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Road Slope Stability Analysis with Limit Equilibrium Method (Case Study: Road Section of Dufa-dufa – Jambula)

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ABSTRACT

Purpose: Landslides are hydrometeorological disasters frequently occurring in many places, particularly during the wet season. Slope stability analysis is the initial stage in defining countermeasures to prevent slope failure and mitigate the negative consequences. This study aims to apply the Limit Equilibrium Method (LEM) to examine the slope stability of the Dufadufa - Jambula road, with the SLIDE version 6.0 application serving as an analytical tool.

Design/methodology/approach: Researchers use field measurement data to build a slide application slope model. The soil data used as input parameters are derived using the Robertson chart to interpret the sonder test findings.

Findings: According to the results, the minimal slope factor of safety (fs) at the area under consideration is 0.247. It demonstrates that the road slope, which is the study location, is in critical condition; in other words, the slope of the Jambula-Dufadufa road segment has the potential to undergo a slide.

Paper type: Research paper

Keyword: *Road Slope, Rocscienceslide Version 6.0, Slope Stability*

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I. INTRODUCTION

Slopes are non-horizontal or sloping terrain surfaces. The gravitational pull increases the driving force due to the difference in elevation between the ground planes. When the shear resistance of the soil on the slope is exceeded, the soil shifts, referred to as a landslide (Hardiyatmo, 2010). Two types of variables cause landslides: (1) internal factors, in which the slide happens without any changes in external conditions, and (2) external factors, which are influences that induce an increase in shear forces with or without changes in soil shear forces (Terzaghi, 1950).

Topographical circumstances sometimes challenge road construction, especially in hilly and mountainous places. Therefore cutting and eroding slopes to build roads is sometimes unavoidable. Changes in slope geometry can increase the driving power of a landslide, which is aggravated further by heavy rains and increasing vehicle traffic (Montoya, 2013). Kogut et al. (2018). It increases the potential of landslides on the slopes along the cliff's cutting parts.

Slope stability analysis is complex since it must consider several parameters. The Limit Equilibrium Method (LEM) and the Finite Element Method (FEM) are commonly used in slope stability analysis (Huang, 2014). Many states that the FEM method has an advantage over the LEM method in that it can examine slope displacements in addition to the safety factor (SF). However, the material's elasticity, which is difficult to determine, has a considerable influence on the mass transfer of soil.

Understanding the possibility of slope failure by knowing the FS value on the slope is enough to serve as the foundation for attempts to control slope failure, allowing the LEM approach to be applied. The Fellenius approach (Fellenius, 1936), the Normal method (Bailey & Christian, 1969), the Bishop Method (Bishop, 1955), and the Spencer Method are some of the most often utilized LEM methods (Spencer 1967). Based on the Mohr-

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coulomb force theory, each technique considers many possible slip surfaces and splits the soil above the slip surface into numerous vertical lines (Zhang & Ding, 2019).

The LEM method's analytical technique has a high level of complexity with numerous variables; hence it takes a long time to complete the study. On the other hand, the rapid development of computational methodologies has made it easier for engineers to accelerate the slope stability study procedure. Several LEM-based computational tools, such as Geo Slope, Slide, Geo Studio, and others, have been widely employed in slope stability modelling. Slide 6.0 was the application utilized in this study.

This research examines the possibility of road slope landslides on the Jambula-Dufadufa road stretch in Ternate, North Maluku. The Rocscience Slide software application calculates slope stability at the research site. The factor of safety determined by the modelling findings represents the slope failure model.

II. METHOD

A. Research Location

The research investigation is on Ternate Island, North Maluku, along the Jambula - Dufadufa road stretch, namely at Km 04+900 - Km 05+020, as depicted in Figure 1. A topographical survey of the research site using a measuring tool called a Total Station theodolite. Researchers then add the topographic measurement results so the Slide program can use them as slope geometry.

