GEOMECHANICAL INFLUENCE ON ROCKMASS DEFORMATION AT HULU TERENGGANU HYDROELECTRIC POWER SURGE CHAMBER CAVERN

MOCHAMAD TRISUGIWO

UNIVERSITI SAINS MALAYSIA

2017

GEOMECHANICAL INFLUENCE ON ROCK MASS DEFORMATION AT HULU TERENGGANU HYDROELECTRIC POWER SURGE CHAMBER CAVERN

by

MOCHAMAD TRISUGIWO

Thesis submitted in fulfillment of the
requirements for the degree of
Master of Science

April 2017

ACKNOWLEDGMENTS

First, I would like to thank the Almighty God for His infinite mercy and protection upon the accomplishment of my study. I would like to express my sincere thanks to my supervisor Prof. Fauziah Binti Ahmad and co supervisor DR. Hareyani Binti Zabidi for their wonderful supervision and their unrelenting support, expert guidance, valuable comments and critical review and constant encouragement throughout the course of this research.

Very special thanks to all staff of SNC Lavalin and TNB for Hulu Terengganu Hydro Electric Project in Terengganu for their contribution in informative support data and facilitation during my research.

Finally, I most gratefully acknowledge my beloved wife & children and friends for all their supported throughout the period of this research.

Sincerely,

Mochamad Trisugiwo

School of Civil Engineering
Universiti Sains Malaysia
2017

TABLES OF CONTENTS

		Page
ACKNOWLEDGEMENTS		ii
TABLE OF CONTENTS		iii
LIST OF TABLES		viii
LIST OF FIGURES		xi
LIST OF SYMBOLS		xix
LIST OF ABBREVIATIONS		xxi
ABSTRAK		xxii
ABSTRACK		xxiii
CHAPTER ONE: INTRODUCTION		
1.1	Background of Study	1
	1.1.1 Geomorphology	3
	1.1.2 Geology	4
1.2	Problem statement	8
1.3	Research Objectives	10
1.4	Scope of Research	10
	1.4.1 Scope of the Work	11
1.5	Thesis Outline	11
CHAPTER TWO: LITERATURE REVIEW		
2.1	Introduction	13
2.2	Deformation in Excavation of Surge Chamber Cavern	16
	2.2.1 Definition of Deformation	16

