THE EFFECT OF THE ROCKMASS PROPERTIES AND GROUNDWATER INFLOW RELATED TO PERFORMANCE OF TUNNEL BORING MACHINE (TBM) AT PAHANG SELANGOR RAW WATER TRANSFER TUNNEL PROJECT (PSRWT)

by

AFIKAH BINTI RAHIM

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

October 2015

ACKNOWLEDGEMENTS

This Master's Degree work was initiated by the several researches on Pahang-Selangor Raw Water Transfer Tunnel (PSRWT) tunnel project.

This study would not have been possible without data provided and financed by the Kementerian Tenaga, Teknologi Hijau dan Air (KeTTHA) and Shimizu - Nishimatsu – UEMB IJM Joint Venture (SNUIJV). In addition, I am thankful to all these contributors this project that has supported financially and given help on fieldwork and participation on conferences.

I am deeply thankful to my supervisor Dr. Hareyani bt. Zabidi, for inspiration and encouragement when needed, and for patiently reading and commenting on my numerous drafts along the way. I wouldn't have to even start this Master's Degree without her trust, efforts and hard work. Thanks again for this opportunity that has started back in 2012.

To my co-supervisor, I would like to thank to Assoc. Prof. Dr. Kamar Shah b. Ariffin. I am grateful for valuable motivation to not to give up towards the end of the writing phase and recommendations on few programs. I am feeling honoured although it was really a short time of knowing such experienced person like him.

I would like to appreciate Assoc. Prof. Ju-ichi Kodama, my supervisor in Hokkaido University, Japan who had invited me to his lab and helped to find solutions regarding on my thesis issues with all the rock mechanics laboratory members like

Mitsui, Najib, Anjula, Badrul, Kohe, helpful technicians and others. Thanks to Prof. Fujii Yoshiaki as co-supervisor for given me a chance to join classes and recommended me for Ph.D level in lab. Thanks for the enjoyable time that we shared days and nights during my stay in Japan, which have giving me such memorable moments in my chapter of life. Being the only girl in the lab wasn't that easy!

Thanks to some lecturers for providing guidelines, important knowledge and moral supports. They are ; Prof. Eric , Prof. Abdul Ghani Rafek, Prof. Hasiah, Prof. John Kuna Raj, Prof. Ng. Tham Fatt, Prof. Azman, Prof. Hussin and Pn. Nor Liza. To my current lecturers in Universiti Gadjah Mada. Pak Sugeng, Pak Budianto Toha, Pak Jarot and other lecturers too, thanks for keeping me going. Thanks to technical departments of Universiti Sains Malaysia, Universiti Malaya and Universiti Gadjah Mada that have given their hands to my work. That means world to me!

I will forever be thankful to my parents, Rahim b. Hamdan & Adzimah Abd. Rahman. I hope that I could pay for all efforts burning the midnight oil to accompany me while writing and checking the thesis, sweats and endless love since the day that I was born. And I'm proud to be a daughter of yours. To my both sisters, Insafinaz Adrine Rahim and Siti Wahida Rahim whom giving me supports from far. Oh Yes, I might describe thousand words to say how much I have to thank my family throughout my life. Bapa', Ma', Along and Mae, this thesis is for all of you guys!! To my little nephew Ian Harith Yazin, thanks for being cute and giving Mamadik such non-stop of colourful yet inspiring moments in my life and the Rahim's. To little Nia Amany Yazin, you are one of the reason why am I stand strong for this masterpiece.

As said, a good support system is important for surviving. Thanks, I would like to mention those wonderful friends that I really value our friendship and supports, there might be list of thousands to mention, but here they are, as I could list up as many as possible. Arbai'yah Saironi, Aiza Shafeeqa Ainan Marzuki, members of Fab Four; Wan Salmah Yang Mohsin, Nuraini Sheik Abdul Jamal, Farah Amelia Zulkepli, former roommates Sharifah Hafizah Syed Abd. Rahim, Mazuin Mohd. Ismail , Hot Wheels girls Nurul Nasuha, Saidatul Sofia, Farrah Dina, Noor Liyana, Nursafawati, Fazlina, Jessica Elyn, Nur Hasanah, Fauzelah and more to mention.

Nor Helmi b. Said, thank you for being my best friend and always helping me to finish this thesis until to the finishing line. I wouldn't have chance to thank you more and yes, I owe you more, and I am promise you, there will be more to come!

Also thanks to Sheikh Fadzil, Rosmaiza, Ahmad Zairul, Ezzat Emir, Tapiwa Ngoroyemoto, Ikram friends, 36 'School on the Move 2013' friends especially Yuuka, Patt, Jenny, Shota, Alessandro, Yohei, Yusaku, Tagama, Massa and Tagashi. And those who has helped me in and out, direct or indirect, I really appreciate the hard work & wish I could write one and each of you to appreciate the efforts and being you for me.

