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by Barlian Dwi Nagara

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Geotechnical Perspective on Dozer-Push Method in Coal Mining Operations

Barlian Dwinagara[1], Raden Hariyanto[2], Oktarian Wisnu Lusantono[3], Prasodo Datu Prabandaru[4]

[1, 2, 4] Faculty of Mineral and Technology, UPN "Veteran" Yogyakarta
[3] PT. Studio Mineral Batubara, Mining Consultant, Yogyakarta

Abstract

The rapid increase of technological development is currently playing a role in the mining industry. The dozer push exploitation method is an alternative to the conventional truck and shovel method. Heavy dozers have the ability to move large amounts of waste material in short distances at a low cost, while trucks and shovels will be more economical if over long distances. Geotechnical assessment becomes one of the critical considerations in making a decision plan and slope design for mining activities where the dozer push activities were carried out. Material conditions greatly affect slope stability, which can be defined as material behavior based on the physical and mechanical properties of the material. The slope stability analysis method used in this study was a combination of two methods, the Limit Equilibrium Method (LEM) and Finite Element Method (FEM). These two combinations of analytical methods will strengthen the justification of the geotechnical perspective. By understanding the behavior of the material on a slope, the risk of a slope failure can be controlled and minimized using a geotechnical perspective. The parameters that will be studied in this study are the physical and mechanical properties of the material against several conceptual design options in terms of the safety factor and probability of landslides on the slopes in the dozer push area.

Keywords: Dozer-push, finite element method, limit equilibrium method, material geomechanics, slope stability.

INTRODUCTION

The use of techniques in mining activities evolves along with technological advancements. The dozer push method is an alternative to the traditional truck and shovel approach. Heavy dozers can carry large volumes of waste material over short distances at a low cost, but trucks and shovels are more cost-effective over long distances. With the using of heavy equipment development in mining activities, dozers have become a major component in mining operations that aim to move overburden to the top layer of coal [1].
Evaluation of slope stability is a fundamental assessment in determining the vulnerability of a slope to landslides. The evaluation methods that are often used are the Limit Equilibrium Method (LEM) and the Finite Element Method (FEM). The LEM is based on grouping potentially unstable soil masses for analysis in the form of vertical slices with finite dimensions and assuming reaction forces along the wedge boundary according to some physical assumptions regarding inter-slice forces and at the base of each slope. This physical assumption is derived from the reaction exerted by the soil material in the unstable wedge area and water pressure.

Meanwhile, the FEM does not limit the mechanical behavior type that can be considered for the slope's material being analyzed. This method uses a continuum mechanics approach because the materials forming the slope are assumed to be one continuum or several continuums separated by known boundaries (e.g., distinct stratigraphy). The applied differential equation is an equation that applies equilibrium and kinematic compatibility in the stress area, as well as material behavior that relates stress to strain. The fluid-mechanical equations governing the behavior of water and its interactions with the solid phase are also

Corresponding author:
barlian.dwinagara@upnyk.ac.id; r.hariyanto@upnyk.ac.id
DOI: *to be assigned*

considered. The advantage of using the FEM method lies in the accuracy of the constitutive model that can be used.

The slope stability assessment for dozer push activities was carried out in this study based on the geometry and forces of the slope that impact the surrounding region. Then the calculation results of slope stability can be used as a reference in every implementation of the dozer push exploitation method for the mining's safety issues.

RESEARCH METHOD

The research method used in this study consisted of primary and secondary data acquisition, data processing, literature study, and data analysis. Laboratory tests were carried out at the Laboratory of Soil Mechanics and Rock Mechanics, Department of Mining Engineering, UPN Veteran Yogyakarta, Geomechanics Laboratory of PT Studio Mineral Batubara, and Soil Mechanics Laboratory, Department of Civil Engineering, Islamic University of Indonesia. Then, the laboratory result tests were processed using the distribution fitting method and descriptive statistics. Conceptual modeling will be carried out using Slide2 and RS2 software owned by PT Studio Mineral Batubara which has been officially licensed from Rocscience™.

Material Geomechanics

In the application of civil engineering and mining, physical and mechanical properties are properties that are used to understand the behavior of a material or known as a geomechanical property. To find out the general geomechanical properties of a material, it can be found out through several tests, both in-situ and ex-situ (laboratory testing). Laboratory testing generally uses international standards such as ISRM (International Society of Rock Mechanics) and ASTM (American Standard Testing Materials).

