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Rock Mass Characterization for Assessment of Safe Cut Slope and Rock Bearing Capacity at Gondang Dam Site, Karanganyar, Indonesia

Sao Sochan[1], I Gde Budi Indrawan*[1], and Dwi Agus Kuncoro[2]

[1]*Department of Geological Engineering, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia*
[2]*BBWS Bengawan Solo, Indonesia*

ABSTRACT. This paper presents results of surface rock mass characterization for assessment of safe cut slopes and allowable bearing capacity of foundation rocks at the construction area of Gondang Dam. The rock mass characterization involved determination of intact rock engineering properties and rock mass quality based on the Geological Strength Index. The rock mass characterization results showed that the research area consisted of moderately to highly weathered and very weak to weak andesite breccia and andesite tuff breccia. The andesite breccia had very poor to fair rock mass quality, while the andesite tuff breccia had poor to fair rock mass quality. The research area was divided into three zones of safe cut slope and allowable bearing capacity. Landslides occurred at natural slopes having poor to very poor rock mass quality and inclinations greater than the determined safe cut slopes.The foundation rock of the embankment dam had fair rock mass quality and 135–280 T/m^2 allowable bearing capacity.

Keywords: Bearing capacity · Geological strength index · Rock mass characterization · Rock mass quality · Safe cut slope

1 Introduction

This research was carried out at Gondang Dam site, which was administratively located in Karanganyar Regency, Central Java Province, Indonesia (Figure 1). Regional geological map produced by Sampurno and Samodra (1997) indicated that the construction area of the Gondang Dam consisted of Quartenary volcaniclastic deposits of Mount Lawu, particularly Lawu Volcanics (Qvl). As the volcanoclastic rocks were mostly weathered and had low strength, stability of reservoir slopes and bearing capacity of the dam foundation rocks were among several issues that had to be addressed for dam safety.

PT. Gracia Widyakarsa (2014) had conducted site investigation for design of the embankment dam. However, the site investigation was limited to the laboratory testing of soil and rock samples obtained from borehole drilling. As engineering geological conditions of rocks in volcanic areas were expected to be highly variable and the rock masses underwent stress relaxation after excavation, rock mass characterization of excavated ground at the construction site was expected to provide useful information to better understand the engineering geological conditions for dam safety.

This paper presents the results of rock mass characterization for assessment of safe cut slope and bearing capacity of foundation rocks in the construction area of the Gondang Dam. The engineering geological conditionsof the construction area are presented and zones of safe cut slope and bearing capacity of foundation rock are highlighted.

2 Methodology

The rock mass characterization involved determination of intact rock engineering properties and rock mass quality. Rock water content was determined following ASTM D 2216-

*Corresponding author: , Department of Geological Engineering, Universitas Gadjah Mada. Jl. Grafika 2 Yogyakarta, Indonesia. E-mail: igbindrawan@ugm.ac.id

Figure 1: Research location.

98 (ASTM International, 1998), while rock density and specific gravity were determined following ASTM D7263-09 (ASTM International, 2009) and ASTM D 854-02 (ASTM International, 2002), respectively. Rock weathering degree was determined following ISRM (1981) classification. Intact rock strength was estimated by point load method following procedures described in ASTM D 5731–02 (ASTM International, 2002). Rock mass quality was estimated by the Geological Strength Index (GSI) (Hoek and Brown, 1997). To assess the safe cut slope and rock bearing capacity for foundationfrom Rock Mass Rating (RMR) (Bieniawski, 1989) as compiled by Singh and Goel (2011), the GSI values were converted to RMR values by applying the empirical GSI-RMR correlation suggested by Hoek and Brown (1997).

3 RESULTS

3.1 Rock units and engineering characteristics

Results of the site investigation indicated that the research area consisted of two rock units, namely andesite breccia and andesite tuffbreccia (Figure 2). Referring to the regional geological map produced by Sampurno and Samodra (1997), the two rock units were likely member of Lawu Volcanic (Qvl). Figure 3 and 4 show typical outcrops of the two rock units. The andesite brecciatypically consisted of 50 % of 2 cm to 1 m-sized andesite fragments, 45 % of medium to coarse sand-sized matrix, and 5 % of tuff. The andesite tuff breccia typically consisted of 30 % of 1 to 20 cm-sized andesite fragments, 30 % of fine sand-sized matrix, and 40 % of tuff.

