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Slope Design for Cost Optimization of Slope Cutting and Reinforcement (Case Study: Trans-Sumatra Toll Road Rengat Pekanbaru Section Lingkar Pekanbaru Junction Pekanbaru Sta. 205+150 - 205+725)

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ABSTRACT

The trans-Sumatra toll road project currently under construction is the Rengat - Pekanbaru toll road construction project, the Pekanbaru ring road section located at km 205 + 150 to km 205 + 725 (575m long). In this section, quite deep excavation work is required as well as quite wide land acquisition which causes expensive land acquisition costs. In this study, slope variations were carried out with steeper angles in order to obtain a smaller road ROW; only additional reinforcement needs to be planned so that the slope is more stable and does not cause landslides. The stability of the varying slope slopes was analyzed using an auxiliary program to obtain the safety factor for each selected slope. In conducting the analysis, the elevation of the groundwater level was varied, namely at the bottom of the excavation (conditions during the dry season), as in secondary data, and at the top of the excavation (conditions during maximum rainfall). Slope stability analysis was also carried out using the ' *theory of cracked soil' approach.* Slope reinforcement using *ground anchors* will be planned if SF <1.0; for slopes that have SF ≥ 1.0, rainwater management will be carried out without reinforcement. The excavation slope at Sta 205+400 with a slope of 1:2 and 1:3 and the groundwater level at the top of the excavation is SF = 1.73; if the analysis is carried out using the cracked soil approach, the safety factor value drops to SF = 0.68. In addition, in the alternative slope gradients, namely alternative 1 with a slope angle of 1:1 and alternative 2 with a slope angle of 2:1, the slope safety factor changes quite drastically to 0.39 in alternative 1 and 0.2 in alternative 2. The cost calculation for alternative 2 with a slope gradient of 2:1 saves excavation work of 183,136.31 m3, 34,375 m2 of land acquisition and reinforcement costs of 3,422 Ground anchor points in cracked soil conditions and groundwater elevation with existing conditions of secondary data. Cost optimization of Rp. 18,423,905,547,-

Keywords : slope, optimal cost, slope variation, groundwater level

INTRODUCTION

The Trans-Sumatra Toll Road Development Project is a concept for developing land transportation that is being carried out progressively across the island of Sumatra. This toll road development project is part of the National Strategic Projects (NSP) for 2014–2024, as it aims to boost economic growth, promote equitable development, enhance community welfare, and support regional development. As part of the project's stages, the construction of the Trans-Sumatra Toll Road for the Rengat–Pekanbaru Section, including the Pekanbaru Ring Road–Pekanbaru Junction, is underway. This project is located in the city of Pekanbaru, Riau Province, as shown in Figure 1.

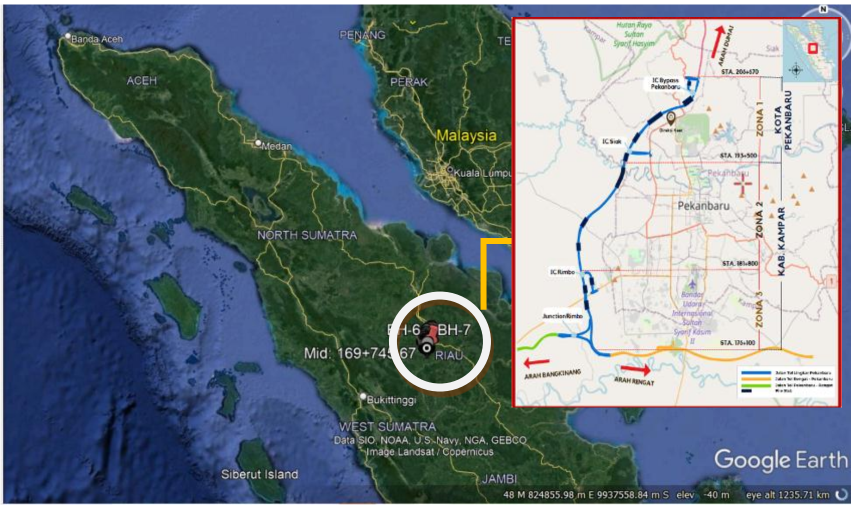


Figure 1. Location of the construction of the Trans-Sumatra Toll Road, Rengat - Pekanbaru Section, Pekanbaru Ring Section - Pekanbaru Junction (Hutama Karya, 2023)

One of the problems that occurred in the project is at Sta. 205+150 -Sta 205+725, namely the existence of quite deep excavation work where the deepest excavation is 21m with different types of soil layers. Based on the results of the soil investigation carried out, as shown in the borelog (Figure 2), the type of soil layer is composed of medium clay to stiff clay to a depth of 7.00 m and sandy clay with a stiff consistency to a depth of 20.00m. SPT values of less than 4 are found at depths of 0.00 – 1.50 m; NSPT 4 – 10 at depths of 1.50 – 7.00 m; NSPT 10 – 25 at an average depth of 7.00 – 24.00 m; and NSPT > 25 are found at depths of 24.00 – 35.00 m. The groundwater level in each recorded borehole fluctuates according to the season, climate variations, and changes in land use functions. Variations in groundwater level depth that occur in the excavation area km 205+150 – 205+725 can be seen in Table 1.

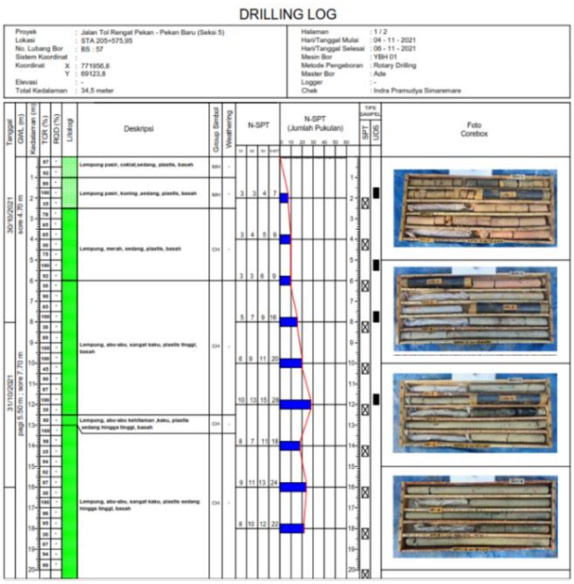


Figure 2. Soil Data from N-SPT Borelog Test Results
[Source: PT. Hutama Karya (Persero) 2022]