Material behavior, in general, can be known by the criteria of material strength [2]. The material strength criteria will observe the material behavior on the permeability, compressibility, shear strength, and deformation of the material itself [3]. Based on the physical properties of soft materials, the material consists of three components, namely solid, water, and air. This happens because the material has a porosity so that water and air can fill the empty space. For engineering purposes, the presence of water in a material can be a challenge because it reduces the strength of the material.

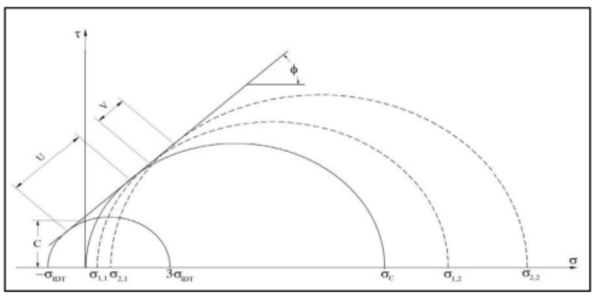

Figure 1. Mohr Coulomb Failure Criterion

The material shear stress criterion can be explained as the relationship between material failure due to a critical combination of normal stresses and shear stresses, depicted by the Mohr strength circle in **Figure 1**. The criteria are expressed by the equation as follows:

$$\tau = c + \sigma \tan\theta \quad (1)$$

Where:

- τ : Shear stress
- c : Cohesion
- σ : Normal stress

θ : Internal friction angle

Slope Stability Analysis and Geotechnical Modelling

A force system works in a slope which, if the balance is disturbed, will cause mass movement. The slope force system can be broken down into a resisting force and a driving force. An unbalanced force system will cause the slope to become unstable. In order to determine the slope stability, calculations that compare the resisting and driving forces are needed. This comparison known as the factor of safety [1], generally stated as follows:

$$FoS = \frac{\tau f}{\tau d} \quad (2)$$

Where:

FoS : Factor of Safety

τ_f : Shear strength

τ_d : Shear stresses

In general, the safety criteria are regulated in the Decree of the Energy and Mineral Resources Minister No. 1827/K/30/MEM/2018 **(Table 1)**. The safety criteria have captured the coverage of safety factor, landslide probability, and landslide severity [2].

Table 1. Factor of Safety Criteria and Landslide Probability

Slope Type	Landslide Severity	Accepted Criteria		
		Static Safety Factor (min)	Dynamic Safety Factor (min)	Probability of Failure (max) PF (FoS≤1)
Single Slope	Low until High	1.1	None	25 - 50%
Interramp Slope	Low	1.15-1.2	1.0	25%
	Intermediate	1.2	1.0	20%
	High	1.2-1.3	1.1	10%
Overall Slope	Low	1.2-1.3	1.0	15 - 20%
	Intermediate	1.3	1.05	10 %
	High	1.3 – 1.5	1.1	5 %

Geotechnical modeling was carried out using limit equilibrium methods and finite element methods. LEM modeling aimed to determine the value of the factor of safety (FoS) based on static and dynamic conditions (in this case pseudo-static) with a landslide probability approach of failure. In addition, FEM modeling was carried out as a verification of the LEM modeling results and to find out the total displacement forecast of the slope material.

Dozer-Push Method

According to MECMining (2016), the advantages of dozer push methods are lower cost of capital, able to move more material (per operator hour than excavator capacity), more flexible, able to work in wet site conditions, simple and fast to mobilize a new dozer fleet. Meanwhile, some weaknesses of this method are the maximum slope of 20° to work on, material moving conditions are relatively rougher and tougher for the operator, shallow site mine only (where the thickness of the top coal is not too high), and not able to push long distances (maximum about 70 meters).

RESULTS AND DISCUSSION

Sampling and Testing

Table 2. Sampling Locations for Laboratory Tests

No	Sample ID	Test Type	Material	Coordinate		
				x	y	z
1	UCS 1	UCS (onsite)	Spoiled DP	0060510	0404132	29
2	UCS 2			0060535	0404110	23
3	UCS 3			0060515	0404118	21
4	UCS 4			0060513	0404119	22
5	UCS 5			0060494	0404121	18
6	UCS 6			0060494	0404144	19
7	UCS 7			0060523	0404128	23
8	UCS 8			0060491	0404715	22
9	UCS 9			0060458	0404773	18
10	UCS 10			0060424	0404812	19
11	UCS 11			0060353	0404820	12
12	UCS 12			0060391	0404803	14
13	UCS 13			0060402	0404791	14
14	DS-14	UCS and Shear Strength	Old wedges coal	0060323	0405205	-10
15	DS-15		New wedges coal	0060199	0404955	3
16	DS-16		Over burden	0060255	0405171	18
17	DS-17		Over burden	0060211	0405208	16
18	DS-18		Soil	0060945	0407582	105
19	UDS10-DS06		Over burden	0060725	0408303	120
20	UDS11-DS07		Over burden	0060715	0408303	116
21	UDS12-DS08		Over burden	0060695	0408424	116
22	UDS13-DS09		Soil	0060207	0407962	81
23	UDS14-DS10		Soil	0060217	0407962	81

