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Assessment of supporting system of Hulu Terengganu hydroelectric surge chamber cavern in Malaysia

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Abstract: When rocks are excavated, the in-situ stress is disturbed and thereby causes a state of instability due to the deformation caused by the creation of space in the in-situ rocks. This research assessed the supporting system used in a surge chamber cavern excavated for Hulu Terengganu hydroelectricity project in the northeast of Peninsular Malaysia. The results obtained were compared with the installed supports. Geological mapping of the excavated region was carried out to outline the discontinuity parameters of the rock. The rock mass quality (Q), the rock mass rating (RMR), the geological strength index (GSI) and the uniaxial compressive strength were evaluated using standard methods and procedures. The strength and rock mass properties were further used to classify the rock and establish the required standard supports for the surge chamber cavern. The wall height is approximately 40 m. It requires systematic bolting with 7 to 11 m length of rock bolt at a maximum wall spacing of 1.5 m. The required reinforce shotcrete falls within a thickness of 50-90 mm. The currently installed shotcrete is within the minimum of 50 mm thickness and has a spacing of 3.0 m along the wall which is too large for reliable safety. The cavity of the crown is critical and to consider unforeseen geological weaknesses in rock mass, maximum safety must be ensured by increasing the current thickness of the shotcrete and reducing the spacing to a maximum of 1.5 m as evaluated using the rock mass properties.

Keyword: Rock mass rating, geological strength index, deformation, shotcrete, cavern

INTRODUCTION

Large underground caverns are excavated for a variety of purposes in civil and mechanical engineering. They can be used for housing turbines, electrical generators and transformers in hydroelectric projects. Caverns are also used for storing liquid or gaseous fuels and underground sports facilities. Because of the capital-intensive nature of the project and the risks associated with public access to these facilities, adequate care must be taken in providing appropriate supports for the caverns to minimize potential risks while at the same time providing cost effective and practical engineering solutions.

As the rock mass is excavated, redistribution of the in-situ stresses occurs resulting in deformation and instability of the rock. Deformation is defined as relaxation of rock mass after the opening that caused changing in shape or size of the tunnel (Li *et al*., 2012; Xing *et al*., 2018). The deformation in a hard rock mass may be manifested as creep or displacement of the intact material along the discontinuities. In intact crystalline rocks, creeping depends on the temperature; time; shear strain and volumetric strain; effective pressure and confining pressure; moisture content and discontinuity geometry (Lacroix & Amitrano, 2013; Riva *et al*., 2018). Creeps in rock joints occur as normal compression and shear movements along the discontinuities (Mutlu & Bobet, 2006) . The movements will arise along the joint system with most unfavourable conditions and direction with respect to the excavation. This is due to the fact that the shear strength of a fracture is generally less than that of intact rock (Cowie & Scholz, 1992).

However, if appropriate supports are constantly installed at the tunnel face immediately after its excavation, the pressure increases with progress of the tunnel face and thus reducing its potential risk factors (Wu *et al*., 2015). (Barton, 2002) emphasized the necessity and increasing use of steel fiber and reinforced shotcrete in underground excavation supports. They submitted that the needed supports are related to the rock mass parameters – Geological Strength Index (GSI), Rock Mass Rating (RMR) and Rock Mass Quality (Q). The use of the Q classification system can be considerably beneficial at the preliminary design stage when less detail information on the rock mass, its state of stress and hydrologic characteristics are available (Barton, 2002).

The studied Surge Chamber Cavern (SCC) is part of the underground power station structure of Hulu Terengganu Hydroelectric Project located on northeast Peninsular in the state of Terengganu, Malaysia. It is on the upper rich of Sg. Terengganu, upper of Kenyir Lake reservoir and 100 km away from Kuala Terengganu. The Surge Chamber Cavern (SCC) is provided to protect the tailrace tunnel from water hammer effect due to fluctuation in load, it is located downstream of the draft tube and discharges into a single inclined long tailrace tunnel under pressure. The SCC has a dimension of 65 m length, 14 m width and 46 m height, constructed 200 m under surface in volcanic jointed rock. It was excavated using drilling and blasting technique from top elevation of 167.7 m to a bottom elevation of 121.5 m.

METHODOLOGY

The main objective of this study is to provide the deformation assessment of engineering geological characteristics of rock masses in the Surge Chamber Cavern (SCC) during excavation and construction until operation of power generation. For this aim, a detailed engineering geological study was carried out in the project area including field investigations, drillings and in-situ and laboratory testing; excavation monitoring comprises of geological mapping; geological over break and supporting system. Empirical and numerical analysis were also carried out.

A total of 14 hydraulic fracture tests were conducted on drill hole UT14-1D at various depths. The discontinuities intersected were analyzed and quantified. The mechanical properties of the rocks were also evaluated to obtain input parameters for the assessment of rock mass quality. The results were modeled to create approximate solutions for major principal stress, displacement of the surge chamber cavern boundary before and after installation supports.