Table 1. Groundwater Depth

No	STA	Ground Water Level (m)
1	166+50	0.30
2	166+100	0.30
3	170+000	3.00
4	174+200	4.00
5	178+500	1.50
6	179+400	3.00
7	180+900	1.00
8	182+650	2.00
9	185+500	2.00
10	190+750	1.50
11	191+600	2.00
12	194+650	2.00
13	196+900	1.00
14	200+200	2.50
15	201+600	3.00
16	204+600	4.00
17	206+100	4.00

[Source: PT. Hutama Karya (Persero) 2022]

The cross-section of the road in the excavation (Figure 3) shows that the width of the excavation base for the planned road width is 25.90 meters, the slope of the existing excavation is very gentle so that the planned road Row becomes very wide, which is around 123m. This causes the cost of land acquisition to be very expensive, which means it is very detrimental and the project becomes inefficient. For this reason, the slope of the road excavation slope needs to be optimized so that the cost of land acquisition and the cost of cutting the excavation and strengthening the slope are not too expensive.

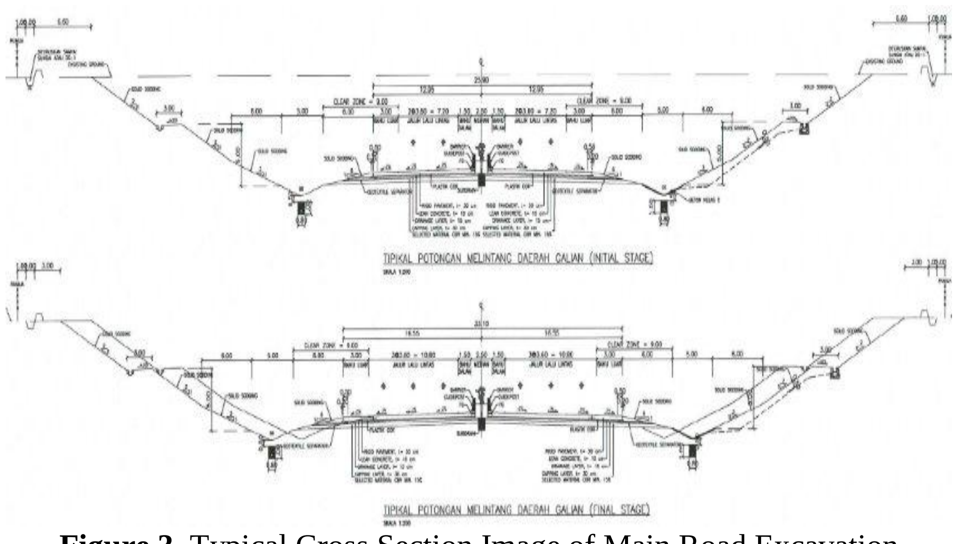


Figure 3. Typical Cross Section Image of Main Road Excavation
[Source: PT. Hutama Karya (Persero)]

LITERATURE REVIEW

Soil Parameters

In this study, several soil parameters are needed to be used as a reference to determine the physical and mechanical properties of the soil. The parameters needed are water content (w), unit weight (γ), specific gravity (Gs), liquid limit (LL), plastic limit (PL), plasticity index (PI), shrinkage limit (SL), permeability (K), cohesion value (C), and internal friction angle (φ). These soil parameters can be obtained directly from laboratory testing results (primary data) or can be determined by correlating the SPT values (NSPT).

To determine the primary soil data, undisturbed soil samples were taken from two locations, namely Sta. 205+400 and Sta. 205+575. The specific gravity value of the soil according to Hardyatmo (2006) is given in Table 2 and the correlation of N-SPT values with other parameter values can be seen in Table 3.

Table 2. Soil Specific Gravity

Soil Type	Specific Gravity
Gravel	2.65 - 2.68
Sand	2.65 - 2.68
Inorganic Silt	2.62 - 2.68
Organic Clay	2.58 - 2.65
Inorganic Clay	2.68 - 2.75
Organic	1.37
Peat	1.25 - 1.8

(Source: Hardyatmo 2022)

Table 3. Soil Properties Based on Standard Penetration Test (N-SPT)

			COHESIONLESS SOIL		
N-Spt Value	0 - 10	11 - 30	31 - 50	> 50	
Specific gravity, $\boldsymbol{\gamma}$, (kN/m3)	12 - 16	14 - 18	16 - 20	18 - 23	
Shear Angle, Ø	25 - 32	28 - 36	30 - 40	> 35	
Consistency	Retrieved	Medium	Solid	Very dense	
			COHESIVE SOIL		
N-Spt Value	< 4	4 - 6	6 - 15	16 - 25	> 25
Specific gravity, $\boldsymbol{\gamma}$, (kN/m3)	14 -18	16 - 18	16 - 18	16 - 20	> 20
q_u (kpa)	< 25	20 - 50	30 - 60	40 -200	
Consistency	Very Soft	Software	Medium	Stiff	Hard

Source: Soil Mechanics, Whilliam T, Whitman, Robert V, 1969

Slope Stability and Slope Reinforcement

A slope needs to be reviewed for its stability so that the planning carried out is safe, meaning it does not collapse. In general, landslides occur when the component of gravity that occurs is greater than the bearing capacity of the soil so that the soil shifts. If a landslide occurs at the base or above the base end, it is called a slope failure (Braja M. Das, 2002). In addition to being caused by the component of gravity that occurs, landslides can be caused by cracks that occur on the slope (cracked soil). According to Mochtar (2020), cracked soil is an approach with the assumption that a slope is cracked so that the slope is prone to landslides. The cracked soil approach is carried out with the assumption that the parameter Cu = 0 kpa. According to research conducted by Kumalasari, et al. (2024). In this study, the cracked soil approach was aimed at determining the impact of cracked soil and the appropriate variations on slope stability in two different areas with different topographic conditions as well.

Slope reinforcement is required for slope conditions with a safety factor of 1.2 (SNI: 8460: 2017). The slope reinforcement is in the form of *a ground anchor* with the specifications of the installation distance along the slope is 3m, diameter 26.5cm, *grade* 1030 and min *break load is*

569 kN. Slope stability modeling, cracked soil approach and *ground anchor* reinforcement will be modeled with the auxiliary program.