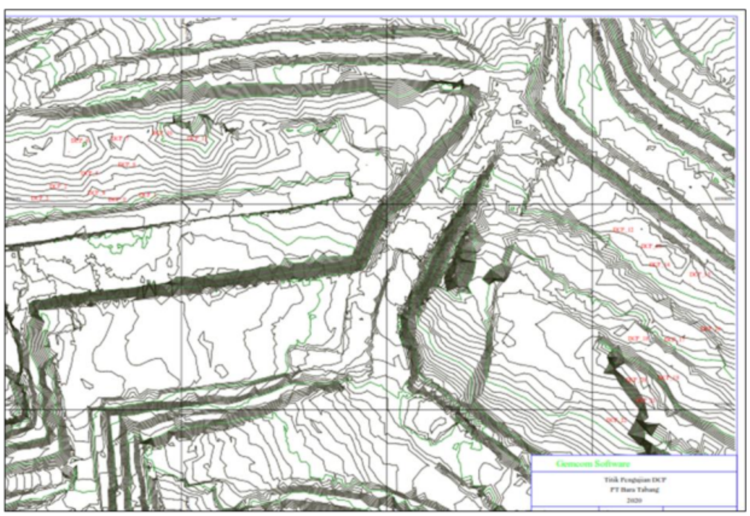

Figure 2. DCP (Dynamic Cone Penetrometer) Test Location

Table 3. DCP Test Result

Location	No	Sample ID	Average DCP Value	Estimated Average CBR Value	Average Soil Bearing Capacity	Average Criteria
			mm/tumbukan	%	kg/cm^2	
West Dozer Push Wedges	1	DCP_01	40.50	6.72	5.27	Poor to Fair
	2		50.94	4.78	4.63	Poor to Fair
	3	DCP_02	37.08	8.11	5.63	Fair
	4		38.00	6.68	5.26	Poor to Fair
	5	DCP_03	27.10	10.84	6.18	Fair
	6		17.09	19.80	7.32	Fair
	7	DCP_04	46.78	16.42	6.96	Fair
	8		36.42	8.89	5.80	Fair
	9	DCP_05	20.11	14.27	6.70	Fair
	10		45.50	6.78	5.29	Poor to Fair
	11	DCP_06	31.67	8.50	5.72	Fair
	12	DCP_07	28.43	9.31	5.89	Fair
	13		31.56	8.63	5.74	Fair
	14	DCP_08	37.56	7.73	5.54	Fair
	15		39.14	6.22	5.13	Poor to Fair
	16	DCP_09	16.50	17.81	7.12	Fair
	17	DCP_10	28.56	9.17	5.86	Fair
	18	DCP_11	22.92	11.10	6.22	Fair
East Dozer Push Wedges	1	DCP_12	10.23	39.61	8.63	Good
	2		25.60	17.19	7.05	Fair
	3	DCP_13	24.43	30.23	8.12	Good
	4		42.27	7.41	5.46	Fair
	5	DCP_14	50.56	8.35	5.68	Fair
	6	DCP_15	13.05	24.42	7.71	Good
	7	DCP_16	66.09	3.67	4.13	Poor to Fair
	8		50.90	6.92	5.33	Poor to Fair
East Dozer Push Wedges (Contact with Fresh Material)	9	DCP_17	27.47	14.90	6.78	Fair
	10		78.60	3.47	4.02	Poor to Fair
	11	DCP_18	27.50	10.37	6.09	Fair
	12	DCP_19	24.17	15.24	6.82	Fair
	13	DCP_20	42.30	9.53	5.93	Fair
	14	DCP_21	12.86	23.49	7.64	Good
	15	DCP_22	20.80	15.50	6.85	Fair

Based on the results of data processing above **(Table 3),** the distribution of soil bearing capacity criteria in the west and east dozer push areas is dominated by Fair (64%), Poor to Fair (24%), dan Good (12%), as shown in **Figure 3.**

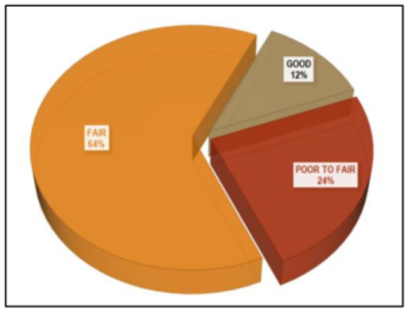

Figure 3. Distribution of Layer Criteria based on %CBR Estimation

The comparison of DCP values in the west and east dozer push areas is shown in **Figure 4.** Based on these results, mentioned that the west dozer push areas have relatively uniform DCP values compared to the east area. On the other hand, the eastern area has a larger data range than the western area.

