Rock Mass Classification System Used for Pahang-Selangor Raw Water Transfer Tunnel

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Abstract The recent Pahang-Selangor raw water transfer tunnel project had resulted in a large amount of rock mass classification data for the assessment of the rock mass class required for the design of tunnel support system. In this project, a rock mass classification by Japan Highway Public Corporation (JH) has been used to assess the rock mass class using geological mapping and geological documentation of the tunnel face and the side walls of the excavated tunnels. Although JH classification had been used for this project, other forms of classification using different criteria from Rock Mass Rating (RMR) and Q-System have also been widely used for tunnelling project all over the world. Since there have been few studies on the relationships among such different criteria of the classification systems, this study mainly focuses on the comparison between the JH and RMR classification systems for the water transfer tunnel. From the correlation analysis among the criteria used in both JH and RMR classification systems, there is higher correlation if the rock mass is in relatively good condition. It was also found that there is less consistency between JH and RMR classifications in the region of 'poor rock'. However, the correlation between both classification systems is still considered suitable to be used in this tunnelling project.

Keywords Rock mass classification · Japan Highway Public Corporation · Rock mass rating

1 Introduction

Rock masses are discontinuous and often have heterogeneous and anisotropic engineering properties. The heterogeneity of the intact rock and rock masses are influenced by a number of factors such as fracturing, bedding and weathering

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[1, 2]. After all, the mechanical behaviour of rock masses is dependent on the strength of the blocks created by random patterns of discontinuities and their strength. However, the classification of the rock mass is an indirect method and does not measure the mechanical properties like deformation modulus directly. Therefore, the classification system is necessary to take into account the factors that influence the stability of the rock masses. The result is an estimate of the stability quantified in subjective terms such as poor, acceptable, good and very good.

Rock mass classifications have played an important role in estimating the strength and deformability of rock masses for determining slope stability, support systems, as well as for considerations on items such as span of excavation, length of advance per round, and construction methods. The rock mass classification systems are used for various engineering designs and stability analyses. For example Liu and Chen [2] approached the application on the rock slope stability assessment for several rock slopes of the Southern Cross-Island Highway in Taiwan. Vardakos et al. [3] estimated the support system for Shimizu Tunnel in Japan and Khabbazi et al. [4] used to estimate the rock mass deformation modulus for tunnel and dam sites in western and northern Iran. The classification of rock masses encountered during tunnel excavation was made through evaluation of the mechanical and hydraulic properties of rock masses, as well as the thickness of overburden. In comparison to many other civil engineering situations, the uncertainties involved in underground rock engineering are high. Therefore, most of the tunnels constructed at present make use of various types of classification systems [5–8]. The rock mass classification system was developed for used at project feasibility and preliminary design stages. It is also used to provide initial empirical estimates of tunnel support requirements and practical engineering tools which forced the user to examine the properties of the rock mass.

1.1 Engineering Rock Mass Classifications

There are several established procedures for rock mass classifications such as Rock Mass Structure Rating (RSR), Rock Mass Rating (RMR), Rock Quality Index (Q System). The most common classification systems used are the RMR system published by Bieniawski in 1973 [9, 10] and Q system, first described in 1974 by Barton and Bieniawski [11]. Many researchers have studied the different rock mass classification systems either to compare or combine the systems. For example Choi and Park [7] made comparisons among different criteria of RMR and Q-system for rock tunnel in Korea and Sapigni et al. [8] used RMR-system to predict TBM performance. Meanwhile Palmström et al. [12] studied the limitations of Q-system. In year 2009, Palmström [13] combined the RMR, Q, and RMi Classification System into one set of tables. These enable the ground quality to be found directly and independently in the three systems from only one set of observations.

In this study, the rock mass condition at the Pahang-Selangor Raw Water Transfer Project (PSRWT) site will be classified using JH classification system. This classification is based on the RMR classification by Bieniawski 1973 [9] and Rock Mass Quality of Q system Barton and Bieniawski [11]. The classification system classified the rock with five parameters obtained. They are material strength, the rock quality designation (RQD), joint spacing, joint and ground water conditions.

