

Mine Slope Stability Analysis CV. Putra Idola Against the Padang-Painan Cross Road with GSI Method and Rock Mass Rating

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ABSTRACT

Rock slope stability in open-pit mining is critically influenced by rock mass quality, which can be evaluated using the Rock Mass Rating (RMR) and Geological Strength Index (GSI) systems. This study, conducted at CV. Putra Idola in West Sumatra, aimed to determine the rock mass characteristics and assess slope stability conditions. Field investigations were carried out using a 15.2-meter scanline method to map discontinuities, complemented by laboratory testing to determine the physical and mechanical properties of andesite and hornfels rocks. The results showed that RMR values ranged from 57 to 75, while GSI values ranged from 53 to 75, classifying Fresh Andesite and Hornfels as “Good” and Weathered Andesite as “Fair.” These classifications were used to derive cohesion and friction angle values, forming a basis for numerical slope modeling using the limit equilibrium method. The findings support improved slope design and landslide risk mitigation in open-pit mining operations.

Keywords

Slope stability, Rock Mass Rating (RMR), Geological Strength Index (GSI), scanline mapping, open-pit mining.

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INTRODUCTION

Mine slopes are essential for the sustainability of mining operations, especially for safety and operational efficiency. Slope stability is affected by various geotechnical elements, such as rock mass properties, discontinuity systems, and hydrogeological conditions [1]. Instability in mining slopes can precipitate landslides, causing substantial material losses, operating interruptions, and jeopardizing worker safety and surrounding populations. Thus, slope stability analysis is crucial in mine design and management to ensure safe and efficient mining operations.

CV. Putra Idola is an andesite rock mining enterprise employing an open-pit mining technique in Padang City, West Sumatra. The mining site is situated next to the Padang–Painan Cross Road, and mining operations in this vicinity present a possible threat to the stability of the surrounding slopes, which may affect road safety and related infrastructure. Optimal slope designs must include safety considerations, encompassing ideal inclination and structural integrity, to avert slope failures [2]. Attaining such designs necessitates precise characterisation of the rock mass. Nevertheless, real-world conditions frequently diverge from initial design assumptions due to natural elements such as weathering, water infiltration, and continuous mining operations, all of which may undermine slope stability [3].

The Rock Mass Rating (RMR) technique is extensively utilized in geotechnical engineering for rock mass categorization and has been revised multiple times to enhance its applicability [4]. Notwithstanding its utility, RMR possesses significant constraints in tackling particular geotechnical issues. The Geological Strength Index (GSI), designed to augment the Hoek–Brown failure criterion, offers a quantitative assessment of rock mass quality based on surface conditions and structural integrity [5][6]. An correct GSI value is vital for determining the failure envelope and deformation modulus of rock masses. This study utilizes both RMR and GSI methodologies to evaluate the conformity of present slope conditions with safe design standards [7][8].

Previous studies conducted at CV. Putra Idola used the Janbu method via Slide 6.0 software to assess slope stability based on safety factor (SF) values [9]. While those studies highlighted the importance of safety factors in evaluating slope conditions, the continuous nature of mining has likely altered the site's geotechnical profile. A more recent investigation is therefore warranted, emphasizing rock mass characterization using updated RMR and GSI approaches to reflect current slope conditions. Another related study examined slope stability at the site using only the RMR method for rock mass classification [10]. However, given the mine's proximity to a public roadway, a more comprehensive evaluation using both RMR and GSI is critical to improving accuracy and ensuring public safety.

Based on these considerations, this study aims to assess the current geotechnical conditions of mine slopes surrounding CV. Putra Idola. The research includes field investigations of discontinuities using the scanline survey method, conducted according to the standards of the International Society for Rock Mechanics and Rock Engineering. The RMR method provides a classification based on key geotechnical parameters, while the GSI method offers insights into rock quality based on geological structure and surface conditions. Combined, these approaches yield a robust understanding of the rock mass characteristics and slope stability at the site. The findings of this study are expected to support more informed slope design and mitigation strategies to minimize landslide risk and protect adjacent infrastructure.