The rock masses in the research area had moderately to completely weathering degree with GSI values ranged from 10 to 45 (Figure 4). Residual soils were also developed particularly on the upper part of the andesite tuff breccia. The andesite breccia had very poor to fair rock mass quality, while the andesite tuff breccia had poor to fair rock mass quality. Table 1 presents the engineering characteristics of rock masses for each GSI range. Following classification proposed by ISRM (1981), the intact rocks of andesite breccia and andesite tuff breccia were categorized as very weak to weak rocks.

3.2 Safe cut slope and bearing capacity

On the basis of RMR values, the rock masses in the research area were sorted into three zones of safe cut slope and allowable bearing capacity,

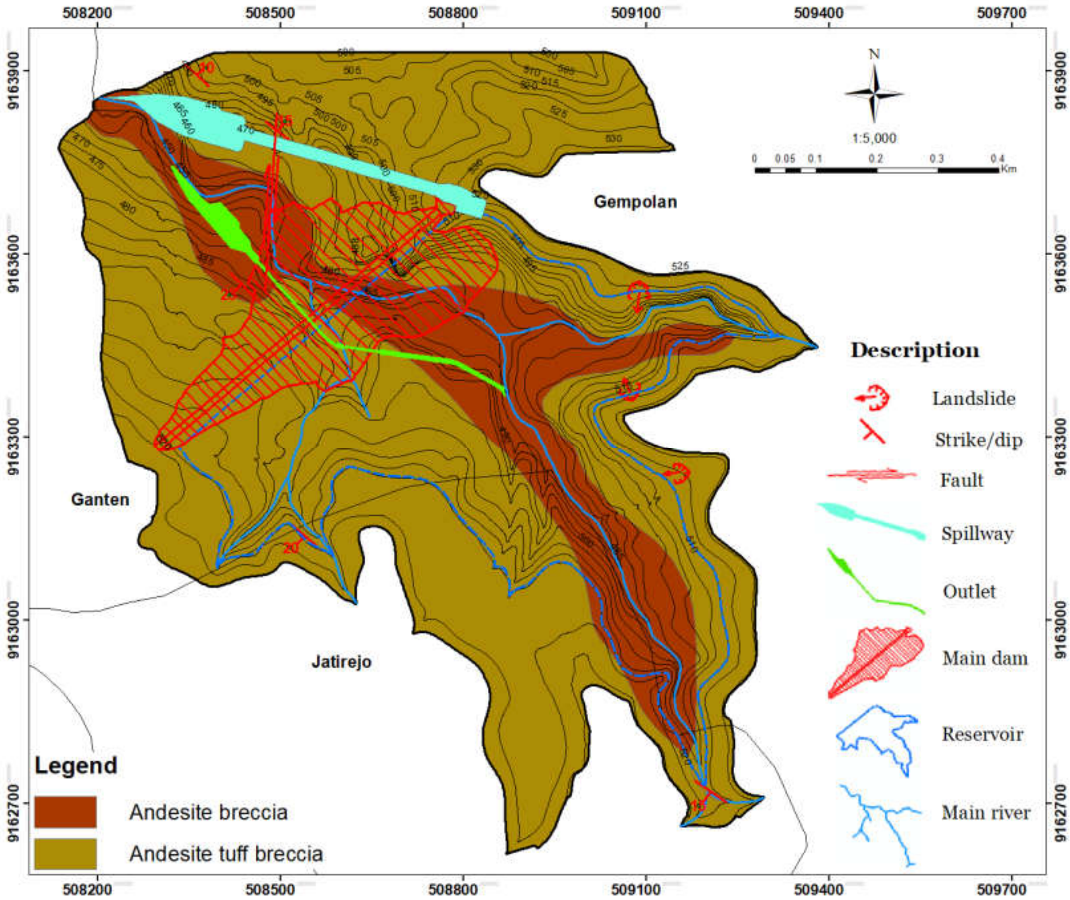

Figure 2: Spatial distribution of rock units in the research area.