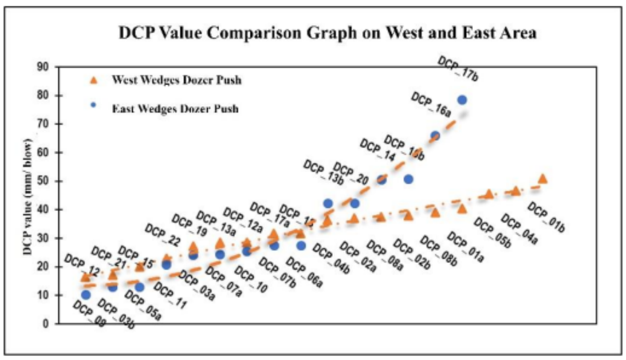

Figure 4. DCP Value Comparison Graph on West and East Area

Material Properties Data

Laboratory test results were processed according to the statistical parameters needed for analysis, as shown in

Table 4.

Table 4. Material Properties Used for Modeling

Material	Parameter	Mean	Std. Dev	Rel. Min	Rel. Max	Dist. Type
Dozer Push 2018	Saturated unit weight (kN/m3)	12.35	1.49	2.26	4.11	Normal
	Unsaturated unit weight (kN/m3)	11.10	0.98	1.60	2.42	Normal
	Cohesion (kN/m2)	31.31	8.49	17.50	23.94	Normal
	Phi	43.29	8.36	20.12	20.52	Normal

Dozer Push 2020	Saturated unit weight (kN/m3)	18.35	2.48	4.50	2.57	Lognormal
	Unsaturated unit weight (kN/m3)	15.12	1.78	3.60	1.85	Lognormal
	Cohesion (kN/m2)	19.36	4.32	5.64	5.61	Lognormal
	Phi	37.05	2.45	3.61	2.48	Lognormal
Truck and Shovel 2018	Saturated unit weight (kN/m3)	12.89	1.48	1.43	3.57	Normal
	Unsaturated unit weight (kN/m3)	11.07	1.11	0.97	2.46	Normal
	Cohesion (kN/m2)	20.25	2.99	6.44	3.43	Lognormal
	Phi	36.94	10.22	13.77	24.26	Normal
Overburden 2018	Saturated unit weight (kN/m3)	20.97	0.97	1.48	3.42	Lognormal
	Unsaturated unit weight (kN/m3)	17.37	1.77	6.25	5.29	Normal
	Cohesion (kN/m2)	137.96	96.22	126.96	206.04	Gamma
	Phi	11.15	4.27	8.8	10.68	Normal
Claystone	Saturated Unit Weight (kN/m^3)	20.38	1.26	5.31	2.70	Lognormal
	Unsaturated Unit Weight (kN/m^3)	16.85	2.76	6.12	3.12	Lognormal
	Cohesion (kn/m^2)	37.86	453.35	34.56	34.71	Lognormal
	Friction Angle (°)	17.13	22.38	10.29	18.81	Gamma
Coal	Saturated Unit Weight (kN/m^3)	12.47	0.57	0.86	2.34	Lognormal
	Unsaturated Unit Weight (kN/m^3)	10.33	0.49	1.44	1.83	Gamma
	Cohesion (kn/m^2)	65.22	563.77	48.81	52.15	Normal
	Friction Angle (°)	24.90	37.56	13.72	14.38	Gamma

Limit Equilibrium Method Modeling

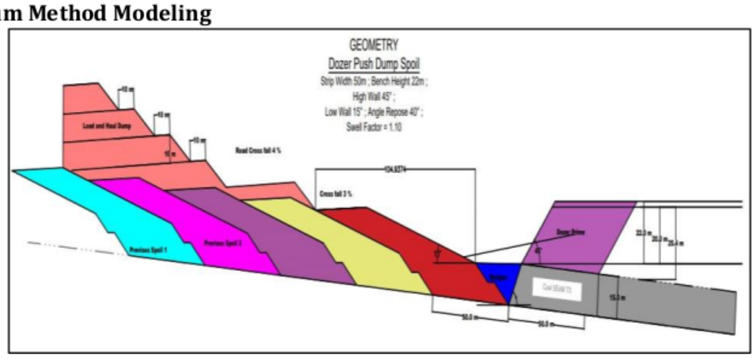

Figure 5. Initial Conditions of Dozer-Push Area

Modeling was carried out based on 2 excavations options, they are:

a. Option 1: bench formation in the dozer-push area
b. Option 2: single slope formation on dozer-push wedges area at 35°.