METHOD

Scanline Method

The scanline method represents a widely recognized and dependable approach for the characterization of discontinuities within rock masses. In this approach, a linear survey is performed on an exposed rock surface, wherein all discontinuities that intersect the survey line are meticulously measured and recorded. This methodology facilitates the detailed characterization of rock mass geometry, encompassing the quantification and orientation of discontinuity sets, the average fracture density, as well as the spatial distribution, orientation, spacing, and trace length of fractures. Comprehensive site investigations are essential to elucidate the fundamental components necessary for characterizing the rock mass structure, while simultaneously considering the intrinsic uncertainties associated with geological data acquisition [11]. This research involved the execution of a 15.2-meter scanline survey aimed at identifying joint structures within the exposed andesite rock formation. The parameters assessed encompass joint orientation, spacing, trace length, and surface conditions. Furthermore, rock samples were obtained for laboratory analysis to ascertain critical physical and mechanical characteristics of the rock mass, including uniaxial compressive strength (UCS) and P-wave velocity, which serve as vital parameters for ensuing geotechnical evaluations [12].

Rock Mass Rating (RMR)

The Rock Mass Rating (RMR) system, also referred to as the Geomechanics Classification, has undergone several modifications to incorporate findings from updated case studies and align with evolving international standards. RMR remains one of the most established systems for evaluating rock mass quality and classifying rock stability. The system assesses rock mass quality based on five fundamental parameters: the strength of intact rock, Rock Quality Designation (RQD), spacing of discontinuities, condition of discontinuities, and groundwater conditions. Additionally, a sixth parameter is used to define the orientation adjustment factor, which categorizes the rock mass into different quality classes [13]. This method provides a standardized and quantitative basis for evaluating rock mass conditions and is instrumental in slope stability analysis and design. In this research, RMR classification, as described in Table 1, was applied to field data collected through scanline mapping, enabling the interpretation of geotechnical conditions and informing recommendations for slope stability at the CV. Putra Idola mining site.

Table 1. RMR parameters and ratings

No	Parameters	Range Of Values							
1	Strength of Intact Rock	Point Load Indeks (MPa)	> 10	4-10	2-4	1-2	Prefered UCS test		
		UCS (MPa)	>250	100-250	50-100	25-50	5-25	1-5	<1
2	Rock Quality Designation	Rating	15	12	7	4	2	1	0
		(%)	100-90	90-75	75-50	50-25	<25		
3	Spacing of Discontinuities	Rating	20	17	13	8	3		
		(m)	>2 m	2-0.6 m	600 - 200 mm	200 - 60 mm	< 60 mm		
4	Condition of Discontinuites	Rating	20	15	10	8	5		
			Very rough Surfaces, Not continuous, No separation Unweathered Wall rock	Slightly rough surfaces Separation <1 mm Slightly weathered walls	Slightly rough surfaces Separation <1 mm Highly weathered walls	Slightly rough surfaces Separation <1 mm Highly weathered walls	Slightly sided surfaces, or Gouge < 5mm thick or Separation 1-5 mm (Continuous)	Soft gouge >5 mm thick or separation >5 mm, continuous	
5	Groundwater condition	Rating	30	25	20	10	0		
		Inflow per 10 m tunnel length (L/m)	None	<10	10-25	25-125	>125		

No	Parameters	Range Of Values				
	Ratio of joint water pressure to major principal stress	0	<0.1	0.1-0.2	0.2-0.5	>0.5
	General description	Completely dry	Damp	Wet	Dripping	Flowing
	Rating	15	10	7	4	0

Geological Strength Index (GSI)

The Geological Strength Index (GSI) classification system was established to address two fundamental factors that considerably affect the mechanical behavior of rock masses: the structural integrity, often referred to as blockiness, of the rock and the state of discontinuities present within it. The original Hoek-Brown failure criterion was developed under the premise that intact rock is characterized solely by micro-defects. In contrast, the Geological Strength Index (GSI) system was introduced to provide a more accurate representation of rock masses that consist of angular, interlocking blocks. In these mass structures, the predominant mechanism of failure is attributed to the sliding and rotation of blocks, rather than the failure of the intact rock itself [14]. This study employed the Geological Strength Index (GSI) alongside the Rock Mass Rating (RMR) to assess the mechanical quality of the rock mass. The calculations were derived from field observations, with a particular emphasis on discontinuity characteristics, as well as laboratory test results pertaining to rock strength parameters. The integration of GSI and RMR facilitates a comprehensive characterization of the geotechnical conditions of the slope, thereby enhancing the precision of slope stability evaluations [15].