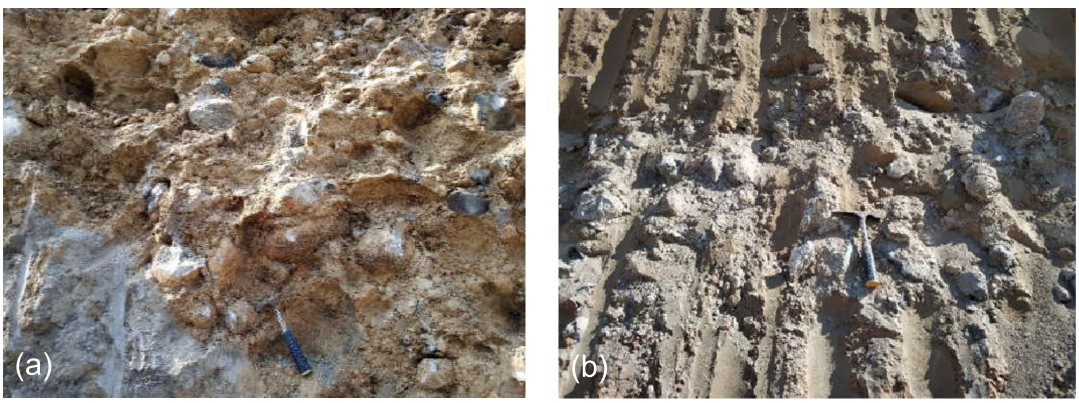

Figure 3: Typical rock outcropsin the research area: (a) andesite breccia; (b) andesite tuff breccia.

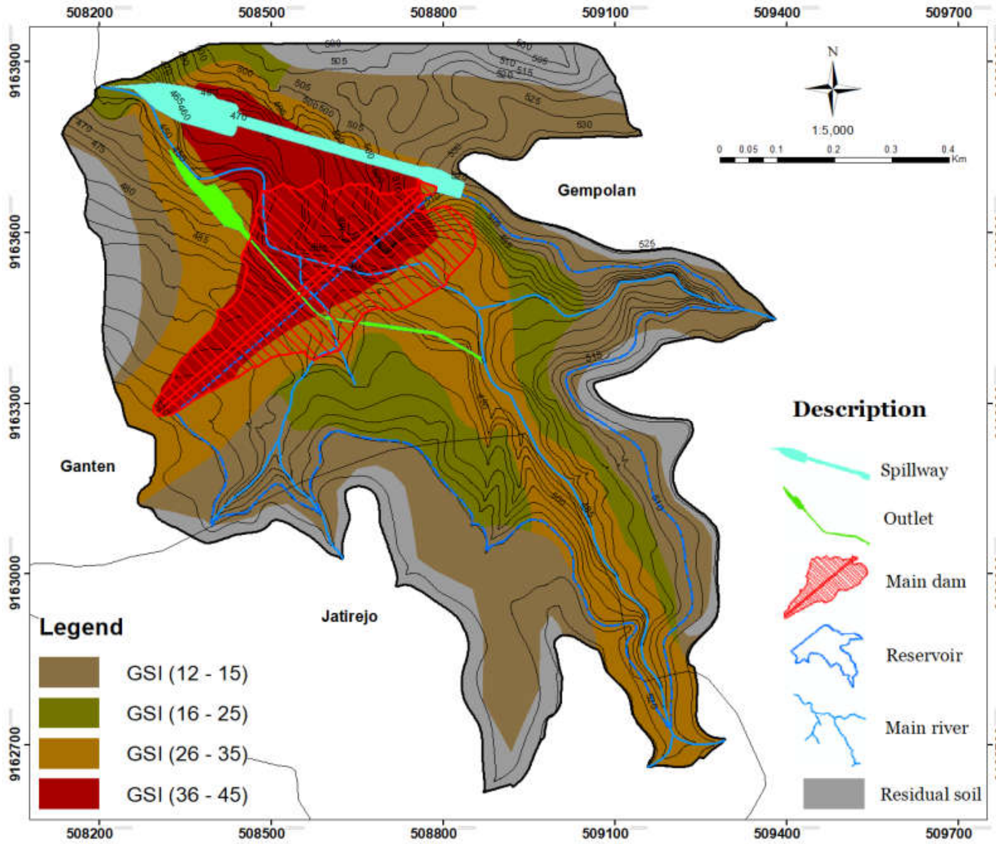

Figure 4: GSI zones in the research area.

Table 1: Engineering characteristics of the rock masses.

