Research Article

Intercorrelations of Rock-Mass Classification Systems in Jakarta–Bandung High-Speed Railway Tunnel No. 6

Hubungan Korelasi Antar Sistem Klasifikasi Massa Batuan di Terowongan Kereta Cepat Jakarta – Bandung No.6

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ABSTRACT

This paper presents a comparative study of three standard rock-mass classification schemes—Rock Mass Rating (RMR), the Q-system, and the Rock Mass Index (RMi)—along the 4.5 km Jakarta–Bandung High-Speed Railway Tunnel No. 6, which traverses predominantly sedimentary formations. Values for each scheme were derived from an extensive program of geotechnical drilling, logging, and in-situ measurements. The data set was then used to establish empirical correlations between every pair of classification systems, accounting for whether individual parameters are shared or omitted. The resulting relationships cover a broad spectrum of sedimentary lithologies and can be applied to other projects set in comparable geological environments.

Keywords: Highway Speed Railways Tunnel; Soft rocks; Rock mass classification

ABSTRAK

Makalah ini menyajikan studi perbandingan tiga sistem klasifikasi massa batuan yang umum diterapkan—Rock Mass Rating (RMR), Q-system, dan Rock Mass Index (RMi)—di sepanjang Terowongan Kereta Cepat Jakarta–Bandung No. 6 sepanjang 4,5 km, yang sebagian besar melintasi formasi sedimen. Nilai untuk setiap parameter pada sistem diperoleh dari hasil pengeboran geoteknik, logging, dan pengukuran in-situ yang ekstensif. Kumpulan data tersebut kemudian digunakan untuk menetapkan korelasi empiris antara setiap pasangan sistem klasifikasi, dengan memperhitungkan apakah parameter individual digunakan bersama atau dihilangkan. Hubungan yang dihasilkan mencakup spektrum litologi sedimen yang luas dan dapat diterapkan pada proyek lain yang berada di lingkungan geologi yang sebanding.

Kata kunci: Terowongan Kereta Cepat; Batuan lunak; Klasifikasi massa batuan

1. INTRODUCTION

Rock-mass classification and characterization frameworks are valued for their straightforward application, which explains their routine use by engineering geologists and rock engineers (Singh & Goel 1999). These schemes are available in descriptive and numerical formats and can be configured for general assessments or tailored to specific design tasks (Bieniawski 1989). Numerical approaches, in particular, condense field observations into a single quantitative score, supply parameters that help predict rock-mass strength, and remain dependable even in hard-rock settings (Palmström 1995; Barton 2002).

Because of these advantages, classification schemes underpin a wide range of rock-engineering works—including slope stabilization, drift and cavern excavation, underground oil storage, and tunnel construction. They also provide quick insight into operational concerns such as cavability, rippability, cuttability, and excavability (Bar & Barton 2017; Barton 2002; Andriani & Parise 2017).

The same ratings allow engineers to estimate key geomechanical properties—cohesion, shear strength, friction angle, compressive strength, deformation modulus, allowable bearing pressure, and support pressure—thereby streamlining communication among specialists and facilitating direct comparison between projects (Basahel & Mitri 2017; Warren et al. 2016; Rahimi et al. 2019). Among today's many options, the Q-system, Rock Mass Rating, and Rock Mass Index see the widest use (Bieniawski 1976; Barton 2002; Palmström 1995), while the Geological Strength Index (GSI)

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has become the preferred tool for general rock-mass description (Hoek et al. 1998; Marinos 2019).

This paper examines empirical links among these schemes for Tunnel No. 6 on the Jakarta–Bandung High-Speed Railway. By analysing data from forty stations along the alignment, we identify the strongest cross-system correlations, determine which input parameters exert the greatest influence, and discuss how variations in those parameters affect the reliability of the resulting relationships.

Table 1. Selected classification schemes (Sadeghi, 2020).