2.2.2 Previous Researches of Deformation 17

2.3 Rock Mass Classification 19

2.3.1 Rock Mass Rating (RMR) 19

2.3.2 Rock Mass Quality (Q system) 20

2.3.3 Geological Strength Index (GSI) 22

2.3.4 New Austrian Tunneling Method (NATM) 22

2.4 Numerical Analyses Method 24

2.4.1 Finite Element Method 24

2.4.2 Boundary Element Method 25

2.4.3 Discrete Element Method 25

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Field Data Collection 29

3.1.1 Surface and Drilling Investigation 29

3.1.2 Geological Mapping 30

3.1.3 Stereographical Projection 32

3.1.3(a) Dip 33

3.1.3(b) Unwedge 38

3.1.4 In-situ Stress Test 42

3.1.4(a) Equipment 44

3.1.4(b) Investigation Procedure 44

3.1.4(c) Data Analysis 47

3.1.4(d) Laboratory Testing 49

3.1.4(e) Discussion 51

3.2 Laboratory Testing 56

3.2.1 Unconfined compressive Test (UCS) 57

3.2.2 Bulk Density 59

3.3 Rock Mass Properties 60

3.3.1 Rock Mass Quality (Q) System 60

3.3.2 Rock Mass Rating (RMR) System 64

3.3.3 Geological Strength Index (GSI) 66

3.3.4 New Austrian Tunneling Method (NATM) 67

3.4. Empirical Analysis 69

3.4.1 Correlation between RMR, Q, GSI and NATM 69

3.4.2 Estimation of Rock Mass Strength and Deformation 71

3.5 Numerical Analysis 72

3.5.1 Phase2 Model 74

3.5.2 RocLab 80

3.6 Instrumentation Monitoring in Cavern 87

3.6.1 Optical Target 88

3.6.2 Multi Point Borehole Extensometer 92

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Geology of Study 97

4.1.1 Geological Face Mapping 100

4.1.2 Structural Geology 101

4.2 Laboratory Result 103

4.2.1 Unit Weight 103

4.2.2 Uniaxial Compressive Strength Test 103

4.3 Analysis of Joints and Failures by Wedges 105

4.3.1 Joint Analysis 105

4.3.2 Interpretation based on dips Analysis 106

4.3.3 Failure (Geological over break) 109

4.4 Rock Mass Classification 118

4.4.1 Q system 118

4.4.2 Rock Mass Rating (RMR) 120

4.4.3 Geology Strength Index (GSI) 124

4.4.4 New Austrian Tunnel Method (NATM) 125

4.4.5 Summary and Discussion of Rock Mass Classification 128

4.5 Excavation and Support 129

4.5.1 Excavation1 129

4.5.2 Supporting 129

4.6 Empirical Analysis 132

4.6.1 Support 132

4.6.1(a) Bolt Length 132

4.6.1(b) Support Pattern 132

4.6.1(c) Discussion of Support 133

4.6.2 Rock Mass Properties 135

4.6.2(a) Deformation Modulus of Rock Mass (E_d) 135

4.6.2(b) Compressive Strength of Rock Mass (σ_{cm}) 136

4.6.2(c) Elastic modulus of rock material 136

4.6.2(d) Tensile Strength of Rock Mass (σ_{tm}) 136

4.6.2(e) RocLab Program 137

4.7 Numerical Analysis 139

4.8 Instrumentation 144

4.8.1 Interpretation Analysis 144

4.8.2 Discussion of Instrument Result 149

4.9 Discussion 158

4.9.1 Evaluation Geomechanical and Insitu Stress of SCC 158

4.9.2 Empirical Analysis Method of Rock Deformation 161

4.9.3 Comparison Numerical Analysis and Deformation 164

CHAPTER FIVE – CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion 167

5.2 Recommendations 169

REFFERENCES 170

APPENDICES

Appendix A [Face Mapping and Rock Mass Classification based on Q-System, RMR & GSI]

Appendix B [Hoek-Brown Failure Criterion-2002 Edition]

Appendix C [Multi Points Borehole Extensometer (MPBX) Monitoring Records].

Appendix D [Cover of Book Reference].

LIST OF PUBLICATION

LIST OF TABLES

		Page
Table 2.1	List of empirical equations suggested for estimating the deformation modulus with required parameters and limitations (Sönmez and Ulusay, 2007)	18
Table 3.1	Summary Joint Sets resulted for dip program analysis.	38
Table 3.2	Summary of salient data used for analysis	48
Table 3.3	The result of hydrofrac analysis of borehole UT14/1D for each depth.	53
Table 3.4	Summary result of in-situ stress test surround power station.	55
Table 3.5	Excavation support categories and their ESR values (After Barton et al., 1974)	62
Table 3.6	Rock mass classes are based on Q-value from face mapping record.	63
Table 3.7	Rock mass class and guidelines for Excavation and Support of 10 m span rock tunnels in accordance with the RMR System (Bieniawski, 1989)	65
Table 3.8	NATM Rock Mass Classes (Geoconsult, 1993 and ONORM B 2203, 1994)	68
Table 3.9	Empirical equation by originator	70
Table 3.10	Correlations between classification systems (RMR,Q and NATM)	70
Table 3.11	RocLab parameter with undisturbed rock mass. Disturbance factor (D) = 0	82
Table 3.12	RocLab parameter with disturbed rock mass, Disturbance factor (D) = 0.8.	83
Table 3.13	Optical measurement record for convergence monitoring.	89
Table 3.14	Optical measurement record for displacement monitoring	90
Table 3.15	Raw data from site field book of MPBX.	92
Table 3.16	Movement relatively between the instrument head and each anchor of MPBX.	93
Table 3.17	Movement of the instrument of MPBX, head and anchors relative to anchor 3 were in stable ground.	93