Location and Time of the Study

The present study was carried out at the mining site of CV. Putra Idola, situated in Teluk Kabung Tengah Village, Bungus Teluk Kabung District, Padang City, as well as in Nagari Siguntur, XI Koto Tarusan District, Pesisir Selatan Regency, West Sumatra Province. The location is situated roughly 30 kilometers to the south of Padang City and can be reached through land transportation, with an estimated travel duration of approximately one hour. The geographical location and accessibility of the site play a crucial role in comprehending the logistical and infrastructural context of the mining operation. [Figure 1](#) provides an illustration of the site's location.

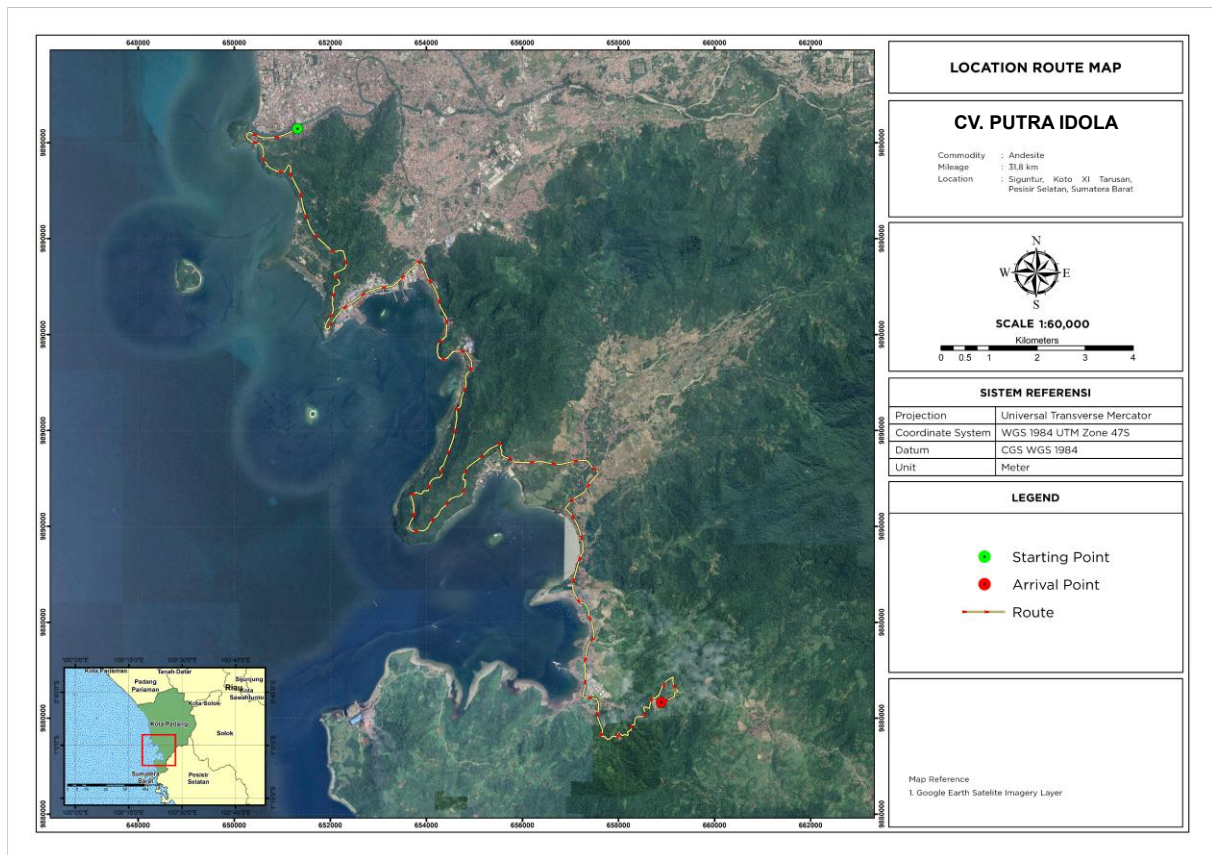


Figure 1. Location Arrival Map

The scope of this research includes rock sampling for laboratory testing, field-based measurement of rock masses using the Scanline method to determine Geological Strength Index (GSI) and Rock Mass Rating (RMR) values, and laboratory analysis to evaluate the physical and mechanical properties of the rock samples.