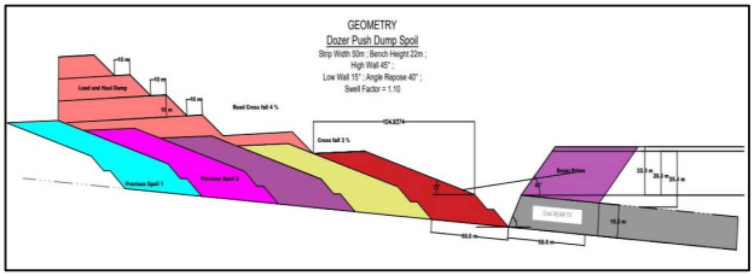

Figure 6. Dozer-push Condition_Option 1

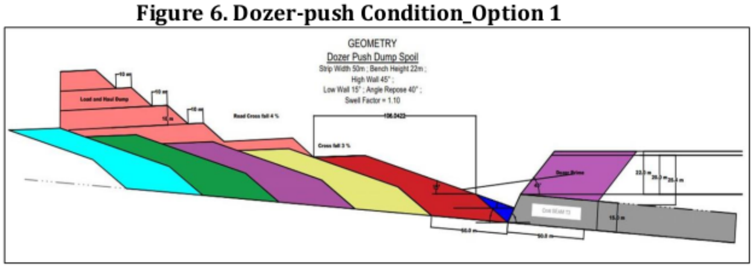

Figure 7. Dozer-push Condition_Option 2

Geotechnical modeling based on the LEM method was used several analytical approaches as follows:

a. Slope stability classification refers to the Decree of Energy and Mineral Resources Minister No 1827 K/30/MEM/2018 for multi-ramp slope and single slope. The approach of landslide severity on multi-ramp slopes is considering (i) the age of the slopes, which is more than 60 days; (ii) the impact of landslides on mining operations; (iii) the ability to implement geotechnical monitoring procedures. Based on this approach, the classification for slope stability on multi-ramp slope is FoS > 1.1 and PF < 10% with high landslide severity criteria.
b. The approach to landslide severity on single slopes is considering (i) the age of the slopes is between 7-14 days; (ii) conditions around the slope location as an active working front; (iii) the ability to implement monitoring and remediation procedures. Based on these considerations, the single slope stability criteria are FoS > 1.1 and PF < 25% with high landslide severity.
c. The modeling was carried out under pseudo-static conditions by considering the vibration factor based on the Indonesia Earthquake Source and Hazard Map at the mining site, which is 0.05g.
d. The modeling uses a combination of material properties based on previous studies and the 2020 update. The material properties have been statistically processed using the distribution fitting method.
e. Slope stability analysis with Limit Equilibrium Method used the GLE/Morgenstern-Price method.
f. Slope condition is half-saturated.
g. Dump Truck CAT 777D transport equipment is loaded with a ground pressure of 628 kN/m^2.

There are two scenarios of geotechnical modeling and analysis in the initial conditions, option 1, and option 2 are as follows:

Scenario 1	Scenario 2
The slope above spoil 4 uses the 2018 Truck and Shovel (TS) properties.	The slope above spoil 4 uses the 2018 Truck and Shovel (TS) properties.
Previous spoils 1, 2, and 3 use the Dozer-push properties in 2018.	Previous spoils 1, 2, 3, and 4 use the Dozer-push properties in 2018.
Previous spoils 4 and 5 use the Dozer-push properties in 2020.	Previous spoil 5 uses the Dozer-push properties in 2020.
Coal-wedges and overburden (dozer-prime) use statistical processing data in August 2020.	Coal-wedges and overburden (dozer-prime) use statistical processing data in August 2020.
	In LEM modeling, the landslide surface was assumed with both circular and non-circular shapes.