Table 4.1	Properties of drilling Investigation surround Power station especially to Surge Chamber Cavern (SCC).	96
Table 4.2	The Summary of geotechnical description and discontinuity condition the Surge chamber Cavern	100
Table 4.3	The Summary rock mass characteristic using Q-system classification in the Surge Chamber Cavern,	100
Table 4.4	Measuring and description of joints in the SCC, total 188 joints	103
Table 4.5	The Summary Laboratory result on variation depth Surround Surge Chamber Cavern	104
Table 4.6	Five Joint Sets and properties based on *dips* analyse (Rocscience, 2014).	107
Table 4.7	Summary input parameter for wedge analysis	110
Table 4.8	Summary of wedge analysis defined 8 wedges which is every wedge have weight, apex height, position at SCC and factor of safety	112
Table 4.9	The summary rock mass characteristic using Q-system classification in the Surge Chamber Cavern	120
Table 4.10	Average of Q value of nine various positions as represent in the SCC	120
Table 4.11	Summary of RMR has descripted and rated of eight parameters at nine various positions in the SCC	121
Table 4.12	Averages of RMR rating has described and rated base of eight parameters at nine various positions in the SCC	121
Table 4.13	Summaries of GSI based on five parameters at nine various positions in the SCC	123
Table 4.14	Averages of GSI rating has described and rated base of five parameters at nine various positions in the SCC	123
Table 4.15	NATM Rock Mass Classes (Geoconsult, 1993 and ONORM B	126
Table 4.16	Correlation between classification systems (Q, RMR and NATM	127
Table 4.17	Average calculated Rock Mass Quality (Q) assessment (top) and Rock Mass Rating (RMR) assessment and GSI assessment	128

Table 4.18	The properties of rock bolts applied on site	131
Table 4.19	The properties of Shotcrete applied on site	131
Table 4.20	The summary of excavation and supports have installed in the SCC. Form El.167 to 116.5 has removed 32,739 m³ muck material,	131
Table 4.21	Supporting applied on site and calculation based on Q-value	134
Table 4.22	Summary Rock Mass Strength and Deformation Parameters based RocLab	137
Table 4.23	Summary input parameters for numerical modelling of the SCC.	139
Table 4.24	The Rock Mass Properties in SCC	158
Table 4.25	The in-situ stresses surround the SCC	159
Table 4.26	The Rock Mass Properties in Nathpa Jhakri Hydroelectric.	160
Table 5.1	Comparison displacement between *phase*^{2} model and MPBX in the SCC	169

LIST OF FIGURES

		Page
Figure 1.1	Location Hulu Terengganu HEP in state of Terengganu Malaysia, Underground Power station in red circle, (Documentation of Hulu Terengganu HEP).	2
Figure 1.2	Underground Powerhouse Station of Hulu Terengganu HEP comprises: Penstock; Transformer Hall; Powerhouse Cavern; Surge Chamber Cavern (SCC); Draft Tube; and some Access Adits. The study area is in Surge Camber Cavern.	2
Figure 1.3	Layout underground powerhouse station of Hulu Terengganu HEP comprises Powerhouse cavern, headrace, draft tube, Surge Chamber Cavern (blue box) and tailrace tunnels	3
Figure 1.4	The regional geological map of Peninsular Malaysia scaled 1:1000.000, and project location (X) in between Lebir fault and Terengganu fault. (Geological Society of Malaysia, 2009)	5
Figure 1.5	General geological map of the project consist: Southern part as main project include Puah dam, Spillway, Power intake, Diversion tunnel, Underground Power Station and Outlet tunnel (in the red box); Northern Part are Tembat Dam, Headrace tunnel and surface Powerhouse. The rock formation are Sedimentary rock on Western, volcanic rock in middle part and argillite-silt-sandstone with granite intrusive at eastern. Note: The red box as detail of Figure 4.3 (Feasibility Study Vol.4A, Geology).	6
Figure 1.6	Geological Map on Puah area (main) Project of Hulu Terengganu HEP on the types of rocks are sedimentary rock on western; volcanic rock on eastern and Intercalation zone in between (dot line). The bedding has striking NW-SW and very steep dipping to SE. The Surge Chamber Cavern (SCC) is in power station at downstream site of Powerhouse (Rock Properties for Design. Hulu Terengganu HEP, 2011).	7
Figure 1.7	Rock foundation on Puah Dam river bed: The Intercalation zone comprises: andesitic agglomerate, carbonaceous shale-sandstone interbedded, andesitic tuff (A); Interbedded siltstone and laminated shale (B); andesite and shale in calcareous matrix and solution pipe (C).	7
Figure 1.8	Squeezing deformation rock reduces the tunnel cross section in the Saint Martin La Porte access adit, Turin Base Tunnel – Lyon Italy (Koshboresh AR., 2010). Supporting shotcrete and rock bolting at second layer	9