1.2 Site Description

To compare the different criteria used in the rock mass classification systems between RMR and JH, PSRWT was selected as a study area. The purpose of the water transfer tunnel is to convey raw water from the Semantan River in Pahang State to a water treatment plant in Selangor State, Malaysia. The diameter of the main tunnel is 5.2 m with 44.6 km in length that crosses the Titiwangsa Main Ranges which mainly consists of granitic rock. The excavation methods for the tunnel used 3 numbers of Hard Rock Tunnel Boring Machine (TBM) and 4 New Austrian Tunnelling Method (NATM). NATM method was adapted for relatively less ground cover (overburden) zones and estimated low grade rock conditions. Figure 1 shows the NATM method at NATM 1 tunnel of the project.

Based on geological investigation and topography, NATM was designed mainly for relatively lower cover sections at the folded Paleozoic sedimentary rock zone. The sections were 5.9 km length at the Inlet and 2.9 km length at the outlet. Figure 2 shows the location of NATM 1 starting from Chainage (Ch.) 858 m to Ch. 2,785 m at the Inlet section.

1.3 Geological Condition

The tunnel alignment is mainly composed of Main Range granitic which forms the backbone of the Peninsular Malaysia and sedimentary rocks of Paleozoic and Mesozoic age. The geological map for the PSRWT tunnel is shown in Fig. 3.

The geology of the tunnel starts from the slightly metamorphosed Devonian sedimentary rocks from the inlet to Ch. 3.8 km while from Ch. 3.8 to Ch. 44.6 km, it consists of coarse to medium-grained granitic rocks forming the main range of Malaysia Peninsular. This rock is mainly black shale to schist, strongly folded by intrusion of granitic rocks in Triassic age. The rock near the boundary to granite is well silicified as hornfels by contacting with granitic rocks.

The estimated major faults crossing tunnel are 6 faults consisting of Karak Fault (Ch. 2.5 km), Krau Fault (Ch. 12.45 km), Bukit Tinggi Fault (Ch. 19.15 km), Lepoh Fault (Ch. 28.6 km), Kongkoi Fault (Ch. 31.35 km) and Tekali Fault (Ch. 39.0 km). Meanwhile the lineaments crossing tunnel alignment are 12, starting

Fig. 1 Excavation of NATM I at Pahang-Selangor raw water tunnel

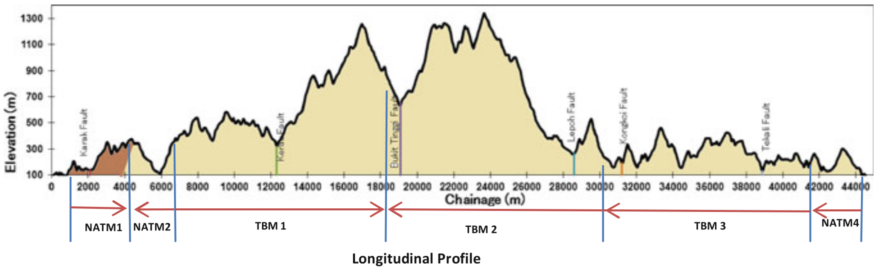


Fig. 2 Typical section of tunnel and arrangement for tunnel work (NATM & TBM)

from L-A to L-N as shown in Fig. 3. There are quartz dykes, which are extremely hard and accompanied by clay zones with less than 1 m thick average on both sides. Also a few quartz veins are developed in lower half downstream of tunnel.

The study area, NATM 1 was composed of sedimentary rocks of Paleozoic and Mesozoic age. The minimum and maximum overburden range from 110 to 235 m, starting at Ch. 858 m to Ch. 2,785. This section has already experienced a folding and seepage in Devonian sedimentary rock zone and Karak Fault at Ch. 2.5 km.

