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Excavation Method of Rock Masses at the Matenggeng Dam, Indonesia

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ABSTRACT. This paper presents the results of engineering geological investigations and determination of rock mass excavation methods in the main dam area of Matenggeng Dam. The study was carried out through engineering geological mapping, core drill evaluation, and supported by laboratory test data. Classifications of rock masses were carried out based on the Geological Strength Index (GSI) and Rock Mass Rating (RMR) to analyze the excavation method. The results showed research area consisted of lithology in the form of andesite, intercalation sandstone - gravelly sandstone unit, intercalation sandstone - siltstone unit, and alluvium deposits. However, the main dam area consists of lithology in the form of intercalation sandstone-siltstone unit and intercalation sandstone-gravelly sandstone unit. The rock masses at the main dam excavation line have a weathering degree from moderately to completely weathered. Intact rocks have Uniaxial Compressive Strength (UCS) values ranging from 1-50 Mpa and are a category of extremely weak to moderate rocks. The rock mass of intercalation sandstone-siltstone with very poor to poor quality (GSI (0 - 58), RMR (8 - 45)), and intercalation sandstone-gravelly sandstone with poor to fair quality (GSI (20 - 59), RMR (20 - 68)). The recommended rock excavation method based on the EXCASS System is diggir, easy ripper, and hard ripper.

Keywords: Matenggeng Dam · Engineering geology · Rock mass classification · Excavation methods.

1 INTRODUCTION

Dam construction is an effort conducted by the Government of Indonesia in improving food security, water security, energy security, and other resilience. Dam infrastructure development needs to be built and developed because it has multipurpose benefits. Matenggeng Dam is one of the dams developed by the Ministry of Public Works and Public Housing, the Directorate General of Water Resources, through The River Basin Organization for Citanduy, in the context of developing the potential of water resources in the Citanduy River Basin. The proposed Matenggeng Dam is located on the Cijolang River, a tributary of the Citanduy River, upstream of the Bantarheulang Dam, in Matenggeng Village, Dayeuh Luhur District, Cilacap Regency, Central Java Province. The right side of the proposed Matenggeng dam is in Ciamis Regency, West Java Province, while the left side is in Cilacap Regency, Central Java Province.

Engineering geological investigations aim to understand the relationship between geological conditions and engineering works, and to provide engineering recommendations for construction projects (Dearman, 1991). One of the applications is determining the rock mass excavation methods that are necessary to consider the existing rock conditions to maintain safety and cost efficiency during the implementation of dam construction. This research uses two rock mass classifications, namely Rock Mass Rating (RMR) by Bieniawski (1989) which is

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used for zone characterisation and Geological Strength Index (GSI) by Hoek *et al.* (2013) to determine the excavation method. Several researchers, such as Wiyasri *et al.* (2022), Arianto *et al.* (2023), and Putera *et al.* (2021), have used this rock mass classification. The determination of the excavation method was carried out using the EXCASS System by Dagdelenler *et al.* (2020) which considers two main parameters, namely Geological Strength Index (GSI) and point load index (Is_{50}). The EXCASS System has been used by several researchers, such as Wisnuaji *et al.* (2023) and Harwinda *et al.* (2022).

Engineering geological investigations have been carried out as part of the design of the Matenggeng Dam (located at Figure 1) by PT. Intimulya Multikencana (2023) and Firdausi (2023) so that the excavation method and buffer system in the tunnel can be determined empirically. Although there has been previous research on engineering geology at the Matenggeng Dam site, there has been no research specifically on engineering geology conditions and rock excavation methods in the main dam area. This research was carried out during the design phase, and no excavation has yet taken place, particularly in the main dam support area. Therefore, this study is expected to provide input and recommendations for the implementation of the Matenggeng Dam construction.

2 METHODOLOGY

2.1 Sample collections and field parameters

The data used in this research consisted of engineering geological mapping, core drills, and laboratory results from subsurface samples. The analysis of rock mass quality at the research site used subsurface data from the results of drilling carried out as many as nine boreholes, namely BMA-1 with a depth of 100 m, BMA-2 with a depth of 150 m, BMA-3 with a depth of 100 m, BMA-4 with a depth 120 m, BMA-5 with a depth 150 m, BMA-6 with a depth 100 m, BMA-7 with a depth 100 m, BMA-8 with a depth 150 m, and BMA-9 with a depth of 100 m as shown on Figure 2. Laboratory testing is carried out directly from drilling results according to the lithology and weathering degree of the rock (ISRM, 1978). Tests were conducted in the form of rock index properties and rock uniaxial compressive strength (UCS) (ASTM D5731-16, 2016). This test is carried out to obtain the parameters used to determine engineering geological characteristics based on Rock Mass Rating (RMR) and Geological Strength Index (GSI).

2.2 Rock mass classification systems

Rock Mass Rating (RMR)

Rock mass rating (RMR) is an engineering classification of rock mass often used for practical purpose in the engineering works (Bieniawski, 1989). Rock mass rating (RMR) has six parameters used for classifying the rock mass, namely 1) uniaxial compressive strength (UCS); 2) rock quality designation (RQD); 3) spacing of discontinuity; 4) condition of discontinuity; 5) conditions of groundwater; and 6) orientation of discontinuity. This parameter can be used to obtain the rock mass quality units of each lithology units at the research location.

