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Rock Mass Classification Using RMR and GSI for Slope Stability at PT Bukit Asam, Tanjung Enim

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ABSTRACT

Evaluating slope stability in tropical open-pit mining environments remains a technical challenge due to the complex geological formations and the influence of dynamic climatic conditions, particularly intense rainfall and high humidity. This study aims to assess the effectiveness of integrating the Rock Mass Rating (RMR) system and the Geological Strength Index (GSI) for classifying rock mass quality and predicting slope stability in such settings. Field data were collected from interbedded claystone and sandstone formations through systematic mapping of RMR parameters, including Rock Quality Designation (RQD), spacing and condition of discontinuities, groundwater presence, and uniaxial compressive strength. Complementary evaluations using GSI focused on block structure, joint surface conditions, and weathering characteristics. The RMR analysis classified the rock mass as Class III (Fair Rock), indicating moderate stability. However, the system's static framework and limited responsiveness to rapid hydrogeological changes posed constraints in capturing the actual slope behavior. In contrast, GSI, with values ranging between 40 and 50, offered enhanced interpretive depth by incorporating qualitative assessments of lithological heterogeneity and structural anisotropy. The adaptability of GSI proved critical in environments where visual and textural indicators of degradation fluctuate spatially and temporally. The combined application of RMR and GSI enabled a more accurate, context-sensitive geotechnical evaluation, bridging the gap between empirical rigidity and field-based complexity. This integrated methodology supports more reliable engineering decisions and enhances the predictive capacity for slope failures in tropical geological settings, emphasizing the necessity for multidimensional classification tools in geotechnical practice.

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1. INTRODUCTION

Open-pit mining operations heavily rely on slope stability to ensure the sustainability and safety of mining activities. Steep slope designs may enhance production efficiency but entail a high risk of landslides, particularly when the rock mass quality is poor. In this context, rock mass classification systems serve as vital instruments for evaluating and designing slope stabilities. One widely adopted system is the Rock Mass Rating (RMR), which incorporates parameters such as uniaxial compressive strength, Rock Quality Designation (RQD), spacing and condition of discontinuities, groundwater conditions, and orientation of discontinuities. Collectively, these parameters provide a technical basis for slope angle design, reinforcement requirements, and potential failure mode analysis (Narimani et al., 2023; Zhang et al., 2022).

However, in tropical regions such as Indonesia, the RMR system faces significant challenges owing to geological complexity, including lithological heterogeneity and intensive weathering. High rainfall conditions in such areas also affect the pore water pressure, influencing slope stability, which is not always adequately accounted for in the static RMR approach (Chen et al., 2023). Thus, complementary methods such as the Geological Strength Index (GSI) are becoming increasingly necessary. The GSI evaluates rock mass quality based on the structural characteristics and surface conditions of discontinuities in a qualitative manner, making it more adaptive to geological variability (Marotti et al., 2023).

Although the application of rock mass classification systems, such as RMR, has long been foundational in slope engineering, their limitations in addressing dynamic environmental conditions and complex geology remain critical constraints. Factors such as intense weathering, groundwater presence, and stress changes due to active mining operations are often insufficiently represented in RMR assessments (Chen et al., 2023). Therefore, new approaches must be integrated to attain a more comprehensive understanding of rock mass conditions.

Original Hoek-Brown Criterion is a method for estimating the strength of jointed rock mass. The criteria developed are from the strength of intact rock and factors are introduced to reduce rock strength based on the characteristics of the discontinuity plane (joint) in the rock mass. This criterion includes the concept of GSI (Geological Strength Index) which provides an estimate of the reduction in rock mass strength due to differences in geological conditions. In the GSI method, rock mass classification is combined with two main parameters, namely Structure Rating (SR) and Surface Condition Rating (SCR). Structure Rating (SR) or structure is seen from the nature of the block and shape, block size and shape that indicate the overall geometry of the rock mass and the proportion of rock volume occupied by discontinuities, while Surface Condition Rating (SCR) or surface conditions are based on observations of the structure (block size and shape) and surface conditions of discontinuities (weathering, alteration, and degree of roughness) (Marinos et al., 2005).