Classification/Characterization system	Form, Type	Main applications	Reference(s)
Terzaghi rock load classification system	D, B, F	Design of steel support in tunnels	Terzaghi (1946)
Lauffer's stand-up time classification	D, G	Tunneling design	Lauffer (1958)
New Australian Tunneling Method (NATM)	D, B, T	Excavation and design in incompetent (overstressed) grounds	Rabcewicz (1965b, 1965a)
Rock classification for rock mechanical purposes	D, G	Input in rock mechanics	Patching and Coates (1968)
Unified classification of soils and rocks	D, G	Based on particles and blocks for communication	Deere and Miller (1966); Zienkiewicz and Stagg (1969)
Rock Quality Designation (RQD)	N, G	Based on core logging; used in other classification systems	Deere and Miller (1966); Deere 1988)
Rock Structure Rating (RSR)	N, F	Design of (steel) support in tunnels	Wickham et al. (1972)
Rock Mass Rating (RMR)	N, F	Design of tunnels, mines, and foundations	Bieniawski (1974)
Q- system	N, F	Design of support in underground excavations	Barton et al. (1974)
Mining Rock Mass Rating (MRMR)	N, F	Mining	Laubscher (1977)
Size-strength classification	N, F	Based on rock strength and block diameter, used mainly in mining	Franklin (1971)
Typological classification	N, F	Use in communication	Matula and Holzer (1978)
Unified Rock Classification System (URCS)	N, F	Use in communication	Williamson (1984)
Basic Geotechnical Description (BGD)	N, F	General applications	ISRM (1981)
Rock Mass Strength (RMS)	N, F	Mining	Stille et al. (1982)
Modified Basic Rock mass rating classification (MBR)	N, F	Mining	(Kendorski et al. 1983)
Surface Rock Classification (SRC)	N, F	Design of support in underground excavations in weak rocks affected by high horizontal tectonic stress	De Vallejo (1983); De Vallejo (1985, 2003)
Slope Mass Rating (SMR)	N, F	Slopes	Romana (1985, 1993)
Simplified rock mass rating (SRMR)	N, F	Mines and Tunnels	Brook and Dharmaratne (1985)
Ramamurthy / Arora	N, F	For intact and jointed rocks	Ramamurthy and Arora (1993)
Geological Strength Index (GSI)	N, F	Design of support in underground excavations	Hoek (1994, 2002); Hoek et al. (1998); Sonmez and Ulusay (1999b); Marinos (2014)
Rock Mass Number (QN)	N, F	Design of support in underground excavations	Goel et al. (1995a)
Rock Condition Rating (RCR)	N, F	Design of tunnels, mines, and foundations	Goel et al. (1995b), Singh and Goel (1999)
Rock Mass index (RMi)	N, F	General characterization, design of support, TMB progress	Palmström (1995)
Modified Rock mass rating classification (MRMR)	N, F	Mining, For weak, stratified, anisotropic and clay bearing rock masses.	Unal (1996)
Rock tunneling quality index by Tunnel Boring Machine excavation (QTBM)	N, F	Tunnel Boring Machine tunnels	Barton (1999)
Continuous Rock Mass Rating (CRMR)	N, F	General applications	Csen and Sadagah (2003)
Rock Mass Excitability (RME)	N, F	TBM tunnels	Von Preinl et al. (2006)
experience-based RMR system	N, F	Tunneling and general applications	Celada et al. (2014)
Rock Mass Quality Rating (RMQR)	N, F	General applications	Aydan et al. (2014)
Rock Bolt Supporting Factor (RSF)	N, F	Tunneling and underground excavations	Mohammadi and Hossaini (2017)
Anisotropic Rock Mass Rating (ARMR)	N, F	Tunneling and general applications	Saroglou et al. (2019)

2. MATERIALS AND METHODS

Geology of the tunnel

According to China Railways Design Corporation (2018), Tunnel No. 6 is located within a strata consisting of Quaternary Pleistocene volcanic sediment layers (clay and silt layers) and Tertiary Miocene Jatiluhur Group sandstone (Mdm), mudstone and volcanic breccias. The surface is covered by clay, silty clay and block rock which belongs to the Quaternary Pleistocene series of volcanic accumulation layers (Qob).

