EXCAVATABILITY METHOD BASED ON ENGINEERING GEOLOGY CONDITIONS IN THE CONSTRUCTION OF RUKOH DAM SUPPLETION TUNNEL, INDONESIA

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ABSTRACT

Determination of excavation technique was one of the essential factors in tunnel construction stability. It also had an impact on the efficiency of the construction phase. However, in the Detail Engineering Design of the Rukoh Dam Suppletion Tunnel, there was no study of the most optimal excavation technique in the construction phase. This study aimed to assess the efficiency of excavation capabilities based on engineering geology conditions. The parameters used in this study are RMR values, GSI values, If-index (discontinuity spacing), Point Load (Is50) values, and Excavation Power Index (EPI). The excavatability classification used the method developed by Abdullatif and Cruden, Pettifer and Fookes, and Tsiambaos and Saroglou. The procedure for evaluating efficiency used the EXCASS system. The tunnel's rock mass quality was poor calcareous siltstone. The excavation method in the tunnel was the top heading and bench with a stand-up time of 10 hours for a 2.5 m span. Based on the result, the most optimal excavation technique used was the easy ripping method for zones 1 and 4, while the digging method was for zones 2, 3, and 5. Even though the recommendations were classified, project cost efficiency studies are required to bolster the recommendations.

Keywords: excavation technique, rukoh dam suppletion tunnel, EXCASS system,

1. INTRODUCTION

Rock mass characteristics are essential in determining the classification of excavation techniques in the tunnel construction phase (Khamehchiyan, et al, 2014). Excavation techniques often used in tunnel construction include digging, ripping, and blasting (Mohammad, et al, 2005). Meanwhile, mechanical excavation is the most widely applied excavation technique in poor rocks. Mechanical excavation consists of digging and ripping techniques (Khamehchiyan, et al, 2014).

Excavatability Assessment is the determination of the excavation techniques based on engineering geological aspects such as geotechnical and geomechanical conditions of a rock mass (Kesimal, et al, 2018). Tunnel excavation is mainly controlled by the strength of intact rock, continuity condition, RQD value, RMR, and GSI value (Dagdelenler, 2021). Therefore, rock mass quality and discontinuity condition analysis are fundamental parameters that must be met in the excavatability assessment.

Based on the detailed engineering design of the Rukoh Dam Suppletion Tunnel, this tunnel is the first suppletion tunnel that separates from the main dam and penetrates a 1025 m long hill (Figure 1). This tunnel also fills the Rukoh Dam with water from the

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DOI: https://doi.org/10.20885/icsbe.vol4.art25

Krueng Tiro river. This tunnel is located in the calcareous siltstone with low weathering to fresh rock (PT Wahana Adya Konsultan, 2019). Based on the previous study, rock mass quality analysis has not been directly correlated with the tunnel excavation method in the research area. The excavation techniques have not been recommended in the tunnel design either. Therefore, the stability of the tunnel needs to be considered during the excavation tunnel (PT Wahana Adya Konsultan, 2019). Mishandling of engineering geology conditions (Chen, et al. 2020 and Wang et al, 2021) or improper excavation methods and support systems (Ya S, et al 2018 and Li Z, et al, 2020) can cause tunnel collapse. Consequently, ensuring optimal excavation techniques is vital.

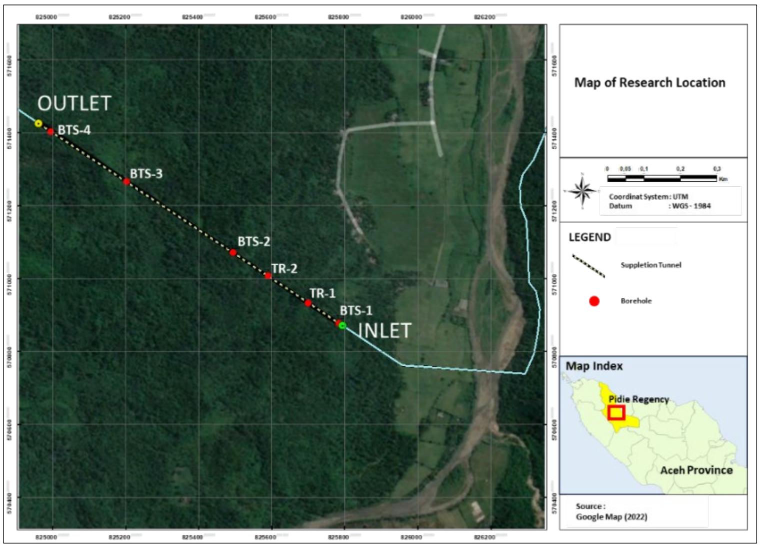

Figure 1. Research Location Map
(Khamehchiyan, et al, 2014)