Research Materials and Equipment

The mining site of CV. Putra Idola, as delineated in the Regional Geological Map of the Painan Sheet issued by the Geological Agency (geologi.esdm.go.id), is located within two predominant geological formations: the Oligo-Miocene Volcanic Rock and the Siguntur Formation, as depicted in Figure 2. The geological structure of the CV. Putra Idola area is defined by the presence of fault systems, accompanied by hilly topographic conditions as depicted in Figure 3.

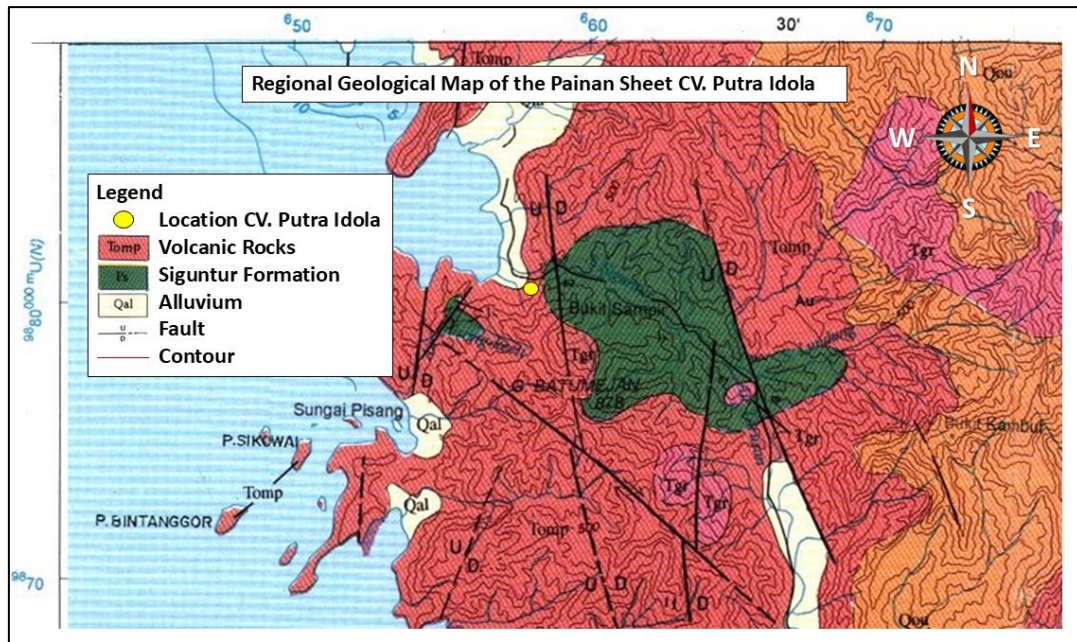


Figure 2. Regional Geological Map of the Painan Sheet CV. Putra Idola

The Oligo-Miocene Volcanic Rock formation is characterized by the presence of reworked andesite fragments, sandy clay, crystalline tuff, and tuff breccia, exhibiting an estimated thickness of up to 700 meters. Conversely, the Siguntur Formation is predominantly composed of quartzite, folded shale, siltstone, and tuffaceous sandstone, exhibiting a total thickness of roughly 2,000 meters. The apparatus employed in this investigation comprises geological compasses, measuring tapes, geological hammers, GPS devices, and geomechanics laboratory instruments for the assessment of physical properties, primary wave velocity (P-wave), and the point load index.