Geological Strength Index (GSI)

The Geological Strength Index (GSI) is a suitable method for determining rock mass quality in bad conditions with a high weathering degree. According to Marinos and Hoek (2000), the Geological Strength Index (GSI) can be determined directly from the outcrop covering two main parameters, namely the condition of the structure (structure) and the condition of its surface (surface condition). In this research, the GSI value was determined based on subsurface data from the results of drilling carried out at the tunnel location. Calculation of subsurface GSI, according to Hoek *et al.* (2013), can be determined using the relationship between Joint Condition and the value of Rock Quality Designation (RQD). The subsurface GSI value can be calculated using the following equation:

$$\mathrm{GSI} = 1.5\mathrm{JCond89} + \mathrm{RQD}/2 \qquad (1)$$

2.3 Rock mass excavation methods

In this research, the rock mass excavation method uses the excavation assessment (EXCASS) System developed by Dagdelenler *et al.* (2020). This method considers two main parameters geological strength index (GSI) and point load index (Is_{50}). These two components

FIGURE 1. Location of Matenggeng Dam.

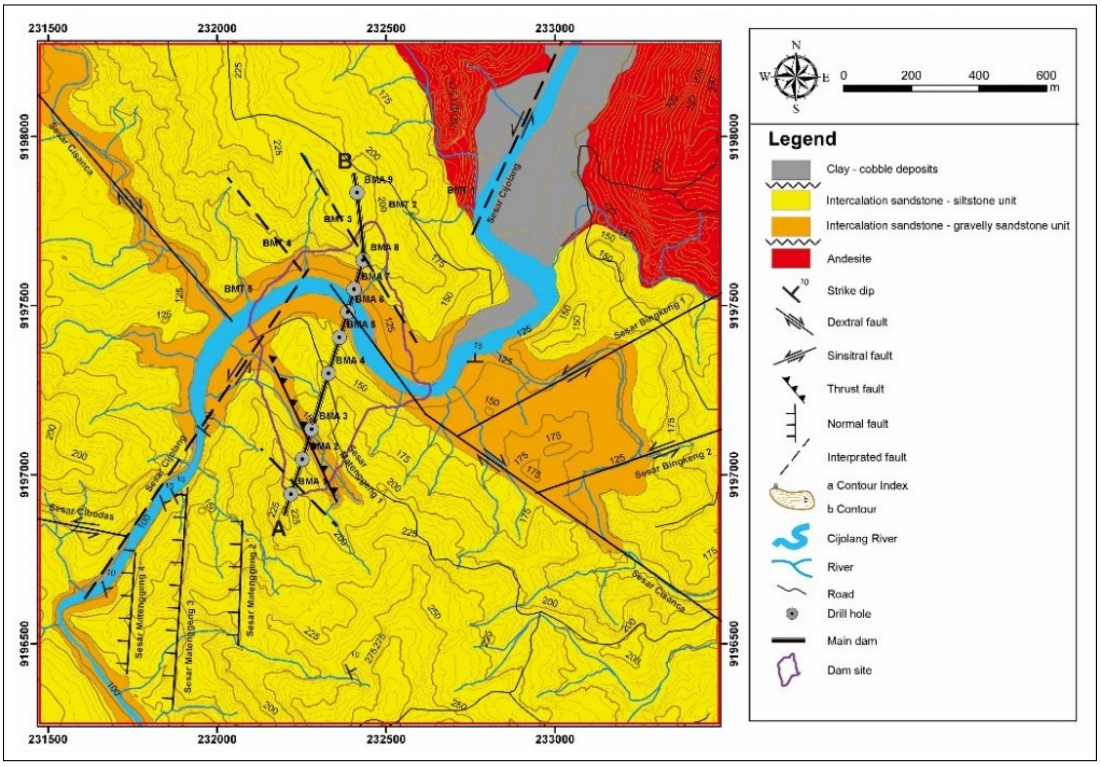

FIGURE 2. Geological map of the research area.

are used to calculate the excavation power index (EPI) and excavation performance rating (EPR) parameters. The EPI is a value to determine the relative strength associated with the excavation method, while the EPR is the deviation from the optimum value of the EPI which ranges from 0 - 100 and is either positive or negative. EPR is a value to determine the ease or difficulty of the excavation method. The classification of excavation methods based on the EPI value, the $\mathrm{EPI}_{\mathrm{opt}}$ or excavation power index optimum is the most optimum value of EPI that occurs when the EPR value is equal to zero. This value is the recommended value for excavation as it is more effective and cost efficient. efficient in terms of cost. To determine the EPIopt value, you can use the following equation:

$$\mathrm{EPI}_{\mathrm{opt}} = 0.77\left(\mathrm{GSI}^2 \times \sqrt{\mathrm{Is}_{50}}\right)^{0.52} \quad (2)$$

3 RESULTS AND DISCUSSION

3.1 Geological condition

Based on the Regional Geological Map of Majenang Sheet (Kastowo and Suwarna, 1996), the research area is covered by three rock formations, namely igneous rock unit (Tm(ab)), Tapak formation (Tpt), and alluvium sediment unit. Geological mapping at a scale of 1:10,000 shows that this area is composed of 4 units, namely andesite, intercalation sandstone – gravelly sandstone unit, intercalation sandstone – siltstone unit, and alluvium deposits as shown in Figure 2. Furthermore, the cross section of the main dam is only composed of intercalation sandstone - gravelly sandstone and intercalation sandstone – siltstone units as shown in Figure 3.

3.2 Lithological characteristics

a. Andesite

This unit is the oldest unit exposed in the research area. The distribution of this unit is on the hills of the northeast side of the research area. The lithology of this unit is found in the form of andesite lava and autoclatic breccia with andesite fragments. This unit has a distribution area of 8.13% of the entire research area. The andesite lithology in the research area is divided into 3 degrees of rock weathering, namely highly weathered, moderately weathered, and slightly weathered.