2 Rock Mass Classifications

2.1 *JH Classification*

Rock classification for tunnel face and wall at this site are based on the standard in the JH classification. The compressive strength, weathering, spacing of joints,

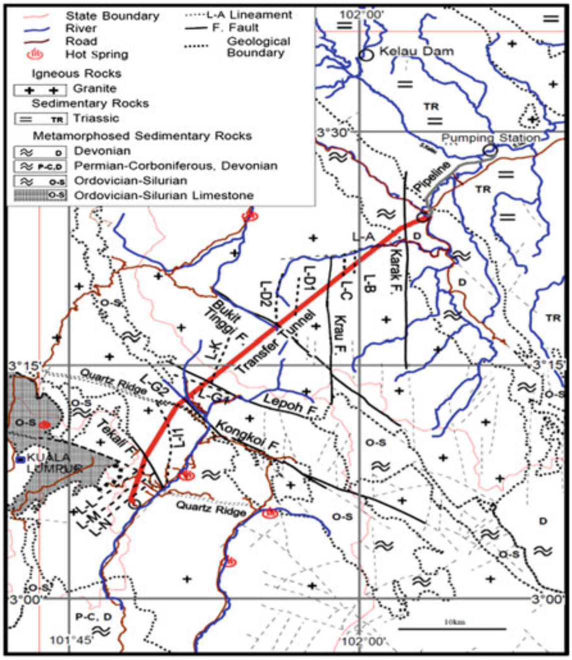


Fig. 3 Geological map around the project site

conditions of joints, and the groundwater condition were estimated from the geological map of tunnel face data sheets. Rock mass was classified from the total points of tunnel face observation based on chart as presented in Fig. 4. The classification of the classes depended on rock categories from soft (layered) to hard rock (massive) conditions and all rock types.

The JH classification is rock mass rating system which relies primarily upon the following four general observation data related to the rock mass strength: compressive strength, weathering, spacing of joints and condition of joints. Overall rating of the rock mass is made by adding the ratings of the parameters, and the total rating (total point) is given a class representing the rock mass quality. Calculated RMR value used to find rock mass classes from very good rock to Faults and crushed rock zone or squeezing zones. General rock conditions corresponding to JH classification classes are listed in Table 1.

2.2 RMR Classification

Bieniawski in 1973 [9], published a detailed rock mass classification called the Geomechanics Classification or Rock Mass Rating (RMR) system for jointed rock masses. The system was originally developed for the calculation of rock load and tunnel support selection. Significant changes have been made over the years with

