REVIEW DAM-BLOCKING TUNNEL BUFFER SYSTEM OF BENER DAM, PURWOREJO, JAWA TENGAH

MUHAMMAD SATYA HIMAWAN DANUARTHA
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ABSTRACT

Analysis of the buffer system in the tunnel pathway of Bener Dam was done in order to ensure whether or not certain support is needed in the process of implementing the construction that will take place. The parameters used as input data are in the form of geometry lining (horseshoe), physical and mechanical properties of the material making up the tunnel pathway, rock mass strength, and GSI (Geological Strength Index) data to get a combination of the RMR buffer system and the Q System. The method used in this review is the finite element method approach on Phase 2 (Rocscience, Inc) software. The results of the geological investigation in 2019 showed that the tunnel was in the andesite and andesite breccia rocks with a quality of rock mass Fair to Good. The tunnel path can be divided into three parts, namely inlet (BH 02/2017), tunnel (BH 3 B/2019), and outlet (BH 5/2019). Tunnel buffer system based on the RMR classification on the Fair to Good rock mass conditions produces a total displacement value ranging from 0.00225-0.0068 m. Whereas, the tunneling buffer system based on the Q System classification produces a total displacement value ranging from 0.0023 to 0.0071 m.

***Keywords** : Bener Dam, Tunnel buffer, buffer system, GSI, RMR.*

1. PREFACE

The function of Diversion tunnel is to diverse river stream which have already blocked by coffferdam, in order to make area around main dam safe from river stream during construction. Plan of diversion tunnel long section is determined by topography condition, geological aspect, geotechnic, structure, and hidrology. This paper focus on analysis of both geology and geotechnic condition around tunnel such as lithology, geological structure, morphology, and another engineering properties of rocks that will influence rock mass condition.

In previous plan of diversion tunnel of Bener Dam, rock mass quality determination used Rock Mass Rating (RMR) only. Whereas in this paper use some empirical methods approach to determine rock mass quality such as Geological Strenght Index (GSI)(Hoek et al. 1998), RMR (Bienawski, 1973), and Q System (Barton et al.1974). Then make a value correlation between those methods. Purpose of this analysis is to precise geology and geotechnic condition along diversion tunnel from inlet to outlet by determine rock mass quality. Therefore, buffer system can be determined precisely and fulfill the standard.

2. METHODS

Buffer system analysis of diversion tunnel is conducted by some parameters input such as line geometry of tunnel (horseshoe), engineering properties of material, rock mass strength, and buffer system combination based on RMR and Q System. Line geometry of tunnel (horseshoe) for Buffer System analysis are got from diversion tunnel redesign. Excavated tunnel has height from floor to crown in 9 m and widht in 9 m.

Rock mass quality determination based on Geological Strength Index (Hoek & Brown , 1998) had done by cores description. Some GSI parameters such as RQD, weathering degree, discontinuity, and surface roughness are considered. Some rock samples or intact rock at tunnel axis were taken for laboratory test such as density, shear strength, uniaxial compressive strength, andd ultrasonic velocity test (young modulus and poisson ratio). Generalized Hoek Brown (Hoek et al. 2002) equation is chosen to make rock mass strength modelling. The equation of Generalized Hoek Brown (Hoek et al. 2002) consist of GSI rating and UCS parameters. UCS value of intact rock is obtained by compression strenght test which follows the procedure on ASTM D2938-95 (ASTM Standards, 1995).

Total displacement and buffer system along Tunnel pathway which will be analyzed is shown at geology long section (Fig. 1). Tunnel buffer system design at BH 02 (2017), BH 03 B (2019), and BH 05 (2019) are based on Rock Mass Rating value (Bienawski, 1979)(Fig. 2). Then that values are compared to Q System (Barton, 2002)(Fig. 3). Correlation of GSI values at 9 m above and beneath the tunnel axis are used to determine appropriate buffer system. After all parameters had obtained, then the next step is creating an interpreting some model with finite element approach on Phase 2 software (Rocscience Inc).