COST CALCULATION

The cost savings of a project are largely determined by the selection of effective and efficient work methods in the field. The selection of this method is based on field work that can be optimized, such as cost expenditures during the economical project planning process and optimal reinforcement. Cost calculations are carried out based on the volume of work and unit price analysis that has gone through the bidding process. Economical planning means planning that does not change the function and strength of the structure but reduces the area of land used, such as making the excavation slope steeper. However, the presence of a steep slope requires slope reinforcement to be planned so that it remains strong and stable. In this case, differences in the use of the types of reinforcement used can also cause differences in cost savings that occur. According to Supiyono (2023), landslide handling in the relocation of the Ponorogo-Trenggalek road stated that ground anchor reinforcement is safer than gabion reinforcement because with *ground anchor reinforcement* the slope safety factor value becomes 1.2 while using gabion the safety factor value is less than 1.

Cost items that can be saved such as excavation work, land acquisition which includes compensation for productive trees, residential buildings and others. These cost items can be saved if there is a narrowing of land acquisition without changing the function of the project itself, such as narrowing the slope of the excavation to be more upright in the toll road construction project.

RESEARCH METHODS

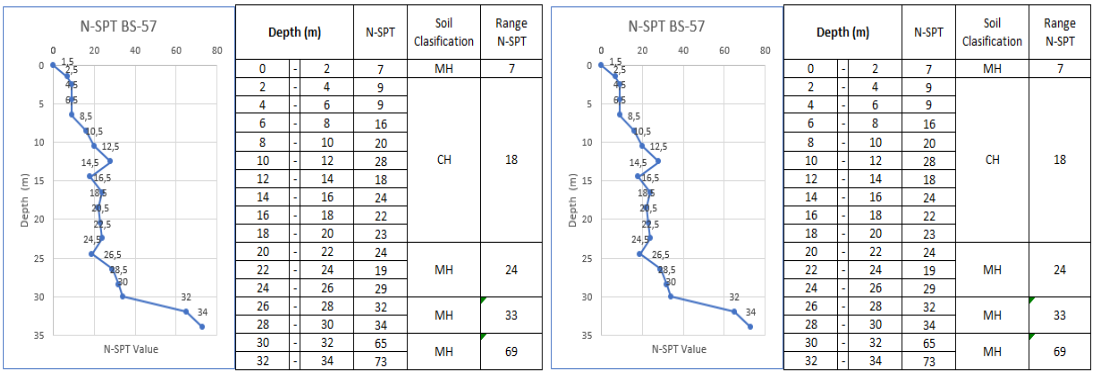
In this study, slope stability analysis was conducted based on secondary data and correlations obtained based on project data and N-SPT correction (Bazaara, 1967). The slope stability analysis conducted was the existing slope stability analysis of the project where the deepest slope slope was 1:3 and the slope slope was 1:2 above it. After that, the alternative slope slope 1 was planned with a slope angle of 1:2 and alternative 2 with a slope angle of 2:1. The three types of slope slopes were then checked for stability with 3 groundwater level elevation (MAT) conditions, namely at the MAT at the bottom of the excavation (at the road front), MAT at a depth as in the secondary data (10m and 14m), and the MAT at the top of the excavation.

After that, the existing slope, the slope of alternative 1 and alternative 2 are checked again for stability using the *cracked soil approach* . This approach is carried out to find out the worst possibility that may occur from the slope in question, namely the change in the value of its safety factor after several years. After that, *ground anchor reinforcement planning is carried out* with the specified specifications. The need for *ground anchor reinforcement* will have an impact on the cost savings that occur because the more *ground anchors* used, the less the cost savings that can be made. After that, a cost savings calculation is carried out for each groundwater level condition in alternative 1 and alternative 2. From this cost calculation, the alternative form of construction (excavation slope and type of reinforcement) that is the most economical, the cheapest but with a strong and safe construction will be determined.

DATA ANALYSIS

Soil Parameters

The data used in this study are the results of the borehole test (N-SPT). Based on the location of the study, the boring test has been conducted at Sta. 205+575 is BS-56 and BS-57 ; the results are presented in (Figure 4). The SPT value (NSPT) is determined at every 2 meters depth; the SPT value is corrected and then used to obtain other required soil parameters. In addition to these data, several soil parameters are obtained from secondary data available on the project. The soil parameter data used in this study are in Table 4.



Depth (m)			N-SPT	Soil Clasification	Range N-SPT
0	-	2	7	MH	7
2	-	4	9	CH	18
4	-	6	9		
6	-	8	16		
8	-	10	20		
10	-	12	28		
12	-	14	18		
14	-	16	24		
16	-	18	22		
18	-	20	23		
20	-	22	24	MH	24
22	-	24	19		
24	-	26	29		
26	-	28	32	MH	33
28	-	30	34		
30	-	32	65	MH	69
32	-	34	73		

Depth (m)			N-SPT	Soil Clasification	Range N-SPT
0	-	2	7	MH	7
2	-	4	9	CH	18
4	-	6	9		
6	-	8	16		
8	-	10	20		
10	-	12	28		
12	-	14	18		
14	-	16	24		
16	-	18	22		
18	-	20	23		
20	-	22	24	MH	24
22	-	24	19		
24	-	26	29		
26	-	28	32	MH	33
28	-	30	34		
30	-	32	65	MH	69
32	-	34	73		

Figure 4. N-SPT Value from Borlog Test
Source: PT. Hutama Karya

Table 4. Soil Parameters (BS-56 and BS-57)

layers	Depth (m)	N - SPT	N - Correction SPT	γ (t/m3)	GS	LL (%)	PL (%)	IP	C Kg/cm2	Ø (°)
1	0 - 2	6	6	1.50	2.60	54.5	24.10	30.40	0.384	21.8
2	2 - 4	10	10	1.50	2.60	54.5	24.10	30.40	0.384	21.8
3	4 - 6	11	11	1.50	2.60	46.1	24.10	30.40	0.384	21.8
4	6 - 8	14	14	1.55	2.70	51.6	19.94	31.66	0.368	18.4
5	8 - 10	16	15.7	1.70	2.70	51.6	19.94	31.66	0.368	17.6
6	10 - 12	18	16.1	1.70	2.70	51.6	19.94	31.66	0.368	17.6
7	12 - 16	20	18.5	1.70	2.70	48.9	17.20	31.70	0.370	17.2
8	16 - 19	32	23.2	1.70	2.70	48.9	17.20	31.70	0.370	17.0
9	19 - 34	55	39	1.70	2.70	48.9	17.20	31.70	0.370	16.3

Source: PT. Hutama Karya

Detailed Engineering Drawing

The initial engineering plan drawing of the project is used as the basis for modeling the slope geometry. The drawing shows that the road width is 29.5m and the total ROW width is 125m; the existing slope slope at the bottom of the excavation is 1:3 and is followed by the slope slope above it, which is 1:2. The depth of the slope excavation at the research location varies; the deepest excavation is 21m. A detailed drawing of the excavation section Sta. 205+575 is given in Figure 5.