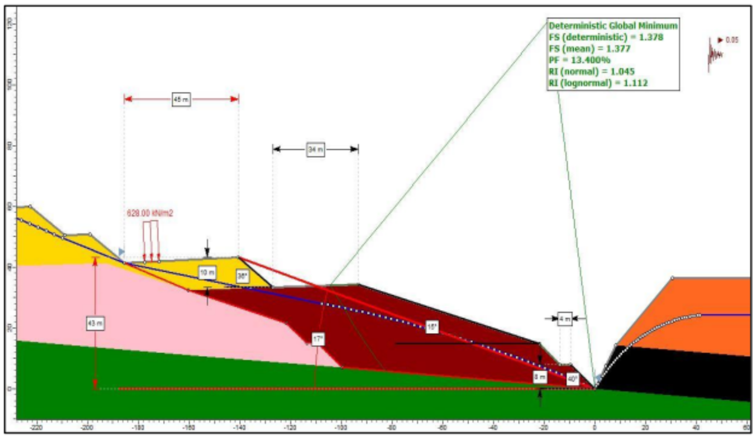

Figure 8. Modeling Result Option 1 Slope Dozer-push (Scenario 1 with 1 DT Unit Load)

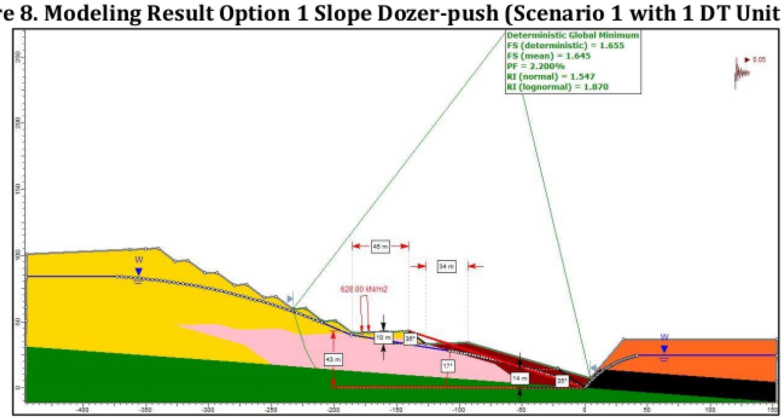

Figure 9. Modeling Result Option 2 Slope Dozer-push (Scenario 1 with 1 DT Unit Load)

Table 5. Recapitulation of Geotechnical Modeling Analysis Results (LEM Method)

Geometry Model	Scenario	Location	Slope Geomtery				FoS		PF (%)	Load
			Overall height (m)	Slope angle (°)	Single height (m)	Slope angle (°)	Deterministic	Mean		
Initial Condition	1	IPD	64	22	8	40	1.74	1.751	0	1 DT
		Dozer-push	43	17			2.11	2.098	0	-
			43	17			1.875	1.861	0.1	1 DT
			43	17			1.608	1.585	0.5	2 DT
		Dozer-prime	-	-	36	50	2.029	1.555	5.15	-
	2	IPD	64	22	8	40	1.74	1.867	0	1 DT
		Dozer-push	43	17			2.142	2.116	0	-
			43	17			1.838	1.816	0	1 DT
			43	17			1.651	1.640	0.1	2 DT
		Dozer-prime	-	-	36	50	2.048	1.571	4.03	-
Option 1	1	IPD	64	22	8	40	1.74	1.751	0	1 DT
		Dozer-push	43	17			1.379	1.378	13.3	-
			43	17			1.378	1.377	13.4	1 DT
			43	17			1.322	1.315	16.7	2 DT
		Dozer-prime	-	-	36	50	1.372	1.275	21.24	-
	2	IPD	64	22	8	40	1.74	1.867	0	1 DT
		Dozer-push	43	17			1.519	1.517	4.6	-
			43	17			1.448	1.442	11.4	1 DT
			43	17			1.380	1.383	0	2 DT
		Dozer-prime					1.372	1.275	21.94	-
Option 2	1	IPD	64	22	8	40	1.742	1.754	0	1 DT
		Dozer-push	43	17			1.674	1.666	1.201	-
			43	17			1.835	1.830	0.1	1 DT
			43	17			1.727	1.728	0.1	2 DT
		Dozer-prime	-	-	36	50	1.688	1.47	8.18	-
	2	IPD	64	22	8	40	1.743	1.870	0	1 DT
		Dozer-push	43	17			1.694	1.681	1.2	-
			43	17			1.655	1.645	2.2	1 DT
			43	17			1.504	1.497	2.6	2 DT
		Dozer-prime	-	-	36	50	1.688	1.465	7.98	-