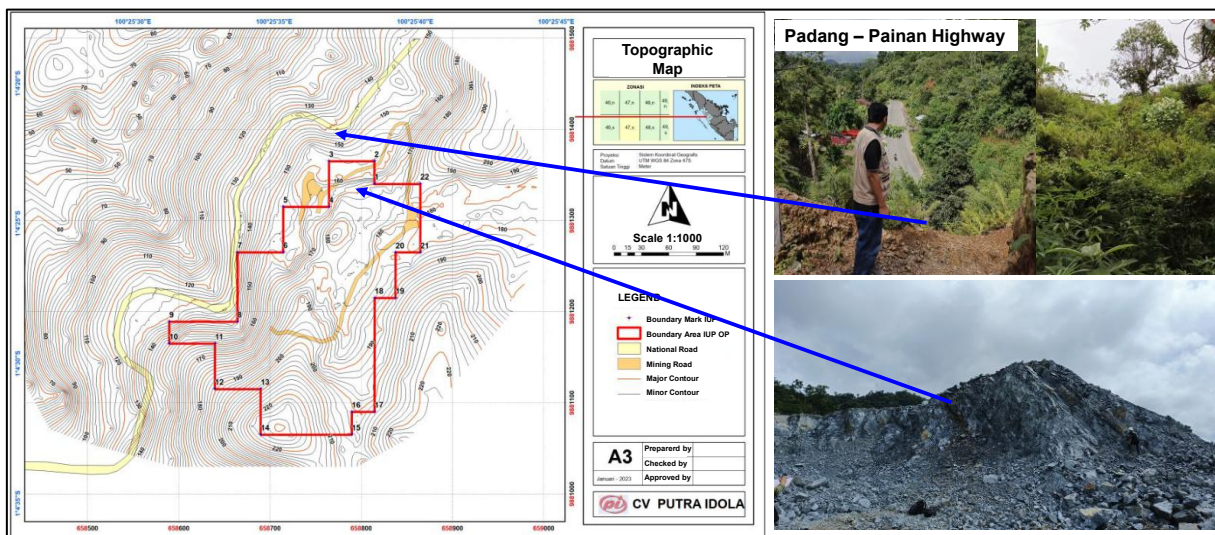


Figure 3. Painan Topographic Map CV. Putra Idola

Research Process

The research methodology, as shown in Figure 4, was organized sequentially to guarantee precise evaluation of rock mass quality and slope stability utilizing the Geological Strength Index (GSI) and Rock Mass Rating (RMR) techniques. The phases are enumerated as follows:

The procedure commences with the collection of field data with the Scanline method, which entails systematic measurements of discontinuities on exposed rock surfaces. Parameters like joint orientation, spacing, length, and surface conditions are documented to comprehend the structural behavior of the rock mass. Subsequent to field measurements, laboratory testing is performed to ascertain the physical and mechanical qualities of the rock specimens. The tests encompass measurements of density, wave propagation velocity, and point load index, which are critical for assessing the rock's strength and deformation properties.

The data acquired from field and laboratory research are utilized to characterize the rock mass through the RMR and GSI categorization systems. These classifications use geological and geomechanical criteria to evaluate overall rock mass quality, which directly influences slope stability assessments. Subsequent to the rock mass classification, an assessment phase is conducted to ascertain if the existing rock mass conditions satisfy the stability criteria. Should the results be considered satisfactory—i.e., demonstrating sufficient strength and integrity—the process is finalized. Nevertheless, if the results indicate subpar rock mass quality, the procedure proceeds with adjustments and additional assessments intended to enhance the rock mass classification. This may entail suggestions for technical modifications or slope design alterations to improve safety and efficacy.

This iterative procedure guarantees that all essential geotechnical elements are methodically examined and that the resultant slope designs are based on dependable, site-specific data.