The field appearance of andesite lava lithology is shown in Figure 4, megascopically greyish black in fresh condition and greyish brown in weathered condition, massive rock structure, interlocking mineral relationships, hypocrystalline crystallinity texture, crystal size <0.1 mm - 2 mm or porphyro-afanitic. This unit has mineral composition of plagioclase, quartz, opaque minerals, pyroxene, and glass materials. Based on its composition, the field name of the rock is andesite.

Based on the description of the andesite petrographic thin section has a phenocryst crystal size of 0.5–2 mm and a ground mass of <0.01 mm, a texture based on crystallinity are hypocrystalline, a texture based on crystal size are fine-medium, a texture based on crystal shape are hypidiomorphic, a texture based on granularity are porphyro-aphanitic, and a special trachytic texture indicating lava flow products. Phenocryst composition: plagioclase (30%), clinopyroxene (10%), orthopyroxene (8%), opaque minerals (5%), hornblenda (4%), and quartz (1%), while the base mass is composed of glass materials (42%) plagioclase microlites (42%). With the petrographic name of Andesite (Streckeisen, 1978).

The field appearance of autolastic breccia lithology is shown in Figure 5, megascopically greyish black, fragmental rock structure, with gravel - boulder size andesite fragments and matrix in the form of andesite material, crystals on the fragments have hypocrystalline crystallinity texture, crystal size 0.5 mm - 2 mm or porphyro-afanitic.

Based on the description of the petrographic thin section of autoclastic breccia fragments, this section has a phenocryst crystal size of 0.5 mm - 2 mm and a ground mass of <0.01 mm, texture based on crystallinity is hypocrystalline, texture based on crystal size is fine-medium, texture based on crystal shape is hypidiomorphic, texture based on granularity is porphyro-aphanitic. Phenocryst composition: plagioclase (25%), clinopyroxene (15%), opaque minerals (5%), hornblenda (10%), and quartz (10%), while the base mass is composed of gelation material (15%) and plagioclase microlites (25%). With a petrographic name of Andesite (Streckeisen, 1978).

b. Intercalation sandstone – gravelly sandstone unit.

This unit overlaps unconformity because of the pause of deposition above the andesite unit in the research area. The distribution of this unit is at the base of the left and right hill pedestals of the research area. In this unit, lithology is found in the form of sandstone, gravelly sandstone, and andesite breccia. This unit has a distribution of 13.91% of the entire research area. The intersection sandstone - gravelly sandstone in the research area is divided into 2 degrees of rock weathering, namely moderately weathered and slightly weathered.

The field appearance of sandstone lithology is shown in Figure 6, megascopically whitish grey in fresh condition and brownish grey in weathered condition, massive rock structure, fine - coarse sand grain size, well-sorted, packing and grain shape not observed, composition of sand-size epiclastic material. Based on its composition, the field name of the rock is Sandstone.

Based on the description of the sandstone petrographic thin section, this rock has a grain

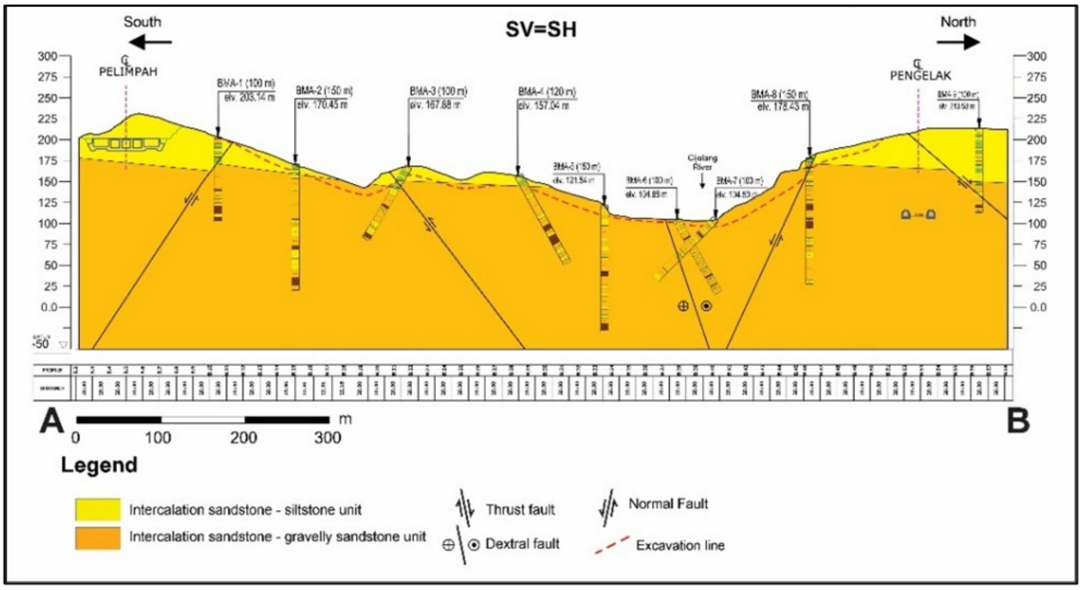

FIGURE 3. Geological cross-section of A–B.

FIGURE 4. Andesite outcrops.

FIGURE 5. Outcrops of autoclastic breccia.