Notes:
(green) : Safe (Multi-ramp FoS > 1.1 dan PF< 10%; Single slope FoS > 1.1 dan PF < 25%)
(yellow) : Critical (Multi-ramp FoS> 1.1 dan PF ≥ 10%; Single slope FoS > 1.1 dan PF ≥ 25%)
(red) : Not Safe (Multi-ramp FoS < 1.1 dan PF ≥ 10%; Single slope FoS < 1.1 dan PF ≥ 25%)

Based on the results of geotechnical modeling and analysis, the recapitulation was obtained as shown in **Table 5**. The results of the geotechnical analysis at the IPD location, dozer-push, and dozer-prime indicates safe conditions i.e., with the FoS value > 1.1; PF < 10% (Multi – ramp) and FoS > 1.1; PF < 25% (Single slope). Critical conditions were found in the dozer-push location option 1 scenario 1 with Mean FoS values range from 1.378 – 1.315 and PF range from 13.3% – 16.7%. Other than that, the dozer-push slope location in option 2 scenario 2 with 1 DT load simulation shows a critical condition with a PF value of 11.4%. Some examples of the LEM method geotechnical modeling can be seen in **Figure 8** and **Figure 9.**

Finite Element Method Modeling

Slope stability modeling with FEM used with the following approach:

1. Modeling was done based on the results of the LEM analysis model.
2. The ratio of vertical and horizontal pressure on the model was 1.
3. Method of failure and strength of the material used Mohr-Coulomb. So that, the calculation of safety factor uses the Shear Strength Reduction (SSR) approach. The FoS value in LEM modeling was a value equivalent to Strength Reduction Factor (SRF).
4. The parameter used in the FEM analysis is the estimated total displacement in the IPD area, Dozer-push slope, and Dozer-prime slopes.

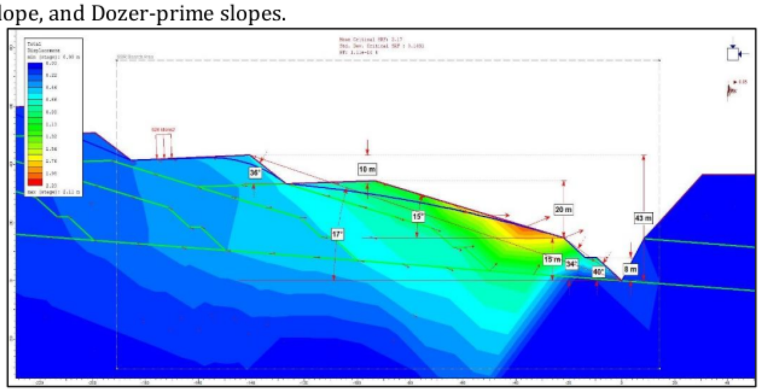

Figure 10. Modeling Result Option 1 Slope Dozer-push (Scenario 1 with 1 DT Unit Load)

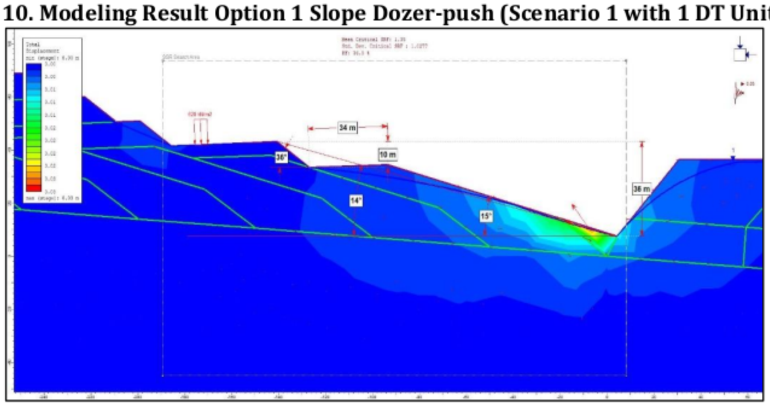

Figure 11. Modeling Result Option 2 Slope Dozer-push (Scenario 1 with 1 DT Unit Load)

Table 6. Recapitulation of Geotechnical Modeling Analysis Results (FEM Method)