Discontinuity Investigation

Discontinuities within each rock unit were examined on surface outcrops situated directly above the tunnel alignment. Geometric and physical attributes were recorded with the scan-line method and from borehole logs following Piteau (1973). Every fracture intersecting a 3 – 10 m measuring tape (the reference line) was logged. Consistent with the International Society for Rock Mechanics guidelines (ISRM, 1978), the study recorded the following parameters: strike and dip, persistence, joint sets number, aperture, hydraulic state, spacing, infilling material, and roughness. Forty survey stations were established along the tunnel trace to map these features. A detailed understanding of such structural discontinuities is essential because they strongly influence rock-mass behaviour and its response to tunnelling activities.

Rock Mass Classification

Rock-mass quality along the tunnel was assessed in 40 segments using three widely accepted schemes: Rock Mass Rating (RMR), the Q-system, and the Rock Mass index (RMi). For RMR, the 1989 revision by Bieniawski was adopted, which evaluates (i) uniaxial compressive strength, (ii) rock-quality designation, (iii) spacing of joints, (iv) joint condition, (v) groundwater conditions, and (vi) joint orientation. The basic RMR value (RMR^{basic}) omits the orientation adjustment.

The Rock Mass index (RMi) (Palmström, 1995) was also applied. RMi provides a measure of the rock mass compressive strength, facilitating derivation of Hoek–Brown failure parameters, preliminary support design, and estimates of tunnel-boring machine (TBM) penetration rates.

$$RMi = \sigma_c \times JP = \sigma_c \times 0{,}2\sqrt{jC} \times Vb^D$$

$$(D = 0{,}37jC^{-0{,}2})$$

Where,

σ_c = intact rock uniaxial compressive strength

jC = the factor of joint condition , is captured by the composite parameter jC, calculated as the product of joint size (jL) and joint roughness (jR) divided by joint alteration (jA), i.e., $jC = (jL \times jR) / jA$.

Vb = the volume of the block, measured in m³; average volume is generally applied. ($Db = \sqrt[3]{Vb}$, which is the equivalent block diameter, measured in m)

JP = a joint parameter that encapsulates the key joint characteristics of the rock mass. ($JP = 0{,}2\sqrt{jC} \times Vb^D$)

The Q-system, first introduced by the Norwegian Geotechnical Institute as an index for assessing rock quality in tunnelling (Barton et al., 1974), was last revised in 2004. The Q-value is determined using the following equation:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

In this notation, RQD denotes the Rock Quality Designation; J_n represents the number of joint sets; J_r quantifies joint-surface roughness; J_a reflects the degree of alteration along joints; J_w is the groundwater (joint-water) reduction factor; and SRF designates the stress-reduction factor

3. DISCUSSION

As new engineered rock-mass classification schemes continue to emerge, practitioners often face a practical question: when two different systems are applied at separate sites, how can the resulting ratings be compared? One solution is to establish empirical correlations that allow the output of one scheme to be estimated from another. Because each system relies on its own set of input variables—some shared, others unique—such correlations serve only as approximate conversion tools rather than direct substitutes for running the original calculations.

Numerous researchers have proposed cross-system correlations, and these relationships tend to tighten when the schemes are applied concurrently across many sites. Representative examples are summarized in Table 2. Drawing on data collected at 40 locations where three widely used empirical methods—Rock Mass Rating (RMR), Rock Mass Index (RMi), and the Q-system—were all applied, the following discussion analyses the interrelationships among these three systems.