Figure 1. Research Location

B. Soil Parameter Analysis based on Robertson Charts (1990)

The parameters of each soil layer used in this study's estimation of the potential for road slope failure were from sonder test findings. The testing aims to evaluate the soil's bearing capacity at each depth and to stratify the earth (Das, 2010). The soil types are identified by assessing the findings of end resistance (qc) and blanket friction readings (fs). End resistance (qc) is the force per unit area value of soil resistance to the tip of the cone. Cover friction (fs) is the soil's shear resistance against the cone sheath measured in force per unit area. Figure 1 depicts the conical and overall resistance values obtained from the two (two) sonder locations tested. It is necessary to get a profile of the horizontal soil layer.

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The Robertson graphical method is used in this study to analyze soil technical data, as illustrated in Figure 2. Soil behaviour type (SBT) is an index derived from the logarithmic relationship between the value of conical resistance (qc) and the resistance ratio (R). This relationship is described formally as an index in equation 1.

$$I_C = \left[(3.47 - \log q_c)^2 + (\log FR - 1.22)^2\right]^{0.5}$$ ………….. (Equation 1)

Where: I_C states the behaviour index of soil types; q_c is the cone resistance; dan FR is the ratio of the adhesive resistance.

Researchers plot Sonder readings for each layer on a Robertson chart. Meanwhile, the determination of soil type is based on the I_C value, which is grouped into nine classifications, as shown in Table 1.

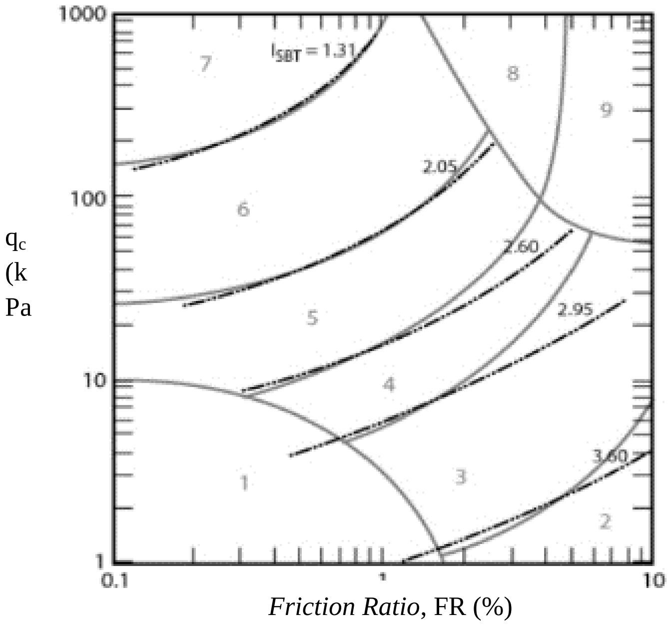

Figure 2. Robertson Chart (Robertson, 1990)

Table 1. Classification of land types based on the value of IC

Zone	*Soil Behaviour Type (SBT)*	I_{SBT}
1	*Sensitive Fine-Grained*	*N/A*
2	*Clay – Organic Soil*	*>3.6*
3	*Clays: Clay to Silty Clay*	*2.95-3.6*
4	*Silt Mixtures: Clayey Silt & Silty Clay*	*2.6-2.95*
5	*Sand Mixtures: Silty Sand to Sandy Silt*	*2.05-2.6*
6	*Sands: Clean Sands to Silty Sands*	*2.31-2.05*
7	*Dense Sand to Gravelly Sand*	*<1.31*

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8	*Stiff Sand to Clayey Sand**	*N/A*
9	*Stiff Fine-Grained**	*N/A*

Sumber : (Robertson, 1990)

C. Slope Stability Modeling with Rocscience Slide

As a slope stability computational tool, the Rocsience Slide is a geotechnical computational tool based on the boundary equilibrium approach (LEM). The Rocscience Slide is part of a suite of geotechnical calculations from Rocscience that includes Swedge, Roclab, Phase2, RocPlane, Unwedge, and RocData.

This application contains numerous slope stability analysis methods, such as Bishop, Janbu, Spencer, Morgensten-Price, and others. The Bishop approach is the only one used in this study. The procedures for slope stability analysis using Rocscience Slide are as follows: (1) modelling stages, (2) identification of calculation methods and parameters, (3) material identification, (4) slip plane determination, (5) running/calculation, and (6) interpretation of the value of the factor of safety. Researchers need complementary software called Slide Interpret to determine the safety factor on the Rocsciece slide.