Figure 1.9	Surge Chamber Cavern during excavation (left) and after excavation with supported (right) showed some geological overbreaks (failures, yellow arrow) during and after excavation. The cavern shows "buckling" condition at both sides of the middle of long wall (down and up-stream).	9
Figure 2.1	Characteristics of rock creep (deformation): (a) Phenomenological behaviour of rock under uniaxial tension, (b) Typical creep behaviour under confining stresses. (After Dusseault & Fordham, 1993)	17
Figure 2.2	The basic structure of the Hoek and Sonmez (2001) GSI chart and possibility for quantification.	23
Figure 3.1	The research flow from data, characterizations and method to get the result for analysing on Geomechanical influence on rock mass deformation at SCC.	28
Figure 3.2	The Q-system tunnel reinforcement design chart (after Grimstad and Barton, 2003)	32
Figure 3.3	The steps creating Dips file, (A) Setup Job control include Project title, format of Global orientation, degree of declination, and Quantities Column; (B) Traverse ID; and (C) Filling, Add and Edit Column.	35
Figure 3.4	The shortcut of choices views (A); View of Scatter Plot (B); Contour Plot (C); and Rosette Plot (D).	35
Figure 3.5	Add Set Window dialog (A), Set Window by wrapping and unweight mean pole / plane displayed as set 1(B).	36
Figure 3.6	The Major Planes Plot option in *Dips* allows viewing PLANES ONLY (B) on a clean stereonet, with poles and contours wrapped (A).	37
Figure 3.7	Project setting comprises: Project title; unit, in case use matric, stress as Mpa as base of calculation in this study. The Q-system tunnel reinforcement design chart (after Grimstad and Barton, 2003)	39
Figure 3.8	A) Coordinates in the prompt line at the button right of the screen, (B) excavation boundary defined in Opening Section View	40
Figure 3.9	Input Data, (A) General, (B) Joint orientations (from Dips result) and selection of many joint combination of wedge, in accordance to site condition, most suitable was combination no. 2 which are joint sets 1,2 and 4 of 20 variations of joint combination. (C) Joint Properties.	41

Figure 3.10	: (A) perspective view, the Unwedge model can be rotated for viewing at any angle interactively with the mouse left button, (B) a 3-dimensional Perspective view and three orthogonal views, in this case Top, Front and Side views of the excavation.	42
Figure 3.11	A sample accessories equipment for hydrofracture test (A) Impression packer to know the fracture orientation; (B) Schematic diagram of Hydrofrac Experiment Set-up (Subrahmayam, 2013).	45
Figure 3.12	A sample typical hydro fracture test showing the graph of injected pressure and flow rate vs. Time (Hydrojacking at Hulu Terengganu, 2014).	46
Figure 3.13	A). Laboratory sample geometry, B) Laboratory testing procedure, C) Typical results of laboratory testing. (Hydraulic Fracture Stress, Hulu Terengganu, Feasibility Report 1997	50
Figure 3.14	Result of laboratory strength testing (Hydraulic Fracture Stress Hulu Terengganu Feasibility Report 1997).	51
Figure 3.15	Summary of result of analysis of field tests plotted on depth and stresses value in (MPa). Three vertical zone based on horizontal stress field orientation which the lowest stress magnitude (Test #8) possibly representation a transition between the upper and lower data sets.	55
Figure 3.16	The average orientation of *Horizontal stress* (σ_H) for the upper part (X-X^1 has orientation 95° to 115°), while at the lower has direction (Y-Y^1, has orientation 130° to 160°). The stress relief in direction Y-Y^1 having more impact than stress relief in direction X-X^1.	56
Figure 3.17	The average orientation of *Horizontal stress* (σ_H) for the upper part ("Orange" has orientation 95° to 115°), while at the lower has direction ("Blue", has orientation 130° to 160°. The stress relief in direction *YY^1 (blue) was having more impact* than stress relief in direction XX^1 (brown). *The average direction of Maximum Horizontal Principle Stress was N145°.*	47 54
Figure 3.18	UCS Test (A) core of intact rock under compress tool, (B) broken rock sample after compressed	60
Figure 3.19	Suggested Q-support chart for selecting permanent support, Bolts and Shotcrete reinforcement for tunnels or caverns in rock. The black, highlighted areas show where estimated Q-values (Barton, 1993)	63
Figure 3.20	Project Setting Phase2 model. Select Project Setting dialog (B)	74