RMR-Q Correlation

Figure 1 displays the RMR–Q correlation for HSR Tunnel No. 6 alongside comparable relationships reported in earlier studies. We can see that the correlation close to the HSR No. tunnel data. 6 is that proposed by Bieniawski (1976). While the correlation proposed by Abad, et al (1983) and Rutldege & Perston (1978) approaches when the value of Q>0.3 while when the value of Q<0.3 has a larger difference.

Based on the plot of the relationship between the empirical rock mass classification of RMR and the Q-system at the HSR No. tunnel location. 6 obtained the correlation equation:

$$RMR = 9{,}7 \ln Q + 43{,}364 \quad (R^2 = 0{,}833)$$

RMR-RMi Correlation

Figure 2 displays the RMR–RMi correlation for HSR Tunnel No. 6 alongside comparable relationships reported in earlier studies. We can see that the correlation is almost the same or close to the HSR No. tunnel data. 6 is that proposed by Hashemi, et al (2009). While the correlation proposed by Kumar, et al (2004) and Sadhegi, et al (2020) does not show any similarities.

Based on the plot of the relationship between the empirical rock mass classification of RMR to RMi at the location of the HSR tunnel No. 6 obtained the correlation equation:

$$RMR = 8{,}428 \ln RMi + 39{,}975 \quad (R^2 = 0{,}926)$$

Table 2. Side-by-side comparison of the correlations reported among different rock-mass classification systems

Researches	Correlation	Estimation parameter
Bieniawski (1976)	RMR = 9ln(Q) + 44	RMR dari Q
Rutledge & Perston (1978)	RMR = 5.9ln(Q) + 43	RMR dari Q
Abad, dkk (1983)	RMR = 10,5ln(Q) + 41,8	RMR dari Q
Kumar, dkk (2004)	RMR = 5,4ln(RMi) + 54,4	RMR dari RMi
	$RMi = 1{,}5Q^{0{,}72}$	RMi dari Q
Hashemi, dkk (2009)	RMR = 7,5ln(RMi) + 36,8	RMR dari RMi
	$RMi = 1{,}082Q^{0{,}4945}$	RMi dari Q
Sadhegi, dkk (2020)	RMR = 10,503ln(RMi) + 30,665	RMR dari RMi
	$RMi = 0{,}7238Q^{1{,}0571}$	RMi dari Q

