Weak rock mass characterization for determination of support system of the DK99-DK100 Jakarta – Bandung speed railway tunnel, Indonesia

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Abstract. Rock mass characterization is a crucial factor in determining a safe design of a tunnel support system. This research is carried out in constructing tunnel DK 99 – DK 100 high-speed railway Jakarta-Bandung, Indonesia. The research includes determining surface and subsurface quality of rock masses based on rock mass classifications of Geological Strength Index (GSI) and the Basic Quality (BQ-System). Both rock mass classifications were then correlated to the Rock Mass Rating (RMR) for the tunnel support system determination. Another support system determination based on the Japanese Society of Civil Engineers (JSCE, 2007) method was also compared. The result showed that the rock masses at the tunnel elevation had very poor to poor quality according to GSI, RMR, and BQ. The rock masses were classified as category class E and DII according to the JSCE competence factor. The recommended tunnel support system based on the RMR are shotcrete, rockbolt, steel set, while those based on the JSCE are shotcrete, rockbolt, steel support, and lining. This paper is expected to provide a better understanding of tunnel construction in weak rock masses, particularly in Indonesia.

1. Introduction
The tunnel DK 99 – DK 100 is one of 12 tunnels built to develop mass transportation infrastructure to reduce congestion, air pollution, and travel time along the Jakarta - Bandung route, located in West Java, precisely in the West Bandung area. Where regionally, the site has a complex geological structure because it is influenced by Java tectonics which can also affect the rock conditions. Therefore, investigating rock mass quality in the characterization of rock that composes the construction site is crucial in designing the tunnel support system.

The tunnel will be built between different types of rock layers; the condition of rock mass quality in each rock layer will affect what kind of support system is effectively applied. This study will use an empirical method to classify the quality of the rock mass, using the GSI classification, the BQ-system, coupled with the RMR as a mutually reinforcing indicator, and the JSCE classification. The various classifications used can be a comparison to anticipate the high uncertainty that may appear in a rock mass classification. Thus, it is hoped that the results of the characterization of rock mass quality in determining the tunnel support system for the DK 99 – DK 100 tunnel can be applied effectively according to geological field conditions.

Geology and rock engineering properties, the study area form by the andesite breccia and the andesite lava (Figure 1); according to the regional geological map [12], the area is influenced by the Older Volcanic Product (Qob) Formation. It consists of breccia, lahar, lava and the composition are between basalt and andesite. The degree of weathering of the rock consists of slightly to completely weathered andesite breccia and slightly weathered andesite lava, tunnel position is in andesite breccia unit with a completely weathered level of weathering. The surrounding rock of the construction site has been classified as surrounding rock class VI (PT. CRDC) [2]; the main engineering characteristic is rock mass
is affected by fault zone with the form crushed stone, breccia as powder, and soil. The specific weight of surrounding rock class VI is 15 – 17 kN/m³.

2. Methodology
The method used in this study consists of two stages, namely surface and subsurface quality of rock mass and determining the tunnel support system based on the quality of the rock mass.

2.1. Surface and Subsurface Quality of Rock Mass
The quality of the surface rock mass was carried out at the tunnel construction site with a mapping area of 920 x 780 m² covering the tunnel path and a map scale of 1:4000. Investigations of rock and soil conditions, rock weathering degree [5], surface GSI measurements [7], and rock sampling were carried out to determine the type of rock that composes the construction location, the quality of the surface rock mass based on surface GSI [7] measurements.

The quality of the subsurface rock mass was carried out by conducting face mapping and data core analysis at the tunnel track location. The face-mapping was taken at four observation points (DK 99+879, DK 99+878, 99+876, and 99+869) in the tunnel, consist of observing, documenting, measuring the quality of the rock mass (GSI, RMR, BQ, and JSCE), and taking samples. The Observation of data from drilling results was carried out from two drilling points located on the tunnel track alignment (17-ZD-020 and 15-ZC-105).