The rock mass was classified based on the Rock Mass Quality (Q), Rock Mass Rating (RMR) and Geological Strength Index (GSI) (Hoek & Brown, 1997; Lin *et al.*, 2011; Palmstrom & Broch, 2006). Core drilling was performed to collect information about the rock mass conditions and the composition of possible weakness zones. Based on the results from the field investigations, the expected ground conditions were evaluated, and the major weakness zones localized and applied for the selection of the final tunnel (cavern) alignment. RocLab was used to evaluate the rock mass and deformation parameters based on Hoek-Brown *failure criterion* (Hoek & Brown, 1997). The strength and rock mass properties were further used to classify the rock and establish the required standard supports for the surge chamber cavern.

The discontinuities intersected were evaluated in terms of orientation, persistence, joint sets number, spacing, aperture, filling and roughness. Stereographic projection was done using Dip 6.0 from Rocscience. Laboratory tests were carried out to determine the unit weight, Young's modulus, Poisson's ratio and uniaxial compressive strength. Rock core samples were collected from borehole drilling investigations. All laboratory tests were conducted in accordance with the relevant ASTM and ISRM standards.

The Rock Mass Quality (Q) was evaluated as suggested by (Barton, 2002) using equation (1).

$$Q = (RQD/Jn).(Jr/Ja).(Jw/SRF) \tag{1}$$

Where RQD = Rock Quality Designation
Jn = Number joint sets
Jr = Joint roughness
Ja = Joint alteration
Jw = Joint water reduction
SRF = Stress Reduction Factor

To meet this end, (Hoek & Brown, 1997) produced the tables used to estimate values for these parameters. The RQD was estimated as suggested by Deere (1989). The support category was chosen based on the chart published by Barton (2002).

The following empirical relationships (Barton & Choubey, 1977) were used to evaluate bolt length as shown in equations (2) and (3):

$$L = 2+(0.15H/ESR) \text{ (For wall)} \tag{2}$$
$$L = 2+(0.15B/ESR) \text{ (For roof)} \tag{3}$$

Where, B = tunnel width, H = tunnel height and ERS = Excavation Ratio Support

RESULTS AND DISCUSSION

Tables 1, 2 and 3 show the summarized average values of rock mass quality (Q), Rock Mass Rating (RMR) and Geological Strength Index (GSI) respectively for nine various positions tested.

The rock strength and deformation parameters as obtained using RocLab is presented in Table 4.

Table 5 compares the installed supports at the site and the one evaluated in this research.

The result has summarized that SCC condition is a good rock with UCS of 50 to100 MPa, good RQD, joint spacing 60 cm to 2 m, slightly rough surfaces, low filling, dry and fair in orientation.

The support category based on Q assessment summaries the SCC has value 12 with rock class is good. The SCC has a crown 12 m of height, as required support

Table 1: Average Q value at 9 various positions in the SCC.

Description/ Rating	RQD %	Joint Set, Jn	Joint Roughness, Jr	Joint Alteration, Ja	Joint Water, Jw	SRF	Q
Description	75 - 90	2-3 Joint set + random	Rough to smth, undulating, slickenside	Slightly alter., little filling	Dry (minor inflow <5l/min)	Med. stress, favourable	Good
Rating	79	6.8	1.4	1.1	1	1.7	Good 12

Table 2: Averages RMR rating at 9 various positions in the SCC.

Description / Rating	UCS MPA	RQD %	Joint Spacing, m	Condition of Discontinuities	Ground Water	Orientation	RMR	Cohesion Mpa	Friction Angle, °
Description	50-100	75-90	0.6 - 20, some less 0.6	Slightly rough, low fill, slickenside	Dry	Fair	Good rock	0.339	39
Rating	7	17	14	19	15	-5	66		

Table 3: Average GSI rating at 9 various positions in the SCC.

Description / Rating	Roughness Rating (Rr)	Weathering Rating (Rw)	Infilling Rating (Rf)	SCR= $R_r+R_w+R_f$	Structure Rating (SR)	GSI	Rock Condition	Classification
Description	Smooth to slighty rough	Fresh to slighty rough	Hard > 5mm	Good, smooth slight w.	Blocky, less joint	60	Blocky	Good
Rating	2.0	5.8	4.7	12.4	62.5			

Table 4: Summary Rock Mass Strength and deformation parameters.

Rock Type	Deformation Modulus, Mpa	Friction Angle (deg.)	Cohesion, Mpa	UCS (Mpa)	Tensile Strength, Mpa
Undisturbed	33,800	55	1.7	8.026	0.267
Disturbed	11,106	48	1.1	3.561	0.086

Table 5: Supporting applied on site and calculation based on Q-value.