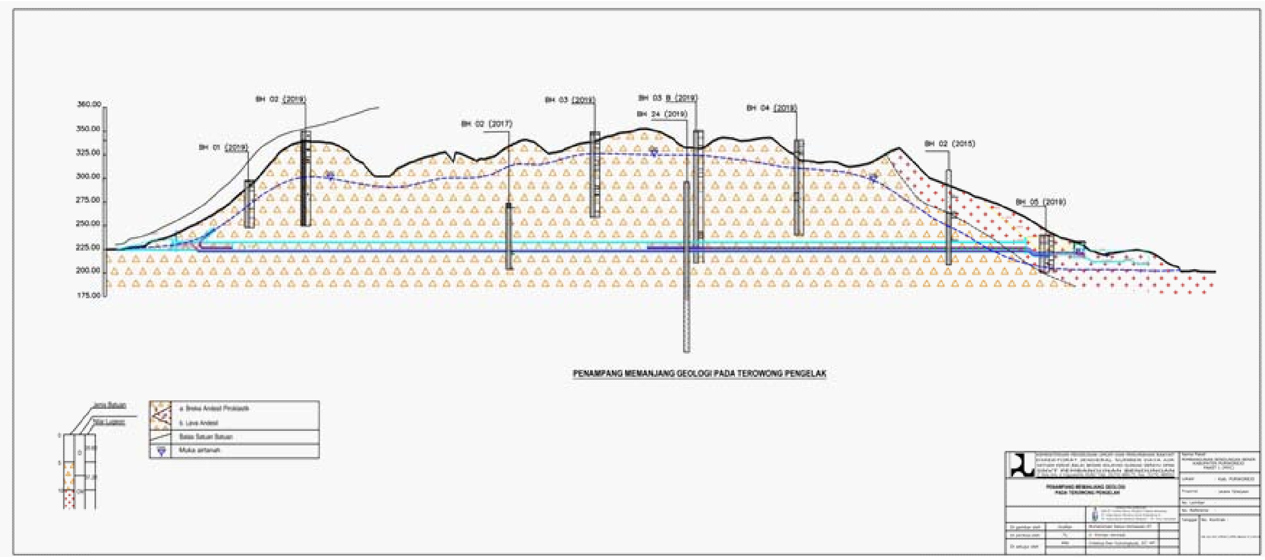


Figure 1 : Geology of diversion tunnel long section

3. RESULT AND DISCUSSION

Geological Strength Index value of rock mass at diversion tunnel pathway was taken at BH 02 (2017), BH 03 B (2019), and BH 05 (2019). BH 02 (2017) consist of andesite breccia with Good rock mass quality and value of GSI = 71.19, with correlation to RMR = 76.19 and Q System = 55.72. BH 03 B consist of andesite breccia with good rock mass quality and value of GSI = 70.86 , with correlation to RMR = 75.86 and Q System = 52.97. BH 05 (2019) consist of andesite with Fair rock mass quality and value of GSI = 52.11, with correlation to RMR = 57.11 and Q System = 2.98. Complete correlation between GSI, RMR , and Q system can be seen at Table 1.

Table 1 : Corellation of *Geological Strength Index* (GSI), *Rock Mass Rating* (RMR), and *Q System* at some bore points BH 02 (2017), BH 12 (2015), and BH 05 (2019) with 9 m above and beneath the tunnel

No	Bore Hole	Total Displacement	Location	Lithology	GSI	RMR	Q system	Rock Mass Quality
						GSI =RMR_{89}-5	$Q = 10^{\frac{RMR-50}{15}}$	
1	BH 02 (2017)	70	Inlet	Andesite Breccia	71.19	76.19	55.72	Good
2	BH 03 B (2019)	140	Tunnel	Andesite Breccia	70.86	75.86	52.97	Good
3	BH 05 (2019)	40	Outlet	Andesite	52.11	57.11	2.98	Fair

Laboratory data and calculation which are used as a material properties at modelling of buffer system in tunnel pathway can be seen at Table 2.