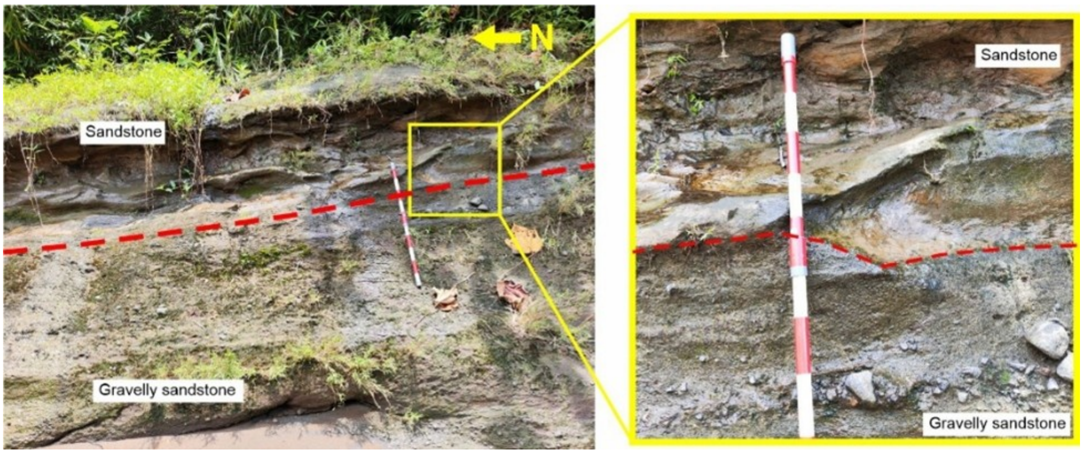

FIGURE 6. Outcrops of intersections sandstone – gravelly sandstone.

size of ¼–1 mm fragments and matrix <1/16 mm, well sorted, subangular-angular grain shape, based on the relationship between grains point contact, fabric matrix supported. Fragment composition: plagioclase (35%), quartz (10%), lithic material (10%), and opaque mineral (7%), matrix: clay-silt material (40%). Based on its composition, the petrographic name of the rock is Feldspathic wacke (Pettijohn, 1975).

The field appearance of the gravelly sandstone lithology in Figure 7, megascopically whitish grey in fresh condition and brownish grey in weathered condition, fragmental rock structure, with granule - pebble size fragments and medium - coarse sand size matrix, poorly sorted, open fabric, matrix supported, and subangular - rounded grain shape. The composition of fragments is lithic andesite and volcanic rocks of granule - pebble size (30%), the matrix is epiclastic material of medium-coarse sand size (70%). Based on its composition, the field name of the rock is gravelly sandstone (Folk, 1980).

Based on the description of the petrographic thin section of the gravelly sandstone matrix, this rock has a grain size of 2–4 mm fragments and 1/16–1 mm matrix, poorly sorted, subangular-angular grain shape, based on intergranular relationships floating mass, matrix supported fabric. Fragment composition: lithic fragments (63%), quartz (3%), and opaque minerals (1%), matrix: silt-sand material (33%). Based on its composition, the petrographic name of the rock is Lithic wacke (Pettijohn, 1975).

The field appearance of andesite breccia lithology is shown in Figure 8, megascopically blackish grey in fresh condition and brownish grey in weathered condition, fragmental rock structure, with pebble - cobble fragments and matrix of medium-coarse sand size, poorly sorted, closed fabric, grain supported, and subangular - rounded grain shape. The composition of the fragments is lithic andesite of pebble – cobble size (85%), the matrix is epiclastic material with a size of medium - coarse sand (15%). Based on its composition, the name of the rock field is Andesite breccia.

c. Intercalation siltstone – sandstone unit

This unit overlies the intercalation sandstone – gravelly sandstone unit at the research area. In this unit, lithologies of sandstone and siltstone are found. This unit has a distribution of 69.78 % of the entire research area. The intersection siltstone - sandstone in the research area is divided into 4 degrees of rock weathering, namely completely weathered, highly weathered, moderately weathered, and slightly weathered.

The field appearance of sandstone lithology is shown in Figure 9, megascopically whitish grey in fresh condition and brownish grey in weathered condition, massive rock structure, fine – coarse sand grain size, well sorted, packing and grain shape not observed, composition of sand-size epiclastic material. Based on its composition, the field name of the rock is Sandstone.

Based on the description of the sandstone petrographic thin section, this rock has a grain

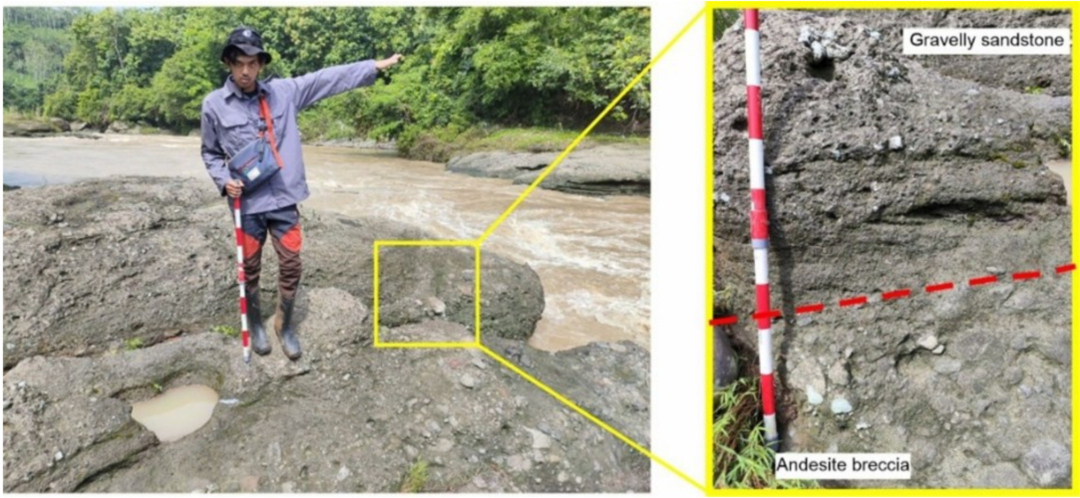

FIGURE 7. Outcrop of gravelly sandstone.

FIGURE 8. Andesite breccia outcrop.