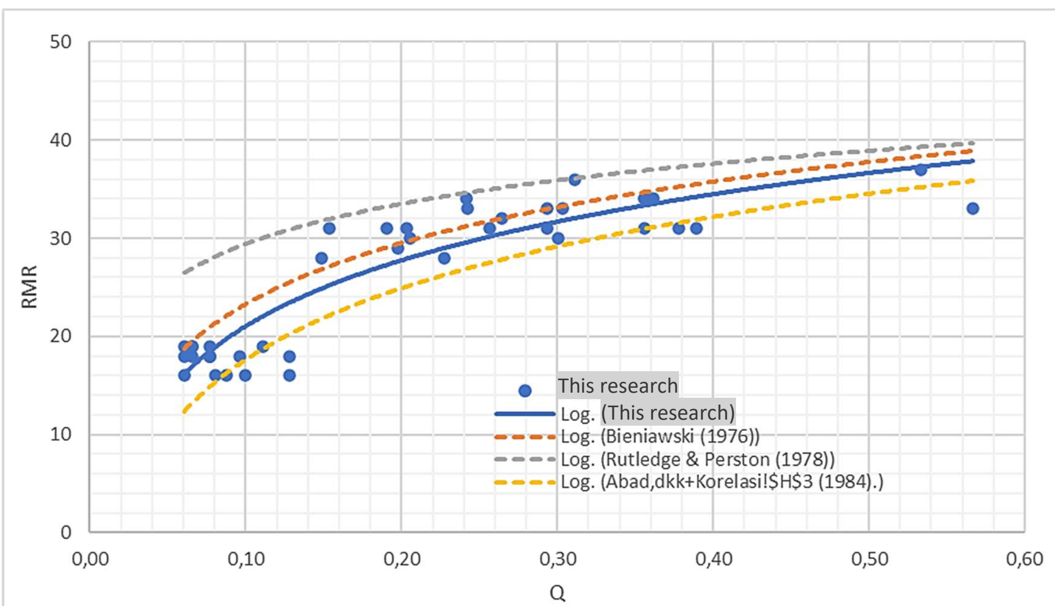

Figure 1. Correlation plot of RMR versus Q-system values from this study alongside data reported in earlier publications.

RMi dan Q Correlation

Correlated RMi and Q data from HSR tunnel No. 6, along with other correlations from previous studies are presented in Figure 3. We can see that no correlation is entirely similar or close to the HSR No. tunnel data. 6, but only certain parts are close. When the Q value <0.1 the correlation proposed by Sadhegi, et al (2020) shows similarity, while when the Q value> 0.5 the correlation proposed by Hashemi et al (2009) shows similarity. The correlation proposed by Kumar et al (2004) does not show any similarity.

Based on the plot of the relationship between the empirical rock mass classification RMi to Q at the HSR tunnel location No. 6 obtained the correlation equation:

$$RMi = 1{,}572Q^{1{,}1124} \quad (R^2 = 0{,}6807)$$

Analysis

Uncertainty in rating certain parameters introduces scatter into the scores produced by each classification scheme. That scatter—combined with the fact that the systems do not all include the same variables—can weaken statistical links between any pair of schemes. To discover which factors most influence those links, we compared every pairing listed in Table 4 using correlation coefficients (R, R^2), root-mean-square error (RMSE), and mean-square error (MSE).

Because joint orientation is explicitly considered in both RMR and RMi but omitted from Q, its inclusion strengthens the RMR–RMi link and simultaneously depresses correlations that involve Q. These insights, however, are based solely on data from the present tunnel site and should be tested against other lithologies and geological settings before broad application.

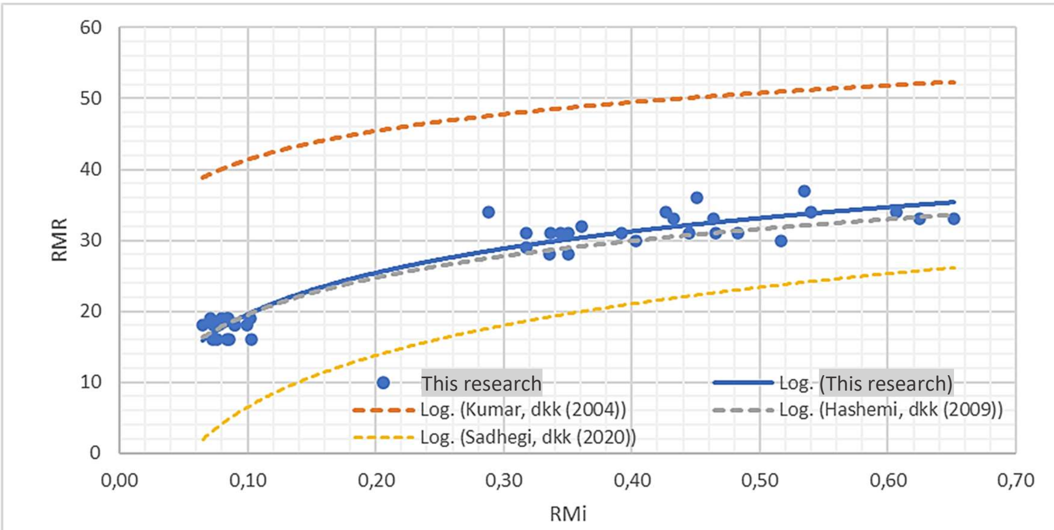

Figure 2. Correlation plot of RMR versus RMi values from this study alongside data reported in earlier publications.

