Recommendations of excavation and support systems of Pamukkulu Dam diversion tunnel based on correlation of rock mass classification between RMR and GSI

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Abstract. This paper presents the results of geological engineering research conducted to determine the character of rock masses, recommendations of tunnel excavation method and support system based on stand-up time estimates in unsupported conditions. The investigation was conducted by observing rock mass quality based on the newest bore log sample test results in 2019 using Rock Mass Rating (RMR) and Geological Strength Index (GSI) rock mass classification. The results showed that area consist of lithology in the form of porphyryc lava basalt and pyroclastic volcanic breccia. Rock mass has a slightly weathering alteration rates. Intact rocks have Uniaxial Compressive Strength (UCS) values ranging from 100-250 Mpa to >250 Mpa and are a category of strong rocks. Rock mass has fair to good rock quality class III-II based on RMR values between 53-69, GSI values between 48-64. The roof span required is obtained from the tunnel planning roof span of 10 meter, with a stand-up time of 70 hours without support system and immediate collapse for 5 days. The recommended excavation methods are excavation by drill and blast on top heading and bench: 1,5-3 meter advance in top heading tunnel face, and then can be recommended support system using rock bolts (20 mm diameter, fully bonded): systematic bolts 4 meter long, spaced 1,5-2 meter in crown and bench with wiremesh in crown then shotcrete: 50-100 mm in crown, and 30 mm in sides, without steel ribs support.

1 Introduction

Geological investigation of subsurface engineering at the site of the diversion tunnel plan using the newest bore log test is carried out to know in detail the type of rock/soil, structure, the strength of rocks, permeability and thickness of the soil layer that will be used as a guideline to determine the design and geometry trace of the tunnel.

Therefore, adequate geological data is needed to support the right methods and stages to be able to reduce the risk of construction failure.

The purpose of the classification of rock mass is to group the types of rock mass based on his behavior, as the basis for understanding the character of each class, provide quantitative data to determine excavations methods and tunnel’s support system.

This research aims to observe and analyze bore log test result to determine the quality of rock mass using Rock Mass Rating (Bienawski, 1989) and Geological Strength Index (Hoek & Brown, 2002) in the Pamukkulu’s Dam diversion tunnel. And then determine the stand-up time of tunnel without support system to provide recommendations on excavation methods and tunnel support systems on tunnel’s rocks that are effectively based on quality profile of rock mass.

Previous studies have been conducted to investigate the quality of rock mass with criepi’s method. High uncertainty in that rock mass classification method requires more analysis of rock quality with other methods namely RMR and GSI, using the latest bore log test data investigation in 2019.

1.1 Location

Pamukkulu Dam is located in Kale Ko’Mara Village, North Polombangkeng District, Takalar Regency, South Sulawesi Province, Indonesia. Diversion tunnel using horseshoe shape with dimensions, diameter 7 meters, 370 meter long section.
2 Geological condition

2.1 Lithology

The research area is located in the southern part of Sulawesi, based on a regional geological map of Lembar Ujungpandang, Bantaeng and Sinjai, Sulawesi (Sukamto and Supriatna, 1982), it appears that the research area was influenced by several lithological formations consisting: Camba Formation (Tmc), Tonasa Formation (Temt), Coastal Alluvium Deposits (Qae) and Baturape Volcano Rocks–Cindako (Tpbv), is shown in Figure 2 below.

Research area dominated by residual soil, slightly weathered basalt lava group, fresh lava-breccia group and tuff lithology group, highly weathered breccia.

2.2 Geological structure

The geological structure in the research area is a fault down with N - S and W-E orientation. Fault is located on the northern part of the main dam, and extends along the coverage area of the dam.

Concerning active faults, the location is approximately 100 km west of the Walanae active fault northwest (NW) – southeast (SE).

3 Methodology

3.1 Rock mass rating (RMR)

The main reason for using the Rock Mass Rating (RMR) classification method is ease and flexibility in a variety of practical purposes in engineering (Bieniawski, 1989). Rock Mass Rating is defined and calibrated based on observations and experiences of use in the excavation civil construction and tunnels design.

This engineering classification system, Bieniawski developed in 1973-1989 utilizes the following six rock parameters, including:

1. Uniaxial Compressive Strength of intact rock material
2. Rock Quality Designation (RQD)
3. Condition of discontinuities, given as:
   - Persistence
   - Separation
   - Roughness
   - Infilling
   - Alteration/Weathering
4. Groundwater conditions
5. Orientation of discontinuities

All of these are measurable in the field and can also be obtained from borehole data. The rating of each of these parameters is summarised to give a value of Rock Mass Rating (RMR). All parameters are measurable in the field and some may also obtain of borehole data.
3.2 Geological strength index (GSI)

GSI was introduced by Hoek (1994) and Hoek, Kaiser and Bawden (1995), can be used to estimating rock mass strength for different geology conditions, but it is less effective for poor or highly weathered rocks.