FIGURE 9. Outcrop of intersection siltstone – sandstone.

size of ¼ - 1 mm fragments and matrix <1/16 mm, well sorted, subangular-angular grain shape, based on the relationship between grains point contact, fabric matrix supported. Fragment composition: plagioclase (35%), quartz (10%), lithic material (10%), and opaque mineral (7%), matrix: clay-silt materials (40%). Based on its composition, the petrographic name of the rock is Feldspathic wacke (Pettijohn, 1975).

The field appearance of siltstone lithology is shown in Figure 9, megascopically greenish grey in fresh condition and brownish grey in weathered condition, massive rock structure, silt grain size, well sorted, packing and grain shape not observed, composition of silt-size epiclastic material. Based on its composition, the field name of the rock is Mudstone.

Based on the description of the petrographic thin section of siltstone, this rock has a grain size of 1/64 - 1/16 mm fragments and matrix <1/64 mm, well sorted, subangular-angular grain shape, based on the relationship between grains point contact, fabric matrix supported. Fragment composition: plagioclase (8%), quartz (5%), lithic material (4%), and opaque minerals (8%), matrix: clay material (75%). Based on its composition, the petrographic name of the rock is Mudrock (Pettijohn, 1975).

d. Clay to cobble deposits.

This unit is a deposit that is not aligned above the intercalation sandstone – gravelly sandstone unit and intercalation siltstone - sandstone unit at the research area. The naming of this unit is done based on the domination of lithology, which is in the form of clay to cobble-size river deposits. The distribution of this unit is along the Cijolang River with a distribution area of 8.18% of the entire research area. The field appearance of the clay – cobble deposit is shown in Figure 10, megascopically grey and brown in colour, with weak cementation and unconsolidated. Grain size <0.1 – >64 mm, poorly sorted, with a composition of clay to cobble-size river material.

FIGURE 10. Outcrops of clay – cobble deposits.

3.3 Geological Structures

Geological structures that develop in the research area are extension joints, dextral faults, sinistral faults, thrust faults, normal faults, and some faults are estimated. Extension faults in the research area have a relative direction orientation of NE–SW and based on the analysis of the main force direction acting on the research area is ENE–WSW (Figure 11). The dextral fault has a relative direction of NW–SE which is in line with the alignment pattern of the Citanduy Fault (Haryanto, 1995 in (Hilmi & Haryanto, 2008)). The sinistral fault has a relative direction orientation of NE–SE which is in line with the pattern of the Cijolang River flow direction and is included in the estimated fault according to (Kastowo & Suwarna, 1996). Meanwhile, the NW–SE thrust fault and the N–S normal fault are interpreted as minor faults resulting from the shift of the shear fault found in the study area. The existence of geological structures is one of the parameters that greatly affect the geological engineering conditions in the study area. This is indicated by the fact that the closer the fault zone is, the quality of the rock mass will be poorer because the degree of weathering of the rock will be higher, and the intensity of the discontinuities will be greater.

3.4 Classification of rock mass quality

Determination of rock mass quality was only carried out on rock core samples at 9 drill holes located in the main dam cross section. The determination of mass quality refers to the Rock Mass Rating (RMR) classification according to Bieniawski (1989) and the Geological Strength Index (GSI) according to Hoek *et al.* (2013). Based on the RMR classification, the surface

TABLE 1. Engineering geological characteristics of the rock mass at the research area.

Weathering Degree Unit	Engineering Characteristics
Highly weathered andesite	Water content 13.21%, dry density 1.11 g/cm^3, specific gravity 2.11 g/cm^3, UCS 28.38 MPa and (Is_{50}) 1.18 MPa
Moderately weathered andesite	Water content 15.39%, dry density 1.33 g/cm^3, specific gravity 2.32 g/cm^3, UCS 38.19 MPa and (Is_{50}) 1.59 MPa
Slightly weathered andesite	Water content 21.63%, dry density 1.34 g/cm^3, specific gravity 2.36 g/cm^3, UCS 38.35 MPa and (Is_{50}) 1.60 MPa
Moderately weathered of intercalation sandstone - gravelly sandstone unit	Water content 13.08 - 21.04%, dry density 1.14 - 1.42 g/cm^3, specific gravity 2.39 - 2.56 g/cm^3, UCS 28.38 - 37.0 MPa and (Is_{50}) 1.18 - 1.54 MPa
Slightly weathered of intercalation sandstone - gravelly sandstone unit	Water content 12.46 - 13.55%, dry density 1.19 - 1.68 g/cm^3, specific gravity 2.36 - 2.79 g/cm^3, UCS 30.59 MPa and (Is_{50}) 1.27 MPa
Completely weathered of intercalation siltstone - sandstone unit	Water content 17.27 - 17.35%, dry density 1.28 - 2.04 g/cm^3, specific gravity 2.12 - 3.92 g/cm^3, UCS 0 MPa and (Is_{50}) 0 MPa
Highly weathered of intercalation siltstone - sandstone unit	Water content 9.09 - 18.49%, dry density 0.88 - 1.14 g/cm^3, specific gravity 1.44 - 2.56 g/cm^3, UCS 19.41 MPa and (Is_{50}) 0.81 MPa
Moderately weathered of intercalation siltstone - sandstone unit	Water content 14.19 - 21.04%, dry density 1.02 - 1.14 g/cm^3, specific gravity 1.85 - 2.39 g/cm^3, UCS 31.85 - 34.69 MPa and (Is_{50}) 1.33 - 1.44 MPa
Slightly weathered of intercalation siltstone - sandstone unit	Water content 13.21%, dry density 1.11 g/cm^3, specific gravity 2.11 g/cm^3, UCS 43.46 MPa and (Is_{50}) 1.81 MPa

