 3 shows the slope cutting sequence analysis from excavation 1 to excavation 14 under normal conditions, which shows a safety factor value above the minimum limit of 1,5. This proves that the slope is safe and stable against potential landslides even though there is a reduction in load due to excavation under normal conditions. Figure 8 shows changes in SF divided into three phases: the initial phase of excavation 1-6 has a superior SF value in the top-down direction of cutting; the second phase of excavation 7 and 8 experiences an increase in SF values from the bottom-up direction of cutting; and the final phase of excavation 9 to 14, the SF values in both cutting directions obtain a stable graph. Overall, under normal conditions, the top-down direction of cutting is the most effective recommendation for implementation in the field.

No.	Phase	Safety Factor (SF) Cutting Direction		Minimum Limit (SNI 8460:2017)	Stability Information
		Top to Bottom	Bottom to Top		
1.	Existing Conditions	2,385	2,385	1,5	Stabil
2.	Excavation 1	2,589	2,224		Stabil
3.	Excavation 2	2,834	2,217		Stabil
4.	Excavation 3	2,881	2,571		Stabil
5.	Excavation 4	2,894	2,595		Stabil
6.	Excavation 5	3,006	2,855		Stabil
7.	Excavation 6	3,145	2,868		Stabil
8.	Excavation 7	3,146	3,259		Stabil
9.	Excavation 8	2,932	3,304		Stabil
10.	Excavation 9	2,926	2,914		Stabil
11.	Excavation 10	2,886	2,905		Stabil
12.	Excavation 11	2,868	2,905		Stabil
13.	Excavation 12	2,887	2,9		Stabil
14.	Excavation 13	2,878	2,878		Stabil
15.	Excavation 14	2,886	2,882		Stabil

Table 3 SF Results of Slope Cutting Stages in Normal Conditions

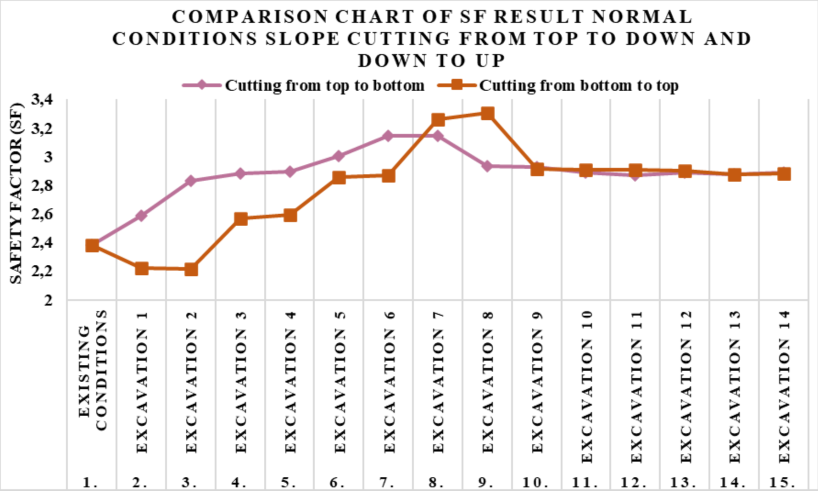

Figure 8 Comparison Chart of SF Results of Slope Cutting Under Normal Conditions From Top to Bottom and Bottom to Top Directions

Analysis of Slope Cutting Stages in Rainy Conditions

Table 4 shows an analysis of the slope cutting sequence from excavation 1 to excavation 14 under rainy conditions, which shows a safety factor value above the minimum limit of 1,5. This proves that the slope is safe and stable against potential landslides, even though there is a reduction in load due to excavation under rainy conditions. Figure 9 shows changes in SF divided into three phases: the first phase for excavations 1-6 has a superior SF value in the top-down direction of cutting; the second phase for excavations 7 and 8 experiences an increase in SF values from the bottom-up direction of cutting; and the final phase for excavations 9 to 14, the SF values in both cutting directions obtain a stable graph. Overall, under rainy conditions, the top-down direction of cutting is the most effective recommendation for implementation in the field.

No.	Phase	Safety Factor (SF) Cutting Direction		Minimum Limit (SNI 8460:2017)	Stability Information
		Top to Bottom	Bottom to Top		
1.	Existing Conditions	2,376	2,376	1,5	Stabil
2.	Excavation 1	2,563	2,195		Stabil
3.	Excavation 2	2,781	2,175		Stabil
4.	Excavation 3	2,847	2,511		Stabil
5.	Excavation 4	2,852	2,511		Stabil
6.	Excavation 5	2,846	2,756		Stabil
7.	Excavation 6	2,977	2,764		Stabil
8.	Excavation 7	2,821	2,96		Stabil
9.	Excavation 8	2,601	2,957		Stabil
10.	Excavation 9	2,61	2,578		Stabil
11.	Excavation 10	2,577	2,579		Stabil
12.	Excavation 11	2,578	2,58		Stabil
13.	Excavation 12	2,581	2,584		Stabil
14.	Excavation 13	2,587	2,571		Stabil
15.	Excavation 14	2,585	2,564		Stabil