In (Figure 5) the height of the left side slope is 18m and the height of the right side slope is 19m. The width of the road is 37m and there are 4 slope traps on the left side slope and the right side slope. The existing slope slope at the bottom of the excavation is 1: 3 and the slope angle above it is 1: 2

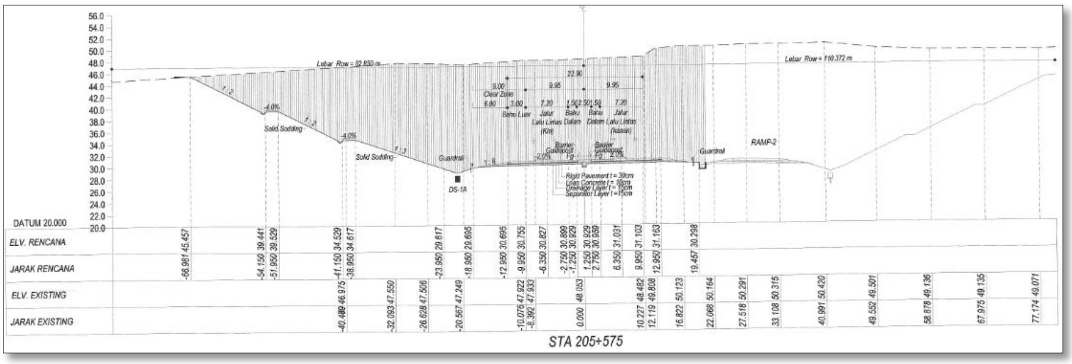


Figure 5. Cross Section of Excavation Sta. 205+575
(Source: PT. Hutama Karya)

Slope Modeling and Slope Stability Analysis

The auxiliary program used for modeling is the Geo5 auxiliary program. Slope modeling is carried out by inputting coordinates according to the existing slope gradient, namely 1:3 and 1:2 (Figure 6), the slope of alternative slope 1 is 1:1 (Figure 7) and the slope of alternative slope 2 is 2:1 (Figure 8).

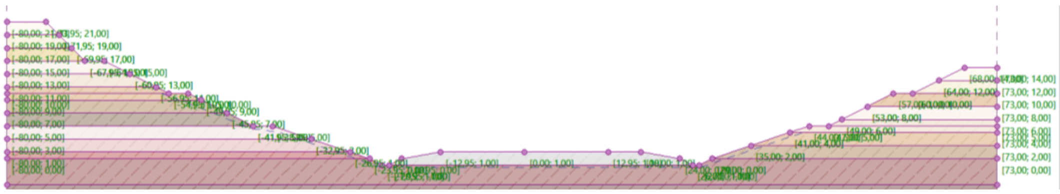


Figure 6. Existing Slope Gradient, slope angle 1:3, 1:2
(Source: Test results)

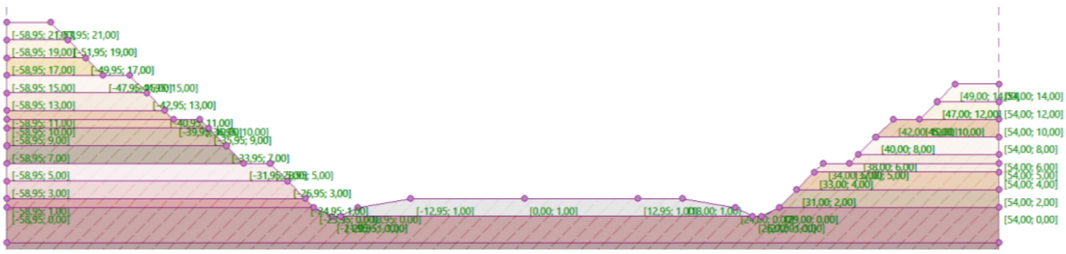


Figure 7. Alternative Slope Gradient 1 Slope Angle 1:1
(Source: Test results)

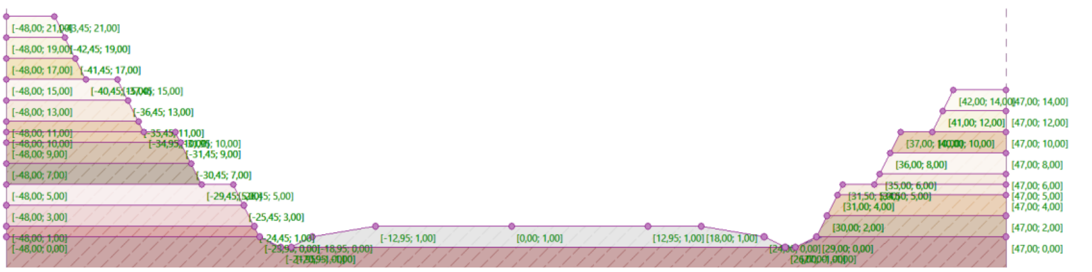


Figure 8. Alternative Slope Gradient 2 Slope Angle 2:1
(Source: Test results)

After the slope geometry modeling is done, the next step is inputting the data of the variation of the groundwater level with the MAT elevation at the base of the excavation (road face), the MAT elevation at a depth of 10m, and the MAT elevation at the top of the excavation; in addition, the input of soil data for each layer is also carried out. Slope stability *analysis* is carried out for conditions with and without the *cracked soil approach* . From the results of *the analysis* , the FS for each slope condition will be known which will then be used as a reference whether the slope requires *ground anchor reinforcement* or not. The results of the slope stability *analysis without the cracked soil approach* are given in (Figure 9); while the results of the slope stability *analysis* with the *cracked soil approach* are given in (Figure 10).