Position	Length of rockbolt, m	Spacing, m	Thickness of shotcrete, mm	Remark
Crown	6	2	100 reinforce (SRF)	Applied on site
Wall	6	3	50 reinforce (SRF)	
Crown	3 - 5	systematic	Un-reinforce 40 - 100	Evaluated Q-value, (Borton's)
Wall	7 - 11	1.3 - 1.5 m	Reinforce 50-90	

in crown are 4.0 m long and systematic rock bolts with unreinforced shotcrete 40-100 mm of thickness. The crown of the cavity is critical and to consider unforeseen geological weaknesses in rock mass. 100 mm thick SFR-40 shotcrete and rock bolts Type R4, 6.0 m long at 2.0 m spacing were currently applied on site.

The height of the wall is 40 m. The systematic support system requires a rock bolt of length 7 to 11 m to be installed at a maximum of 1.5 m wall spacing. The required reinforce shotcrete falls within a thickness of 50-90 mm as shown in Table 5. The currently installed shotcrete is within the minimum of 50 mm thickness and has a spacing of 3.0 m along the wall which is considerably too large for dependable safety. The cavity of the crown is dangerous and to consider unforeseen geological weaknesses in rock mass, maximum safety must be ensured by increasing the current thickness of the shotcrete and reducing the spacing to a maximum of 1.5 m as evaluated using the rock mass properties.

CONCLUSION

The rock mass has been classified based on the Q, RMR, and GSI classification systems as good rock. The strength and deformation parameters of rock mass from empirical correlation have varying results. The orientations of the discontinuities and the state of the in-situ stresses of the surge chamber is significantly affecting its stability. The supporting system requires more reinforcement at smaller spacing to ensure the stability of the wall and roof of the excavated Surge Chamber Cavern for enhanced safety.

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REFERENCES

Barton, N., 2002. Some new Q-value correlations to assist in site characterisation and tunnel design. Int. J. Rock Mech. Min. Sci., 39, 185-216. https://doi.org/10.1016/S1365-1609(02)00011-4.

Barton, N. & Choubey, V., 1977. The shear strength of rock joints in theory and practice. Rock Mech., 10, 1–54. https://doi.org/https://doi.org/10.1007/BF01261801.

Cowie, P.A. & Scholz, C.H., 1992. Physical explanation for the displacement-length relationship of faults using a post-yield fracture mechanics model. J. Struct. Geol., 14, 1133–1148. https://doi.org/10.1016/0191-8141(92)90065-5.

Deere, D.U., 1989. Rock Quality Designation (RQD) After Twenty Years, Contract Report GL-89-1. https://doi.org/10.1016/B978-0-12-385878-8.00004-5.

Hoek, E. & Brown, E.T., 1997. Practical estimates of rock mass strength. Int. J. Rock Mech. Min. Sci., 34, 1165–1186. https://doi.org/10.1016/S1365-1609(97)80069-X.

Lacroix, P. & Amitrano, D., 2013. Long-term dynamics of rockslides and damage propagation inferred from mechanical modeling. J. Geophys. Res. Earth Surf., 118, 2292–2307. https://doi.org/10.1002/2013JF002766.

Li, Z.H., Feng, X.T., Li, S.J., Zhou, H., Chen, B.R., Zhang, C.Q. & Hu, S., 2012. Contribution to damaged formation and evolution of time behavior during the deep buried tunnel excavation. In: Rock Mechanics: Achievements and Ambitions - Proceedings of the 2nd ISRM International Young Scholars' Symposium on Rock Mechanics.

Lin, D.-M., Shang, Y.-J., Sun, F.-J., Sun, Y.-C., Wu, F.-B. &Liu, Z.-Q., 2011. Study of strength assessment of rock mass and application. Yantu Lixue/Rock Soil Mech., 32.

Mutlu, O. & Bobet, A., 2006. Slip propagation along frictional discontinuities. Int. J. Rock Mech. Min. Sci., 43, 860–876. https://doi.org/10.1016/j.ijrmms.2005.11.012.

Palmstrom, A. & Broch, E., 2006. Use and misuse of rock mass classification systems with particular reference to the Q-system. Tunn. Undergr. Sp. Technol., 21, 575–593. https://doi.org/10.1016/j.tust.2005.10.005.

Riva, F., Agliardi, F., Amitrano, D. & Crosta, G.B., 2018. Damage-Based Time-Dependent Modeling of Paraglacial to Postglacial Progressive Failure of Large Rock Slopes. J. Geophys. Res. Earth Surf., 123, 124–141. https://doi.org/10.1002/2017JF004423.

Wu, X., Liu, H., Zhang, L., Skibniewski, M.J., Deng, Q. & Teng, J., 2015. A dynamic Bayesian network based approach to safety decision support in tunnel construction. Reliab. Eng. Syst. Saf., 134, 157–168. https://doi.org/10.1016/j.ress.2014.10.021.

Xing, Y., Kulatilake, P.H.S.W. & Sandbak, L.A., 2018. Effect of rock mass and discontinuity mechanical properties and delayed rock supporting on tunnel stability in an underground mine. Eng. Geol., 238, 62–75. https://doi.org/10.1016/j.enggeo.2018.03.010.

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