GSI can estimate the strength and deformation characteristics of rock masses that are required for underground excavation analysis. (Hoek and Brown, 1980).

One of the most important factors in estimating rock mass through GSI is to obtain a Uniaxial Compressive Strength of intact rock material value that describes the level of weathering of rocks. The approximate value of UCS in the field according to Hoek et al. (1998) is seen in Table 5 below.

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Table 5. Field estimates of UCS intact rock pieces (Hoek et al., 1998)
3.3 Correlation between RMR and GSI

Classification of rock mass with the GSI system is a development of the rock mass classification of the RMR system. Hoek and Karzulovic (2000) explained that the mass of rocks with GSI>25 and RMR>23, GSI values can be calculated by the following Equation:

\[
\text{GSI} = \text{RMR}_{89} - 5
\]

The RMR_{89} value is the base of RMR value (Bieniawski, 1989) by providing a value of groundwater with a value weight of 15 (dry conditions) and a joint orientation value with weight of 0 (zero). The equation above should not be used for rock mass with very poor quality or with a GSI value<25.

Table 6. Quality class of rock mass based on a linear correlation between RMR and GSI rating (Hoek and Karzulovic, 2000)

| Rock Mass Classification | Rock Mass Quality |
|--------------------------|-------------------|
| Very Poor RMR <21        | 21-40             |
| Poor RMR 21-40           | 41-60             |
| Fair RMR 41-60           | 61-80             |
| Good RMR 61-80           | 81-100            |
| Very Good RMR >81        |                   |

3.4 Stand-up time

The term stand-up time was first used by Lauffer in Lauffer’s rock mass classification and then further developed by Lauffer for excavation using tunnel boring machines purposes. Stand-up time is defined as the length of time the tunnel can support itself without additional supporting structures.

The stand-up time estimation is very important because it will affect the excavation cycle, the required support structure, and the tunnel excavation method. The stand-up time developed by Lauffer is then correlated with rock mass classification and the most frequently applied in tunnel construction work is the RMR and stand-up time correlation by Bieniawski. The correlation by Bieniawski can be seen in Fig. 6.

3.5 Excavation methods and support system

Based on the lowest RMR value of each borehole point on diversion tunnel use to determine guide for excavation and support system in rock tunnels, provide that the tunnel is horseshoe shaped, roof span width 10 meters, vertical stress below 25 Mpa, using drill and blast methods.

Table 7. RMR classification guide for excavation and support in rock tunnels (Bieniawski, 1989).

4 Result and discussion

In this research has been investigated soil and rocks below the surface of the tunnel site using the following stages of work below:

1. Geological mapping and determination of bore log point location;
2. Conduct core bor tests at predetermined points;
3. Description of rocks, determination of rock mass class and value, using correlation of RMR and GSI methods;
4. Determine how long the roof span tunnel can withstand collapse without the tunnel’s support system [Fig.6];
5. Determine excavation methods and support system in rock tunnels [Table 7].

This study used the correlation between stand-up time and RMR to determine how long the roof span tunnel can withstand collapse without the tunnel’s support system. The RMR value used to correlate with stand-up time is the lowest RMR value of each borehole point due to the correlation between GSI and RMR on the site.
Table 8. Bore log test distribution. (Soil & Rock Investigation, 2020)

| No. | Bore Hole | Depth (m) | Elevation (m spel) | Located   |
|-----|-----------|-----------|--------------------|-----------|
| 1   | BW.02     | 30        | 100.032            | Inlet     |
| 2   | BW.05     | 40        | 110.512            | Plinth & Tunnel |
| 3   | BW.07     | 40        | 105.918            | Outlet    |

Referring to rock mass classification (RMR and GSI) conducted observations on samples of core bore test results with the following results:

Table 9. Lithology description and rock mass rating on BW-02 (Inlet Tunnel)

| From | To    | Disc. | Sep. | Roughs | Infilling | Weather | Total |
|------|-------|-------|------|--------|-----------|---------|-------|
| 0    | 8     | Soil Clay | 65.8 | 0.2-0.6 | 3-10     | Slight R >5 Slight W | Drip Favor |
| 12   | 13    | 10     | 2    | 4      | 3        | 2       | 5     | -2    |
| 16   | 30    | Basalt Porfiri | 75.2 | 0.2-0.6 | 3-10     | Slight R >5 Slight W | Wet Favor |
| 12   | 17    | 10     | 2    | 4      | 3        | 2       | 5     | 7     | -2    |