The research's primary goal is to assess the efficiency evaluations of selected excavatability classifications in the Rukoh Dam Suppletion Tunnel. The excavatability category uses the method developed by Abdullatif and Cruden, Pettifer and Fookes, and Tsiambaos and Saroglou (Abdullatif and Cruden, 1983; Pettifer and Fookes, 1994; and Tsiambaos and Sroglou, 2010). The method for evaluating efficiency uses the EXCASS system (Dagdelenler, et al, 2020). This research will also contribute as a case study on applying optimization analysis of excavation techniques in the tunnel construction phase.

2. METHODOLOGY

Determining the tunnel excavation method at the research site consisted of two fundamental parameters. The first parameter used the Rock Mass Rating (RMR) value as a reference in selecting excavation stages. The second parameter used a combination of Geological Strength Index (GSI) values, discontinuity spacing (If-index), Point Load (Is50) values, and Excavation Power Index (EPI) values as the basis for the assessment method for tunnel excavation.

2.1 GEOLOGICAL INVESTIGATION AT THE TUNNEL SITE

Geological investigations at the tunnel site consisted of surface and subsurface geological investigations. The surface geological investigation was carried out through geological mapping in the field (US Department of the Interior Bureau of Reclamation, 2001). In this research, geological mapping was carried out with a mapping area of 1,5 x 1,5 km^2

at the research site. The elevation contours were made based on the Topographic Map of Rukoh Dam Suppletion Tunnel (PT Waskita Karya (Persero), 2019). The geological trajectory map covered the entire research area with fifty observation points in the field.
The subsurface geological investigation at the Rukoh Dam Suppletion Tunnel was conducted during two drilling projects in 2020 and 2022. In 2020, P.T. Wahana Adya Konsultan carried out four drill points (BTS-1, BTS-2, BTS-3, and BTS-4). In 2022, PT. Waskita Karya (Persero) carried out four drill points (TR-1, TR-2, TR-3, and TR-4) PT. Wahana Adya Konsultan, 2019 and PT. Waskita Karya (Persero), 2022). The rock mass quality was calculated using these core data at the tunnel height, as shown in Figure 2 (ISRM, 2018). As an outcome of rock mass classification, the RMR and GSI value may be used to classify the tunnel excavation method.

Figure 2. Sample of core drill data at BTS-2 (poor rock quality) (PT Wahana Adya Konsultan, 2019)

2.2 ROCK MASS CLASSIFICATION

Bieniawski initially introduced the RMR method in 1989 (Bieniawski, 1989). The RMR method was based on five parameters (P1–P5). P1 was the uniaxial compressive strength (UCS) value, P2 was the RQD value (Deere D U and Deere D W, 1989), P3 was the spacing of discontinuity, and P4 was the discontinuity condition. Finally, P5 was the specific groundwater condition at the rock site (Bieniawski, 1989).

$$RMR = P1 + P2 + P3 + P4 + P5 \quad (1)$$

Visual inspection of rock mass from the borehole was used to compute the GSI value on the subsurface. However, structural problems and discontinuities were the most relevant factor in determining its value (Hoek, et al, 2013). Therefore, a discontinuity condition (JCond) from the drilled rock mass was required to determine the subsurface rating.
The RMR method also correlated with GSI on parameters P2 and P4 (Palmstrom and Stille, 2010). However, the value of relief with high and complete weathering was not considered to calculate the RMR and GSI ratings (Deere D U, 1963). Therefore, the GSI rating can be calculated by equation 2 (Hoek and Brown, 1997). This method can also calculate GSI values from subsurface borehole samples.

$$GSI = 1.5J_{Cond89} + (RQD/2) \quad (2)$$

2.3 EXCAVATIBILITY ASSESSMENT METHOD

Before conducting an excavation assessment, it was necessary to know the stages of tunnel excavation, stand-up time, and the required tunnel support system. This research determined the stages of tunnel excavation, stand-up time, and support systems using empirical methods based on the RMR value at the research site.

The RMR value, GSI value, If-index, and Is50 value can be used as excavatability classification parameters. Based on Abdullatif and Cruden, the RMR value was used as a parameter of excavatability classifications (Abdullatif and Cruden, 1983). Therefore, the excavatability type can be classified in Table 1.

