

Rock Mass Classification on Opak Fault Impacted Zone in Mengger Hill, Bantul, Yogyakarta

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Abstract

In 2006, Mengger Hill has been affected by an earthquake with a value of 5.9 Richter Scale. It has some outcrops that show an offset between the bedding planes that indicated it as one of the impacted fault zone. Due to the post-earthquake effect and future potential seismic hazards, this research was established to evaluate the quality of rock mass condition because this hazards potential is located close to residential areas and designated to be used as Geosite and tourist attractions. Rock mass stability analysis will be conducted as a main step for risk control and risk mitigation. This research will be focused on determining the types of constituent rocks, rock strength, and rock mass classifications using *RMR* (Rock Mass Rating) and *SMR* (Slope Mass Rating) methods to determine the rock mass quality and support recommendation for the slope of Mengger Hill as an initial development for a sustainable Geoheritage.

The study began with a rock sampling to determine the rock characteristics and scanline method to measure the orientation set of the discontinuities along the slope. The rock samples that has been taken is done for a Point Load Test in Laboratory. The results show that the constituent rock of the rock mass is dominated by massive tuff from the Semilir Formation and has I_s (*Point Load Index*) values between 0.27 to 0.78 MPa that converted into σ_c (Uniaxial Compressive Strength) using Kramadibrata's Equation (1992) with a range between 3.22 to 9.25 MPa. The orientation set is indicating a wedge sliding potential with *RMR* value of 65 (Good Rock) and *SMR* value of 80 (IIa - Good). The support recommendation is a spot bolting, fence, and toe ditch (optional) to handle debris in the form of blocks failure.

Keywords: Geosite, PLI, RMR, SMR, UCS

1. Introduction

A rock mass is a structure consisting of intact rock and discontinuity planes, which can be in the form of bedding planes, cracks, fractures, folds, foliation planes, joints, and faults. Therefore, this can be influenced by the nature of the constituent rocks and the orientation of the discontinuities in the field (Aydan, 2018). Because it has high anisotropy factors, the rock mass quality can be measured by doing an empirical approach such as *RMR* (Rock Mass Rating) and its modifications *SMR* (Slope Mass Rating) that could be implied in slopes (Bienawski, 1983, as cited in Romana, 1985). *RMR* is used because it could quantify the site conditions not only as an intact rock, but also considering its structural weakness from the fracture frequency, intact rock strength from *PLI* & *UCS*, groundwater condition, *RQD* (Rock Quality Designation), and discontinuities conditions. The

summation of this classification is not yet consider the geometrical relation that influences the failure type's potential. At the limitations of *RMR*, *SMR* is used to add the correction factors due to specific rock failure potential such as wedge, slide, and toppling failure from kinematic analysis in order to get a valid rock mass quality in site specific.

In 2006, Yogyakarta was hit by a 5.9 Richter Scale earthquake. This earthquake left traces in the form of rock movements known as the Opak Fault. It also caused after-seismic deformation on the rock mass with a range of 0.3 to 9.1 cm on June 2006 - June 2008 which indicates that this is a potentially dangerous zone for earthquakes that may occur in the future (Abidin, et. al., 2009). Based on research by Fathonah, et. al. (2014), it is known that this fault is a normal fault with the decline occurring in the western block and the eastern block remaining in place. This fault

extends northward at N 35° E in Pundong District. This post earthquake effect also caused a high liquefaction potential on the residential and tourism areas near Opak Fault that has to be replanned as the prevention to mitigate future potential seismic hazards (Wahyuni, et. al., 2025). The potential for further seismic danger is indicated by an active fault movement in the eastern block of Opak Fault with a range value of -0.040 to 0.023 m/year that is larger than the western block's displacement with a range value of -0.011 to 0.038 m/year. It is also estimated that the next tectonic earthquake could possibly reach a maximum magnitude value of 6.5 Mw or equal to 6.5 Richter Scale (Ullinuha, et. al., 2022).

Contrary to the potential seismic dangers described above, the Yogyakarta government has designated the Opak Fault area on Mengger Hill as a Geoheritage site based on the Keputusan Menteri Energi dan Sumber Daya Mineral 2021. This designation was followed by a master plan to support the area as a tourist destination with attractions based on beautiful scenery, local wisdom, and as well as evidence, and a reminder that Yogyakarta was once hit by a devastating earthquake (Vitasurya, et. al., 2023). Based on this designation, this geoheritage plan must be fully studied to understand the characteristics of the rock mass as a prevention, disaster mitigation, and risk assessment. As a geotechnical data support of this plan, this research was established to assess the quality of rock mass in Mengger Hill area to create a sustainable geoheritage site. The goals of this research are to obtain support installation recommendations based on the rock mass condition on Opak Fault impacted area.