III. RESULTS AND DISCUSSIONS

A. Sonder Test Results

Figure 3 depicts the sonder test findings at the research site. The sonder test findings graphically illustrate the relationship between the resistance value and depth. In this graph, the resistance value comprises the cone tip resistance and the overall resistance, which is the sum of the tip and frictional resistance. Sonder test findings revealed that a q_c value of 210 kg/cm2 was achieved at a depth of 7.20 m at sonder point 1, and a q_c value of 210 kg/cm2 was obtained at a depth of 1.60 m at sonder point 2.

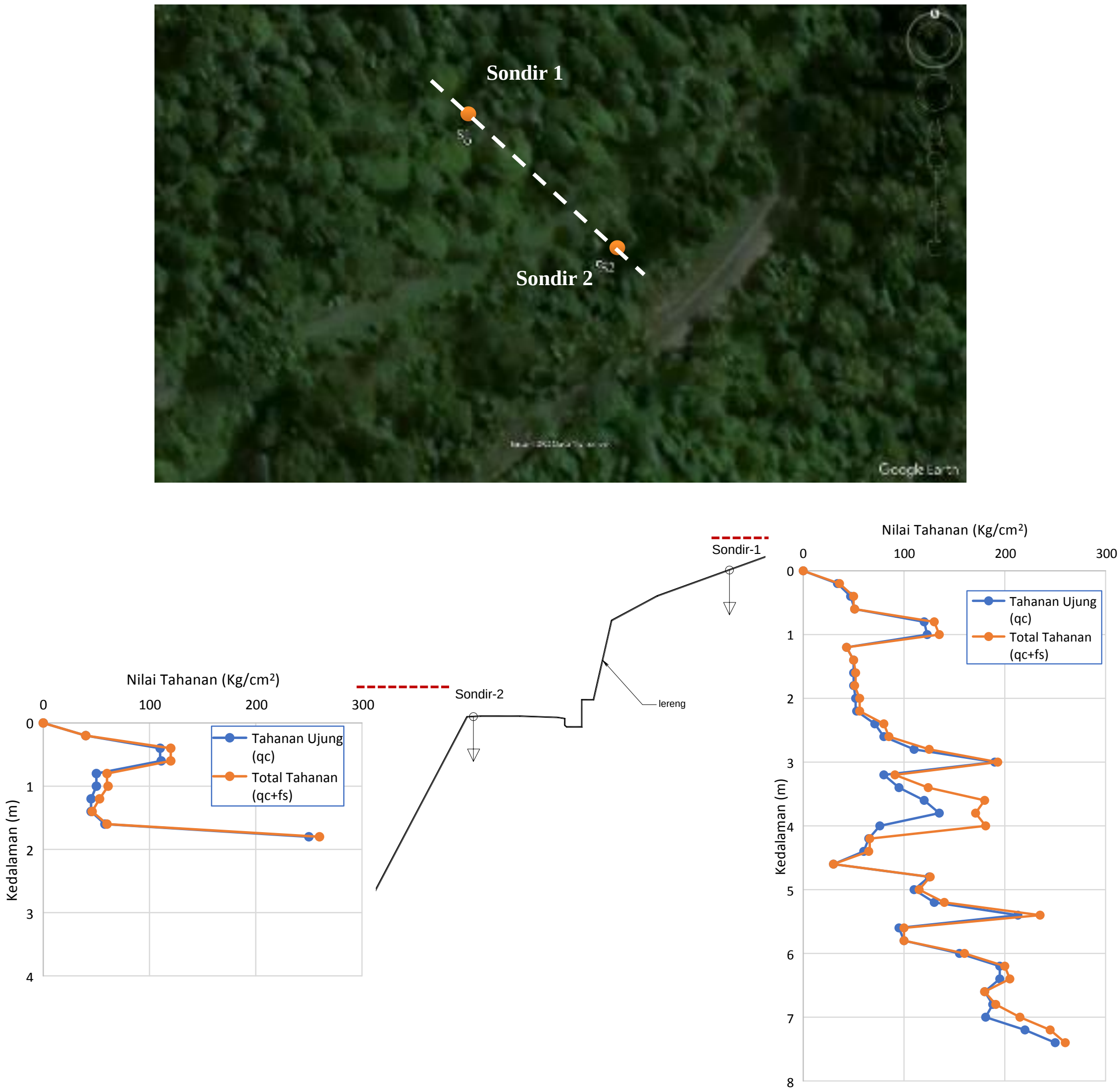

Figure 3. Sonder Results Mapping

Furthermore, the resistance value at a depth of 0.60 m - 0.80 m at sonder point 1 is 80 - 90 kg/cm2, but the q_c value at a depth of 0.20 m - 0.40 m at sonder point 2 is 70 - 80 kg/cm2. The similarity of the graphic patterns suggests that the soil layers in this segment have similar soil properties.