Table 2 : Laboratory data and material *properties* input\

No	Sample Code	Bulk Unit Weight	Specific Gravity (Sg)	Young's Modulus	Poison Ratio	UCS	Lithology	GSI	Rock Mass Quality	mb	s	a
		MN/m^3		MPa		MPa				MPa	MPa	MPa
1	BH 02 (2017)	0.016	1.98	-	0.5	29.814	Andsite Breccia	62.50	Good	5.241	0.016	0.502
2	BH 02 (2017)	0.016	1.89	-	0.4	19.702	Andsite Breccia	77.50	Very Good	8.955	0.082	0.501
3	BH 03 B (2019)	0.022	2.712	1758.933	0.364	16.249	Andsite Breccia	75.00	Good	8.190	0.062	0.501
4	BH 03 B (2019)	0.026	2.776	4260.833	0.444	34.350	Andsite Breccia	87.50	Very Good	12.798	0.249	0.500
5	BH 05 (2019)	0.022	2.093	625.09	0.358	7.68	Andesite	50.00	Fair	3.354	0.004	0.506

Result of buffer system based on RMR (Fig. 2), can be described below :

(a) BH 02 (2017) and BH 03 B (2019) has Good rock mass quality, kind of buffer system is locally bolt and shotcrete.

Locally bolt in crown 3 m long, spaced 2.5 m, with occasional wire mesh. Whereas shotcrete 5 cm in crown where required

(b) BH 05 (2019) has Fair rock mass quality, kind of buffer system is systematic bolt and shotcrete. Systematic bolts 4 m long, spaced 1.5-2 m in crown and walls with wire mesh in crown. Whereas shotcrete 5-10 cm thickness at crown and 3 cm at side.

Rock mass class	Excavation	Support		
		Rock bolt (20 mm diameter fully grouted)	Shotcrete	Steel sets
Very good rock RMR = 81 - 100	Full face, 3 m advance	Generally, no support required except for occasional spot bolting		
Good rock RMR = 61 - 80	Full face, 1.0-1.5 m advance, Complete support 20 m from face	Locally, bolt in crown 3 m long, spaced 2.5 m, with occasional wire mesh	50 mm in crown where required	None
Fair rock RMR = 41 - 60	Heading and bench, 1.5-3 m advance in heading. Commence support after each blast. Complete support 10 m from face	Systematic bolts 4 m long, spaced 1.5-2 m in crown and walls with wire mesh in crown	50-100 mm in crown and 30 mm in side	None
Poor rock RMR = 21 - 40	Top heading and bench. 1.0-1.5 m advande in top heading. Install support concurrently with excavation 10 m from face	Sistematic bolts 4-5 m long, spaced 1-1.5 m in crown and wall with wire mesh	100-150 mm in crown and 100 mm in sides	Light to medium ribs spaced 1.5 m where required
Very poor rock RMR < 20	Multiple drift 0.5-1.5 m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting	Systematic bolts 5-6 m long, spaced 1-1.5 m in crown and walls with wiremesh. Bolt invert	150-200 mm in crown, 150 mm in sides and 50 mm on face	medium to heavy ribs spaced 0.75 m with steel lagging and forcepoling if required. Close invert

Legend : BH 02 (2017) and BH 03 B (2019 | BH 05 (2019)

Figure 2 : Buffer System at tunnel pathway based on RMR Bienawski (1989) around BH 02 (2017), BH 12 (2015), and BH 05 (2019)

Buffer system at tunnel pathway based on Q System classification (Lwin, 2009) is depend on three factors such as Q value, tunnel roof span and ESR value (Excavation Support Ratio). Height of tunnel lining in this paper is 9 m with ESR value 1.3 (Barton et al. 1974). Then Q value is obtained by corellation between GSI, RMR, and Qsystem. Result of buffer system based on Q system (Fig. 3), can be described below :

(a) BH 02 (2017) and BH 03 B (2019) has Good rock mass quality, therefore no support required.