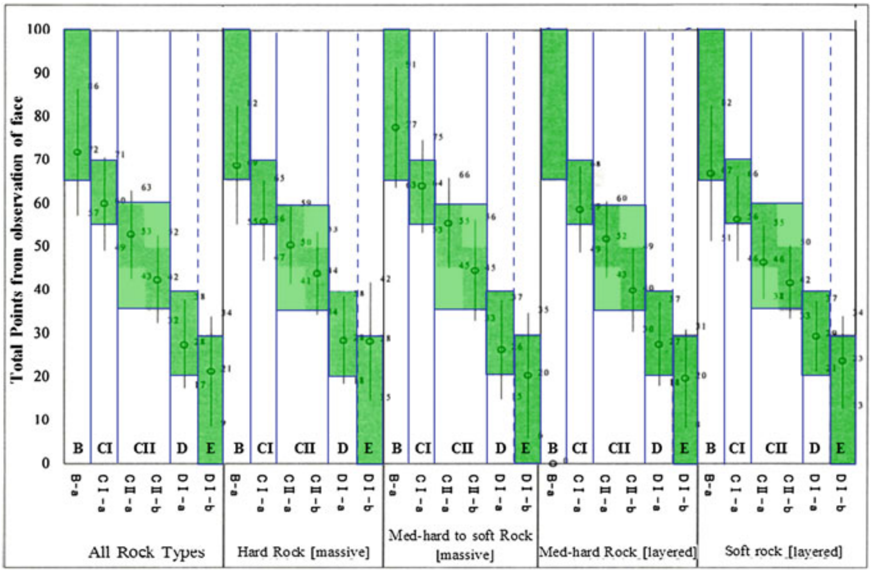


Fig. 4 JH classification rock mass classes

Table 1 JH rock mass classes ratings

Rock mass class	Description
A	Very good rock, hard and fresh
B	Good rock, hard and fresh but affected by weathering
CI	Fair rock, rock is weathered, some clay in joints
CII	Fair to poor rock weathered, loosed rock mass
DI	Very poor rock: considerably weathered rock mass, soft zones, partially soil properties
DII	Extremely poor rock: as above with potential rockfall
E	Faults and crushed rock zone, squeezing zones

Table 2 RMR rock mass classes ratings

RMR ratings	81–100	61–80	41–60	21–40	<20
Rock mass class	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

revisions in 1974, 1975, 1976 and 1989 [9–11]. RMR uses six parameters that are readily determined in the field; which are uniaxial compressive strength of the intact rock, Rock Quality Designation (RQD), spacing of discontinuities, condition of discontinuities, ground water conditions and orientation of discontinuities.

Table 3 Comparison of input parameters

Input parameters		Values or rating	
		RMR	JH
Compressive strength of intact rock	Very low strength (1–5 MPa)	1	0
	Low strength (5–25 MPa)	2	6
	Moderate strength (25–50 MPa)	4	12
	Medium strength (50–100 MPa)	7	18
	High strength (100–250 MPa)	12	25
	Very high strength (>250 MPa)	15	31
Rock quality designation (RQD)	Very good (90–100 %)	20	22
	Good (75–90 %)	17	22
	Fair (50–75 %)	13	16
	Poor (5–50 %)	8	11
	Very poor (<25 %)	5	5
Joint spacing	Very large spacing (Spacing >2 m)	20	22
	Large spacing (0.6–2 m)	15	16
	Moderate spacing (200–600 mm)	10	11
	Small spacing (60–200 mm)	8	5
	Very small spacing (<60 mm)	5	0
Joint condition	Very favour	30	26
	Slightly favour	25	19
	Moderately	20	13
	Unfavourable	10	6
Joint orientation	Very favourable	0	–
	Favourable	−2	–
	Fair	−5	–
	Unfavourable	−10	–
	Very unfavourable	−12	–
Ground water condition	Dry/Moist (<1 L/min)	15	0
	Wet (<10 L/min)	10	−5
	Dripping water (<25 L/min)	7	−7
	Flowing water (<125 L/min)	4	−10

The rating is an outcome of a supervised classification of each parameter. Calculated RMR value used to find rock mass classes from very good rock to very poor rock. The rating for the each parameter is summarized in Table 2.

3 Discussion

JH and RMR classification systems are based on a rating of three principal properties of a rock mass. These are the intact rock strength, the frictional properties of discontinuities and the geometry of intact rock defined by the discontinuities. In order to investigate the influence of these parameters, the approximate total range in values for JH and RMR are used as a basis of comparison. Table 3