Geometry Model	Scenario	Location	Slope Geometry				Estimated Total Displacement Max (m)
			Overall height (m)	Slope angle (°)	Single height (m)	Slope angle (°)	
Initial condition	1	IPD	64	22	8	40	2.09
		Dozer-push	43	17			1.86
		Dozer-prime	-	-	36	50	0.31
	2	IPD	64	22	8	40	2.14
		Dozer-push	43	17			2.22
		Dozer-prime	-	-	36	50	0.33
Option 1	1	IPD	64	22	8	40	3.81
		Dozer-push	43	17			2.11
		Dozer-prime	-	-	36	50	0.56
	2	IPD	64	22	8	40	3.92
		Dozer-push	43	17			2.22
		Dozer-prime					0.56
Option 2	1	IPD	64	22	8	40	4.42
		Dozer-push	43	17			0.03
		Dozer-prime	-	-	36	50	0.75
	2	IPD	64	22	8	40	4.9
		Dozer-push	43	17			0.03
		Dozer-prime	-	-	36	50	0.79

Based on the results of geotechnical modeling and analysis, the recapitulation was obtained as shown in **Table 6**. The geotechnical analysis results with the FEM method shown that the dozer-push slope model in option 2 has a smaller total displacement estimate than the slope model option 1. The estimated total displacement value in option 2 is 0.03 m, while option 1 is in the range of 2.11 – 2.22. Some examples of geotechnical modeling using the FEM method can be seen in **Figure 10** and **Figure 11**.

Geotechnical Analysis

Geotechnical analysis related to slope stability will consider to the FoS parameters, PF, and estimated total displacement from LEM and FEM modeling results. The relationship between each of parameters's condition and scenarios is shown in **Figure 12** and **Figure 13**. Based on the FEM analysis on the slopes of dozer-push scenario 1 and scenario 2 have estimated total displacement maximum range from 0.03 – 2.11 m and 0.03 – 2.22 m, respectively.

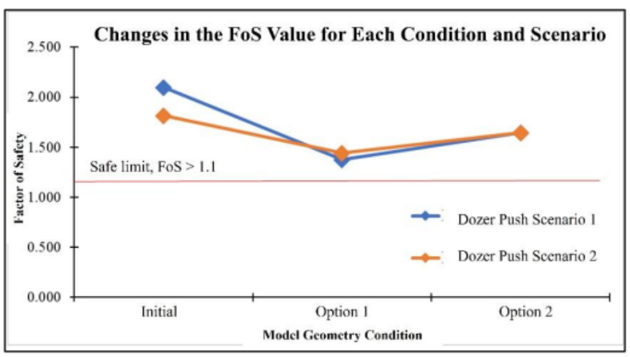

Figure 12. Graph of FoS Slope Change in Dozer push Area

Based on geotechnical modeling, it is known that Scenario 2 has a change in FoS and PF values that are greater than Scenario 1. This means that the distribution of Dozer-push 2020 material properties will be significant for slope stability. Based on the FoS and PF parameters, Option 2 has a relatively stable condition for slope stability compared to Option 1, especially on Dozer-push slopes. From the FEM analysis results, it can be seen that the contours of the estimated total displacement in the Dozer-push slope are concentrated in the uphill area. From these results shown that even though Option 2 classified as a right slope stability, it still has significant potential for movement which almost reaches the critical limit. Therefore, a grea geotechnical monitoring system is needed to address the potential for movement in the dozer-push area.

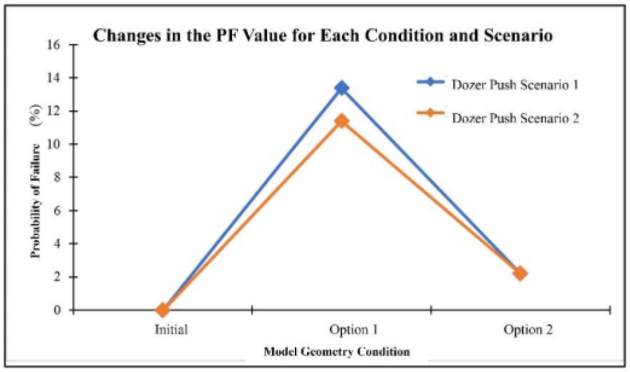

Figure 13. Grafik Perubahan Nilai PL Lereng *Dozer-push*

CONCLUSIONS

1. Geotechnical monitoring using DCP needs to be carried out to see the level of material density in the mine site. The recommended penetration index value is less than **37.20 mm/blow**.
2. From the results of geotechnical analysis, option 2 is recommended as a Dozer-push/wedges slope geometry. This is because it is in accordance with the slope stability criteria for multi-ramp slopes with FoS > 1.1 and PF < 10%. Although the result is safe, it still close to the critical condition classification. Therefore, compaction is needed to get closer to safer stability.
3. There is a movement potential in the uphill dozer-push area. In order to anticipate the potential, periodic geotechnical monitoring is required.

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