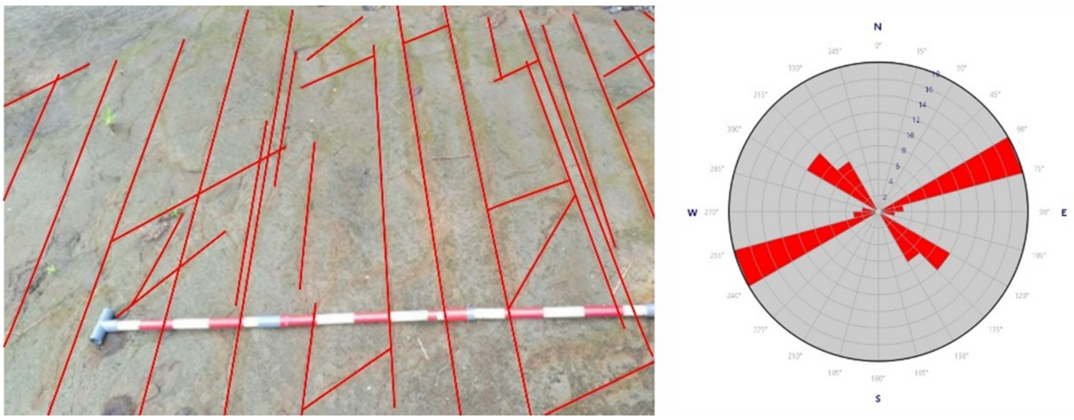

FIGURE 11. Typical extension joints in the research area and the rose diagram.

rocks in the study area can be divided into 4 classes, namely very poor rock mass quality (0-20), poor rock mass quality (21–40), medium rock mass quality (41–60), and good rock mass quality (61-80) as can be shown in the cross section of RMR rock mass quality in the main dam (Figure 12).

a. Very poor quality of intercalation siltstone - sandstone unit

This unit has a weathering degree of completely weathered - residual soil (level V–VI) with rock strength <1 MPa and the condition of the rock mass cannot be described, so that it has an RMR value <20 which is included in very poor quality. Based on the value of 1.5 $Jcond89 + RQD/2$, this unit has a GSI value <20.

b. Poor quality of intercalation siltstone - sandstone unit

This unit has moderately - highly weathered (level III-IV) with rock strength 1 - 25 MPa, RQD 10 - 60%, discontinuity spacing <0.06 - 0.2 m, discontinuity condition (persistence 1 - 3 m, aperture 1 - 5 mm, slickenside - slightly rough, gouge none, weathering moderately - slightly waethered), damp - dripping groundwater condition, unfavorable - favorable discontinuity orientation so that it has RMR value 21 - 40 which is included in poor quality. Based

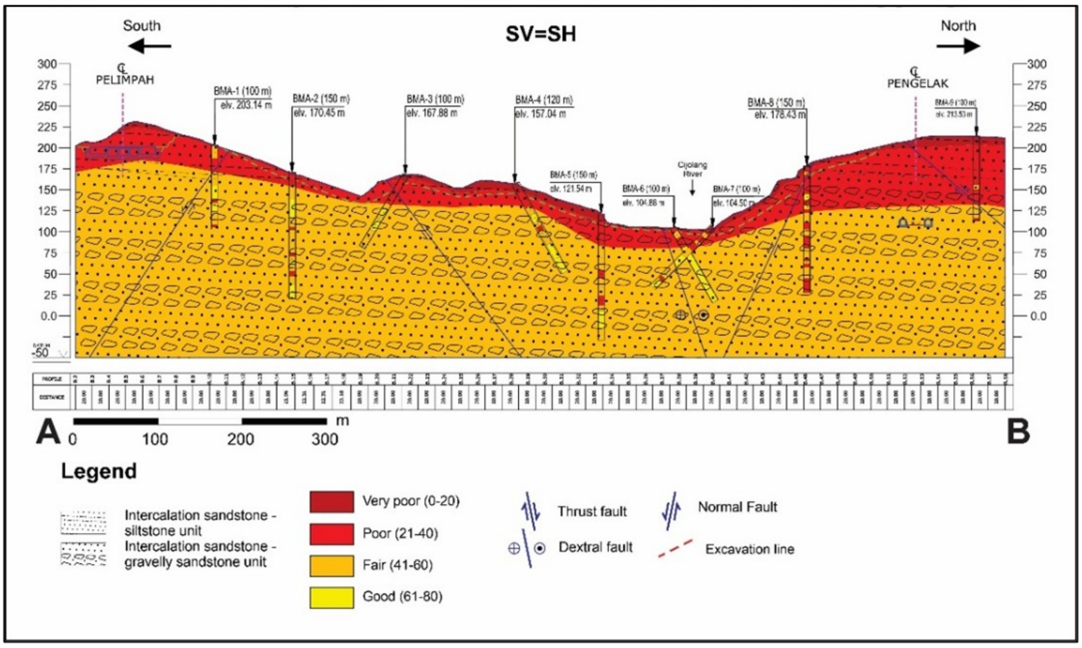

FIGURE 12. The rock mass quality cross-section of A – B.

on the value of 1.5 $Jcond89 + RQD/2$, this unit has a GSI value of 30 - 65.

c. Poor quality of intercalation sandstone - gravelly sandstone unit

This unit has slightly - highly weathered (level II-IV) with rock strength 1 - 50 MPa, RQD 40 - 60%, discontinuity spacing 0.06 - 0.6 m, discontinuity condition (persistence 1 - 3 m, aperture 1 - 5 mm, slightly - very rough, gouge hard filling <5 mm - none, weathering slightly waethered), dripping groundwater condition, unfavorable - fair discontinuity orientation so that it has RMR value 21 - 40 which is included in poor quality. Based on the value of 1.5 $Jcond89 + RQD/2$, this unit has a GSI value of 25 - 65.