Table 1. Excavability assessment based on RMR [10].

RMR Value	Excavability Class
$60 \leq RMR \leq 100$	Blasting
$31 \leq RMR \leq 60$	Ripping
$RMR \leq 30$	Digging

The GSI, If-index, and Is50 values were parameters in the excavation assessment chart from (Pettifer and Fookes, 1994 and Tsiambaos and Sroglou, 2010). Meanwhile, to assess the efficiency of the excavation method, the EXCASS System method was used as the basis for evaluation (Dagdelenler, et al, 2020).

The If Index and the value of Is50 were parameters from the method developed by Pettifer and Fookes (Pettifer and Fookes, 1994). If Index was determined with the formula:

$$\mathrm{If} = \frac{3}{\mathrm{Jv}} \quad (3)$$

While the value of the volumetric joint number (Jv) was obtained from the calculation formula developed by (Palmstrom, 2001):

$$\mathrm{Jv} = (110 - \mathrm{RQD})/2.5 \quad (4)$$

The Is50 value was the point load value of a rock mass. This value was obtained by converting the UCS value from the laboratory results. Based on ISRM standards, the following conversion formula can be used (IRSM, 1981):

$$\mathrm{Is50} = \frac{\mathrm{UCS}}{20} \quad (5)$$

The Excavability graph from Tsiambaos and Saroglou used the parameter values of GSI and Is50 (Tsiambaos and Sroglou, 2010). In this method, there were two alternatives offered. The different options can be told apart by their Is50 values. For example, the graph of rocks with an Is50 value of more than 3 MPa differs from those with an Is50 value of less than 3 MPa.

Meanwhile, to assess the excavation method's effectiveness, the EXCASS System can be used in this study. The GSI and Is50 values were used as inputs to the calculation of the EPI value (Dagdelenler, et al, 2020). The formula used is as follows:

$$\mathrm{EPI_{opt}} = 0.77\,(\mathrm{GSI}^2 \times \sqrt{\mathrm{Is50}}\,)^{0.52} \qquad (6)$$

3. RESULT AND DISCUSSIONS

3.1 GEOLOGICAL CONDITION

The surface lithology found at the Rukoh Dam Suppletion Tunnel was calcareous siltstone. Based on surface geological mapping, the tunnel's location had a stratigraphy with a young to the old sequence consisting of the alluvium, the calcareous siltstone unit, and the calcareous sandstone unit. In addition, the core drill data analysis proved the tunnel elevation's lithology condition. As a result, the lithology in the sub-surface was similar to the surface, as shown in Figure 3.

3.2 THE RESULT OF ROCK MASS CLASSIFICATION

This study also classified the rock mass quality at tunnel elevation. Based on the assessment, the entire drilling data was classified as fresh calcareous siltstone. The groundwater condition was above the tunnel elevation. The UCS value at the tunnel elevation ranged from 4.75 to 6.5 MPa. Based on the map in Figure 3, the strike was perpendicular to the tunnel alignment, and the dip goes from 44° to 47°. Table 2 presents the rock mass classification in the research area.

The rock mass quality assessment at eight drill points shows that the RMR value at the tunnel elevation is in the calcareous siltstone with poor quality, while the GSI value is in the poor to fair. After knowing the rock mass quality, an overlay is carried out between the rock quality values and the tunnel design. The result of the overlay process is the zoning of the tunnel construction. Figure 4 shows the tunnel construction zoning based on engineering geology conditions.