The GSI offers a more flexible framework for depicting the geotechnical properties of rock masses, particularly in heterogeneous geological settings. By evaluating the block structure and surface conditions of discontinuities, the GSI provides a more realistic portrayal of the rock mass condition. The integration of the RMR and GSI is believed to enhance the accuracy and reliability of slope stability assessments, as both systems complement each other in terms of quantitative and qualitative geotechnical evaluations (Narimani et al., 2023; Singh et al., 2023).

In coal mining environments, such as Tanjung Enim, geological and hydrological variability necessitates adaptive rock mass classification systems. Studies have indicated that the stress distribution and geomechanical behavior in mining zones are significantly influenced by faults and surrounding rock conditions (Zhou et al., 2023). In such contexts, the RMR is used to evaluate rock strength and cohesion based on field data and laboratory tests, whereas the GSI reinforces the analysis through direct observations of structural and surface rock conditions. This integrated approach has been further strengthened by modern monitoring technologies, such as photogrammetry and GIS, which help identify fracture density and surface conditions, thus enhancing the accuracy of GSI assessments (Shao et al., 2022).

Numerical models have been developed to support slope stability analyses by simulating failure mechanisms and identifying critical slip surfaces. Tools such as the Finite Element Method (FEM) and Strength Reduction Method (SRM) are often used in conjunction with RMR and GSI parameters to achieve this aim (Deliveris et al., 2022). Moreover, under steep and unstable slope conditions, this approach has proven effective for designing support systems, such as rock bolts and retaining walls, based on probabilistic slope stability predictions (Shu et al., 2023). Therefore, the integration of the RMR and GSI not only provides more accurate assessments but also facilitates more responsive engineering decisions to on-site challenges.

Although the integration of RMR and GSI has been effective in various studies, most research remains limited to homogeneous geological settings or areas with high data accessibility. A significant research gap exists due to the lack of empirical studies directly applying this combined approach under tropical conditions characterized by high weathering and extreme lithological variability. Previous research has largely focused on conceptual aspects or numerical simulations without robust validation from actual field data in areas with high rainfall and dynamic groundwater pressure (Chen et al., 2023; Johari et al., 2022).

Few studies have examined the relationship between the RMR-GSI classification results and the slope design parameters. This warrants research testing this approach under tropical conditions at the PT Bukit Asam coal mine in Tanjung Enim. This study assessed the rock mass classification and slope stability at PT Bukit Asam Tbk. open-pit mine in Tanjung Enim using the integrated Rock Mass Rating (RMR) and Geological Strength Index (GSI) systems. The novelty of this study lies in the application of combined RMR and GSI under tropical geological conditions, with field data from the rainy season. This research encompassed primary field data collection and laboratory tests. The results aim to develop an accurate model for rock mass classification to support safe mine-slope design in tropical regions.

2. METHOD

2.1. Materials

This research was conducted at the open-pit mine of PT Bukit Asam Tbk., Tanjung Enim, South Sumatra. The lithology at the research site comprised claystone and silty sandstone with varying fracture characteristics. The tools used included a geological hammer, compass, GPS, digital camera, and measuring tape. The research materials consisted of primary data from field observations and secondary data from laboratory tests on the uniaxial compressive strength (UCS) of intact rocks.

2.2. Sample Preparation

Data collection was carried out using the scanline method over a length of 2.7 m to record the number of fractures, fracture spacing, physical conditions of the fractures, and surrounding environmental conditions of the slope. Rock samples were collected from the research site for UCS laboratory testing, in accordance with standard uniaxial compressive strength testing procedures.