(b) BH 05 (2019) has Fair rock mass quality, kind of buffer system is systematic bolt 2 m long and 2 m spaced, whereas shotcrete 10 cm thickness at crown and side.

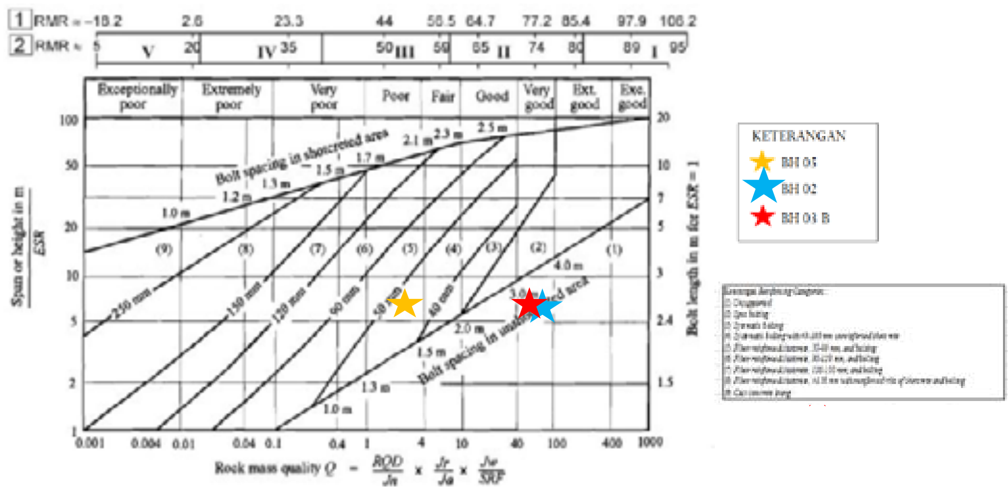


Figure 3 : Buffer System at tunnel pathway based on Barton (2002) around BH 02(2017), BH 03 B (2019), and BH 05 (2019)

Figure 4 show approximation of stand up time around tunnel excavation at BH 02 (2017), BH 03 B (2019), and BH 05 (2019) before buffers are installed. Good rock mass quality at BH 02 (2017) and BH 03 B (2019) have 2-3 months stand up time (without support). However, RMR (Bienawski, 1989) suggest that the excavation should follow some standards such as : Full face, 1-1.5 m advance, complete support 20 m from face. Fair rock mass quality at BH 05 (2019) has 10-20 days stand up time (without support). However, RMR (Bienawski, 1989) suggest that the excavation should follow the standard such as : Heading and bench, 1.5- 3 m advance in heading, commence support after each blast, complete support after 10 m from face.