Table 10. Lithology description and rock mass rating on BW-05 (Plinth & Tunnel)

| From | To    | Disc. | Sep. | Roughs | Infilling | Weather | Total |
|------|-------|-------|------|--------|-----------|---------|-------|
| 0    | 8     | Soil Clay | 66.4 | 0.2-0.6 | 3-10     | Slight R >5 Slight W | Drip Favor |
| 12   | 13    | 10     | 2    | 4      | 3        | 2       | 5     | -2    |
| 25   | 40    | Basalt Porfiri | 82.9 | 0.3-10  | 3-10     | Slight R >5 Slight W | Drip Favor |
| 12   | 17    | 15     | 2    | 4      | 3        | 2       | 5     | -2    |

Table 11. Lithology description and rock mass rating on BW-07 (Outlet Tunnel)

| From | To    | Disc. | Sep. | Roughs | Infilling | Weather | Total |
|------|-------|-------|------|--------|-----------|---------|-------|
| 0    | 15    | Soil Clay | 61   | 0.2-0.6 | 3-10     | Slight R >5 Slight W | Drip Favor |
| 25   | 40    | Basalt Porfiri | 65.2 | 0.2-0.6 | 3-10     | Slight R >5 Slight W | Drip Favor |
| 12   | 17    | 15     | 2    | 4      | 3        | 2       | 5     | -2    |

Source: Calculation

It was found that this area consists of lithology in the form of residual soil (clay and highly weathered sand) and porphyry lava basalt. Generally rock mass has a slightly weathering rate, and RMR value between 53-60 present category of class No.III describe as fair rock [Table 3].

Fig. 8. Stand-up time based on BW.02 point (Inlet Tunnel)

Based on [Fig.8], the lowest RMR value at BW.02 borehole point is correlated using stand-up time chart by Bieniawski. The roof span required is obtained from the tunnel planning roof span of 10 m, which has a stand-up time of 70 hours without rock support system and immediate collapse for 5 days.

Fig. 9. Stand-up time based on BW.05 point (Plinth & Tunnel)

Based on [Fig.9], the lowest RMR value at BW.05 borehole point is correlated using stand-up time chart by Bieniawski. The roof span required is obtained from the tunnel planning roof span of 10 m, which has a stand-up time of 70 hours without rock support system and immediate collapse for 5 days.

Fig. 10. Stand-up time based on BW.07 point (Outlet Tunnel)

Based on [Fig.10], the lowest RMR value at BW.07 borehole point is correlated using stand-up time chart by Bieniawski. The roof span required is obtained from the tunnel planning roof span of 10 m, which has a stand-up time of 70 hours without rock support system and immediate collapse for 5 days.


Intact rock has Uniaxial Compressive Strength (UCS) values ranging from 100-250 Mpa and >250 Mpa and belongs to the category of rocks with very good strength. Geological Strength Index (GSI) rating between 48-64 and Rock Mass Rating (RMR) between 53-69 both presents categories of fair to good rocks class III-II [Table.5].

The average RMR value at every borehole point above is correlated using a stand-up time chart by Bieniawski [Fig.5]. The roof span required is obtained from the tunnel planning roof span of 10 meters, with a stand-up time of 70 hours without support system.

Refers to the tunnel’s excavation method and support system guide in [Table.7], the recommended excavation method is excavation by drill and blast on top heading and bench tunnel face.

And then make recommendation tunnel’s support system using rock bolts and wiremesh-shotcrete combination without steel ribs support.

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References

1. Z.T.Bieniawski, InJ.A.Hudson(Ed.) Classification of rock masses of rock engineering: The RMR system and future trends, comprehensive rock engineering, 3:553-574 (1993)

2. D. Deere, R. Miller, Engineering Classification and Index Properties for Intact Rock, in New Mexico: Technical Report No. AFWL-TR-65-116, Air Force Weapons Laboratory, Kirkland Air Force Base (1979)

3. E. Hoek, P. Marinos, M. Benissi, Bull Eng Geol Environ 57, 151–160 (1998)

4. P.G. Marinos, V. Marinos, E. Hoek, The Geological Strength Index (GSI): A characterization Tool for Assessing Engineering Properties of Rock Masses, 87-94 (2007).

5. Balai Besar Wilayah Sungai Pompengan-Jeneberang, Soil and Rock Investigation Diversion Tunnel of Pamukkulu Dam, Takalar, in Geological Report (2020)

6. R. Sukamto, S. Supriatna, Peta Geologi Lembar Ujungpandang,Bantaeng dan Sinjai, Sulawesi, (1982)