2. Methodology

2.1. Observation Location

Geographically, the research location is located at coordinates 433,373 mE and 9,127,569 mN, which is geologically dominated by pyroclastic rocks from the Semilir Formation. The Semilir Formation consists of tuff, lapilli tuff, pumice lapilli, pumice breccia, and shalestone (Wijayanti, 2022). The regional geological map can be seen in Fig. 1 with red marks indicating data collection points.

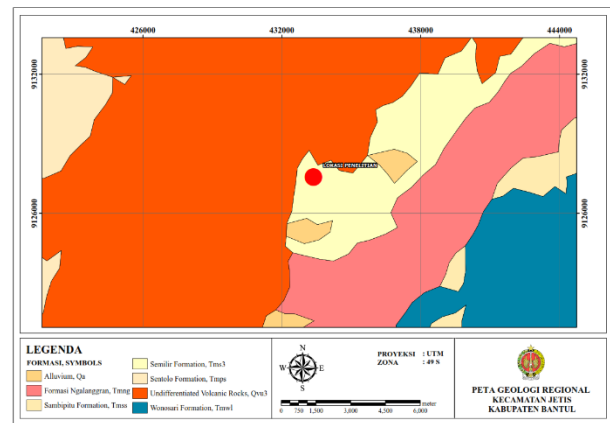


Fig. 1. Regional Geological Map.

The observation point showed that the outcrop is consisted of pyroclastic rock types as shown in Fig. 2. It has a white-grey colour in fresh condition and a bit brownie colour when it gets weathered. The structure are a massive type bedding plane that have more than 1 meter long of each rock layers. The grain size ranges from 0.04 mm to more than 0.006 mm that classified as fine ash (< 2 mm). The mineral composition of the rock consists of SiO₂ or silica (predominantly glass). Based on the observation, the rocks in this location are classified as tuff (Schmidt, 1981).



Fig. 2. Rock Mass Outcrop in Mengger Hill.

On the western slope, there are indications of recent landslides in the form of large blocks. This can be seen in Fig. 3 (indicated by red marks), which shows the remains of landslides at the foot of the slope where the data was collected.

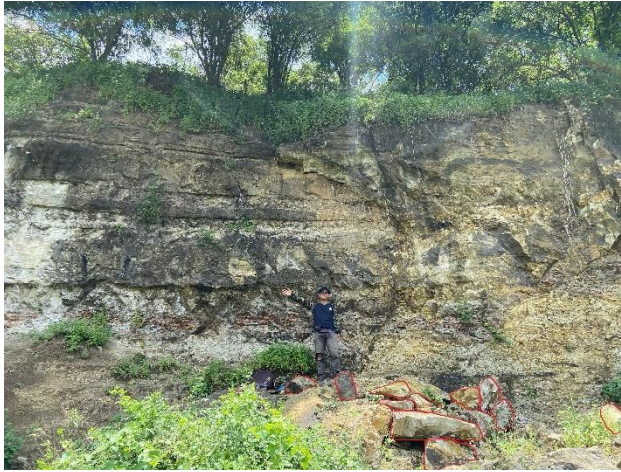


Fig. 3. Large Blocks Failures Next to The Western Slope.

2.2. Point Load Test

Point Load Test is a test aimed at determining the test index in the strength classification of rock materials (ISRM, 1981). This test will measure the Point Load Strength Index (I_s) value of the test specimen, where the test could be done in 4 types of test.

The first type is the axial test. It used a cylindrical sample or a core drilling shaped sample with a cone distance (D) that have to be more than the half of the width (W) as the diameter and also less than the length of diameter itself as the sample requirement ($0.5 W < D < W$). The point load must be conducted from the circular area at the top and bottom sides from the core sample (axial sides).

The second type is the diametral test. It also used a core drill sample that must have a requirement of D (cone distance) as the diameter of circular sides and the point load must be conducted on the tube covers (diametral sides) where the central point length (L) has to be more than the half of the circle's diameter ($L > 0.5 D$).