Rock mass	Engineering characteristics
Disintegrated rock pieces with very poor surface quality (GSI: 10 – 15)	Andesite breccia had intact rock strength (Is_{50}): 0.08 MPa, w: 44.08 %, γ_d: 10.70 kN/m^3, G_s: 2.71.
Disintegrated rock pieces with poor surface quality (GSI: 16 – 25)	• Andesite breccia had intact rock strength (Is_{50}): 0.134 MPa, w: 28.92 %, γ_d: 13.03 kN/m^3, G_s: 2.64. • Andesite tuff breccia had intact rock strength (Is_{50}): 0.07 MPa, w: 32.13 %, γ_d: 10.85 kN/m^3, G_s: 2.65.
Disintegrated rock pieces with poor surface quality (GSI: 26 – 35)	• Andesite breccia had intact rock strength (Is_{50}): 0.086 MPa, w: 43.84 %, γ_d: 10.83 kN/m^3, G_s: 2.63. • Andesite tuff breccia had intact rock strength (Is_{50}): 0.11–0.43 MPa, w: 6.65–20.76 %, γ_d: 15.11–20.90 kN/m^3, G_s: 2.57–2.77.
Disintegrated rock pieces with fair surface quality (GSI: 36 – 45)	• Andesite breccia had intact rock strength (Is_{50}): 0.37 MPa, w: 17.24 %, γ_d: 13.21 kN/m^3, G_s: 2.69, n: 55.78 %, e: 1.22, S: 36.89 %. • Andesite tuff breccia had intact rock strength (Is_{50}): 0.098–0.177 MPa, w: 2.75–17.98 %, γ_d: 15.93–23.49 kN/m^3, G_s: 2.60–2.70.

Note: w = water content, γ_d = dry unit weight, G_s = specific gravity, Is_{50} = point load strength.

i.e., very poor rock mass quality (RMR 17–20) had less than 40° safe cut slope angle and bearing capacity ranged from 30 to 45 T/m^2; poor rock mass quality (RMR 21–40) had a maximum of 45° safe cut slope angle and bearing capacity ranged from 45 to 135 T/m^2; and fair rock mass quality (RMR 41–50) had a maximum of 55° safe cut slope angle and bearing capacity ranged from 135 to 280 T/m^2. The criteria for safe cut slope and allowable bearing capacity of rock masses in the research area are summarized in Table 2, while the zones of safe cut slope and allowable bearing capacity of rock masses are shown in Figure 6.

Natural slopes at the right (east) side of the dam reservoir had poor to very poor rock mass quality and relatively steep inclinations ranged from 35º to 55º (Figure 4). Two of three landslides identified during the field are shown in Figure 6, where the locations of those landslides are shown in Figure 5. The landslides likely occurred due to the natural slopes having greater than 45º angle, while they should have a 40º safe cut slope determined from the rock mass quality analysis. In term of bearing capacity, the embankment dam was designed to be constructed on the fair quality of foundation rock having allowable bearing pressure ranged from 135 to 280 T/m^2.

4 CONCLUSION AND RECOMMENDATION

The rock mass characterization results indicated that the research area consisted of moderately to completely weathered and very weak to weak andesite breccia and andesite tuff breccia. The andesite breccia had very poor to fair rock mass quality, while the andesite tuff breccia had poor to fair rock mass quality. The research area was divided into three zones of safe cut slope and allowable bearing capacity. Three landslides occurred at natural slopes having poor to very poor rock mass quality and inclinations greater than the determined safe cut slopes. The foundation rock of the embankment dam had fair rock mass quality and 135–280 T/m^2 allowable bearing capacity.

Further studies to determine stability of the embankment dam body constructed on the foundation rock and stability of the reservoir slopes under seismic load are required for dam safety and beyond the scope of this paper.

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Table 2: Criteria for safe cut slope and allowable bearing capacity of rock mass in the research area.

GSI	**12 – 15**	**16 – 25**	**26 – 35**	**36 – 45**
RMR	17 – 20	21 – 30	31 – 40	41 – 50
Rock mass quality	Very poor	Poor		Fair
Safe cut slope (°)	<40	45		55
Bearing capacity (T/m^3)	30 – 45	45 – 135		135 – 280