and fill in data on (A) and then click OK.

Figure 3.21 Steps of boundaries excavation with fill the ordinate of each border for SCC 75

Figure 3.22 Mesh Setup (A) and (B) Result of boundaries 76

Figure 3.23 Field Stress Properties from in-situ stress prior to excavation 77

Figure 3.24 Define Material (Rock Mass) Properties (A) Entering dialog box (B) 77

Figure 3.25 Assign Properties (A); dialog box (B); excavated boundary result (C) 78

Figure 3.26 The Major Principal Stress 79

Figure 3.27 RocLab graph with undisturbed rock mass, *Disturbance factor (D) = 0,* by clicking the side bars to fill value of *sigci, mi, GSI, D and MR* based selecting an existing valuable data.
(A) Input Parameter for Hoek-Brown criterion, by clicking the side bars to fill value of *sigci, mi, GSI, D and MR* based selecting an existing valuable data 83

Figure 3.28 RocLab graph with *disturbed rock mass*, *Disturbance factor (D) = 0.8.* 84

Figure 3.29 (A) Input Parameter for Hoek-Brown criterion, by clicking the side bars to fill value of *sigci, mi, GSI, D and MR* based selecting an existing valuable data. 85

Figure 3.30 (A) Cavern cross section at Ch. 0+16.8with optical targets (red dots) and extensometer (blue lines); (B) Optical targets (white points) on excavation stage 88

Figure 3.31 (A) Measurement of 3D optical targets; (B) Point target P1,P2…P5, as displacement points or also as convergence points as required 88

Figure 3.32 Convergence monitoring graph 89

Figure 3.33 Displacement monitoring graph 90

Figure 3.34 The sketch of typical Multi Point Borehole extensometer (MPBX) and located on crown and or on the wall of cavern (Monthly report Hulu Terengganu HEP 2014). 92

Figure 3.35 Graph showed movement of the head and anchors relative to anchor 3 in stable ground 94

Figure 4.1	Cross section position of to Surge Chamber Cavern (SCC) and drilling investigation surround power station in the volcanic andesitic rock. The SCC constructed at elevation 167.7 ~ 121.5 m; has % RQD value excellent (≈100%) as shown in Appendix A-A5 and A-A6.	96
Figure 4.2	Rock Foundation on invert of SCC: The massive Andesitic TUFF strong and fresh with Calcite seam (A), Andesitic Agglomerate [Ignimbrite] strong and fresh (B). No contact bedding. Polished core showed matric and clasts has welded as agglomeratic texture, (C)	97
Figure 4.3	Rock mass on upstream wall (A) and downstream Wall (B) with some geological over- breaks (yellow triangle) due to wedges of vertical joints	98
Figure 4.4	Rock mass on upstream wall (right) and downstream wall (left) and right wall D shape in middle. The vertical joints are dominant at both the walls with some geological over- breaks	98
Figure 4.5	Geological Map, Developed Tunnel Plan of SCC Project Hulu Terengganu HEP. *The jointed volcanic rock* (andesitic agglomerate-tuff*)*, at least four joint sets, and the main joints are closed joints intersect tunnel axis nearly perpendicular to SCC axis with very steep dipping to northern	98
Figure 4.6	Peninsula has divided into three major belts, Western, Middle and Eastern (left). The project area (crossed circle) is in Eastern Belt in between **Lebir fault** and **Terengganu fault** on Seismotectonic Map of Peninsular Malaysia (DMGM, 2008) **.**(right). Rose diagram shows the frequency of all major lineament ***(faults)*** direction (from RADARSAT imagery of the Peninsula)	94 94
Figure 4.7	A) The Contour plot shows most concentrate on North-East part as J1, the Planes are shown joint sets: in blue (J1); red (J2), green (J3); black (J4) and grey (J5). The red BOLT is SCC axis. B) Shown density of concentration	95
Figure 4.8	A) Rosette Diagram indicate density of strike it was NNW – SSE and NNE – SSW which was near parallel to Horizontal stress. B) summary the orientation of Horizontal Stress; Major Joint Sets and Regional Lineaments to the Axis of Surge Chamber Cavern (SCC)	97
Figure 4.9	**A)** Theoretical of north-south primary compression resulting first-second and third order fault and associated fold direction (after Moody and Hill). **B)** Major Lineament (white line) that is interpreted as faults based RADARSAT imagery of Peninsula; Rose diagram shows the frequency of all directions. X is location	101