B. Sonder Data Interpretation

Researchers plot each value from the sonder test results onto the Robertson graph based on the findings of calculating the soil type behaviour index (I_C) using Equation 1. Figure 4 depicts the I_C distribution of sonder points 1 and 2. The distribution of I_C values on the Robertson chart demonstrates that sand and mixed sand dominate the soil type at sonder 1. Meanwhile, the soil of Sonder 2 ranges widely from loam to sandy. The findings of visual observations on exposed soil at sonder locations 1 and 2 (shown in Figure 5) support the interpretation of soil types at the study site.

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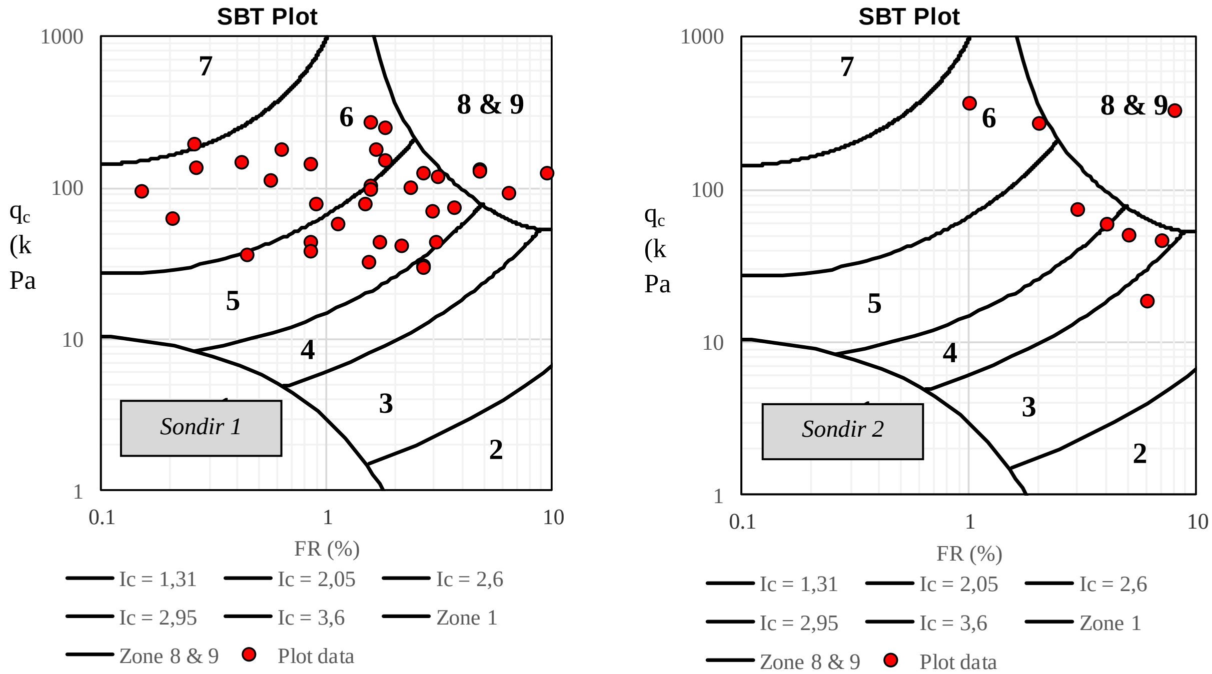