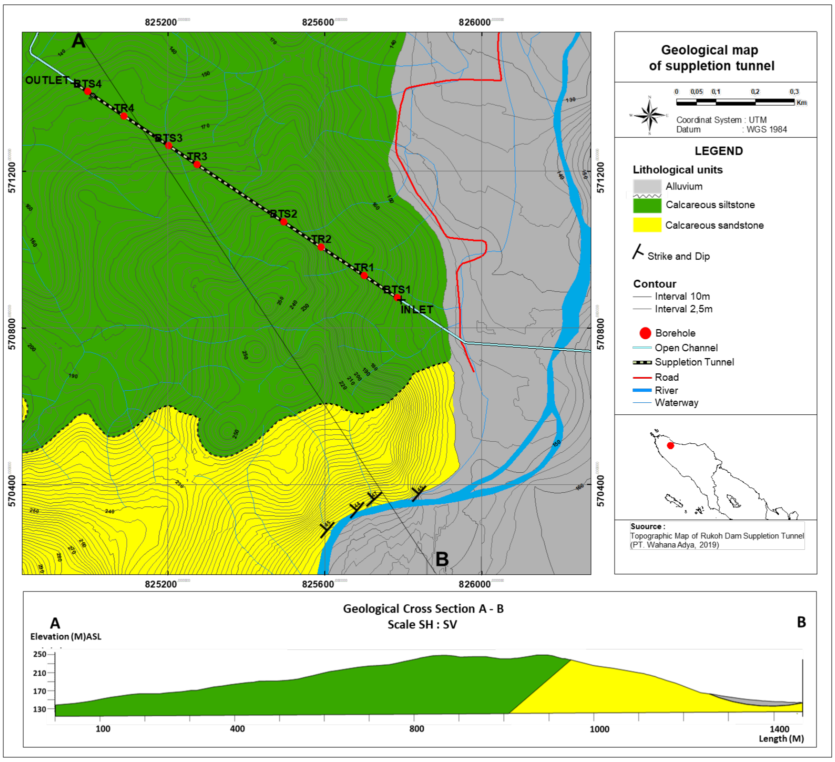

Figure 3. Geological map and geological cross-section of suppletion tunnel (PT. Waskita Karya (Persero), 2019)

Table 2. Rock mass classification of suppletion tunnel.

Bore Hole	Elevation (M)ASL			RMR		GSI	
				Nilai	Class	Value	Class
BTS-1	141.60	-	135.60	35	Poor	40	Poor
TR-1	141.06	-	135.06	40	Poor	49	Poor
TR-2	140.40	-	134.40	30	Poor	33	Poor
BTS-2	139.70	-	133.70	28	Poor	29	Poor
TR-3	138.40	-	132.40	35	Poor	41	Poor
BTS-3	138.06	-	132.06	21	Poor	15	Poor
TR-4	137.30	-	131.30	24	Poor	21	Poor
BTS-4	136.75	-	130.75	30	Poor	31	Poor

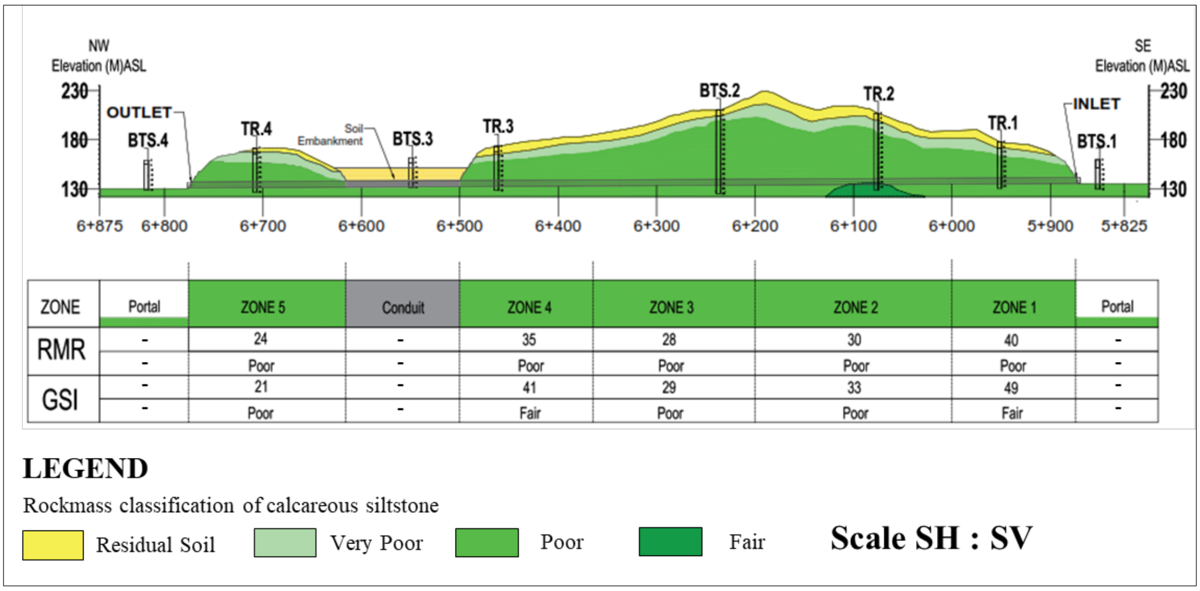

Figure 4. Tunnel construction zoning.

3.3 EXCAVATION METHOD

Based on tunnel construction zoning in Figure 4, it can be proposed the excavation method in the Rukoh Dam Suppletion Tunnel (Pettifer and Fookes, 1994). After the tunnel has been excavated, a support system is erected. The support system ensures the tunnel's stability until the support is completely fixed and suited for use. Table 3 shows the proposed excavation method and support system depending on the RMR value.

