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Stability Analysis of evasion tunnels using the Rock Tunneling Quality Index (Q-System) method on the construction of the Bagong DAM Trenggalek, East Java

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Article info	Abstract
	The Bagong Dam evasion tunnel is part of the dam construction which functions to drain the water flow so that the dam work can be done. In planning the construction of evasive tunnels, it is necessary to study the geological, geotechnical and structural conditions of the tunnel. This study is intended to provide an overview of the subsurface and engineering geological conditions of the research area, so as to determine the stability of the evasion tunnel and then provide recommendations for the support to be used. The method used is the Rock Tunneling Quality Index (Q-System) method to determine the buffer to be used in the construction process. Based on the analysis of the subsurface geological conditions of the study area, there are three rock layers, namely: sandstone, breccia and limestone. In the Q-System analysis, the rock mass class value ranges from 0.451 to 0.651 with Very Poor quality and the rock mass class value is 1.162 with Poor quality. At the four drill points BH-09, BH-03, BH-10 and BH-11, the recommendation for support is obtained with the type of support (B+5) and SRF+B

1. Introduction

The construction of the evasive tunnel serves as a channel to circumvent the river flow. In the construction of evasive tunnels, one of the stages of activity is excavation to change the topography according to the design [1]. Bagong Dam is a dam designed to have a tunnel as a water evasion along ± 860 m. Tunnel construction activities require various stages of readiness to reach the construction stage. There are 8 feasibility studies, in this case the role of geology, especially in the field of engineering geology, is very influential in determining the manufacture of tunnel designs by taking into account the safety and disaster factors that exist in the development area [2]. Engineering geological studies can determine the criteria for rock in each excavation according to its classification. Before determining a recommendation, it is necessary to study the geomechanics of the rock, so that in making the tunnel it is possible to obtain the stability of the rock mass in it. These properties include rock mass properties, groundwater, mineral fillers, rock structure, weathering, and other geological conditions such as earthquake potential, and lithology which is very influential in the classification of rock masses used [3]. Rock classification based on the Q-System obtained in geological studies by knowing the rock mass, through the calculation of the Excavation Span Ratio (ESR). So that it can be known the proper handling in digging tunnel evasion [4] [5].

Regionally geologically, the research area is included in the Southern Mountains of East Java, which borders the Depression lane, which is occupied by Mount Wilis [6]. The study area consists of three formations, the Mandalika Formation which is dominated by hard clastic volcanic rocks; The Jaten Formation which is dominated by soft sedimentary rocks, and the Wonosari Formation which is dominated by hard limestones [7].

Table 1. Classification of Rock Mass Based on Q value [4]

Q-value	Group	Class
40-10		Good
40-400	1	Very Good
400-1000		Extremely Good
0,1-1		Very Poor
1-4	2	Poor
4-10		Fair
0,001-0,01	3	Extremely Poor
0,01-0,1		Extremely Poor

Located on the Bagong River, Sumurup Village-Sengon Village, Bendungan District, Trenggalek Regency, East Java Province, this dam is geographically located at 07 96' 7" South Latitude and 111 70' 51' East Longitude.