The third type is the block test. It requires a block sample shaped with D as the cone distance that has to be more than 0.3 of its W as width and also less than the full width itself ($0.3 W < D < W$). The central point length of load has the same requirement as the diametral test where the L has to be more than the half of its cone distance ($L > 0.5 D$).

The last type of point load test is the irregular lump test that will be explained more detail below. Since the rock samples from Bukit Mengger are irregular in shape, this test will be carried out in accordance with the irregular lump test standard based on ISRM (1981). The dimensional requirements for this test are as shown in Fig. 4 where W represents the average width of W_1 and W_2 , D is the distance between the cones that have to be greater than 0.3 W and less than W itself.

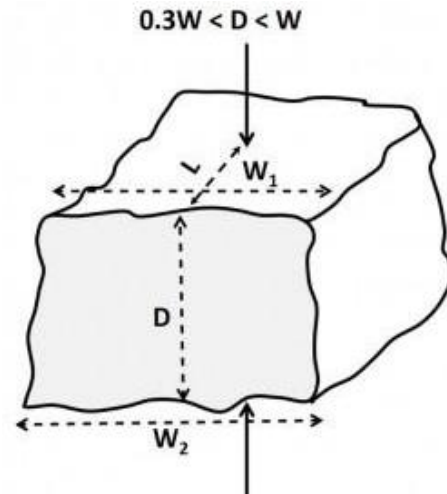


Fig. 4. Dimensional Requirement for Irregular Lump Test.

W can be measured by using Eqn. 1.

$$W = \frac{W_1 + W_2}{2} \quad (1)$$

Then, the distance between cones have to be converted into Equivalent Core Diameter (D_e) using Eqn. 2 where D_e are the inverted equation of circular area.

$$D_e = \sqrt{\frac{4 W \times D}{\pi}} \quad (2)$$

After D_e has been measured, Point Load Index (I_s) can be calculated using Eqn. 3.

$$I_s = \frac{P}{D_e^2} \quad (3)$$

Adjustments need to be made so that the I_s results are in accordance with the standard results, which are core samples with a diameter of 50 mm using the Greminger's equation (1982), as shown in Eqn. 4.

$$I_{s(50)} = F \times I_s \quad (4)$$

Where F are the correction factor for the shape effect as shown in Eqn. 5.

$$F = \left(\frac{D_e}{50}\right)^{0.45} \quad (5)$$

The conversion of $I_{s(50)}$ values to σ_c (Uniaxial Compressive Strength) was performed using the Kramadibrata Equation (1992) for conversion in rocks with grain sizes similar to claystone as shown in Eqn. 6.

$$\sigma_c = 11.82 \times I_{s(50)} \quad (6)$$

2.3. Empirical Approach

The empirical approach is a type of approach that uses previous cases and their correlation to current cases, which will generally be applied in pre-design studies or feasibility studies (Aydan, 2018). The empirical approach used in this study is

a method of classifying rock mass based on RMR (Bienawski, 1989) and SMR (Romana, 1985).

2.3.1. Rock Mass Rating

RMR are function of 6 parameters that consist of intact rock strength, RQD (Rock Quality Designation), spacing of discontinuities, condition of discontinuities, groundwater conditions, and orientation of discontinuities (Bienawski, 1989). RMR could be calculated by summing-up the rating of each parameters using Eqn. 7 where RQD will be measured using Priest & Hudson equation (1982) in Eqn. 8.

$$RMR = R1 + R2 + R3 + R4 + R5 \quad (7)$$

$$RQD = 100e^{0.1\lambda}(0.1\lambda + 1) \quad (8)$$

λ is a linear frequency of joint that can be measured by dividing the joint counts by its total length of measurement.

2.3.2. Slope Mass Rating

SMR are an adjustment and modification for RMR that was developed by Romana (1985). This rating system could be applied for rock slope with this following equation.

$$SMR = RMR + (F_1 \times F_2 \times F_3) + F_4 \quad (9)$$

Where F_1 is the correction for the joint set's dip direction alignment to the slope's dip direction, F_2 is the joint set's dip influence, F_3 is the slope's dip influence, and F_4 is the excavation method which created the slope (naturally, mechanically, or created by drill and blasting).

The suggested support for rock slope could be chosen by looking at the SMR values which will be classified as one of nine sub-classes below.

Table 1.
SMR Classes and Suggested Supports For Rock Slope (Romana, 1985).