As a result, the tunnel's excavation method was the top heading and bench method with a Stand-up time of 10 hours for a 2.5 m span. The tunnel was also enhanced with systematic rock bolts, wire mesh, steel ribs, and shotcrete.

Table 3. Excavation method.

Zone	RMR			
	Value	Class	Excavation Method	Support System
1	40	Poor	Top heading and bench: Advance 1.0-1.5 m in the top heading; Install parallel support - 10 m from the face.	Rock bolts: length = 4-5 m, spacing = 1-1.5 m Steel Ribs: Light to moderate ribs, spacing = 1.5 m Shotcrete: 10-15 cm in the crown and 10 cm insides Stand-up time 10 hours for a 2.5 m span
2	30	Poor		
3	28	Poor		
4	35	Poor		
5	24	Poor		

3.4 EXCAVATION ASSESSMENT

RMR, GSI, If Index, and Is50 value are excavatability classification parameters. Table 4 shows the parameters used in the capability assessment in the research area.

Table 4. Excavability assessment parameters.

Zone	RMR	GSI	If	Is50 Mpa	Efficiency Parameters	
					$GSI^2\sqrt{Is50}$	EPI
1	40	49	0,153	0,23	1151	30
2	30	33	0,105	0,25	545	20
3	28	29	0,088	0,26	429	18
4	35	41	0,150	0,29	905	27
5	24	21	0,101	0,22	207	12

Based on the RMR value parameter developed by Abdullatif and Crude, Excavatability classifications were carried out by ripping and digging methods (Abdullatif and Cruden, 1983). Table 5 details the Excavatability categories for each zone in the tunnel.

Table 5. Excavability assessment based on RMR

Zone	RMR	Excavatability classifications
1	40	Ripping
2	30	Digging
3	28	Digging
4	35	Ripping
5	24	Digging

(Abdullatif and Cruden, 1983)

Figure 5 is the result of a tunnel excavation graph plot based on the method of (Pettifer and Fookes, 1994). The parameters used are the If Index and the Is50 value, resulting in the excavation method digging hard in all zones.

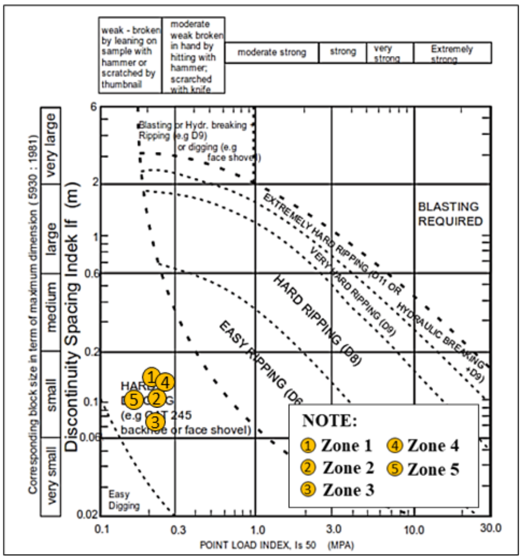

Figure 5. Excavability assessment based on Pettifer & Fookes graph (Pettifer and Fookes, 1994)

Based on the analysis results using the method of (Tsiambaos and Saroglou, 2010), excavatability classifications in zones 1 and 4 use the ripping method, while the digging method is used in zones 2, 3, and 5. Figure 6 shows the parameter plots on the excavation graph plot where the value Is50 < 3Mpa.

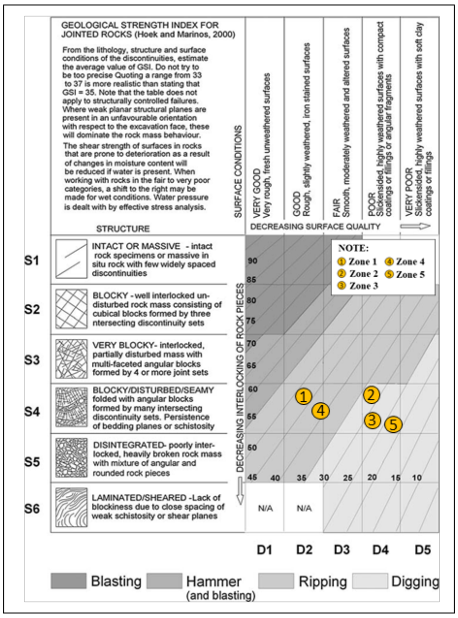

Figure 6. Excavability assessment based on Tsiambaos & Saroglou graph [12].