The purpose of this study is to recommend the right buffer system in the Bagong Dam Evasion Tunnel. knowing the geological conditions of rock engineering around the tunnel both surface and subsurface so that an analysis can be carried out to determine the buffer system using the Rock Tunneling Quality Index (Q-System) method. From this research, it is hoped that it can provide input to stakeholders regarding the selection of supports using the Rock Tunneling Quality Index (Q-System) method and provide references to the same problem in other locations so that they can provide additional knowledge in the field of science, especially in the fields of geology and civil engineering [8]. The data used in this study is core drilling data (coring). While the method used for subsurface modeling is using the Horizontal Lithoblending method with solid model interpolation using Rockworks software.
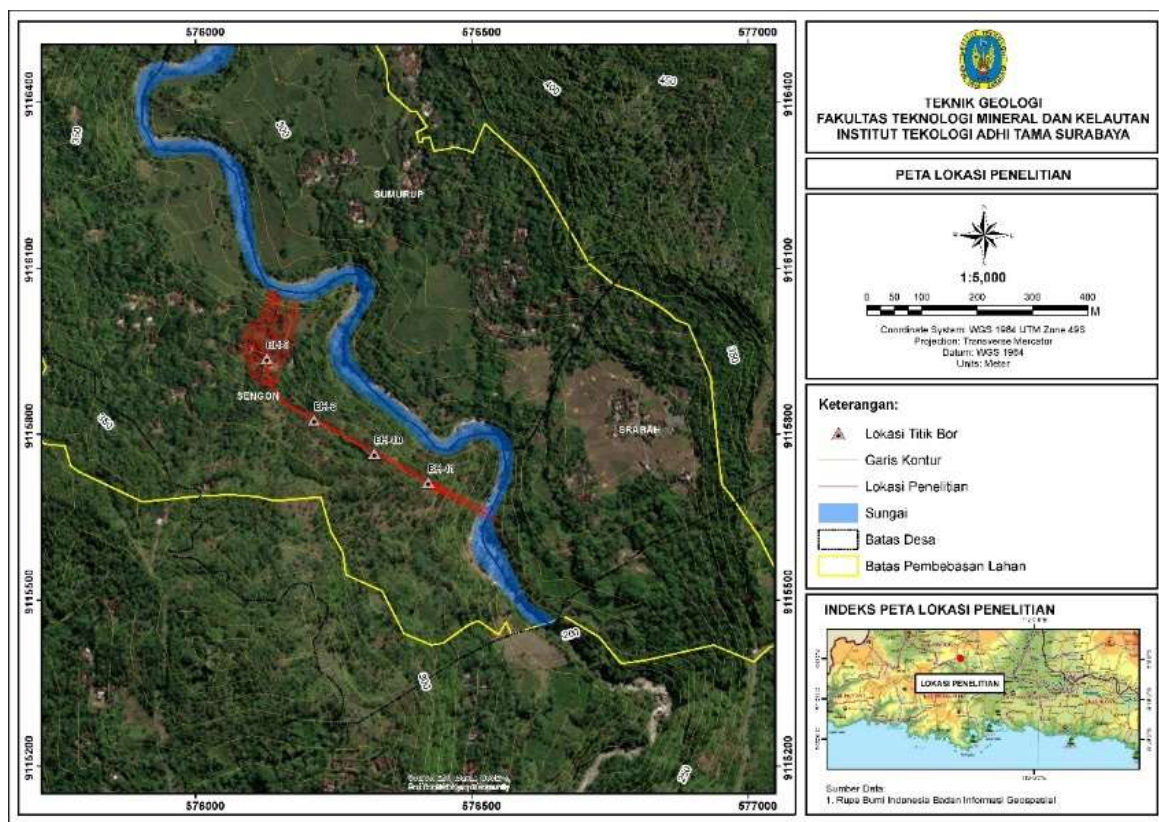

Figure 1. Site map investigation

Table 2. Rock Mass Rating (RMR) value

(a). BH-09 Sta 1+50 – 3+00			(b). BH-03 3+00 – 4+00		
Parameter	Value	Rating	Parameter	Value	Rating
UCS (Mpa)	11.1923	2	UCS (Mpa)	12.0896	2
RQD (%)	37	8	RQD (%)	66	13
Fracture Distance (m)	0.6-2	15	Fracture Distance (m)	0.6-2	15
Fracture condition	Rough open <1 then the wall is a little weathered	25	Fracture condition	Rough open <1 then the wall is a little weathered	25
Ground water condition	watery	7	Ground water condition	watery	7
Fracture orientation	Good	-2	Fracture orientation	Good	-2
RMR Total		55	RMR Total		60
(c). BH-10 4+00 – 5+0000			(d). BH-11 Sta 5+00 – 6+50		
Parameter	Value	Rating	Parameter	Value	Rating
UCS (Mpa)	15.9103	2	UCS (Mpa)	30.132	4
RQD (%)	35	8	RQD (%)	26	8
Fracture Distance (m)	0.6-2	15	Fracture Distance (m)	0.6-2	15
Fracture condition	Rough open <1 then the wall is a little weathered	25	Fracture condition	Rough open <1 then the wall is a little weathered	25
Ground water condition	watery	7	Ground water condition	watery	7
Fracture orientation	Good	-2	Fracture orientation	Good	-2
RMR Total		55	RMR Total		57