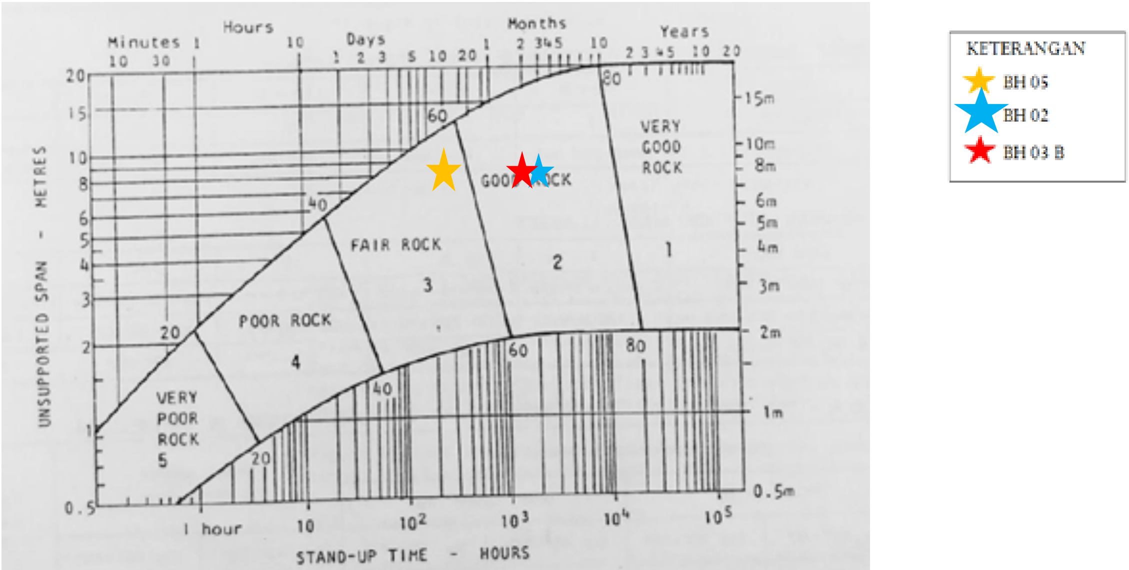
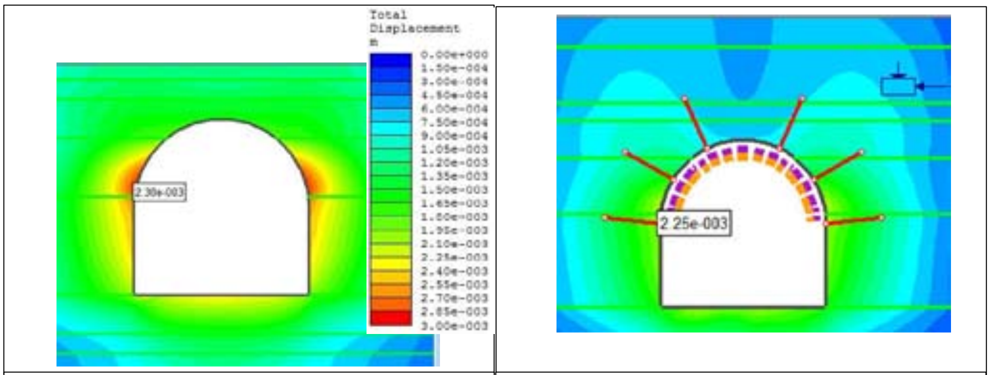


Figure 4 : Approximate stand up time of unsupported excavation around BH 02(2017), BH 03 B (2019), and BH 05 (2019) (Bienawski, 1974)

Total displacement value after the model had created at inlet or BH 02 (2017) is 0.00225 (RMR) and 0,0023 (Q System). At tunnel or BH 03 B (2019) is 0.0068 (RMR) and 0.007 (Q System). At outlet or BH 05 (2019) is 0.0054 (RMR) and 0.0051 (Q System). Summary of total displacement at inlet (BH 02/2017), tunnel (BH 3 B/2019), and outlet (BH 05/2019) are at Table 3. Result of modelling at BH 02 (2017), BH 03 B (2019), and BH 05 (2019) completely can be observed at Figures 5-7.

Table 3 : Summary of buffer system and result of total displacement value from modelling

Bore Hole	Rock Mass Quality	Classification	Total Displacement (m)	Buffer System	
BH 02	Good	RMR	0.00225	*Rockbolt*	L= 3m, S = 2.5m
				Wiremesh	conditional
				Shotcrete	H =5 cm
		Q System	0.0023	*Rockbolt*	-
				Shotcrete	-
BH 03 B	Good	RMR	0.0068	*Rockbolt*	L= 3 m, S = 2.5 m
				Wiremesh	crown
				Shotcrete	H = 5 cm (crown),
		Q System	0.007	*Rockbolt*	-
				Shotcrete	-
BH 05	Fair	RMR	0.0054	*Rockbolt*	L= 4 m,S = 2 m
				Wiremesh	conditional
				Shotcrete	H =5 cm (crown) and H = 3 cm (wall)
		Q System	0.0051	*Rockbolt*	L = 2 m, S = 2m
				Shotcrete	H = 10 cm