SMR classes	SMR values	Suggested supports
Ia	91-100	None
Ib	81-90	None, scaling is required
IIa	71-80	(None, toe ditch, or fence), spot bolting
IIb	61-70	(Toe ditch or fence nets), spot or systematic bolting
IIIa	51-60	(Toe ditch and/or nets), spot or systematic bolting, spot shotcrete
IIIb	41-50	(Toe ditch and/or nets), systematic bolting/anchors, systematic shotcrete, toe wall and/or dental concrete
IVa	31-40	Anchors, systematic shotcrete, toe wall and/or concrete (or re-excavation), drainage
IVb	21-30	Systematic reinforced shotcrete, toe wall and/or concrete, re-excavation, deep drainage
Va	11-20	Gravity or anchored wall, re-excavation

2.4. Work Flow

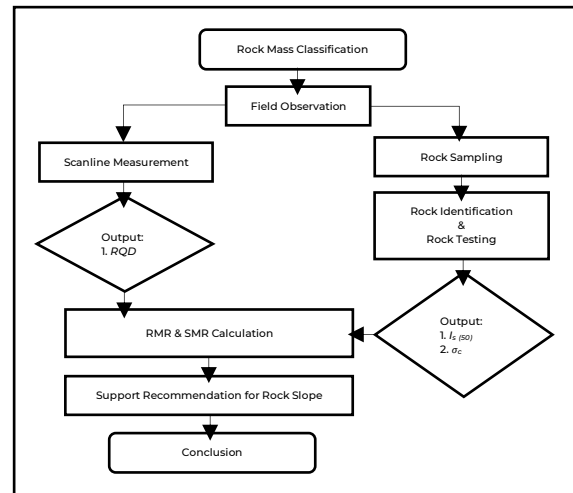


Fig. 5. Workflow of Research.

3. Result and Discussion

The point load test was done for 5 irregular lump tuff samples. The dimensional requirements was prepared and checked before the rock had to be tested to validate that the D have to be less than W and greater than $0.3 W$. The tests was conducted at Rock Mechanics Laboratory of UPN "Veteran" Yogyakarta as shown in Fig. 6. Result of the point load tests can be seen in Table 2.



Fig. 6. Point Load Test at Rock Mechanics Laboratory.

Table 2.
Intact Rock Strength Tests Result

No.	A (mm ²)	D _c ² (mm ²)	F	P (N)	I ₅₀ (MPa)	σ_c (MPa)
S1	3,010	3,834.39	1.10	3,000	0.78	9.25
S2	3,619	4,610.19	1.15	2,700	0.59	6.92
S3	6,105	7,777.07	1.29	3,500	0.45	5.32
S4	10,824	13,788.53	1.47	7,000	0.51	5.99
S5	8,640	11,006.37	1.39	3,000	0.27	3.22

The σ_c value of intact rock at this observation site ranges from 3.22 to 9.25 MPa. This range is classified as rating of 2 for σ_c value ranges from 5

to 25 MPa and also rating of 1 for σ_c value ranges from 1 to 5 MPa. To analyze the worst-case scenario, the lowest rating was selected in the RMR value weighting for the intact rock strength parameter.

In measuring the orientation and spacing of discontinuities using the scanline method, the results showed orientations of 7 joints over a scanline length of 2 meter. The scanline length was considered to be 10 times the estimated spacing. The spacing was early estimated about 10 to 20 cm per joint. Result for the the dip and dip direction measurement from geological compass can be seen in Table 3 following with the true spacing result from scanline which are also shown in Table 4. It shows 2 classification of spacing ranges for RMR rating. Same as the rating for the first parameter, the smallest rating will be chosen for the pesimistic scenario (8 rating).

In addition to orientation parameters, measurements were also taken for other discontinuous field parameters, such as the width of non-discontinuous fields with a variation value of 0.1 to 1 mm (< 1 mm) and the persistence of fractures (length of discontinuous fields) with an average length of 1.9 meters.

In the qualitative assessment, visual observations were made of the category of features that were classified as closed features because the gaps in the fracture planes were not filled with material or minerals. Then, the roughness level of the rock mass was classified as slightly rough, coupled with the moderately weathered condition of the rock due to age and the impact of the Opak Fault itself. The groundwater conditions in the observation site is completely dry without any signs of moisture on the rock surface.