2. Methodology

Rock Tunnelling Quality Index (Q-System) method is rock mass classification for the installation of supports in underground excavations. Q-System weighting is based on numerical interpretation of rock mass quality based on parameters. RQD (Rock Quality Designation): (1). Total stock/Joint Set Number (Jn); (2) Joint Roughness Number (Jr); (3). Degree of Alteration or Filling Along the Weakest Joint Alteration Number (Ja); (4) Water Flow/Joint Water Reduction Number (Jw); (5) Stress Reduction Factor (SRF) [4]. In this system, Rock masses are classified into nine categories based on the value of Q, as can be seen in table 1, the concern is the discontinuity and joint areas. The number of Q varies from 0.001-1000 and is calculated using the following equation;

$$Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Information:
RQD : *Rock Quality Designation*
Jn : *Joint Set Number*
Jr : *Joint Roughness Number*
Ja : *Joint Alterasi Number*
Jw : *Joint Water Reduction Factor*
SRF : *Stress Reduction Factor*

Table 3. *Geological Strenght Index* (GSI) value for rock mass Bagong Dam Evasion Tunnel

Bore Hole	RMR	GSI (RMR-5)
BH-09	55	50
BH-03	60	55
BH-10	55	50
BH-11	57	52

Table 4. RQD, Jn, Jr and Ja value at each drill point

Bore Hole	Rock Quality Designation (*RQD*)		Joint Set Number (*Jn*)		Joint Roughness Number (*Jr*)		Joint Alteration Number (*Ja*)	
	RQD (%)	Class	Jn	Descrip	Jr	Descrip	Ja	Descrip
BH-09	37%	Poor	1	Massive, none/slightly fracture	4	Discontinue fracture	0.75	Quartz
BH-03	66%	Fair	1		4		0.75	
BH-10	35%	Poor	1		4		0.75	
BH-11	26%	Poor	1		4		0.75	

3. Results and discussions

3.1. Technical Geology Research Area

Geological conditions and technical properties of evasive tunnel foundations in determining rock mass class are known from the results of core drilling and in-situ tests that have been carried out [9]. The results are displayed in core drilling format. There are 4 drill points along the evasion channel (BH-09, BH-03, BH-10 and BH-11) [10]. From the results of these investigations, a geological engineering profile along the plan of the evasion tunnel has been made [11]. The geological profile shows the subsurface geology, rock mass class, stand up time, and proper support. From these geological profiles it can be seen the geological conditions along the tunnel path and also the technical geological conditions [12]. The following are the results of the RMR for the Bagong Dam evasion tunnel [13]. The research was conducted at several locations, namely BH-09 Sta. 1+50-3+00, BH-03 Sta 3+00-4+00, BH-10 Sta. 4+00-5+00 and BH-11 Sta 5+00-6+50 which are shown in Table 2.

3.2. The Strength of the Whole Rock Mass

Calculation of rock mass strength using the Hoek-Brown criteria requires the value of the Geological Strength Index (GSI) [14]. GSI calculations can be based on the RMR value. The Geological Strength Index (GSI) values obtained for rock masses at several locations are as follows Table 3.

3.3. Rock Mass Class

Determination of rock mass class classification, using the Q-System method. Based on the parameters of Rock Quality Designation (*RQD*), Joint Set Number (*Jn*), Joint Roughness Number (*Jr*), Joint Alteration Number (*Ja*), as follows Table 4. Water reduction in Joint Water Roduction (*Jw*), Stress Reduction Factor (*SRF*), Weight values (*ESR*) as follows Table 5.

3.4. Calculation of Rock Tunneling Quality Index (Q-System) Value

After calculating the Q value using Equation 1, the Q value of each drill point is obtained as follows Table 6.