of project

Figure 4.10 Joint sets as wedges **A)** Three Joint sets on downstream wall Elv. 140-136, Ch.0+15-20 **B)** Three joint sets on Downstream wall at EL 143-127, Ch. 0+13 – 0+18 The joint sets J1= 83/245; J2= 74/316; J4= 22/242 and J5= 55/79. 109

Figure 4.11 A) Selection of joint combination, the combination J1/J2/J4 of 20 has selected. B) Wedge 2,7 and 9 as possible failure and happened on site 111

Figure 4.12 3D Wedge view resulted from wedge analysis has defined 8 wedges which are wedge 2, 7, 9, 10, 1, 5, 8 and 4. The wedges 2, 7 and 9 happened as failures on site 112

Figure 4.13 Some Geological over-breaks on the wall of SCC as such in model. The position of the over break has illustrated in Figure 4.15. 114

Figure 4.14 Biggest geological overbreak, 249m³ at EL 143-127 Ch. 0+13 – 0+18 Downstream wall. As wedge no.2, comprises combination J1, J4 and J2. The collapse happened after completed support in the SCC, the other hand Draft Tube Tunnel just opened. 113

Figure 4.15 Section along centre line of SCC, the view to wall. Position of major geological over-breaks were interpreted, on the upstream wall (blue); on the downstream wall (red) and on right wall / end of wedge (yellow). 116

Figure 4.16 Orientation of Surge Chamber Cavern (SCC) to the Horizontal Stress as Main Stress; Regional Lineaments and Major Joint. 117

Figure 4.17 Form of geological face mapping record (sample) shows Rock mass characteristic using nine parameter of Q-system classification, Q value= 25; rock classification = B. The Q-value was proposed to determined rock classification and suggested support type. 119

Figure 4.18 Form of geological face mapping based on RMR to determined rock class and predicted rock mass properties Cohesion; friction angle and Deformation Modulus empirically. 115

Figure 4.19 A sample form of classification rock mass based on GSI as very good and blocky rock, GSI= 65 124

Figure 4.20 The systematic support comprises: Shotcrete Fiber Reinforce (SRF)-40S shotcrete (**100 mm** in thickness) and R4-**6m** rock bolt (**2.5m** spacing) on Vault; SRF-40S shotcrete (50mm in thickness) R4-6m rock bolt(3m spacing) on four side walls; and R1-4m random rock bolt (3m spacing) if required. (A) view to 130

upstream wall and (B) section 4 view to left wall

Figure 4.21 Support category chart indicating SCC roof= 4 and wall= 5 (in the red box. **Noted:** ESR=1 for chamber 134

Figure 4.22 RocLab programme strength and deformation parameters of rock mass for undisturbed rock mass *D=0.8*. 138

Figure 4.23 Excavation boundaries at Power station cavern from left to right are: Transformer Cavern; Powerhouse Cavern and Surge Chamber Cavern 141

Figure 4.24 Maximum principle stress as *sigma1* surrounds Power station after excavation of SCC on right crown, magnitude was 18 MPa, upstream wall 57 MPa and 2.8 MPa 142