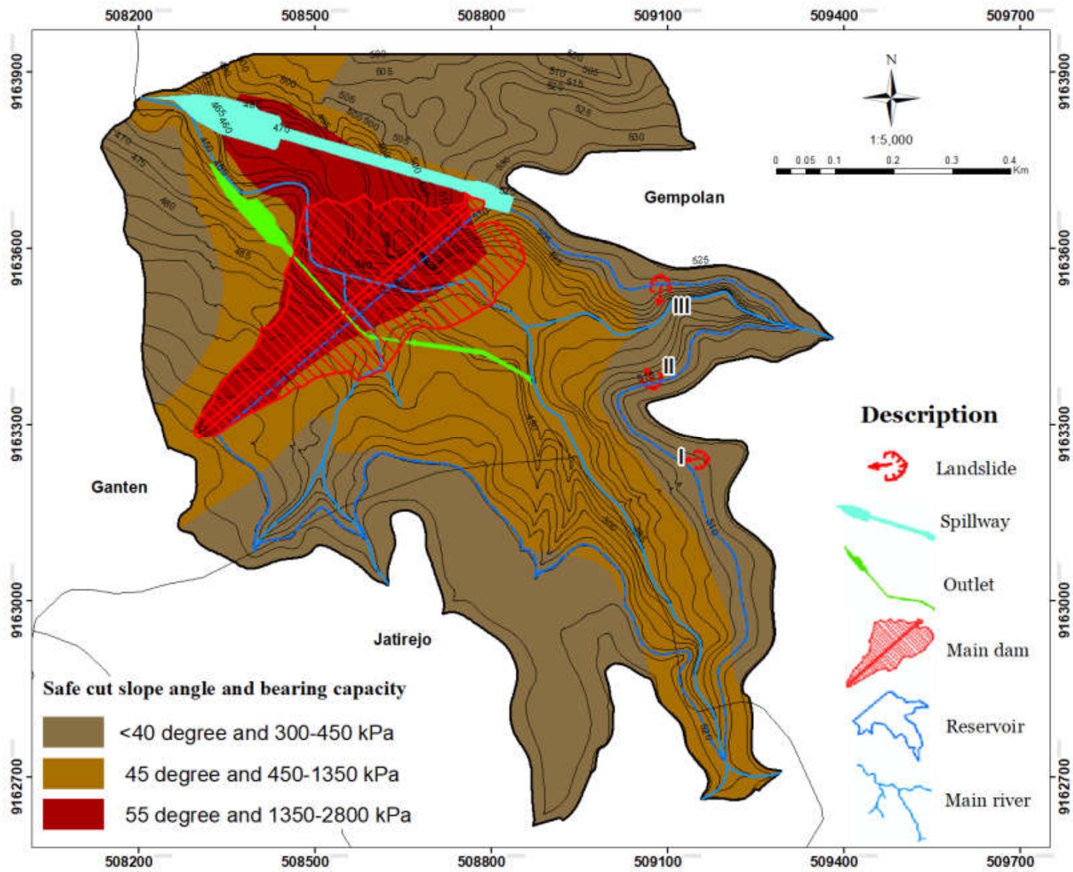

Figure 5: Zones of safe cut slope and allowable bearing capacity of rocks in the research area.

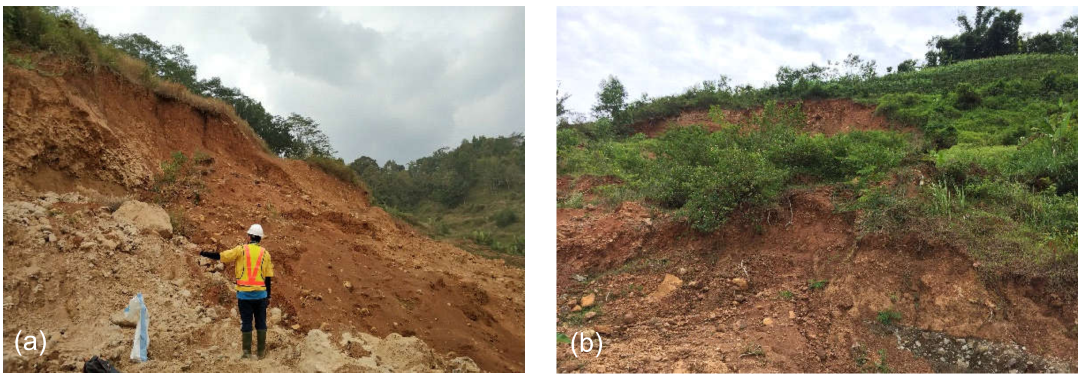

Figure 6: Typical landslides of the natural reservoir slopes: (a) Landslide I and (b) Landslide II. Locations of these landslides are shown in Figure 5.