a. Stress Ratio (k) = 2
Total Displacement = 0.0023 m

b. Stress Ratio (k) = 2
Total Displacement = 0.00225 m

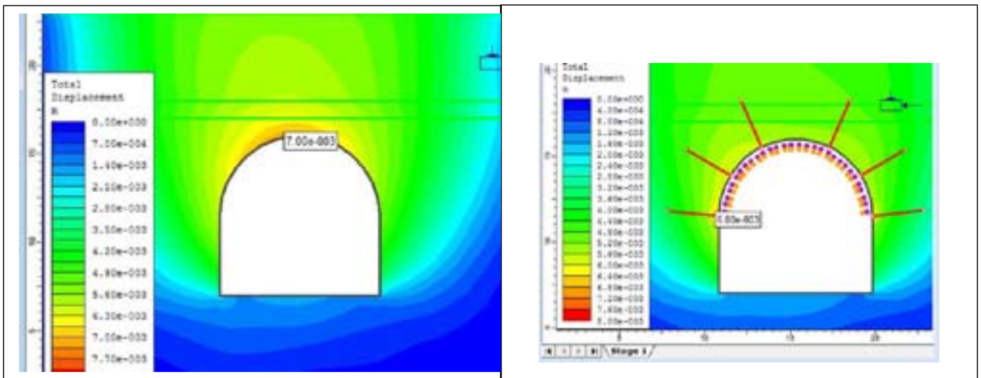
Buffer system :

1. Rock bolt D 22 , 3 m long , 2.5 m spaced. Only in crown.
2. Shortcrete 5 cm thickness with wire mesh only in crown.

Figure 5 : Result of numerical analysis with Phase 2 (Rocscience, Inc) at BH 02 (2017) buffer system based on Q system and RMR

Modelling result at BH 02 (2017)(Fig. 5) which use buffer system with Q System and RMR classification show the largest total displacement is on diversion tunnel crow*n* because the *Overburden* above the diversion tunnel affect total displacement. BH 02 (2017) has the largest total displacement without buffer system (based on Q System) is 0.0023 m, or larger than buffer system based on RMR which has value 0.00225 m, the difference is 0.00005 m. Around tunnel crown at BH 02 point when use Q system classification or not supported has yellow-red contour with total displacement 0.0018-0.0023 m, while RMR classification has green-yellow contour with total displacement 0.0012-0.0021 m. Therefore RMR classification with combination rockbolt 3 m long, 2.5 m spaced, shotcrete 5 cm thickness, and wiremesh has better stability than Q system classification (unsupported).

Modelling result at BH 03 B (2017)(Fig. 6) which use buffer system with Q System and RMR classification show the largest total displacement is on diversion tunnel crow*n*. The overburden above diversion tunnel at the middle pathway is thicker than BH 02 (2017) so that BH 03 B (2019) has larger total dispacement value, although they has same rockmass quality (Good). BH 03 B (2019) has the largest total displacement without buffer system (based on Q System) is 0.007 m, or larger than buffer system based on RMR which has value 0.0068 m, the difference is 0.0002 m. Around tunnel crown at BH 03 B point when use Q system classification or not supported has yellow-red contour with total displacement 0.0028-0.007 m, while RMR classification has green-yellow contour with total displacement 0.0032-0.0064 m. Therefore RMR classification with combination rockbolt 3 m long, 2.5 m spaced, shotcrete 5 cm thickness, and wire mesh has better stability than Q system classification (unsupported).