2.3. Research Design

Rock mass classification was performed using the Rock Mass Rating (RMR) and Geological Strength Index (GSI) methods. The RMR parameters include the uniaxial compressive strength of intact rock (UCS), Rock Quality Designation (RQD), fracture spacing, fracture conditions (persistence, separation, roughness, weathering, and infilling), and groundwater conditions. RQD was calculated using the following formula (Tabel 1):

$$\mathrm{RQD} = 100\, e^{-0,1\lambda}\,(0,1\lambda + 1) \tag{1}$$

where e is a constant or Euler number (≈ 2.7182818284) and λ is the average brittle frequency per meter. The fracture index (λ) = (defined as fractures)/(scanline length). The assessment followed the block scheme and weathering levels shown in Figure 1. The criteria for rock mass quality classification based on the RMR values are presented in Table 2.

Table 2. Rock Mass Quality Classification Based on RMR Values

Class	Rock Mass Quality	RMR Score
I	Very Poor	0–20
II	Poor	21–40
III	Fair	41–60
IV	Good	61–80
V	Very Good	81–100

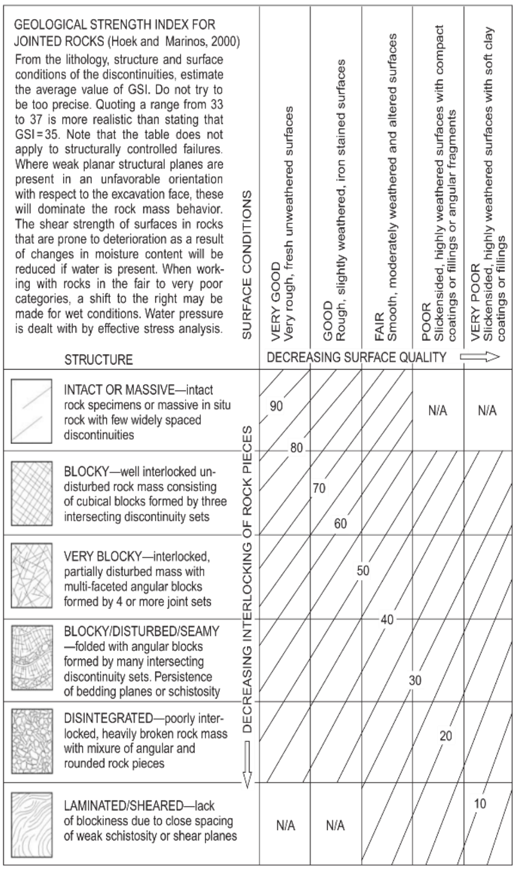

Figure 1. Geological Strength Index (GSI) assessment.

Table 1. Classification analysis on fracture data using the RMR (Rock Mass Rating)

No	Parameter	Range of values					
1	Strength of intact rock material						
	Point Load Strength Index	>10 MPa	4-10 MPa	2-4 MPa	1-2 MPa	-	
	Uniaxial Compressive Strength	>250 MPa	100-250 MPa	50-100 MPa	25-50 MPa	5-25 MPa	<5 Mpa
2	RQD (%)	90-100%	75-90%	50-75%	25-50%	<25%	
3	Spacing of Discontinuities	>2 m	0,6-2 m	200-600 mm	60-200 mm	<60 mm	
4	Length / Persistence						
	Separation	None	<0,1mm	0,1-1,0mm	1-5mm	>5mm	
	Roughness	Very rough	Rough	Slightly Rough	Smooth	Slickensided	
	Infilling (Gouge)	None	Hard Filling <5 mm	Hard Filling <5 mm	Soft Filling >5 mm	Soft Filling >5 mm	
	Weathering	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed	
5	Groundwater	Completely dry	Damp	Wet	Dripping	flowing.	

3. RESULTS AND DISCUSSION

3.1. Results

The rock mass quality in the study area was analyzed using the Rock Mass Rating (RMR) method, based on the weighted scores of various parameters collected from field observations and laboratory testing. At the observation site, the lithology was dominated by mudstone with 13 visible fractures over a 2.7-meter scanline. The uniaxial compressive strength (UCS) was recorded as below 1 MPa, which corresponds to a score of 0. The Rock Quality Designation (RQD) yielded a value of 92.7%, resulting in a maximum score of 20.