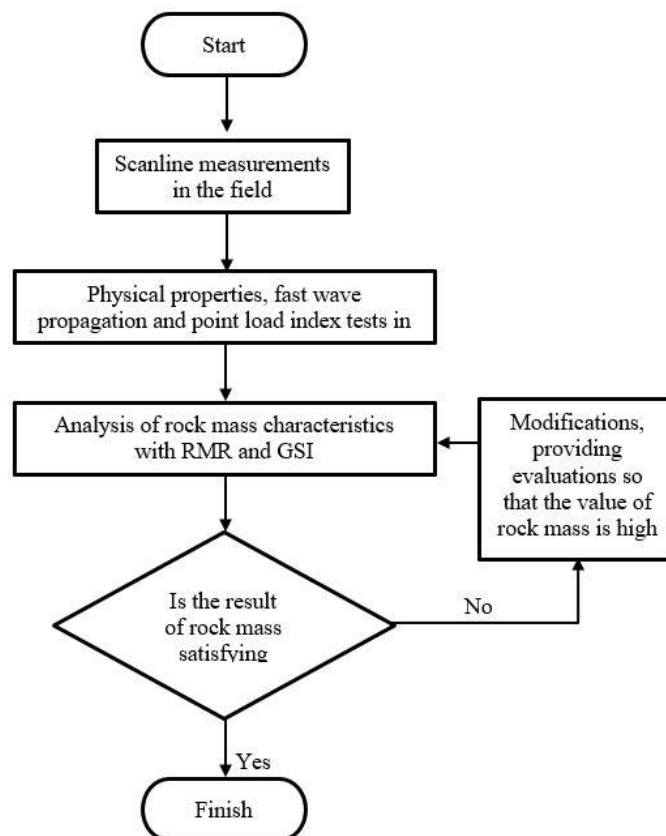


Figure 4. Research Flow Chart

RESULT AND DISCUSSION

Laboratory Test Results

Laboratory analysis is essential in slope stability modeling, as it supplies the technical data required to assess the mechanical behavior of the rock mass forming the slope. This study conducted laboratory tests that concentrated on the physical properties of the rock as well as the point load index. The results presented herein constitute the essential input parameters required for the calculation of Rock Mass Rating (RMR) and Geological Strength Index (GSI) values, as illustrated in [Figure 5](#).



Figure 5. Rock Sampling and Laboratory Testing of Rock Samples

1. Physical Properties of Rocks

Testing the physical properties of rocks is essential for characterizing the rock material and validating field observations [16]. These properties, including density, porosity, and moisture content, are critical in understanding the material's mechanical response under stress. The detailed results of the physical properties analysis conducted in the laboratory are summarized in [Table 2](#).

Table 2. Results of Physical Properties of Rocks

Parameters	Symbol	Fresh Andesite	Weathered Andesite	Hornfels
Original Contents	γ_n (g/cm ³)	2,75	2,56	2,66
Dry Fill Weight	γ_o (g/cm ³)	2,75	2,51	2,63
Saturated Weight	γ_w (g/cm ³)	2,76	2,58	2,67
Pseudo-Type Weights	g/cm ³	2,75	2,51	2,63
Original Specific Gravity	g/cm ³	2,78	2,69	2,72
Natural Moisture Content	wn (%)	0,21	1,98	0,86
Saturated Water Content	wsat (%)	0,39	2,68	1,24
Degree of Saturation	S (%)	57,04	74,89	69,9

Parameters	Symbol	Fresh Andesite	Weathered Andesite	Hornfels
Porosity	n (%)	1,08	6,67	3,26
Void Ratio	e	0,01	0,07	0,03
Fast propagation ultrasonic waves	Vp (m/s)	6574	5490	5123

2. Point Load Index

The point load index test, as illustrated in [Table 3](#), was performed in accordance with ASTM standards, which are globally acknowledged for assessing the strength characteristics of rock specimens [11]. This index serves as an indirect indicator of rock strength and is especially useful for samples that exhibit irregular shapes or pose challenges when subjected to conventional uniaxial compression testing methods. The results of the point load strength index were subsequently transformed into Uniaxial Compressive Strength (UCS) values, which constitute the initial parameter utilized in the RMR classification system—specifically, the strength of intact rock.

Table 3. Point Load Index Test Results

Sample	P (kN)	Is (MPa)	IS(50)	UCS (MPa)
Fresh Andesite	15,66	7,64	6,29	144,60
Weathered Andesite	7,94	3,50	2,81	64,67
Hornfels	7,12	3,13	2,50	57,51

Results of Rock Mass Classification (RMR) Analysis

1. RMR Classification Parameters

The Rock Mass Rating (RMR) system assesses rock quality through the analysis of five key parameters: the uniaxial compressive strength (UCS) of intact rock, Rock Quality Designation (RQD), the spacing of discontinuities, the condition of discontinuities, and the prevailing groundwater conditions. The parameters were obtained through field measurements utilizing the scanline method, further supported by laboratory testing, as illustrated in [Figure 6](#). The analysis presents a thorough evaluation of the rock mass classification within the designated study area, as shown in [Figure 7](#).