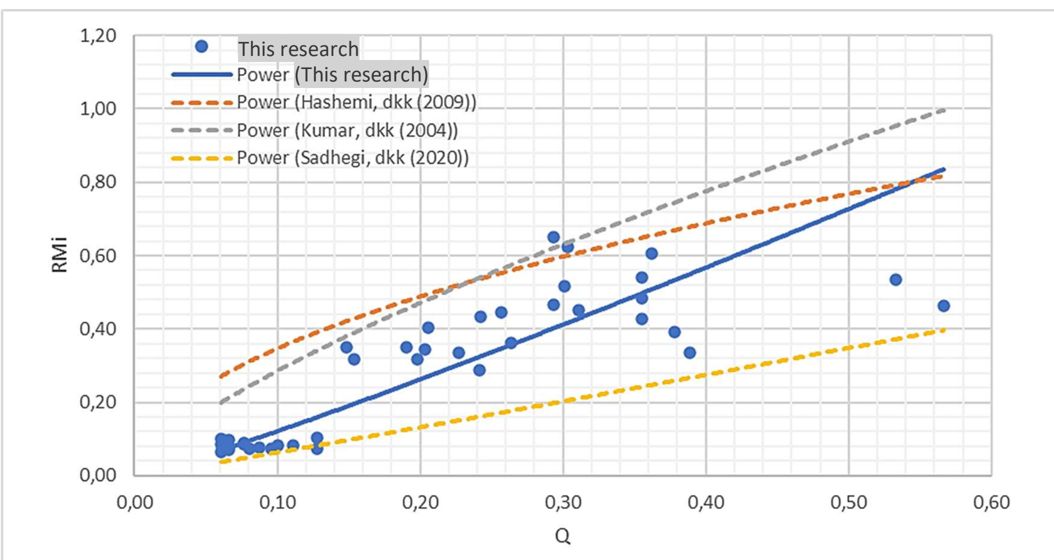

Figure 3. Correlation plot of RMi versus Q-system values from this study alongside data reported in earlier publications.

Table 3. Parameters in the classification system applicable to underground excavations

Parameter	Classification systems		
	RMR	Q	RMi
Block Size	-	-	√
Discontinuity orientation	√	-	√
Sets of discontinuity	-	√	√
Discontinuity spacing	√	√	√
Strength of discontinuity	√	√	√
Stresses condition	-	√	-
Groundwater condition	√	√	-
Strength of intact rock	√	√	√

Table 4. The relationships provided are based on the data at the research site

Equations	Correlation coef.		MSE	RMSE	Conflicting parameters
	R	R^2			
$\boldsymbol{RMR = 9,7 \ln Q + 43,364}$	0,913	0,833	8,713	2,952	Number of discontinuity sets, discontinuity orientation, stress conditions
$\boldsymbol{RMR = 8,428 \ln RMi + 39,975}$	0,962	0,926	4,856	2,204	Block size, number of joint sets, groundwater conditions
$\boldsymbol{RMi = 1,572Q^{1,1124}}$	0,825	0,6807	0,013	0,115	Block size, joint orientation, groundwater conditions, stress conditions

4. CONCLUSION

The rock mass classification system — RMR, Q, and RMi — prove suitable for designing the HSR Tunnel No. 6, and the analysis reveals clear correlations among these systems for the rock mass conditions encountered at the site:

Logarithmic relationship of the value of Q to the value of RMR:

$$RMR = 9{,}7 \ln Q + 43{,}364 \quad (R^2 = 0{,}833)$$

The logarithmic relationship of the value of RMi to the value of RMR:

$$RMR = 8{,}428 \ln RMi + 39{,}975 \quad (R^2 = 0{,}926)$$

Power relationship from the value of Q to the value of RMi:

$$RMi = 1{,}572Q^{1{,}1124} \quad (R^2 = 0{,}6807)$$

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