The spacing of the discontinuities was measured to be 1.66 m, corresponding to a rating of 15. The persistence of the fractures averaged 0.44 m (score: 6), separation was 0.36 mm (score: 4), and the roughness was categorized as smooth (score: 1). No infilling was observed in the fractures, and weathering was classified as moderate (score: 3). Groundwater conditions were noted to be damp because of the rainy season at the time of data collection, giving a score of 10. The combined score from these parameters resulted in a total RMR value of 59, categorizing the rock mass as Fair Rock (Class III).

Table 3. Rock Mass Rating (RMR) Scoring Results

Parameter	Rating	Description
Uniaxial Compressive Strength (UCS)	0	<1 Mpa
Rock Quality Designation (RQD)	20	92,7
Spacing of dicontinuities	15	1,66
Length, persistence	6	0,44 m
Separation	4	0,36 mm
Roughness	1	Smooth
Infiling (gouge)	-	-
Weathered	3	Moderately weathered
Ground water	10	damp
RMR Value	59	fair rock

Table 3 presents a detailed breakdown of the RMR score based on eight critical parameters that influence the classification of rock mass quality. The uniaxial compressive strength (UCS) was the lowest-rated component, contributing zero to the total owing to values below 1 MPa, indicating very weak rock material. In contrast, the Rock Quality Designation (RQD) achieved a maximum score of 20, reflecting high rock integrity based on core recovery. The spacing of discontinuities, which influences the mechanical stability of the rock, contributed significantly, with a rating of 15. Other moderate contributors included persistence (6), separation (4), weathering (3), and groundwater (10), each representing the physical and hydrological states of the observed fractures. Roughness scored lowest among these at 1, signifying smoother joint surfaces. Altogether, the cumulative score of 59 places the rock mass in Class III, categorized as Fair Rock, which implies moderate stability and potentially necessitates localized support interventions in geotechnical applications. Figure 2 presents a visual documentation of the fracture system observed at the site. This image includes a long-range and close-up view of the fracture pattern aligned with an azimuth of N 194° E.

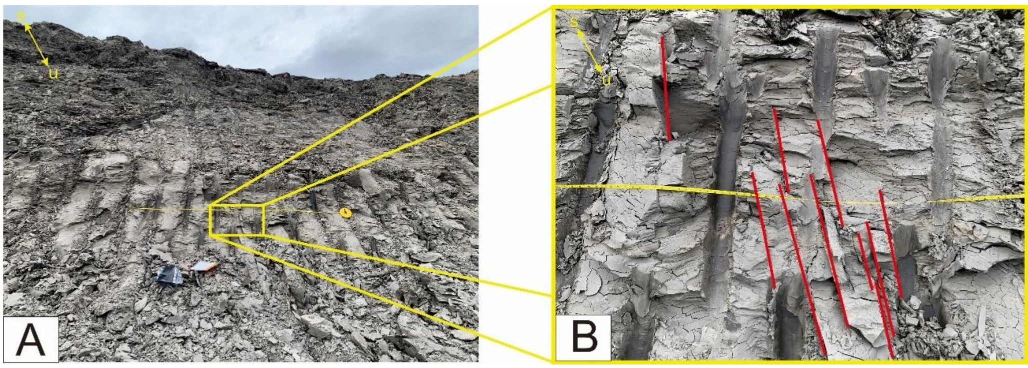

Figure 2. a) distant view with azimuth N 194° E; b) close view with azimuth N 194° E

The Geology Strength Index (GSI) is evaluated through qualitative observation of surface structure and rock mass discontinuity conditions found in the field. Interburden layer D-E1 shows two dominant lithologies: mudstone and silty sandstone. The mudstone exhibits fresh gray to dark gray color, clay grain size (≤1/256 mm) with moderate weathering and massive and compact structure, while the silty sandstone appears brownish gray, very sand grain size (0.0625 – 0.125 mm), and soft coarseness.

The GSI assessment uses the standard Hoek-Brown GSI chart to interpret the surface characteristics, where both lithologies are placed in the "very blocky" zone. This categorization is supported by field evidence, including visible joints and moderate discontinuity features such as discontinuity spacing and surface roughness. GSI values range between 40 and 50, which correspond to fair to good rock mass conditions. These observations were confirmed visually and documented in Figure 4, which depicts the GSI assessment chart along with photographic evidence of blocky structures observed at the site. This correlation underlines the moderate structural integrity of the interloaded rock mass and its mechanical behavior under geotechnical stress.