Figure 4. Plotting sonder data on Robertson Chart

Figure 5. Visualization of soil types at sonder points 1 and 2

Researchers use the interpretation results to calculate the soil's technical parameters, with the results of the study of the soil's technical properties at sonder points 1 and 2 presented in Tables 2 and 3, respectively.

Table 2. The results of the calculation of the technical parameters of the soil at Sonder Point 1

Depth (m)	*Soil Type*	*Average Value*		
		γ (kN/m³)	*φ' (deg)*	*c' (kPa)*
0-0.2	*SANDS 1*	*16.53*	*37.91*	*0.00*
0.2-0.4	*SAND MIX 1*	*17.43*	*37.47*	*0.00*
0.4-0.8	*SANDS 2*	*19.54*	*43.84*	*0.00*
0.8-2.6	*SAND MIX 2*	*17.53*	*35.30*	*0.00*

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Depth (m)	*Soil Type*	*Average Value*		
		γ (kN/m³)	*φ' (deg)*	*c' (kPa)*
2,6-2,8	*SANDS 3*	*18.28*	*43.30*	*0.00*
2.8-3.0	*SAND MIX 3*	*19.19*	*37.29*	*0.00*
3.0-3.8	*VSF*	*16.79*	*24.80*	*8.22*
3,8-4,4	*SAND MIX 4*	*17.58*	*33.97*	*0.00*
4,4-5,2	*SANDS 4*	*18.90*	*39.97*	*0.00*
5,2-5,4	*SAND MIX 5*	*18.50*	*37.15*	*0.00*
5,4-6,6	*SANDS 5*	*18.21*	*40.46*	*0.00*
6,6-6,8	*SAND MIX 6*	*21.05*	*40.80*	*0.00*
6,8-7,2	*SANDS 6*	*20.28*	*42.17*	*0.00*

Table 3. The results of the calculation of the technical parameters of the soil at Sonder Point 2

Depth (m)	*Soil Type*	*Average Value*		
		γ (kN/m3)	*φ' (deg)*	*c' (kPa)*
0-0.4	*SANDS 1*	*19.30*	*44.78*	*0.00*
0.4-0.6	*VSF*	*18.61*	*19.71*	*7.23*
0.6-0.8	*SAND MIX 1*	*18.72*	*18.85*	*8.26*
0.8-1.0	*SANDS 2*	*18.72*	*18.37*	*8.62*
1.0-1.2	*G. SAND 1*	*15.69*	*24.78*	*2.93*
1.2-1.4	*SAND MIX 2*	*16.98*	*34.58*	*0.00*
1.4-1.6	*SANDS 2*	*19.77*	*45.98*	*0.00*

D. Computing Slope Stability with Slides Ver. 6.0

Researchers use the findings of soil technical parameter calculations based on Robertson's (1990) graphic interpretation to generate geometric models in the Rocscince Slide program. The soil layer is categorized

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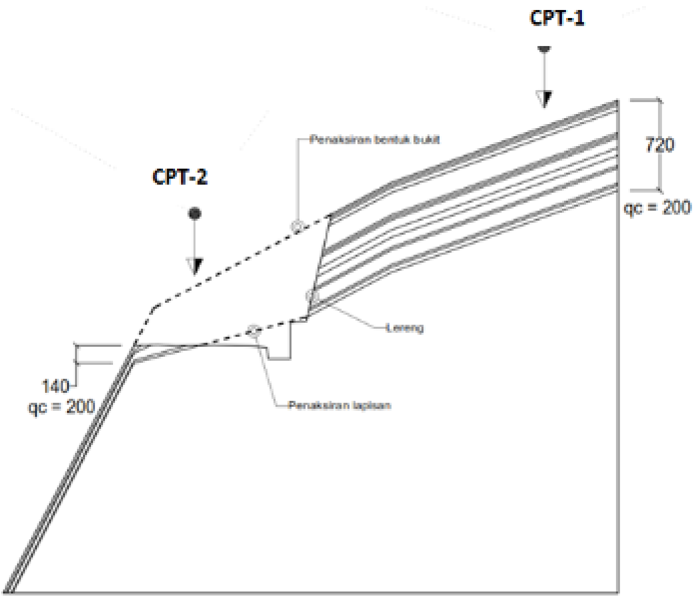
according to its depth based on the average technical parameter value. Slope geometry modelling is done using AutoCAD software rather than the Rocscience Slide application to simplify and provide a more realistic model.