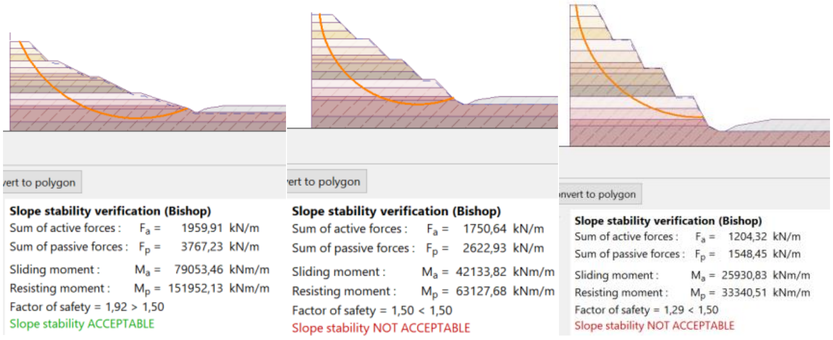


Figure 9. Results *of the analysis* of the slope stability assistance program without the *cracked soil approach*
*(*source: Test results)

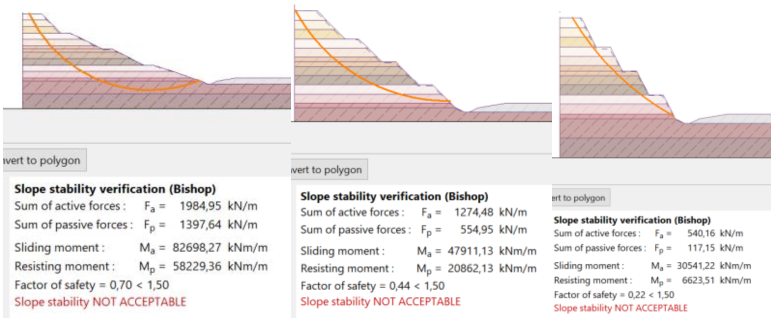


Figure 10. Results of *the analysis of* the slope stabilization assistance program using the *cracked soil approach*
(Source: Test Results)

Ground Anchor Reinforcement

This stage is carried out after knowing the safety factor of the excavation embankment which is less than 1.2. Calculation of *ground anchor reinforcement* in the auxiliary program is carried out by inputting coordinates and specifications in the auxiliary program. Input of coordinates and specifications *of ground anchors* can be seen in (Figure 12).

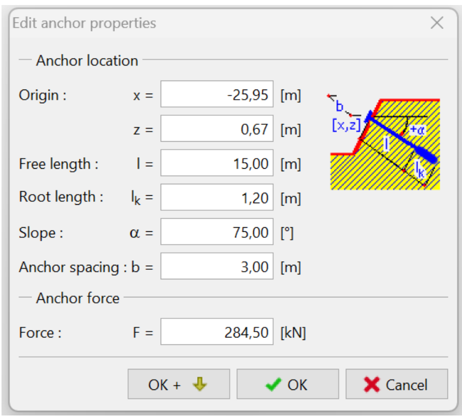


Figure 12. Input Coordinates and *Ground Anchor Specifications*
(Source: Test Results)

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At the stage of inputting the tensile strength specifications of *the ground anchor reinforcement, the force* value is 284.5 obtained from the *min break load value* divided by two to ensure the safe value of the force received by an *anchor*. The following is an example of *analysis* with *ground anchor reinforcement* so that the safety factor value reaches a value of 1.2 in (Figure 13).

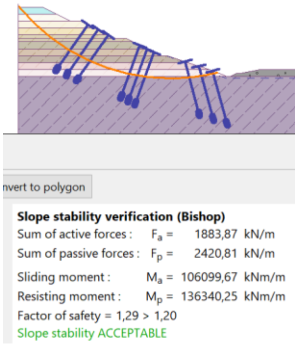

Figure 13. analysis for safety factor 1.2
(Source: Result Geo5)

Cost Analysis

The unit price used in this study is the bid price and the unit price that has been used in the project. The unit price value includes excavation work items, *ground anchors*, and land acquisition; the unit price value used in this study is given in Table 5.

Table 5. Unit Price

No	Item	unit	Unit Price
1	Land Acquisition	m2	Rp. 200,000
2	Ground Anchor	m'	Rp. 1,385,000
3	Excavation	m3	Rp. 89,090

Source: PT. Hutama Karya, PT. Sonel Jaya Mandiri

Work items can be added according to field conditions if suitable rainwater management is needed to be implemented at the location. The recommended rainwater management is to use a sling channel and coated with geomembrane on the outermost concrete pipe layer so that water does not seep out of the channel. In addition, drilling is carried out well holes that are useful for lowering the groundwater level so as not to affect slope stability.

RESEARCH ANALYSIS

Back Analysis

1. Existing and Alternative Slope Stability Analysis

   Based on the slope stability analysis that has been carried out with the auxiliary program in this study, it is known that the decrease in FS is due to a steeper slope. The steeper the slope angle, the smaller the safety factor value. In addition, variations in groundwater levels also greatly affect the safety factor value of a slope. The shallower a groundwater level is, the smaller the safety factor value. Conversely, the deeper the groundwater level elevation, the greater the safety factor value.

   On the existing slope with a slope angle of 1:3 and 1:2, the safety factor value is 2.53; after the slope is changed to alternative 1, which is a slope angle of 1:1, the safety factor becomes 1.96. Likewise, in alternative conditions 2 where the slope angle is 2:1, the safety factor becomes 1.75. The summary of the results of the analysis of the safety factor value is given in (Figure 13); (Figure 14); and (Figure 15).

No	Depth (m)	Sta 205+400 Laboratory Data					
		Eksisting					
		GWL = 0, C = 0	GWL = 14, C = 0	PEAK GWL C = 0	GWL = 0, C = 0	GWL = 14, C = 0	PEAK GWL C = 0
		Angel of Slope 1:3 1:2			Angel of Slope 1:3 1:2		
		Left Slope (SF)	Left Slope (SF)	Left Slope (SF)	Right Slope (SF)	Right Slope (SF)	Right Slope (SF)
1	2	9,14	8,75	5,94	12,99	11,87	8,96
2	4	5,21	4,83	4,76	7,19	6,94	5,70
3	5	5,06	4,62	3,88	5,95	5,66	4,35
4	10	3,86	3,14	2,67	3,89	3,77	2,82
5	14	3,43	2,85	2,43	3,47	3,21	2,33
6	15	3,03	2,68	2,22	3,01	2,93	2,20
7	20	2,77	2,10	1,96			
8	21	2,53	2,12	1,92			
9	22	2,42	2,00	1,73			

Figure 13. Summary of the Results of the Analysis of Safety Factor Values before using the *cracked soil approach* for existing slope conditions of 1:3 and 1:2.
(Source: Test results.)