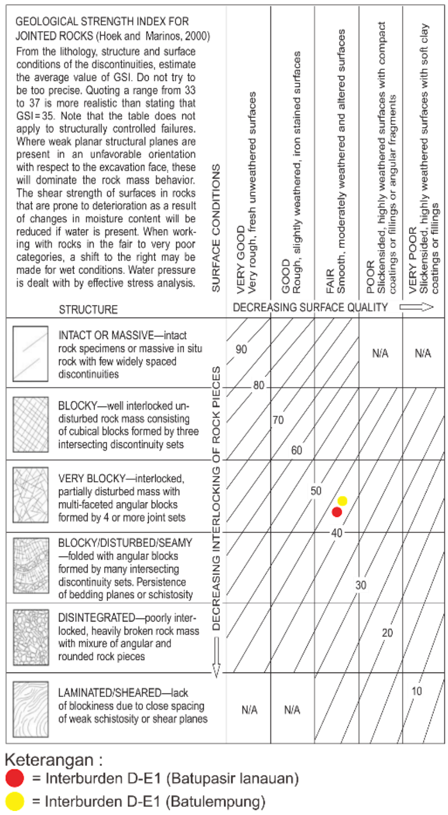

Figure 3. Results Geological Strength Index (GSI) assessment.

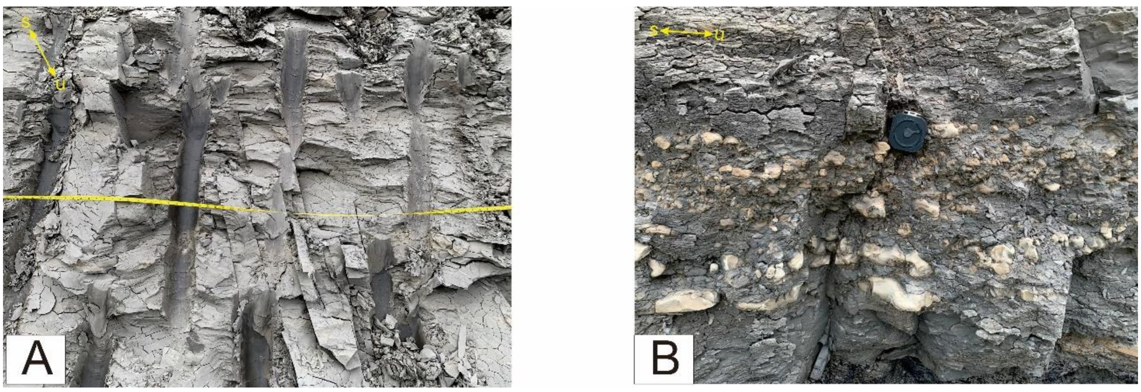

Figure 4. a) Close proximity of claystone with azimuth N 194° E; b) Close proximity of siltstone with azimuth N 098° E.

3.2. Discussion

The results of the RMR analysis must be interpreted considering the geological and climatic complexities inherent to tropical regions. The study site, characterized by high rainfall and humid conditions, presents challenges that are not fully captured by the static nature of the RMR system. Tropical terrains often exhibit dynamic changes in groundwater and pore pressure owing to intense precipitation, potentially undermining slope stability even when the RMR values suggest moderate stability (Chen et al., 2023). The RMR classification at the site yielded a value of 59, categorizing it as Fair Rock (Class III); however, this classification does not dynamically adjust for sudden hydrogeological fluctuations. Such environmental effects may contribute to the overestimation of slope stability, thereby necessitating the incorporation of adaptive or complementary methods (Narimani et al., 2023).