[Figure 6](#). Scanline in the Field



Figure 7. Data Collection Locations

a. Uniaxial Compressive Strength (UCS)

Laboratory testing revealed that the Point Load Index (PLI) values were 6.3 MPa for fresh andesite, 2.81 MPa for weathered andesite, and 2.5 MPa for hornfels. These values were converted to UCS using the standardized correlation defined in ASTM guidelines [17]. The resulting UCS values formed the basis for determining the first parameter in the RMR system, as shown in Table 4.

Table 4. RMR Values Compressive Strength Test

Description	Description Strength	Rating
Fresh Andesite	UCS 100 - 250 MPa	12
Weathered Andesite	UCS 50 - 100 MPa	7
Hornfels	UCS 50 - 100 MPa	7

b. Rock Quality Designation (RQD)

The RQD values were determined through direct field observations of joint frequency at exposed rock outcrops [18]. A scanline length of 15.2 meters was utilized, extending from the designated starting point to the endpoint. The RQD values were calculated utilizing the standard formula, with the measurement results presented in Table 5. This parameter offers an understanding of the extent of fracturing present within the rock mass.

$$RQD = 100 \times 10^{-100} \times \lambda((0.1\lambda) + 1)$$

Table 5. RMR Values RQD Parameters

Description	%	Rating
Fresh Andesite	80	17
Weathered Andesite	70	17
Hornfels	80	17

c. Joint Space

Field measurements across the three rock types revealed an average discontinuity spacing ranging between 0.6 and 2.0 meters. According to the RMR classification table, this corresponds to a rating of 15 points. These values are documented in Table 6 and reflect the structural integrity and block size within the rock mass.

Table 6. RMR Values discontinuity spacing of Joint Parameters

Description	m	Rating
Fresh Andesite	0.6 - 2	15
Weathered Andesite	0.6 - 2	15
Hornfels	0.6 - 2	15

d. Joint Conditions

Table 7. RMR Values of Joint Condition Parameters

No	Position	Description	Persistence	Separation	Roughness	Infilling	Weathering
1	0	Fresh Andesite	21 (Value 0)	1 (Grade 4)	Slightly Rough (Grade 3)	Clean (Grade 6)	Moderately (Grade 3)
2	1.1	Fresh Andesite	21 (Value 0)	5 (Value 1)	Rough (Value 5)	Calcite (Grade 4)	None (Grade 6)
3	7.24	Fresh Andesite	12 (Value 1)	20 (Value 0)	Slightly Rough (Grade 3)	Shale (Value 2)	Slightly (Value 5)
4	7.35	Fresh Andesite	12 (Value 1)	1 (Grade 4)	Smooth (Value 1)	Clean (Grade 6)	None (Grade 6)
5	8.85	Fresh Andesite	5 (Value 2)	1 (Grade 4)	Smooth (Value 1)	Calcite (Grade 4)	Slightly (Value 5)
6	9.2	Weathered Andesite	5 (Value 2)	1 (Grade 4)	Smooth (Value 1)	Shale (Value 2)	Highly (Value 1)
7	9.5	Weathered Andesite	5 (Value 2)	30 (Value 0)	Smooth (Value 1)	Shale (Value 2)	Decomposed (Value 0)
8	14.8	Hornfels	7 (Value 2)	0 (Grade 6)	Slightly Rough (Grade 3)	Clean (Grade 4)	Moderately (Grade 3)
9	15.2	Hornfels	7 (Value 2)	0 (Grade 6)	Slightly Rough (Grade 3)	Clean (Grade 4)	Moderately (Grade 3)

e. Groundwater Conditions on the Slope Face

The direct observation of the slope face across the various rock types—fresh andesite, weathered andesite, and hornfels—revealed an absence of visible water seepage or droplets. Consequently, all sites were classified as exhibiting dry groundwater conditions, which positively influences slope stability ratings within the RMR framework, as depicted in [Table 8](#).