d. Fair quality of intercalation siltstone - sandstone unit

This unit has a moderately - highly weathered weathering level (level III-IV) with rock strength 1 - 25 MPa, RQD 20 - 80%, discontinuity spacing <0.06 - 0.6 m, discontinuity condition (persistence 1 - 3 m, aperture 0.1 - 5 mm, slickenside -rough, gouge none, weathering moderately - slightly waethered), groundwater condition dripping - damp, discontinuity orientation favorable - very favorable so that it has RMR value 41 - 60 which is included in medium quality. Based on the value of 1.5 $Jcond89 + RQD/2$, this unit has a GSI value of 40 - 70.

e. Fair quality of intercalation sandstone - gravelly sandstone unit

This unit has slightly – moderately weathered (level II-III) with rock strength 5 - 50 MPa, RQD 60 - 85%, discontinuity spacing 0.06 - 0.6 m, discontinuity condition (persistence 1 - 3 m, aperture 0.1 - 5 mm, smooth - very rough, gouge none, weathering moderately - slightly waethered), groundwater condition dripping - damp, discontinuity orientation favorable - very favorable so that it has RMR value 41 - 60 which is included in medium quality. Based on the value of 1.5 $Jcond89 + RQD/2$, this unit has a GSI value of 55 - 75.

f. Good quality of intercalation sandstone - gravelly sandstone unit

This unit has a slightly weathered (level II) with rock strength 25 - 50 MPa, RQD 75 - 100%, discontinuity spacing 0.6 - 2 m, discontinuity condition (persistence 1 - 3 m, aperture 0.1 - 1 mm, slightly - very rough, gouge none, weathering slightly waethered), groundwater condition dripping - damp, discontinuity orientation very favorable so that it has an RMR value of 61 - 80 which is included in good quality. Based on the value of 1.5 $Jcond89 + RQD/2$, this unit has a GSI value of 70 - 88.

Based on the results of the engineering geological investigation, it has been determined that the quality of rock mass in the research area is greatly influenced by the presence of geological structures and the degree of rock weathering. When rocks get closer to geological structures and the surface, the degree of rock weathering gets higher, so the quality of the rock mass also becomes higher. The results of the research also show some differences in rock mass quality by Firdausi (2023). This is due to differences in the scope and direction of the cross-sections created in this research. The cross-sections in this research pass through more geological structures in the study area, resulting in more varied rock mass quality.

3.5 Rock mass excavation method

The determination of the rock mass excavation method was carried out in the dam site that is above the excavation line on the cross section of the dam. The determination of the excavation method is based on the point load index for each degree of rock weathering and the GSI value. Table 2 and Figure 13 show the results of determining the rock mass excavation method using the EXCASS System in the excavation zone of the dam site area.

The recommended rock mass excavation method used in the excavation zone of the dam site area with each EPIopt value. The above excavation method determination is the most efficient method for excavation. However, when the EPIopt value is close to the excavation method classification limit, the method above or below can still be used if it is within the range of the EPR value with the consequence that the excavation effectiveness will be reduced.

4 Conclusion

The research area consisted of lithology in the form of andesite, intercalation sandstone - gravelly sandstone unit, intercalation sandstone - siltstone unit, and alluvium deposits. However, the main dam area consists of lithology in the form of intercalation sandstone-siltstone unit and intercalation sandstone-gravelly sandstone unit. The rock masses at the main dam excavation line have a weathering degree from moderately to completely weathered. Intact rocks have Uniaxial Compressive Strength (UCS) values ranging from 1-50 MPa and are a category of extremely weak to moderate rocks. The rock mass of intercalation sandstone - siltstone with very poor to poor quality (GSI (0 - 58), RMR (8 - 45)), and intercalation sandstone - gravelly sandstone with poor to fair quality (GSI (20 - 59), RMR (20 - 68)). The recommended rock excavation method based on the EXCASS System is diggir, easy ripper, and hard ripper.

References

Arianto, B., Budi Indrawan, I.G., & Warmada, I.W. (2023). Multi-Rock Mass Classification Systems for the Assessment of Excavation Method and Support Design of Spillway Tunnel, Sidan Dam, Bali, Indonesia: E3S Web of Conferences, v. 468, p. 1–7, doi: 10.1051/e3sconf/202346802004.

ASTM (American Society for Testing and Material) D5731−16 (2016). Standard Test Method for Determination of the Point Load Strength Index of Rock and Application to Rock Strength Classifications: Annual Book of ASTM Standards, v. 22, p. 1–11, doi: 10.1520/D5731-16.methods.

Bieniawski, Z.T. (1989). Engineering rock mass classifications: Canada, John Wiley dan Sons, Inc, 251 p.

Dagdelenler, G., Sonmez, H., & Saroglou, C. (2020). A flexible system for selection of rock mass excavation method: Bulletin of Engineering Geology and the Environment, v. 79, p. 5355–5369, doi: 10.1007/s10064-020-01877-w.

Dearman, W.R. (1991). Engineering geological mapping: Oxford, Butterworth-Heinemann Ltd, doi:10.1007/BF02634605.

Firdausi, A.A. (2023). Analisis Sebaran Litologi, Struktur Geologi, dan Kualitas Massa Batuan dengan Data LiDAR di Area Terowongan Bendungan Matenggeng [Thesis]: Yogyakarta, Universitas Gadjah Mada, 159 p.

Harwinda, Z.B., Wilopo, W., & Indrawan, I.G.B. (2022). Excavatability Method Based on Engineering Geology Conditions in the Construction of Rukoh Dam Suppletion Tunnel, Indonesia: 7th International Conference on Sustainable Built Environment, v. 4, p. 260–271, doi: 10.20885/icsbe.vol4.art25.