2.1.1 Geological Strength Index (GSI)
The quality of rock mass is determined by GSI [7] based on observations of the structure, surface conditions, and the level of rock mass weathering in face mapping. In core drill sample analysis, the quality of rock mass was determined based on GSI Index for poor and very poor rock mass, which will be explained in chapter 3.1.2. The value of GSI was then correlated to the RMR to find the value of rock
mass quality according to the correlation proposed by Osgoui & Ünal (2005) for weak rock mass class in Zhang et al. (2019) [14] shown in equation (1)

$$RMR_{89} = 20 \ln \left( \frac{GSI}{6} \right)$$  \hspace{1cm} (1)

2.1.2 GSI Index for Poor and Very Poor Rock Mass
Osgoui & Ünal (2005) have made efforts to characterize poor and very poor rock masses using the GSI Index approach. To determine the GSI-Index requires two indicators, namely Broken Structural Domain (BSTR) and the Joint Condition Index (Ijc) [10]. BSTR values based on size and composition can be seen in Figure 2, and the Joint condition index based on the filling and weathering degree can be seen in Figure 3. The GSI index is used to determine the subsurface GSI value of the drilled sample and was correlated to the RMR to find the value of poor and very poor rock mass quality, as shown in equation (2) above.

![Figure 2](image2.png)

**Figure 2** Various types of BSTR [1]

![Figure 3](image3.png)

**Figure 3** Joint condition index determination by [2]

2.1.3 Basic Quality (BQ) System
Value of BQ-system is determinate by two-parameter, namely rock strength (Rc) and rock mass integrity (Kv). The BQ-Correction by formula from Feng & Hudson (2021) [4] to determinate BQ Value in equation (2) and BQ-Correction in equation (3)

$$BQ = 90 + 3Rc + 250Kv$$  \hspace{1cm} (2)

$$[BQ] = BQ - 100 (K_1 + K_2 + K_3)$$  \hspace{1cm} (3)

Where Rc is Rock strength (MPa), Kv is Rock mass Integrity (Vpm, km/sec). K1 is the correction coefficient for the influence of underground water, K2 is the correction coefficient for the result of the orientation of the principal weak structural planes, and K3 is the correction coefficient for the influence of the initial stress state. The BQ value is converted into RMR by the equation from Wang et al. (2021) [13], as shown in equation (4).

$$RMR = (BQ - 80.79)/(6.09)$$  \hspace{1cm} (4)
2.1.4 Japan Society of Civil Engineering (JSCE)

In determining the rock class based on the JSCE, the author uses JSCE (2007) ground classification, adopted as Guidelines for Excavation Planning Methods and Road Tunnel Strengthening System in Mixed Soil – Rock Media. By the Ministry of Public Works and Public Housing of Indonesia [8]. This classification considers seven parameters: elastic wave velocity (km/sec), rock type, geological condition (effect by water and lithologic character, interval discontinuity, condition of discontinuity). Boring core condition (RQD) [3], Competence factor in equation (5), and situation of the tunnelling and standard of the displacement.

\[ \text{Competence Factor} = \frac{q_u}{\gamma H} \] (5)

Where \( q_u \) is the unconfined compressive strength (UCS) of the ground (kN/m\(^2\)), \( \gamma \): unit weight of the ground (kN/m\(^3\)), and H: depth of cover (m) [6]

2.2 Determining Tunnel Support System

The Tunnel support system determined with an empirical method that is based on Rock Mass Rating RMR [1] and Japan Society of Civil Engineering [6]

3. Results and Discussion

The position of the DK 99 - DK100 tunnel is in an andesite breccia rock unit with a very high weathering level. Based on the weathering degree of rock [5], the research location can be divided into slightly – moderately - highly and completely weathered andesite breccia and slightly weathered lava basalt. Surface GSI measurements [7] show that the tunnel path lies in the rock mass quality is very poor to poor. GSI and RMR calculation results from face mapping are shown in Table 1, and Table 2 shown GSI – RMR calculation from core drill result.