Figure 4.25 : Minor principle stress as *sigma3* around Power Station cavern after excavation. The magnitude of minor principle stress was 0.0 MPa on both the wall while on the crown 1.75MPa. 142

Figure 4.26 Total displacement around the opening after the excavation was 5 mm on downstream wall (D/S) of SCC while on upstream (U/S) wall and crown were only 2 mm. 143

Figure 4.27 Deviatoric stress [$\sigma_1 - \sigma_3$] around the opening indicated that stress concentration on surround the crown ~ right shoulder maximum 12 MPa. 143

Figure 4.28 Position of Instrumentations in SCC as shows on profile of downstream-upstream wall plan view and cross section at Ch. 16.8m; Optical target (red dot) for Displacement and Convergence monitor and Borehole Extensometer (blue lines or blue box) for rock mass deformation 148

Figure 4.29 Illustration of displacement based on monitoring record, the convergence movement of long wall (upstream and downstream wall) at A, cross section. The divergence movement on roof (arch/crown) and left/right walls at B (longitudinal section) of Surge Chamber Cavern (SCC) 149

Figure 4.30 Borehole Extensometer No.M4-1 at Ch.16.8 El. 167 on Crown 151

Figure 4.31 Borehole Extensometer No.M4-2 at Ch.16.8 El. 162 D/S wall 152

Figure 4.32 Borehole Extensometer No.M4-3 at Ch.16.8 El. 162 U/S wall 153

Figure 4.33 Borehole Extensometer No.M4-4 at Ch.21.4 El. 148 Right wall 154

Figure 4.34 Borehole Extensometer No.M4-5 at Ch.16.8 El. 142 D/S wall 155

Figure 4.35	Borehole Extensometer No.M4-6 at Ch.16.8 El. 142 U/S wall	156
Figure 4.36	Borehole Extensometer No.M4-7 at Ch.34.7 El. 162 Left wall	157
Figure 4.37	Two underground cavern D shapes have physically near same rock mass properties but applied different supporting in quality and quantities, on B has rock bolt closer in spacing and bigger diameter was success to minimize failure	160
Figure 4.38	The eight wedges position are wedge 2,7,9,10,1,5,8 and 4; the wedges at position 2, 7 and 9 have been happened as failures or collapses during and after excavation as shown in Figure 4.13 and 4.14.	163
Figure 4.39	Displacement in Phase^2 model (A) and displacement in the SCC based on monitoring data on the Crown and Upstream and Down Stream wall.	164

LIST OF SYMBOLS

A	Empirical constant for equation
a	Empirical constant for equation
B	Width of tunnel for equation
B	Empirical constant for equation
c	cohesion (kPa)
Cg	Competency factor
D	Disturbance factor
D_b	Block diameter
D_e	Equivalent dimension of excavation
ESR	Excavation support ratio
E_i	Young's modulus
E_m	Deformation modulus of rock mass (GPa)
E_d	Deformation modulus of rock mass (GPa)
FS	Safety factor
f_σ	Massivity parameter
H	Height of the overburden
JC	Joint conditions
JP	Jointing parameter
J_a	Joint alternation number
J_n	Joint set number
J_r	Joint roughness number
J_v	Volumetric joint count
J_w	Joint water reduction number
jA	Joint alteration

jL	Joint length
jR	Joint roughness
K	Horizontal to vertical stress ratio
k	Stress ratio
m_i	Hoek and Brown constant of intact rock
m_j	Hoek and Brown constant of rock mass
P_{roof}	Support pressure on roof
Q	NGI tunneling quality index
Q_c	Normalization of Q value
Q_N	Stress free from Q
s_i	Hoek and Brown constant of intact rock
Sj	Hoek and Brown constant of rock mass
V_b	Block volume
W	Width of opening
Φ	Internal friction angle (o)
β	Block shape factor
γ	Unit weight or density of rock
υ	Poisson's ratio
σ_{cm}	Uniaxial compressive strength of rock mass
σc	Uniaxial compressive strength of intact rock (MPa)
σh	Horizontal stress (MPa)
σv	Vertical stress (MPa)
$\sigma_{\theta roof}$	Tangential stress at roof
$\sigma\theta wall$	Tangential stress at wall