Fig. 7. Scanline Measurement

Table 3. Dip and Dip Direction Results

Dip (...°)	Dip Direction (N ...° E)
81	118
56	084
52	060
50	065
44	057
53	056
69	062

Table 4. Spacing Results

Joint	True Spacing (m)	Classification
1 to 2	0.3	0.2 - 0.6
2 to 3	0.065	0.06 - 0.2
3 to 4	0.11	0.06 - 0.2
4 to 5	0.14	0.06 - 0.2
5 to 6	0.28	0.2 - 0.6
6 to 7	0.53	0.2 - 0.6

RQD for this rock mass are calculated using Eqn. 8.

$$RQD = 100e^{0.1\left(\frac{7 \text{ joint}}{1,49 \text{ meter}}\right)} \left(0.1\left(\frac{7 \text{ joint}}{1,49 \text{ meter}}\right) + 1\right) = 91.91 \%$$

This value is classified as a rating of 20 (90 – 100 %) for its parameter in RMR.

RMR can finally be calculated after six parameters have been met using Eqn. 7.

$$RMR = 1 + 20 + 8 + 20 + 15 = 64$$

64 value means that the rock mass quality on Mengger Hill is classified as Good Rock (Class No. II) with an empirical rock mass friction angle of 37° and empirical rock mass cohesion of 320 kPa. Before doing the SMR calculation, the kinematic analysis need to be done first in order to know about the failure potentials. Kinematic analysis show the orientation set has one joint set that has dip value of 54° and dip direction N 064° E where the slope dip are 84° and slope dip direction are N 331° E. The failure potential has the biggest percentage at Wedge Failure as shown in Fig. 8 where the percentage are 38.10 %.

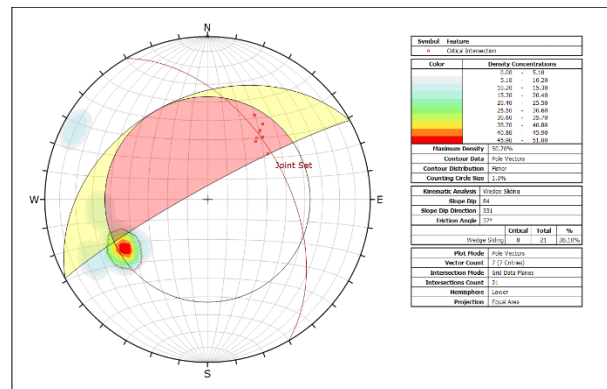


Fig. 8. Kinematic Analysis

Based on this basis, SMR calculations will be performed for potential wedge failure, where calculations for each F factor can be seen in Table 5.

Table 5.
SMR Calculation

Parameter	Dip	Dip Dir.
Slope	84	331
Joint	54	64
Intersect	54	38
Correction Factor	F1	0.15
	F2	1
	F3	0
	F4	15
Method	Rating	Class
RMR	64	II
SMR	79	Ila

SMR calculation rating classified as good quality rock mass with the Ila sub-class that ranges from 71 – 80. It indicates that the rock mass stability is stable with a potential failure of block failures. These results match and correspond to the field conditions previously seen in Fig. 3 regarding the presence of large rock blocks at the base of the slope when the observation was conducted. This good class have an empirical probability of failure 0.2 or 20 % which means the rock mass still has the potential to collapse and needs to be monitored regularly. Spot bolting needs to be installed on several rock blocks that are considered to be at risk of collapse.

4. Conclusion

This study concludes that Mengger Hill has a dominant rock constituent of pyroclastic rock with a massive tuff type from Semilir Formation. The Point Load Test gave an $I_{s(50)}$ value ranges from 0.27 to 0.78 MPa with σ_c conversion ranges from 3.22 to 9.25 MPa. From the previous scanline method, rock mass classification shows an RQD with a value of 91.91 % and a total of summed-up RMR parameters at 64 (Class II). This RMR value then corrected based on the kinematic analysis that indicates a wedge failure potential. SMR calculation of Mengger Hill shows a 79 value (Ila – Good) that recommend a spot bolting, fencing, and toe ditch for handle the probability of block failures.

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This journal is dedicated to supporting the development of a better and more sustainable Yogyakarta Geopark. In addition, this publication is also intended as a contribution by the author as part of the Jogja Geopark Youth Forum, which fully supports the creation of a master plan based on the preservation of the Opak Fault Bukit Mengger geological heritage site

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