Hilmi, F. & Haryanto, I. (2008). Pola Struktur Regional Jawa Barat: Bulletin of Scientific Contribution, v. 6, p. 57–66.

Hoek, E., Carter, T.G., & Diederichs, M.S. (2013). Quantification of the geological strength index chart, in 47th US Rock Mechanics / Geomechanics Symposium 2013, v. 3, p. 1757–1764.

ISRM (1978). Suggested methods for the quantitative description of discontinuities in rock masses: International Journal of Rock Mechanics and Min-

TABLE 2. The calculating excavation method based on EXCASS System in the excavation zone of the dam site.

Lithology	Weathering degree	RMR	GSI	Is_{50}	$GSI^2 \times \sqrt{Is_{50}}$	EPI_{opt}	Excavation Method
Residual soil and clay – cobble deposits	-	Very poor	0	0	0.00	0.00	Digger
Sandstone - siltstone	Completely weathered	Very poor	0	0	0.00	0.00	Digger
Sandstone	Highly weathered	Poor	28	0.81	705.60	23.32	Easy Ripper
Sandstone	Moderately weathered	Poor	36	1.38	1522.46	34.79	Easy Ripper
Siltstone	Highly weathered	Poor	26	0.81	608.40	21.59	Easy Ripper
Gravelly sandstone	Moderately weathered	Poor	43	1.18	2008.53	40.18	Easy Ripper
Gravelly sandstone	Moderately weathered	Fair	55	1.18	3285.99	51.90	Hard Ripper
Gravelly sandstone	Slightly weathered	Fair	55	1.27	3409.00	52.90	Hard Ripper

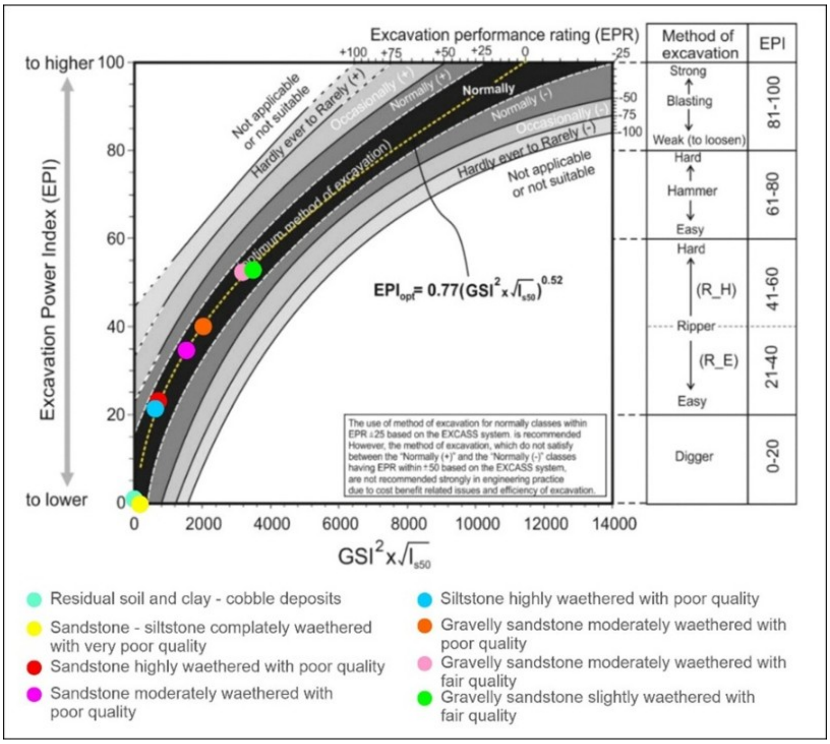

FIGURE 13. Results of rock mass plotting in the excavation zone of the dam site area.

ing Sciences & Geomechanics Abstracts, v. 15, p. 319–368.

Kastowo, N. & Suwarna (1996). Peta Geologi Lembar Majenang, Jawa: Bandung, Pusat Penelitian dan Pengembagan Geologi, 1:100.000, 1p.

Marinos, P. & Hoek, E. (2000). GSI: A geologically friendly tool for rock mass strength estimation, in Proceedings of the GeoEng 2000 at the International Conference on Geotechnical and Geological Engineering, Melbourne, p. 1422–1446.

Pettijohn, F.J. (1975). Sedimentary Rocks: New York, Harper and Row Limited.

Putera, D.A., Hendrayana, H., & Indrawan, I.G.B. (2021). Engineering Geological Characteristics Based on Rock Mass Rating (RMR) and Geological Strength Index (GSI) in Jlantah Dam Intake Tunnel, Karanganyar District, Central Java Province: E3S Web of Conferences, v. 325, p. 08003, doi: 10.1051/e3sconf/202132508003.

Streckeisen, A.L. (1978). Classification and nomenclature of volcanic rocks, lamprophyres, carbonatites, and melilitic rocks: Neues Jahrbuch für Mineralogie Abhandlungen, v. 134, p. 1–14.

Wisnuaji, H., Setiawan, H., & Setiawan, N.I. (2023). EXCASS system and Rock Mass Rating (RMR) classification for determining excavation method and tunnel support at Pelosika Dam Spillway Tunnel: IOP Conference Series: Earth and Environmental Science, p. 1–11, doi: 10.1088/1755-1315/1233/1/012008.

Wiyasri, Y., Titisari, A.D., Dita, S.P., & Indrawan, I.G.B. (2022). Engineering Geology of Diversion Tunnel Area at the Meninting Dam Construction, West Lombok, Province of West Nusa Tenggara, Indonesia: Journal of Applied Geology, v. 7, p. 11–24, doi: 10.22146/jag.57293.