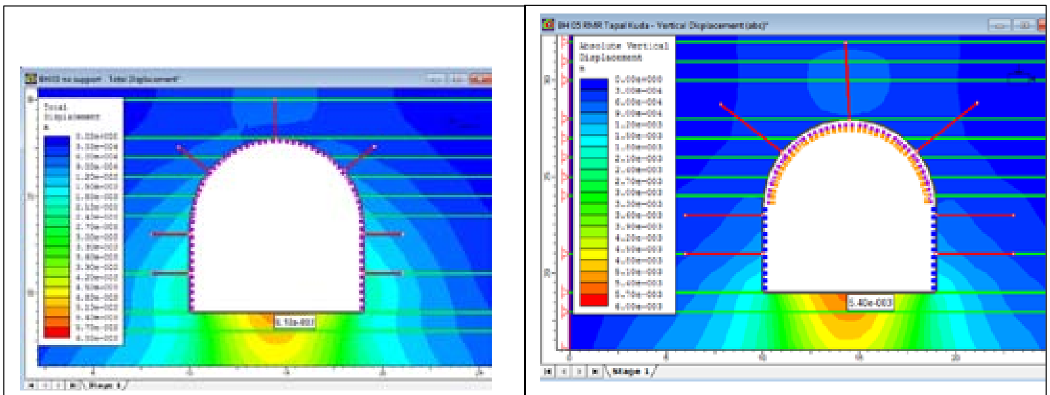
a. Stress Ratio (k) = 2
Total Displacement = 0.007 m

b. Stress Ratio (k) = 2
Total Displacement = 0.0068 m
Buffer system :

1. Rock bolt D 22 , 3 m long, 2.5 m spaced. Only in crown
2. Shortcrete 5 cm thickness with wire mesh only in crown

Figure 6 : Result of numerical analysis with Phase 2 (Rocscience, Inc) at BH 03B (2019) buffer system based on Q system and RMR

Modelling result at BH 05 (2019)(Fig. 7) which use buffer system with Q System and RMR classification show the largest total displacement is on diversion tunnel floor because outlet floor has poor to fair rock mass quality. BH 05 (2019) has the largest total displacement based on RMR is 0.0054 m, or larger than buffer system based on Q system which has value 0.0051 m, the difference is 0.0003 m. Around tunnel crown at BH 05 point when use Q system classification has green-red contour with total displacement 0.0021-0.0051 m, while RMR classification has green-red contour with total displacement 0.0024-0.0054 m. Therefore Q System classification with combination rockbolt 2 m long, 2 m spaced, shotcrete 10 cm thickness has better stability than RMR classification with rockbolt 4 m long, 2 m spaced, shotcrete 5 cm thickness at crown and 3 cm at wall.



a. Stress Ratio (k) = 2 Total Displacement = 0.0051 m Buffer system : 1. Rock bolt D 22 , 2 mlong, 2 m spaced. In crown and wall 2. Shortcrete 10 cm thickness on crown and wall	b. Stress Ratio (k) = 2 Total Displacement = 0.0054 m Buffer system : 1. Rock bolt D 22 , 4 m long , 2 m spaced in crown and wall 2. Shortcrete 5 cm thickness with wire mesh in crown 3. Shotcrete 3 cm thickness on wall

Figure 7 : Result of numerical analysis with Phase 2 (Rocscience, Inc) at BH 05 (2019) buffer system based on Q system and RMR

4. CONCLUSION

Based on Geological Investigation 2019, rock mass quality at inlet or BH 02 (2017) and tunnel or BH 03 B (2019) consist of andesite breccia with good rock mass quality while at outlet BH 05 (2019) consist of andesite with air rock mass quality. Finite element analysis utilizing *software* Phase 2 (Rocscience, Inc) conclude that RMR classification can reduce total displacement effectively at good rock mass (inlet and tunnel), the values are 0.00225 m (0.225 cm) and 0.0068 m (0.68 cm). Whereas Q-System classification can reduce total displacement effectively at fair rock mass (outlet), the value is 0.0051 m (0.51 cm). Buffer system which will be installed must refer to actual condition during excavation. Few bore hole can not figure out all condition of rock mass along diversion tunnel pathway, it only an estimation and the real condition could be different at some segments.

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