| No | STA/DK Face Mapping & Bench | Rock Type | GSI Face Mapping | RMR | Rock Mass Class |
|----|-----------------------------|-----------|------------------|-----|-----------------|
| 1  | 99+879                      | III       | 10 15            | 10.2 18.3 | V (<20)         |
|    |                             | II        | 10 15            | 10.2 18.3 | Very Poor       |
|    |                             | I         | 15 25            | 18.3 28.5 | IV (21 - 40) Poor |
| 2  | 99+878                      | III       | 10 15            | 10.2 18.3 | V (<20)         |
|    |                             | II        | 10 15            | 10.2 18.3 | Very Poor       |
|    |                             | I         | 15 25            | 18.3 28.5 | IV (21 - 40) Poor |
| 3  | 99+876                      | III       | 10 15            | 10.2 18.3 | V (<20)         |
|    |                             | II        | 10 15            | 10.2 18.3 | Very Poor       |
|    |                             | I         | 10 15            | 10.2 18.3 |                 |
| 4  | 99+869                      | III       | 10 15            | 10.2 18.3 | V (<20)         |
|    |                             | II        | 10 15            | 10.2 18.3 | Very Poor       |
|    |                             | I         | 10 15            | 10.2 18.3 |                 |

The face-mapping on the face of the excavation shows the rock surface has undergone high weathering, some have turned into soil containing clay and few fragments, but the rock structure can still be seen. Visually, the structure looks disintegrated and poorly interlocked.
The GSI classification was chosen because it is easy to use in field observations and poor rock conditions due to significant tectonic influences and high weathering rates. In accordance with the results of geological studies, the research area is dominated by volcanic rocks, highly weathering degrees, and affected by tectonic processes.

### Table 2 Core drill GSI and RMR result

| No | Borehole & Depth (m) | Rock Type | GSI Index | RMR | Rock Mass Class |
|----|----------------------|-----------|-----------|-----|----------------|
| 1  | 15-ZC-105 13-19      | Andesite Breccia Completely Weathered | R0 (Clayey Rock) | R0 (Clayey Rock) | 0 | Very Poor |
|    | 20-24                |           |           |     | V (<20)        |
| 2  | 16-ZD-020 20-25      | Andesite Breccia Completely Weathered | 10 | 22 | 10.2 | 26.0 | IV (21 - 40) Poor |
|    | 26-30                |           |           |     | IV (21 - 40) Poor |

**Figure 4** Broken structural domain (BSTR) from core drill number 16-ZD-020

**Figure 5** Modified GSI Index from core drill number 16-ZD-020

In the boundary between rock and soil is the UCS value of 1 MPa [11], the results of the drilling sample test show that it is included in the rock category. Visually the size of sand, gravel, and broken material can be seen; therefore, the GSI value classification uses the Osgoui & Ünal (2005) [10] equation is considered the most suitable for use.
### Table 3 BQ-system – RMR result

| No | STA/ DK Face Mapping/ Borehole | Range of BQ System | Rock Mass BQ Index | RMR (Wang, 2021) | Rock Mass Class       |
|----|--------------------------------|--------------------|-------------------|------------------|-----------------------|
|    |                                | Min | Max | V (<250) | Min | Max | V (<20) Very Poor |
| 1  | 99+879                         | 137 | 187 | 9.2      | 17.4 |     |                  |
| 2  | 99+878                         | 137 | 187 | 9.2      | 17.4 |     |                  |
| 3  | 99+876                         | 137 | 187 | 9.2      | 17.4 |     |                  |
| 4  | 99+869                         | 137 | 187 | 9.2      | 17.4 |     |                  |
| 5  | 15-ZC-105                      | 143 | 193 | 10.2     | 18.4 |     |                  |
| 6  | 16-ZD-020                      | 149 | 211 | 11.2     | 21.4 |     |                  |