No	Depth (m)	Sta 205+400 Laboratory Data					
		Alternative 1					
		GWL = 0, C	GWL 14m C	PEAK GWL C	GWL = 0, C	GWL 14m C =	PEAK GWL C
		Angel of Slope 1:1			Angel of Slope 1:1		
		Left Slope (SF)	Left Slope (SF)	Left Slope (SF)	Right Slope (SF)	Right Slope (SF)	Right Slope (SF)
1	2	8,84	8,63	5,83	10,23	9,31	8,32
2	4	4,67	4,68	3,85	5,83	4,87	4,72
3	5	4,49	4,36	3,35	4,82	4,79	4,06
4	10	2,92	2,79	2,27	3,00	3,04	2,43
5	14	2,57	2,46	2,01	2,40	2,44	1,90
6	15	2,35	2,30	1,87	2,23	2,25	1,75
7	20	2,11	1,88	1,65			
8	21	1,96	1,66	1,50			
9	22	1,86	1,60	1,45			

Figure 14. Summary of the Results of the Analysis of Safety Factor Values before using the *cracked soil approach* for alternative condition 1 with a slope of 1:1.
(Source: Test results.)

No	Depth (m)	Sta 205+400 Laboratory Data					
		Alternative 2					
		GWL = 0, C	GWL 14m C	PEAK GWL, C =	GWL = 0, C =	GWL 14m C =	PEAK GWL, C = 0
		Angel of Slope 2:1			Angel of Slope 2:1		
		Left Slope (SF)	Left Slope (SF)	Left Slope (SF)	Right Slope (SF)	Right Slope (SF)	Right Slope (SF)
1	2	8,63	8,03	5,44	7,71	7,34	7,19
2	4	3,74	3,73	3,11	4,64	4,27	3,99
3	5	3,19	3,59	2,92	4,42	4,18	3,80
4	10	2,45	2,37	2,11	2,6	2,51	2,10
5	14	2,24	2,11	1,59	2,12	1,92	1,62
6	15	1,99	1,90	1,54	2,09	1,88	1,48
7	20	1,81	1,59	1,35			
8	21	1,75	1,40	1,29			
9	22	1,68	1,36	1,25			

Figure 15. Summary of the Results of the Analysis of the Safety Factor Value before using the *cracked soil approach* for alternative conditions 2 with a slope of 2:1.
(Source: Test results.)

`2. Crackedsoil Phenomenon

The slope safety factor value decreases quite drastically if the analysis approach used is the cracked soil phenomenon; this occurs because of the weakening of the soil layer until the cohesion parameter (C) = 0. This can be seen from the *analysis results* in the auxiliary program after the cracked soil approach is carried out; the safety factor value decreases drastically from the initial condition safety factor value. The safety factor value from the analysis results using the cracked soil phenomenon approach is given in (Figure 16) for existing conditions with a slope of 1: 3 and 1: 2; in (Figure 17) for alternative 1 with a slope of 1: 1; and in (Figure 18) for a slope of 2: 1.

No	Depth (m)	Sta 205+400 Laboratory Data					
		Eksisting					
		GWL = 0, C = 0	GWL = 14, C = 0	PEAK GWL C = 0	GWL = 0, C = 0	GWL = 14, C = 0	PEAK GWL C = 0
		Angel of Slope 1:3 1:2			Angel of Slope 1:3 1:2		
		Left Slope (SF)	Left Slope (SF)	Left Slope (SF)	Right Slope (SF)	Right Slope (SF)	Right Slope (SF)
1	2	1,47	1,37	0,92	1,60	1,55	1,1
2	4	1,42	1,35	0,85	1,52	1,51	1,07
3	5	1,40	1,32	0,82	1,50	1,47	0,85
4	10	1,39	1,28	0,76	1,44	1,38	0,83
5	14	1,27	1,19	0,73	1,38	1,35	0,81
6	15	1,25	1,12	0,72	1,28	1,11	0,78
7	20	1,22	1,08	0,70			
8	21	1,21	0,99	0,70			
9	22	1,15	0,92	0,68			

Figure 16. Summary of the Results of the Analysis of the Safety Factor Value of the existing cracked soil phenomenon
(Source: Test results for existing conditions of slopes of 1:3)

No	Depth (m)	Sta 205+400 Laboratory Data					
		Alternative 1					
		GWL = 0, C = 0	GWL 14m C = 0	PEAK GWL C = 0	GWL = 0, C = 0	GWL 14m C = 0	PEAK GWL C = 0
		Angel of Slope 1:1			Angel of Slope 1:1		
		Left Slope (SF)	Left Slope (SF)	Left Slope (SF)	Right Slope (SF)	Right Slope (SF)	Right Slope (SF)
1	2	1,34	1,08	0,69	1,48	1,33	0,87
2	4	1,26	1,01	0,65	1,46	1,23	0,79
3	5	1,24	0,97	0,61	1,33	1,08	0,72
4	10	1,21	0,94	0,57	1,07	0,95	0,7
5	14	1,15	0,89	0,55	0,91	0,81	0,64
6	15	1,1	0,87	0,54	0,87	0,73	0,6
7	20	0,97	0,76	0,47			
8	21	0,91	0,7	0,44			
9	22	0,89	0,61	0,39			

Figure 17. Summary of the Results of the Analysis of the Safety Factor Value of the existing cracked soil phenomenon Source: Results of testing alternative condition 1 with a slope of 1:1.
(Source: Test results.)

No	Depth (m)	Sta 205+400 Laboratory Data					
		Alternative 2					
		GWL = 0, C = 0	GWL 14m C = 0	PEAK GWL, C = 0	GWL = 0, C = 0	GWL 14m C = 0	PEAK GWL, C = 0
		Angel of Slope 2:1			Angel of Slope 2:1		
		Left Slope (SF)	Left Slope (SF)	Left Slope (SF)	Right Slope (SF)	Right Slope (SF)	Right Slope (SF)
1	2	1,02	0,86	0,46	1,18	1,09	0,75
2	4	0,94	0,83	0,44	1,14	1,08	0,72
3	5	0,90	0,8	0,42	1,06	1,06	0,68
4	10	0,87	0,77	0,34	0,79	0,79	0,47
5	14	0,82	0,75	0,29	0,68	0,61	0,33
6	15	0,80	0,73	0,26	0,58	0,54	0,26
7	20	0,78	0,64	0,23			
8	21	0,77	0,57	0,22			
9	22	0,73	0,53	0,20			

Figure 18. Summary of the Results of the Analysis of the Safety Factor Value of the existing cracked soil phenomenon Source: Results of testing alternative conditions 2 with a slope of 2:1.
(Source: Test results.)