Additionally, the complex lithological variability typical of tropical geological formations, including alternations of claystone and silty sandstone, can introduce discontinuity characteristics that deviate from the RMR parameter assumptions. The RMR often lacks the resolution to account for heterogeneous weathering profiles and variable joint patterns that evolve over time owing to both mechanical and chemical processes in tropical climates (Chen et al., 2023). Thus, while the RMR framework remains essential for preliminary assessments, its effectiveness in such settings can be limited without supplementary methods that consider environmental dynamics and lithological heterogeneity (Muarif et al., 2022).

The GSI evaluation, with values ranging from 40 to 50, reinforced the intermediate classification suggested by the RMR but offered additional insights into the structural quality of the interburden. The combination of a blocky structure and moderate joint development aligns with fair-to-good rock mass behavior. This classification reflects conditions in which the rock mass, although not entirely intact, exhibits a degree of structural coherence conducive to moderate stability (Hasan et al., 2023). Notably, the adaptability of the GSI to visual and qualitative descriptors makes it particularly suited for heterogeneous and visually variable lithologies, such as those observed in this study, including interbedded claystone and sandstone units with variable weathering and joint characteristics (Barton et al., 2023). The visual classification process in the GSI allows for the direct accommodation of such surface indicators, enabling geotechnical evaluations that better align with the reality of tropical, heterogeneous formations, where joint orientation, weathering state, and structural anisotropy vary significantly over short distances (Johari et al., 2022).

Furthermore, the GSI system incorporates parameters related to weathering, joint surface conditions, and structural orientation that are not explicitly weighted in the RMR scoring. These parameters allow a more holistic assessment of rock mass integrity, especially in environments characterized by high climatic variability and complex geological evolution (Dong et al., 2022). This makes the GSI more responsive to the tropical weathering phenomena and geomorphological complexity commonly encountered in the study area (Singh et al., 2023; Yang et al., 2023). By capturing features such as surface roughness, degree of weathering, and joint interconnectivity, the GSI provides added interpretive value that complements the more rigid numerical structure of the RMR. Consequently, the combined use of RMR and GSI provides a more comprehensive geotechnical characterization, allowing for a nuanced interpretation of slope stability that considers both empirical ratings and field-based qualitative assessments, particularly in settings where lithological heterogeneity and climatic factors exert significant influence(Uno et al., 2025).

This integrative approach not only enhances the reliability of design decisions but also addresses the gap identified by previous researchers who advocated for the blending of empirical and probabilistic models to manage uncertainties in slope stability prediction ((Shu et al., 2023; Zhang et al., 2022). The concurrent application of RMR and GSI in this study exemplifies such integration, demonstrating improved alignment with the geological and environmental realities of tropical mining sites. By considering both quantitative parameters and qualitative field-based observations, this method enables a more adaptive and context-sensitive evaluation of the slope conditions. This allows for a better understanding of the influence of joint orientation, material variability, and hydrological response under dynamic climatic influences. The inclusion of visual and structural inputs from the GSI, alongside the established empirical metrics from the RMR, results in a multidimensional analysis that is better equipped to anticipate instability triggers. This is particularly critical in tropical regions, where conventional models may underrepresent the speed and severity of the environmental changes affecting slope integrity (Johari et al., 2022).

4. CONCLUSIONS

This study demonstrated that the integration of the Rock Mass Rating (RMR) and Geological Strength Index (GSI) offers a more comprehensive framework for slope stability assessment in tropical mining environments. The RMR classification identified the rock mass as Fair Rock (Class III), while the GSI provided complementary insights into structural coherence and weathering conditions, particularly relevant to heterogeneous lithologies such as interbedded sandstone and claystone. The limitations of the RMR in capturing dynamic hydrogeological changes and lithological variability were effectively mitigated by the adaptability of the GSI, which incorporates qualitative parameters such as surface conditions and structural anisotropy.

The combined use of RMR and GSI not only enhanced the reliability of geotechnical interpretations but also aligned the analysis with the environmental and geological complexities inherent to tropical regions. This integrative approach contributes to more informed design decisions and offers practical advantages for mine safety and planning. Future studies should expand the dataset across multiple climatic periods and incorporate real-time monitoring to further refine the predictive capabilities of the classification framework.

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