Table 5. Jw, SRF value at each drill point

Bore Hole	Joint Water Reduction Number (*Jw*)			Stress Reduction Factor (*SRF*)		Weight values (*ESR*)	
	Jw	Water Pressure	Descrip	SRF	Descrip	ESR	Descrip
BH-09	0.66	1.0 -2.5	Small water flow (<5L/min), washing occurs on the stiff filler	200	Big rock breaking and deformation dynamics directly on massive rock	1.6	For permanent mines, power generation aqueducts (excluding high pressure), drift and heading in large excavations
BH-03	0.66	1.0 - 2.5		200		1.6	
BH-10	0.66	1.0 - 2.5		200		1.6	
BH-11	0.66	1.0 - 2.5		200		1.6	

Hole	Litology	RQD	Jn	Jr	Ja	Jw	SRF	ESR	Q-System value
BH-09	Breccia	37	1	4	0.75	0.66	200	1.6	0.651
BH-03	Limestone	66	1	4	0.75	0.66	200	1.6	1.162
BH-03	Breccia	66	1	4	0.75	0.66	200	1.6	1.162
BH-10	Breccia	35	1	4	0.75	0.66	200	1.6	0.616
BH-11	Limestone	26	1	4	0.75	0.66	200	1.6	0.458

4. Conclusion

The ESR value used for the evasion tunnel is 1.6 and the equivalent dimension is 3.11. From the results of the research, with poor rock conditions, the maximum opening without using supports is only 1.5m, far below the planned tunnel dimensions of 4.98, so opening a tunnel without using supports is very unlikely [15], so the right support is determined in the excavation process.

Based on the Q System method, the rock mass class for the breccia layer in BH-09 is Very Poor with a weight value of 0.651. The sandstone layer in BH-03 is Poor with a weight value of 1,162. The sand layer in BH-10 has a rock class of Very Poor with a weight value of 0.616. While the rock class in the limestone layer is Very Poor with a weight value of 0.451 (see table 7). Support recommendations based on the Q System method are rockbolt in the breccia layer at BH-09 and in the sandstone layer BH-10 with 1.5m spacing in the shortcrete area and 1.28 spacing in the area without shortcrete. In the sandstone layer at BH-03 it is recommended to use rockbolt support with a spacing of 1.8 in the shortcrete area and a spacing of 1.3 in the area without shortcrete [16]. While the limestone layer in BH-11 is recommended for a fiber reinforced shortcrete support system with bolting 5-9 cm, bolt spacing of 1.3m in the shortcrete area and the bolt spacing in the area without shortcrete 1.2 m (table 8).

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Table 7. Tunnel Buffer Determination

Bore Hole	Q-Value	Equivalent Dimension	Rock Quality	Buffer Category	Information
BH-09	0.651	3.11	Very Poor	B(+5)	Recommended support fall into category 4, where the bolt type is systematic bolt with 1.5 m spacing in the shortcrete area and 1.28 m spacing in the area without shortcrete (unreinforced shortcrete of 4-5cm).
BH-03	1.162	3.11	Poor	B(+5)	Recommended support fall into category 4, where the bolt type is systematic bolt with a spacing of 1.8 m in the shortcrete area and 1.3 m spacing in the area without shortcrete (unreinforced shortcrete of 4-5cm).
BH-10	0.616	3.11	Very Poor	B(+5)	Recommended support fall into category 4, where the bolt type is systematic bolt with 1.5 m spacing in the shortcrete area and 1.28 m spacing in the area without shortcrete (unreinforced shortcrete of 4-5cm).
BH-11	0.458	3.11	Very Poor	SFR+B	Recommended supports fall into category 5, fiber reinforced shortcrete and bolting, 5-9 cm, bolt spacing in shortcrete areas is 1.3 m and bolt spacing in areas without shortcrete is 1.2m.

Bore Hole	Stand Up Time			
	Roof Span	Q-Value	RMR	Collapse Time (Hour)
BH-09	4.98	0.651	50	1 week / 168 hour
BH-03	4.98	1.162	55	28 day / 672 hour
BH-10	4.98	0.616	50	1 week / 168 hour
BH-11	4.98	0.458	52	2 week / 336 hour

Table 8. Determination of Stand Up Time

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