CPT-1

Kedalaman (m)	Jenis	Rerata		
		γ (kN/m^3)	φ' (deg)	c' (kPa)
0-0,2	SANDS 1	16.53	37.91	0.00
0,2-0,4	SAND MIX 1	17.43	37.47	0.00
0,4-0,8	SANDS 2	19.54	43.84	0.00
0,8-2,6	SAND MIX 2	17.53	35.30	0.00
2,6-2,8	SANDS 3	18.28	43.30	0.00
2,8-3,0	SAND MIX 3	19.19	37.29	0.00
3,0-3,8	VSF	16.79	24.80	8.22
3,8-4,4	SAND MIX 4	17.58	33.97	0.00
4,4-5,2	SANDS 4	18.90	39.97	0.00
5,2-5,4	SAND MIX 5	18.60	37.15	0.00
5,4-6,6	SANDS 5	18.21	40.46	0.00
6,6-6,8	SAND MIX 6	21.05	40.80	0.00
6,8-7,2	SANDS 6	20.28	42.17	0.00

CPT-2

Kedalaman (m)	Jenis	Rerata		
		γ	φ' (deg)	c' (kPa)
0-0,4	SANDS 1	19.30	44.78	0.00
0,4-0,6	VSF	18.61	19.71	7.23
0,6-0,8	SAND MIX 1	18.72	18.85	8.26
0,8-1,0	SANDS 2	18.72	18.37	8.62
1,0-1,2	G. SAND 1	15.69	24.78	2.93
1,2-1,4	SAND MIX 2	16.98	34.58	0.00
1,4-1,6	SANDS 2	19.77	45.98	0.00

Figure 6. Building a geometry model in AutoCAD

As illustrated in Figure 6, researchers save the modelling results in a file with the suffix *.dxf. The following step is to import the geometry file into the RocScience Slide application and define each layer in the geometry model based on the interpretation of the soil layers, as illustrated in Figure 7.