Fig. 5 The correlation between the RMR and JH

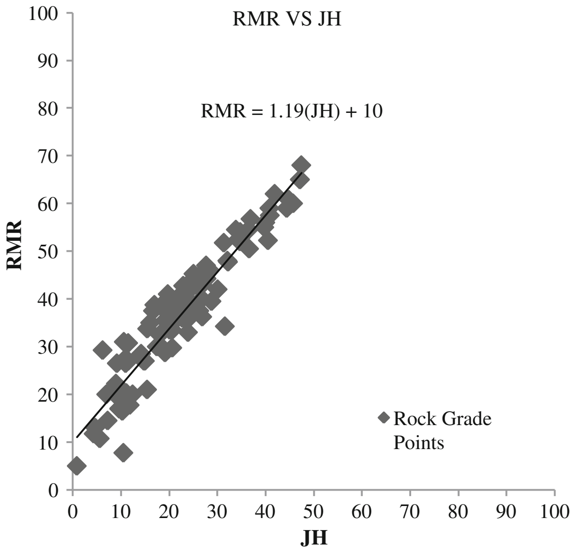
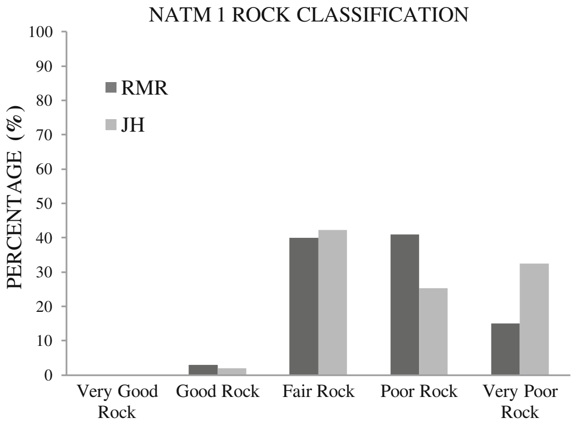


Fig. 6 The distribution of rock mass class for NATM 1



shows the comparison of common input parameters with the values or ratings used in RMR and JH classifications.

The excel spreadsheet is used to estimate the total values of RMR rating, based on the percentage of the differences in both classification systems. A scatter plot in Fig. 5 shows the correlation between RMR and JH. The linear relationship between RMR and JH classification systems is in the form of RMR = 1.19 (JH) + 10.

The bar chart in Fig. 6 shows the rock classification in the percentage of the RMR and JH for NATM 1. According to the chart, less than 5 % for both classification systems is classified as a 'good rock' which is class B for JH and class I

Table 4 JH and RMR rock classifications

JH	Rock conditions	RMR	Rock conditions
A	Very good rock, hard and fresh	I	Very good rock
B	Good rock, hard and fresh but affected by weathering	I–II	Good rock
CI	Fair rock, rock is weathered	II	Fair rock
CII	Fair to poor rock weathered	III	
DI, DII	Very poor rock	IV–V	Poor rock
E	Fault and crushed rock zone	V	Very poor rock

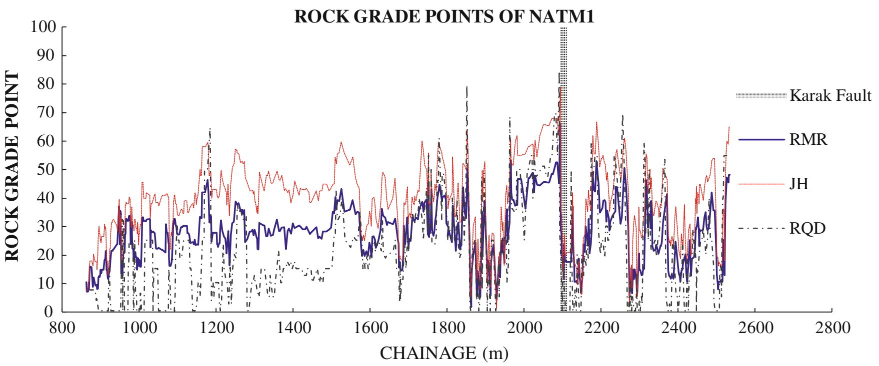


Fig. 7 Comparisons between the RMR, JH classification systems and RQD

or II for RMR. It can be classified that 95 % of the ground condition at NATM 1 classes from 'fair rock' to 'very poor' rock. The classes range from CI/CII, DI/DII to E for JH and III to V for RMR Classifications.