LIST OF ABBREVIATIONS

GSI	Geological Strength Index
RMi	Rock Mass index
RMR	Rock mass rating value
RQD	Rock Quality Designation
SCR	Surface Condition Rating
SR	Structure Rating
SRF	Stress Reduction Factor.
Sr	Size ratio
Sg	Sungai
UCS	Uniaxial Compressive Strength
URCS	Unified Rockmass Classification System
WCS	Weakening coefficient system

PENGARUH GEOMEKANIKAL PADA PERUBAHAN BENTUK JASAD BATUAN TENAGA HIDRO ELEKTRIK GEGOA KEBUK PASUAN HULU TERENGGANU

ABSTRAK

Kebuk Pasuan (Surge Chamber Cavern: SCC) adalah sebahagian daripada stesen kuasa bawah tanah Projek Hulu Terengganu Hydro Electric (HEP) disediakan untuk melindungi terowong Tailrace daripada kesan pukulan kerana bebanan turun naik air; ia terletak di bahagian hilir daripada rumah kuasa dan pelepasan di bawah tekanan ke terowong panjang Tailrace. SCC mempunyai bentuk D dengan dimensi lebar 14 m, tinggi 46 m, panjang 65 m dan dibina 200 m di bawah permukaan.

Permasalahannya ialah SCC digali dalam formasi batuan gunung berapi dicirikan mengandungi kekar, isotropi, homogen, dan bertekanan. Kehadiran 'lengkokan' di bahagian tengah dinding panjang, beberapa kegagalan seperti lampau-pecah secara geologi dan SCC telah dibina tanpa sokongan lapisan konkrit.

Objektif kajian adalah bertujuan pengelasan ciri batuan, sifat mekanik, dan keadaan tekanan in-situ jisim batuan; menganalisis kesan jisim batuan; dan membandingkan antara analisis baerangka dan pemantauan akibat perubahan bentuk daripada SCC. Daripada mengumpulan data tapak , uji makmal dan analisis dengan perisian *Dip*, *Unwage* dan *Phase*^{2} untuk analisis secara berangka..

Dari kajian ini telah dibuat kesimpulan bahwa kualiti batuan baik, telah mengalami perubahan bentuk digambarkan dibahagian dinding SCC sebagai lengkokan, beberapa lampau-pecah secara geologi / runtuhan dan rayapan. Anjakan maksimum adalah 25.65 mm dibahagian tengah dinding panjang, Puncak anjakan berlaku dalam tempoh penggalian dan masih menerus sebagai rayapan dan bergerak kurang atau sama dengan 0.05 mm per bulan.

GEOMECHANICAL INFLUENCE ON ROCK MASS DEFORMATION AT HULU TERENGGANU HYDROELECTRIC POWER SURGE CHAMBER CAVERN

ABSTRACT

The Surge Chamber Cavern (SCC) as part of underground power station in Hulu Terengganu Hydro Electric Project (HEP) is provided to protect the tailrace tunnel from water hammer effect due to fluctuation of water. The SCC is located is located downstream of the powerhouse and discharges in to a single inclined long tailrace tunnel under pressure. The SCC has D shape with dimension of 14 m span, 46 m high, 65 m length and constructed 200 m under surface.

The problem statements are the SCC was excavated in jointed volcanic rock formation, homogeneous isotropic, and has stressed; presence of "buckling" at middle section of long walls; some geological overbreaks and the cavern has constructed without concrete support (unlined).

The objective this study are characterised of rock, mechanical properties, in-situ stress condition of rock mass; analyse the effect of rock mass properties due to the deformation and to compare between the numerical analysis and monitoring data due to deformation of SCC. The data collected on site were used to analysis *Dip, Unwedge and Phase2* software for numerical analysis and analysing of displacement monitoring.

From this study, it was concluded that rock mass of SCC classified as a good rock however it was deformed, it was visualized on site as buckling, some overbreak/collapse and creep, the maximum displacement 26.45 mm on the middle of long-wall. The peak displacement had been happened during excavation period and observing shows the displacement is still continuing as creep, ≤0.05 mm/ month.