### Table 4 Rock mass classification based on JSCE

| No | STA/ DK Face Mapping/ Borehole | Competence Factor | Rock Mass Class |
|----|--------------------------------|-------------------|-----------------|
| 1  | 99+879                         | 0.81              | E               |
| 2  | 99+878                         | 0.40              | E               |
| 3  | 99+876                         | 0.31              | E               |
| 4  | 99+869                         | 0.32              | E               |
| 5  | 15-ZC-105                      | 0.64              | E               |
| 6  | 16-ZD-020                      | 1.42              | DII             |

**Figure 6** Profile of rock mass quality at the study area
The rock mass quality analysis using four classifications shows that the tunnel path consists of two rock mass quality: section DK 99+050 - DK 99+985 and DK 99+870 - DK 99+842 are very poor rock mass quality, section DK 99+875 - DK 99+985 is poor rock mass quality as shown in the profile of subsurface rock mass quality in Figure 3. The condition of very poor and poor rock mass quality cannot be separated from the geological conditions of rock in the study area which influence by high weathering degree, and consists of quaternary deposits and volcanic debris in the vicinity. The thickness of this quarterly deposit in the [12] regional formation is estimated to be around 150 m. The poor rock conditions are also influenced by the tectonic setting of the West Java area, where there is an active fault approximately 6 km south of the study area, causing the area to become a weak zone affecting the quality of the rock mass.

| No | STA/ DK Face Mapping/ Borehole | Tunnel Support System | JSCE | RMR |
|----|-------------------------------|-----------------------|------|-----|
| 1  | 99+879                        | Shotcrete, Rockbolt, Steel Support, and Lining. |      |     |
| 2  | 99+878                        | Shotcrete, Rockbolt, Steel Support, and Lining. |      |     |
| 3  | 99+876                        | Additional Support (Pre support: Forepoling with filling and injection) |      |     |
| 4  | 99+869                        | Rockbolt (Systematic bolts 5-6m long, spaced 1-1.5 m in the crown and the walls with wire mesh. Bolt invert) |      |     |
| 5  | 15-ZC-105                     | Steel Set (Medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if required. Close Invert) |      |     |
| 6  | 16-ZD-020                     | Rockbolt: Length 2.0-3.0m, area of installation top heading and bench. |      |     |
|    |                               | Steel support: type H100, spacing 1.0m |      |     |
|    |                               | Shotcrete: thickness 10-12cm |      |     |
|    |                               | Lining: thickness 20cm |      |     |

4. Conclusions
The analysis of rock mass quality shows that the study area consists of: very poor quality (GSI value 0-20, RMR class V <20, BQ < 250, JSCE ground classification class E), and poor quality (GSI 21-40, RMR class IV 21-40, BQ < 250, JSCE ground classification class DII). The quality of the rock mass result does not show a considerable difference, so the use of the rock mass correlation equation is appropriate. The recommended tunnel support system based on JSCE shows recommendations for support systems, Section One for DK 100+050 - DK 99+960 and DK 99+875 - DK 99+842 Bench I, II, III are recommended to use shotcrete, rockbolt, steel support, lining, and additional support: pre-support forepoling with filling and injection, Section two on DK 99+875 - DK 99+960 Bench I, II, III it is recommended to use rockbolt (length 2 - 3m at installation on top heading and bench, steel support spacing 1m, shotcrete thickness 10-12 cm, lining thickness 20 cm, while according to RMR on DK 100+050 - DK 99+960 and DK 99+875 - DK 99+842 Bench I, II, III it is recommended to use shotcrete (150-200mm in crown 150 mm in sides, and 50 mm on face), Rockbolt (Systematic bolts 5-6m long, spaced 1-1.5 m in crown and walls with wire mesh, bolt invert), Steel Set (Medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if required, close invert) and on DK 99+875 - DK 99+960 bench I, II, III recommended using Rockbolt (Systematic bolts 4-5m long, space d 1-1.5m in crown and walls with wire mesh. bolt invert), shotcrete (100-150 mm in the crown, and 100 mm in the sides), Steel Set (Light to medium ribs spaced 1.5 m where required).
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