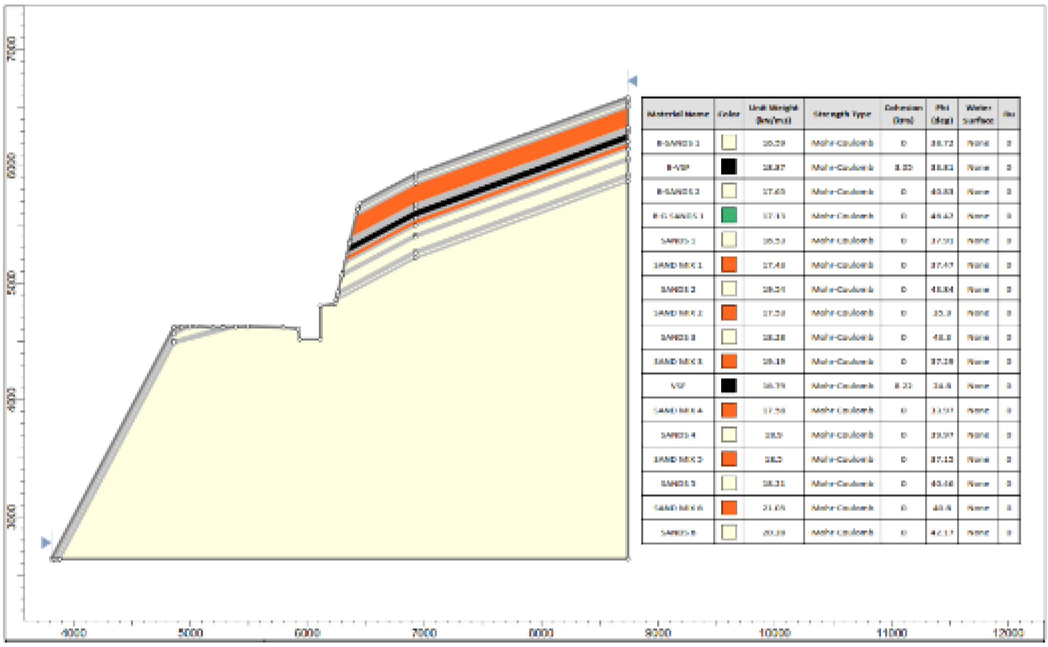


Figure 7. Slope geometry model with stratification of soil layers

Figure 8 depicts the findings of the slope stability analysis at the research site. These findings indicate that the cross-section of the road under consideration has a factor of safety (FoS) value of less than one, with a minimum FoS of 0.247. It shows that the slope under consideration is in critical condition, implying that the risk of slope failure on this road stretch is relatively high.

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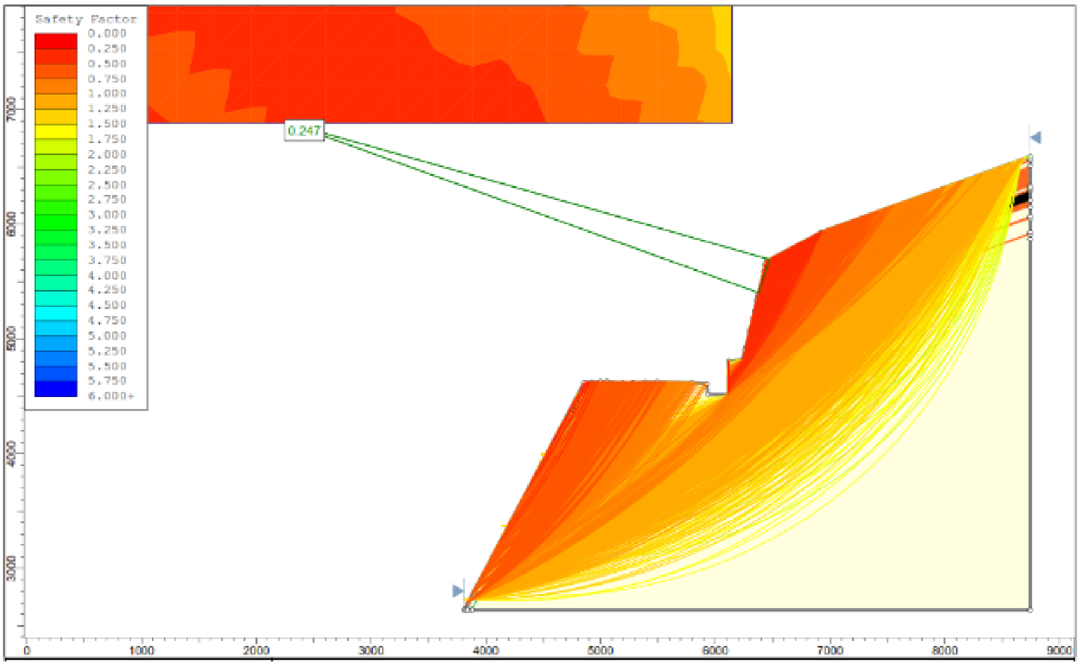

Figure 8. The computational results of landslide fields using RocscienceSlide

IV. CONCLUSIONS

1. Slope stability analysis using the LEM approach, namely the use of Rocscience Slide in computing slope stability, gives greater convenience, speed, and accuracy than manual analysis.
2. The computational findings of the slope stability of the Jambula-Dufadufa road segment yield a minimum safety score of 0.208. Most modelling results indicate a safety factor value of less than 1. As a result, the slope stability at the research site is critical, with the possibility of a landslide.

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