Comparison for both classification systems gives the percentage of 'fair rock' almost the same for both systems but it is slightly different for the 'poor' and 'very poor' rock classes' condition. This happened because from total ratings of RMR, it gives the exact figure between rock classes, while JH gives a range of figures for rock masses classes.

General rock conditions corresponding to JH and RMR classifications are summarized in Table 4. The delineation of regions of the rock mass from 'very good' to 'very poor' between JH and RMR is based on comparison of rock mass classifications for both systems. The classes for 'Good rock' conditions range from B to A and II to I for JH and RMR classification systems respectively. For rock condition 'Fair rock' grade in RMR, it has been considered as the rock grade ranging from 'Fair rock' to 'Fair to Poor rock' in JH.

Comparison also had been made for the total grade point ratings between JH, RMR and RQD. The consistency between JH and RMR classifications indicates that RMR system has smaller ratings about 9–19 % compared to JH classification (Fig. 7). Basically, JH classification has higher ratings for the 3 parameters: strength of intact rock, weathering alteration and spacing of discontinuities, only condition of discontinuities has lower rating than RMR system. From the correlation analysis among the criteria used in both JH and RMR classification systems, there is higher correlation if the rock mass is in relatively good condition.

4 Conclusion

The comparison of two or more classification systems will generally lead to better and more accurate results. It is important to know that the parameters give average values, and that it might be significant variation between the lowest and highest value and rating for most of them. The conclusion could be drawn from the current study that although total rating of RMR is lower than JH, the classes of rock conditions between both classification systems still remain the same. It was also found that there is less consistency between JH and RMR classifications in the region of 'poor rock' and 'very poor rock'. However, the correlation between both classification systems is considered suitable to be used in this tunnelling project.

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References

1. C. Edelbro, *Rock Mass Strength: A Review* (Luleå tekniska universitet, Luleå, 2003), pp. 1402–1536
2. Y.-C. Liu, C.-S. Chen, A new approach for application of rock mass classification on rock slope stability assessment. Eng. Geol. **89**(1–2), 129–143 (2007)
3. S.S. Vardakos, M.S. Gutierrez, N.R. Barton, Back-analysis of Shimizu Tunnel No. 3 by distinct element modeling. Tunn. Undergr. Space Technol. **22**, 401–413 (2007)
4. A. Khabbazi, M. Ghafoori, G. R. Lashkaripour, A. Cheshomi, Estimation of the rock mass deformation modulus using a rock classification system. Geomech. Geoeng. **8**(1), 46–52 (2013)
5. G. Wang, Y. Shi, H. Liu, J. Kou, Z. Shan, C. Zhou, The Rock Mass Classification Methods for Deep Buried Tunnels, no. 574, pp. 1–9 (2006)
6. H. Stille, A. Palmström, Classification as a tool in rock engineering. Tunn. Undergr. Space Technol. **18**(4), 331–345 (2003)
7. S.Y. Choi, H.D. Park, Comparison among different criteria of RMR and Q-system for rock mass classification for tunnelling in Korea. Tunn. Undergr. Space Technol. **17**, 391–401 (2002)
8. M. Sapigni, M. Berti, E. Bethaz, A. Busillo, G. Cardone, TBM performance estimation using rock mass classifications. Int. J. Rock Mech. Min. Sci. **39**(6), 771–788 (2002)
9. Z.T. Bieniawski, Engineering classification of jointed rock masses. Trans. S. Afr. Inst. Civil Eng. **15**(12), 335–344 (1973)
10. Z.T. Bieniawski, *Engineering Rock Mass Classifications* (Wiley, New York, 1989), p. 251

11. N. Barton, Z.T. Bieniawski, RMR and Q: setting records straight. Tunnels Tunn. 26–29 (2008)
12. A. Palmström, N. As, Use and misuse of rock mass classification system with particular reference to the Q-System, **21**, 575–593 (2006)
13. A. Palmström, Combining the RMR, Q, AND RMi Classification System, http://www.rockmass.net, 25, (2009)