Table 4 SF Results of Slope Cutting Stages in Rainy Conditions

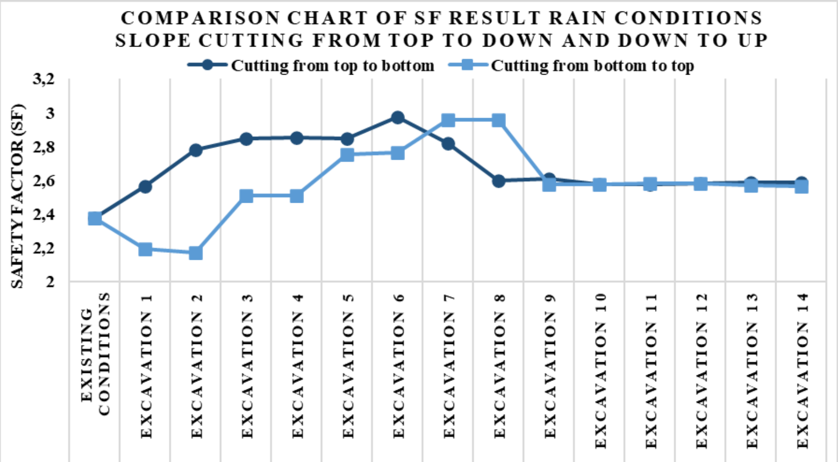

Figure 9 Comparison Chart of SF Results of Slope Cutting in Rainy Conditions From Top to Bottom and Bottom to Top Directions

Under normal and rainy conditions, cutting a slope from top to bottom increases the safety factor (SF) value due to reduced thrust on the soil, while cutting from bottom to top causes a decrease in the SF value due to the loss of soil retaining force at the foot of the slope, while the soil thrust above it is still fully active. Based on this statement, recommendations for the most effective cutting direction to be implemented in the field are obtained, namely cutting from top to bottom.

The benefit of performing staged cutting calculations in this analysis is that the critical phase can be identified before excavation reaches the final design geometry. The SF trend in each phase provides an early-warning basis for determining whether the next cut can proceed, whether the cutting direction should be modified, or whether drainage and temporary reinforcement are required. Without this staged evaluation, the risk of selecting an unsafe excavation sequence increases, especially when the slope toe is removed first or when rainfall infiltration reduces shear strength; these conditions can accelerate displacement, increase pore-water pressure, and trigger local or progressive slope failure [11]–[13].

Comparison of Slope Cutting Stage Analysis Results Under Normal and Rainy Conditions

Figures 10 and 11 consistently show that the safety factor (SF) under normal conditions is always higher than during rainfall. This demonstrates that the impact of rainwater infiltration into the soil mass can trigger increased pore water pressure while reducing the shear strength of the slope. After rainfall, the SF value decreases due to water infiltration, which causes the slope to become saturated and unstable due to the increased load, resulting in a higher risk of landslides than under normal conditions [9]. According to Muchtaranda et al. [10], the drastic level of slope stability against the risk of failure can be triggered by the low SF value in rainy conditions compared to conditions without the influence of rainfall.

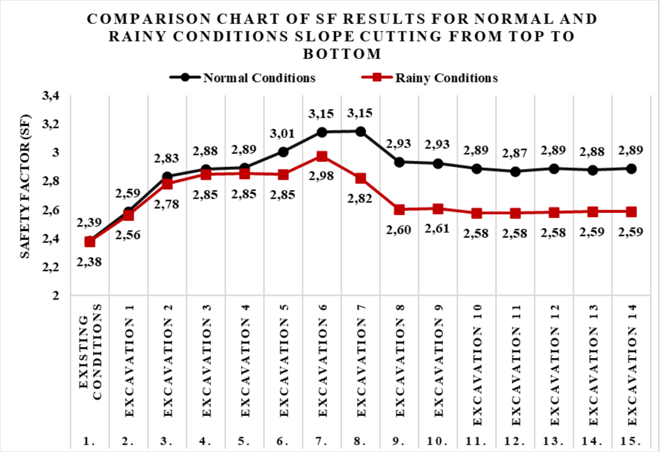

Figure 10 Comparison Chart of SF Result For Normal and Rainy Conditions Slope Cutting From Top to Bottom

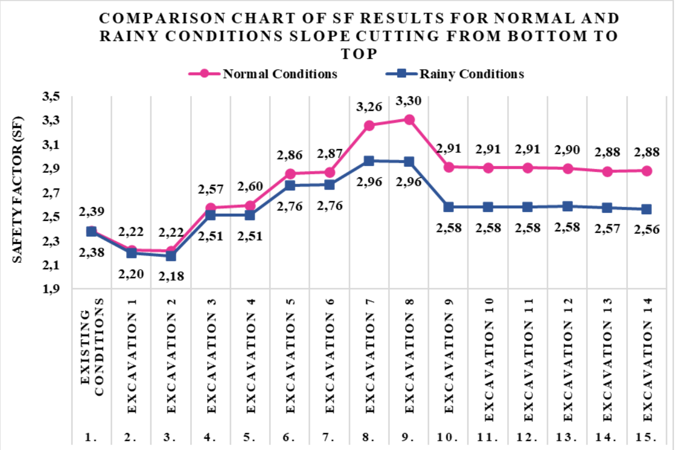

Figure 11 Comparison Chart of SF Result For Normal and Rainy Conditions Slope Cutting From Bottom to Top

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CONCLUSION

Based on the results of the simulation analysis of the slope cutting stages using Plaxis 2D that has been carried out, the following conclusions can be drawn:

1. The soil stratification at the site consists of five distinct clay layers, with consistencies ranging from very soft, soft, medium, stiff, to hard.
2. Soil parameter data in the Mohr-Coulomb model on Plaxis 2D was obtained from the correlation table of N -SPT data and laboratory results.
3. Slope cutting was performed by simulating 14 cutting phases. The top-down cutting method used a height of 2.5 m, while the bottom-up cutting method used a slope of <45°.
4. The top-down and bottom-up cutting methods, both under normal and rainy conditions, produce SF > 2 (stable). However, the top-down cutting method is the most effective recommendation because the cutting begins by reducing the soil thrust on the slope, which can increase the safety factor (SF). These staged calculations are also beneficial for detecting temporary critical conditions; if they are omitted, the field cutting sequence may fail to identify unstable intermediate phases and may increase the risk of local or progressive failure.

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