3. Slope Reinforcement

Ground anchor slope reinforcement requirement in this study is calculated for slope stability under conditions with a cracked soil phenomenon approach because the safety factor value is below 1.20. The *ground anchor reinforcement requirement* is tabulated as given in (Figure 19).

STA	Lereng eksisting					
	MAT = 0		MAT = 10m atau 14m		MAT puncak	
	lereng kiri (bh)	lereng kanan (bh)	lereng kiri (bh)	lereng kanan (bh)	lereng kiri (bh)	lereng kanan (bh)
Ground anchor						
205+150 - 205+400	N/A	N/A	N/A	N/A	750	417
205+400 - 205+725	N/A	N/A	758	N/A	1083	1192
	0		758		3442	
STA	Lereng alternatif 1					
	MAT = 0		MAT = 10m atau 14m		MAT puncak	
	lereng kiri (bh)	lereng kanan (bh)	lereng kiri (bh)	lereng kanan (bh)	lereng kiri (bh)	lereng kanan (bh)
Ground anchor						
205+150 - 205+400	583	250	833	333	917	500
205+400 - 205+725	867	1083	1192	1083	1083	1408
	2783		3442		3908	
STA	Lereng alternatif 2					
	MAT = 0		MAT = 10m atau 14m		MAT puncak	
Ground anchor	lereng kiri (bh)	lereng kanan (bh)	lereng kiri (bh)	lereng kanan (bh)	lereng kiri (bh)	lereng kanan (bh)
205+150 - 205+400	750	417	1167	667	1250	875
205+400 - 205+725	1083	1192	1300	1408	1950	2113
	3442		4542		6188	

Figure 19. Ground Anchor Reinforcement Requirements on Alternative Slopes
(Source: Test results.)

4. Cost Savings Analysis

The efficiency of the volume of work items that occurred due to the steeper slope in this study was the width of the land that became narrower and the volume of excavation work that became less. The slope reinforcement in the form of ground anchors was an additional cost in the planning of increasingly steep slopes. Details of the reduction in the width of the land at each station are given in (Figure 20); while the savings in the volume of excavation work are given in (Figure 21).

Sta	Eksisting			Alternatif 1			Alternatif 2		
	koordinat kiri	koordinat kanan	Lebar total (m)	koordinat kiri	koordinat kanan	Lebar total (m)	koordinat kiri	koordinat kanan	Lebar total (m)
205+150	-70,00;0,00	38,00;0,00	108,00	-52,00;0,00	28,00;0,00	80,00	-44,00;0,00	23,50;0,00	67,50
205+250	-83,00;0,00	53,00;0,00	136,00	-61,00;0,00	40,10;0,00	100,10	-52,00;0,00	33,00;0,00	85,00
205+400	-80,00;0,00	73,00;0,00	153,00	-59,00;0,00	54,00;0,00	113,00	-48,00;0,00	47,00;0,00	95,00
205+575	-82,00;0,00	128,00;0,00	210,00	-57,00;0,00	97,00;0,00	154,00	-47,00;0,00	85,00;0,00	132,00
205+650	-63,00;0,00	175,00;0,00	238,00	-46,00;0,00	129,00;0,00	175,00	-37,00;0,00	112,00;0,00	149,00
205+725	-44,00;0,00	190,00;0,00	234,00	-33,00;0,00	139,00;0,00	172,00	-24,00;0,00	122,00;0,00	146,00

Figure 20. Land Reduction Value Due to Alternative 1 and Alternative 2
(Source: Calculation Results)

NO	LOKASI	luas galian	RATA2	PANJANG	VOLUME
1	205+125,00		-		-
2	205+150,00	31,12	15,56	25,00	388,97
3	205+175,00	41,31	36,21	25,00	905,37
4	205+200,00	59,28	50,29	25,00	1.257,37
5	205+225,00	100,27	79,77	25,00	1.994,29
6	205+250,00	148,50	124,38	25,00	3.109,60
7	205+275,00	203,97	176,24	25,00	4.405,91
8	205+300,00	254,31	229,14	25,00	5.728,52
9	205+325,00	287,26	270,79	25,00	6.769,67
10	205+350,00	202,78	245,02	25,00	6.125,58
11	205+375,00	231,68	217,23	25,00	5.430,75
12	205+400,00	484,00	357,84	25,00	8.945,95
13	205+425,00	242,93	363,46	25,00	9.086,56
14	205+450,00	223,66	233,29	25,00	5.832,32
15	205+475,00	201,32	212,49	25,00	5.312,26
16	205+500,00	228,84	215,08	25,00	5.377,04
17	205+525,00	229,53	229,19	25,00	5.729,64
18	205+550,00	234,88	232,20	25,00	5.805,08
19	205+575,00	247,00	240,94	25,00	6.023,48
20	205+600,00	257,49	252,25	25,00	6.306,13
21	205+625,00	248,33	252,91	25,00	6.322,70
22	205+650,00	152,37	200,35	25,00	5.008,73
23	205+675,00	128,63	140,50	25,00	3.512,57
24	205+700,00	72,66	100,65	25,00	2.516,18
25	205+725,00	13,91	43,29	25,00	1.082,17
26	205+750,00	-	6,96	25,00	173,90
			Volume total		113.150,76

NO	LOKASI	luas galian	RATA2	PANJANG	VOLUME
1	205+125,00		-		-
2	205+150,00	54,92	27,46	25,00	686,54
3	205+175,00	72,92	63,92	25,00	1.598,00
4	205+200,00	104,63	88,77	25,00	2.219,29
5	205+225,00	176,97	140,80	25,00	3.519,97
6	205+250,00	262,11	219,54	25,00	5.488,54
7	205+275,00	360,01	311,06	25,00	7.776,55
8	205+300,00	448,87	404,44	25,00	10.110,99
9	205+325,00	507,03	477,95	25,00	11.948,66
10	205+350,00	357,92	432,47	25,00	10.811,82
11	205+375,00	408,91	383,42	25,00	9.585,43
12	205+400,00	191,00	299,96	25,00	7.498,93
13	205+425,00	428,77	309,88	25,00	7.747,12
14	205+450,00	394,77	411,77	25,00	10.294,21
15	205+475,00	355,34	375,05	25,00	9.376,29
16	205+500,00	403,91	379,63	25,00	9.490,63
17	205+525,00	405,12	404,52	25,00	10.112,97
18	205+550,00	414,57	409,85	25,00	10.246,13
19	205+575,00	436,12	425,34	25,00	10.633,60
20	205+600,00	454,48	445,30	25,00	11.132,47
21	205+625,00	438,30	446,39	25,00	11.159,73
22	205+650,00	268,94	353,62	25,00	8.840,55
23	205+675,00	227,04	247,99	25,00	6.199,78
24	205+700,00	128,25	177,65	25,00	4.441,13
25	205+725,00	24,55	76,40	25,00	1.910,06
26	205+750,00	-	12,28	25,00	306,93
			Volume total		183.136,31