The efficiency of the recommended excavation techniques was evaluated using the EXCASS System. GSI and Is50 values are used as inputs in the calculation of tunnel excavation optimization (Dagdelenler, et al, 2020). The plot results on the EXCASS System graph (Figure 7) show that the easy ripping method is the most efficient method used in zones 1 and 4, while the digging method is used in zones 2, 3, and 5.

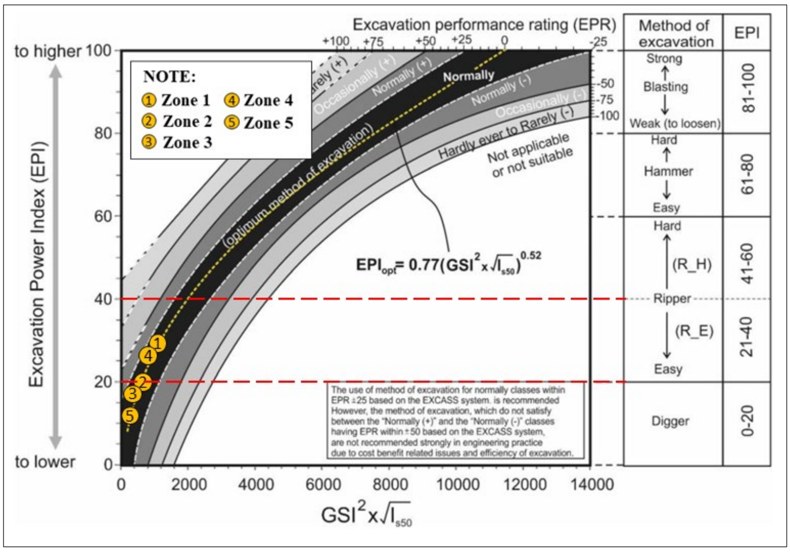

Figure 7. Efficiency assessment based on EXCASS system (Dagdelenler, et al, 2020).

As a result, excavatability classifications show similarities in excavation techniques in all tunnel zones based on the Abdullatif and Cruden method and Tsiambaos and Saroglou method but based on the Pettifer and Fookes method show different excavation techniques. So, based on the efficiency evaluation using the EXCASS System, the most optimal excavation technique used is the easy ripping method for zones 1 and 4, while the digging method is for zones 2, 3, and 5 (Table 5).

Table 5. Excavatability Assessment Result

Zone	Excavatability classifications			Assessment Result
	Abdullatif and Cruden (1983)	**Pettifer and Fookes (1994)**	**Tsiambaos and Saroglou (2010)**	**EXCASS system Dagdelenler et al (2020)**
1	Ripping	*Hard Digging*	*Ripping*	*Easy Ripping*
2	Digging	*Hard Digging*	*Digging*	*Digging*
3	Digging	*Hard Digging*	*Digging*	*Digging*
4	Ripping	*Hard Digging*	*Ripping*	*Easy Ripping*
5	Digging	*Hard Digging*	*Digging*	*Digging*

4. CONCLUSIONS

The lithology of the tunnel is calcareous siltstone with poor rock mass quality based on the RMR classification. With poor rock quality, the proper excavation method in the tunnel is the top heading and bench methods with parallel support 10 m from the tunnel face. This excavation method has a stand-up time of 10 hours for a 2.5 m span.

According to the study research, rock masses of the same quality do not necessarily have the same excavatability classes. Consequently, comparing rock mass classifications like GSI, ID Index, Is50 value, and EPI value significantly impact establishing excavatability types.

The excavation techniques in all tunnel zones are similarly based on the Abdullatif and Cruden method and the Tsiambaos and Saroglou method. However, the excavation techniques are different based on the Pettifer and Fookes method. So, based on the EXCASS System's efficiency evaluation, the most optimal excavation technique for zones 1 and 4 is the easy ripping method, but the digging method is optimal for zones 2, 3, and 5. Regardless of the appropriate excavation technique, additional cost and equipment analysis studies are required to evaluate the project's cost-effectiveness.

5. ACKNOWLEDGMENTS

The authors are grateful to the Sumatera I River Basin Organization (BWS) and P.T. Waskita Karya (Persero) for their permit and support data for this research. In addition, financial support from the Human Resource Development Agency of the Ministry of Public Works and Housing Indonesia is gratefully acknowledged.

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