Table 8. RMR Rating Groundwater Condition Parameters

Description	Description Groundwater	Rating
Fresh Andesite	Completely Dry	15
Weathered Andesite	Damp	10
Hornfels	Damp	10

Geological Strength Index (GSI) Classification Parameters

At the CV. Putra Idola site, a complete Rock Mass Rating (RMR) assessment was performed in the field. The Geological Strength Index (GSI) value was subsequently derived from the RMR using an empirical correlation, as outlined by Hoek and Marinos [19]. The equation applied is:

$$GSI = (RMR - "15.4")/0.8$$

The computed GSI values indicate the overall quality of the rock mass and were categorized according to the relevant GSI classifications. The classifications reveal that the fresh andesite and hornfels are classified as "good" rock mass, whilst the weathered andesite is designated as "medium" quality. These classifications facilitate additional geotechnical investigation and guide the design of slope stabilization techniques in the study region.

Summary of Rock Mass Classification Values from Scanline Results

Based on the results obtained through scanline field measurements and laboratory testing, the characteristic values of the rock mass—namely Rock Quality Designation (RQD), Rock Mass Rating (RMR), and Geological Strength Index (GSI)—were determined. The detailed results of these data analyses are presented in [Table 9](#).

Table 9. Rock Mass Classification Values

No.	Parameters	Symbol	Fresh Andesite	Weathered Andesite	Hornfels
1	Rock Quality Designation	RQD (%)	80 (Good)	70 (Fair)	80 (Good)
2	Rock Mass Rating (Average)	RMR	75 (Class II - Good)	57 (Class III - Fair)	67 (Class II - Good)
3	Geological Strength Index	GSI	75 (Good)	53 (Medium)	65 (Good)

The RMR values obtained from different rock units, each exhibiting unique geotechnical properties and design criteria, are essential references in engineering contexts related to rock mass stability [20]. Based on the properties of the rock mass, it is possible to recommend values

for cohesion and the internal friction angle. The parameters in question serve as critical inputs for modeling slope stability, especially within the context of numerical simulations employing the limit equilibrium method, shown in Table 10.

Table 10. Design parameters and engineering properties based on RMR values [21]

No.	Parameters	RMR				
		81-100	61-80	41-60	21-40	<20
1	Classification	Very good	Good	Fair	Poor	Very poor
2	Cohesion (MPa)	>0.4	0.3-0.4	0.2-0.3	0.1-0.2	<0.1
3	Internal friction angle (°)	>45	35-45	25-35	15-25	<15
4	Safe cut slope (°)	>70	65	55	45	<40

CONCLUSION AND RECOMMENDATION

Conclusion

This research has illustrated that the geological conditions of the rock mass at the CV. Putra Idola mining site exhibit variability in quality as determined by geomechanical classification. The Rock Mass Rating (RMR) classifies Fresh Andesite and Hornfels as Class II (Good), with respective scores of 75 and 67. In contrast, Weathered Andesite is categorized as Class III (Fair), with a score of 57. The Geological Strength Index (GSI) values support these classifications, indicating that Fresh Andesite and Hornfels are categorized as good-quality rock masses, while Weathered Andesite is classified as moderate. The classifications established herein serve as the foundation for identifying critical geotechnical parameters, including cohesion and internal friction angle, which are vital inputs for conducting slope stability analysis through numerical modeling techniques. The amalgamation of field data, scanline observations, and laboratory testing significantly improves the reliability of assessments based on RMR and GSI. Moreover, the findings of this study substantiate the advancement of slope stability models employing the Limit Equilibrium Method, wherein safety factors may be assessed in accordance with regulatory standards, including those specified in KepMen-ESDM No. 1827 K/30/MEM/2018.

Recommendation

To build upon the findings of this study, it is recommended that future work incorporate numerical slope modeling using the Limit Equilibrium Method, augmented with dynamic factors such as seismic loading and groundwater conditions, which can significantly influence slope stability. Additionally, the delineation of safe setback distances from the mining boundary to critical infrastructure—particularly the adjacent national road—is essential to mitigate risk to the public. Employing three-dimensional numerical modeling approaches is also encouraged, as they offer greater accuracy in representing complex slope geometries and geological discontinuities, thereby producing safety factor estimates that better reflect actual field conditions. These enhancements would contribute to more robust geotechnical designs and safer slope management practices in open-pit mining operations.

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