Figure 21. Savings Volume of Excavation Work Alternative 1 and Alternative 2
(Source: Calculation Results)

Based on the land narrowing and reduction of excavation volume that has been given above, cost savings that occur due to steeper slope, namely alternative 1 (slope angle 1:1) and due to alternative 2 (slope angle 2:1) can be calculated. Details of cost savings can be seen in (Figure 22). From the calculation results, the largest savings value is determined as the most optimum cost, namely alternative 2 with a slope of 2:1 and groundwater level elevation at the base of the excavation. The efficiency value is Rp. 18,423,905,547 with land efficiency of 34,375 m2, excavation efficiency of 183,136 m3 and requires 3,442 points of Ground Anchor reinforcement.

ALTERNATIF 1

GWL Puncak

No	Item	satuan	Volume	Harga
1	Tanah	m2	24.111	Rp 4.822.120.000
2	Soil nailing	m'	-	Rp -
3	Ground Anchor	m'	3.908	-Rp 5.413.041.667
4	Galian	m3	113.151	Rp10.080.600.785
5				
		Total Harga		Rp 9.489.679.119

GWL Kedalaman 10m dan 14m

No	Item	satuan	Volume	Harga
1	Tanah	m2	24.111	Rp 4.822.120.000
2	Soil nailing	m'	-	Rp -
3	Ground Anchor	m'	3.442	-Rp 4.766.708.333
4	Galian	m3	113.151	Rp10.080.600.785
5				
		Total Harga		Rp10.136.012.452

GWL Dasar Galian

No	Item	satuan	Volume	Harga
1	Tanah	m2	24.111	Rp 4.822.120.000
2	Soil nailing	m'	-	Rp -
3	Ground Anchor	m'	2.783	-Rp 3.854.916.667
4	Galian	m3	113.151	Rp10.080.600.785
5				
		Total Harga		Rp11.047.804.119

ALTERNATIF 2

GWL Puncak

No	Item	satuan	Volume	Harga
1	Tanah	m2	34.375	Rp 6.875.000.000
2	Soil nailing	m'	-	Rp -
3	Ground Anchor	m'	6.188	-Rp 8.569.687.500
4	Galian	m3	183.136	Rp16.315.613.880
5				
		Total Harga		Rp14.620.926.380

GWL Kedalaman 10m dan 14m

No	Item	satuan	Volume	Harga
1	Tanah	m2	34.375	Rp 6.875.000.000
2	Soil nailing	m'	-	Rp -
3	Ground Anchor	m'	4.542	-Rp 6.290.208.333
4	Galian	m3	183.136	Rp16.315.613.880
5				
		Total Harga		Rp16.900.405.547

GWL Dasar Galian

No	Item	satuan	Volume	Harga
1	Tanah	m2	34.375	Rp 6.875.000.000
2	Soil nailing	m'	-	Rp -
3	Ground Anchor	m'	3.442	-Rp 4.766.708.333
4	Galian	m3	183.136	Rp16.315.613.880
5				
		Total Harga		Rp18.423.905.547

Figure 22. Cost Savings Calculation for Alternative 1 and Alternative 2
(Source: Calculation Results)

CONCLUSION

This research was conducted at the location of Sta 205+150 to sta 205+725 to obtain the optimization of cutting and strengthening costs for cracked soil conditions and the specified alternative slopes. The modeling results using the auxiliary application and the calculation of the optimization of cutting and strengthening costs are as follows:

1. The slope of the existing road excavation slope with the lowest slope slope is 1:3 and with a slope of 1:2 above it does not affect its stability, proven to be safe with a safety factor value of more than 1.2. The safety factor value has been varied with different groundwater level conditions, namely at groundwater level = 0m (base of excavation), groundwater level at secondary data conditions and peak groundwater level of slope 14m and 21m (excavation peak).
2. The slope of the excavation for alternative road 1 (slope 1:1) and alternative 2 (slope 2:1) has been proven to have a lower effect on stability compared to the existing slope:

	Alternative 1	Alternative 2
	Slope Angle 1:1	Slope Angle 2:1
Safety Factor	3.86	2.92
Depth (m)	10	10

There is land narrowing in alternative 1 with a slope of 1:1 and alternative 2 with a slope of 2:1 as follows:

	Alternative 1	Alternative 2
Sta.	Slope Angle 1:1	Slope Angle 2:1
205+400	113 m	95 m
205+575	154 m	132 m

3. *cracked soil* phenomenon approach (the occurrence of soil weakening due to the loss of fine grains by rainwater that passes through cracks and leaves coarser grains so that they behave like sand) greatly influences slope stability. The safety factor of each slope is as follows:

	Existing	Alternative 1	Alternative 2	Ground Anchor
	Slope Angle 1:3	Slope Angle 1:1	Slope Angle 2:1	Point
Safety Factor	1.21	1.96	1.66	3.442
Depth (m)	10	10	10	4,542

4. Variations in groundwater level elevation on slope stability cause the safety factor value to be lower due to differences in dry volume weight (γ_{dry}) values due to groundwater level fluctuations . At sta. 205+400 at a excavation depth of 21m, the safety factor value is as follows:

	Alternative 1	Alternative 1	Alternative 1
	GWL 0	GWL 14m	Peak GWL
Safety Factor	1.96	1.66	1.5
Depth (m)	21	21	21

5. The most cost-effective alternative 2 with a slope of 2:1 and groundwater elevation at the bottom of the excavation. The efficiency value is Rp. 18,423,905,547 with land efficiency of 34,375 m2 , excavation efficiency of 183,136 m3 and requires 3,442 points of Ground Anchor reinforcement.

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