'To a place where much of this was invented, elaborated, or pondered and where a friendship developed that even the writing of a book could not spoil. Thanks all.'

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

C	Cohesion
d	Distance
D	Specimen diameter
E	Young's Modulus
L	Length of the specimen
P	Maximum load at failure
p,q,r	Invariants
R	Radius
t_s	Travel time
Vp	Velocity of P-wave
ν	Poisson's Ratio
σ	Horizontal stress
β	Angle between the normal to the fracture plane and the horizontal plane
φ	Friction angle of the fracture
σ_c	Uniaxial compressive strength of rock
$\sigma_{1,f}$	Major principle stress at failure
$\sigma_{a,f}$	Applied failure stress
$\sigma_{d,w}$	Pressure resulting from dead weight of top disk and loading ram
s_V	Overburden Load
σ_x	Normal stress distribution in x-direction
σ_y	Normal stress distribution in y-direction
σ_{xy}	Shear stress distribution

$\sigma_{d,w}$	Pressure resulting from dead weight of top disk and loading ram (kPa)
∂x	Direction of rock blocks

LIST OF ABBREVIATION

AR	Advancing Rate
ASTM	American Society for Testing and Materials
BE	Boring Energy
BTS	Brazillian Tensile Strength Test
Ch.	Chainage
FEM	Finite Element Method
IMIA	International Association of Engineering Insurers (IMIA)
ISRM	International Society for Rock Mechanics
JHS	Japanese Highway System
Jn	Joint set number
Jr	Joint roughness number
Jw	Joint water reduction factor
L-x	Lineament
MGT	Mesin Gerekan Terowong
PR	Penetration rate
RMR	Rock mass rating
SRF	Stress reduction factor
TBM	Tunnel boring machine
SRTM	Shaded relief topographical map
SHR	Schmidt hammer rebound
TD	Tunnel distance
UCS	Uniaxial Compressional Strength Test

KESAN DARI CIRI-CIRI JASAD BATUAN DAN PERGERAKAN AIR BAWAH TANAH TERHADAP PRESTASI MESIN GEREKAN TEROWONG (MGT) BAGI PROJEK PENYALURAN AIR MENTAH PAHANG SELANGOR (PPAMPS)

ABSTRAK

Pergerakan air bawah tanah ke dalam terowong boleh mengakibatkan bahaya dan merupakan faktor penting yang mempengaruhi kemajuan prestasi gerekan terowong. Di dalam kajian ini, sistem kekar lokal dianalisis bagi menghubungkan pergerakan air bawah tanah dan orientasi kekar di sepanjang 2000 meter tempat kajian TBM-1, Karak sepanjang pembinaan Projek Penyaluran Air Mentah Pahang – Selangor (PPAMPS). Geologi kawasan terowong adalah terdiri daripada batuan granit Main Range dan bersambungan dengan batuan meta-sedimen daripada Formasi Karak. Secara strukturnya, TBM-1 didominasi oleh arah Utara- Selatan, Utara Barat - Tenggara dan Timur Laut-Tenggara. Sesar yang memotong batuan granit Main Range menyebabkan banyak kekar terhasil di daerah Karak. Lokasi yang berpotensi dengan kemasukan air bawah tanah yang banyak adalah terbahagi kepada tiga; iaitu set kekar yang selari dengan garisan lineamen utama, iaitu 90 darjah dengan arah pandu terowong, 45 darjah dengan garisan lineamen atau kedua-dua sistem linemen dan membelah lompang dan membentuk zon poket air. Sekurang-kurangnya kesemua set garisan lineamen topografik berkait dengan zon sesar-air. Analisis unjuran streografik dan plot Rosette mendapati bahawa orientasi kekar didominasi oleh 3 tren silang-potong antara satu sama lain. Kekar tersebut adalah terdiri daripada ; tren Kuala Lumpur – Bukit Tinggi, tren Utara-Selatan and tren Tenggara-Barat

Daya, yang berkait dengan Barat Laut-Tenggara Bukit Tinggi dan Zon Sesar Kuala Lumpur, sesar Utara-Selatan dan sesar Tenggara-Barat Daya. Keputusan dari ujian mekanikal seperti Ujian Kekuatan Mampatan Sepaksi, Kekuatan Tensi Brazil dan Kekuatan Mampatan Tiga Paksi menunjukkan bahawa jasad batuan menjadi lemah dengan nilai basah adalah hampir separuh daripada nilai kering. Melalui ujian kaedah finit elemen yang dilakukan dengan menggunakan parameter daripada ujian mekanikal mendapati bahawa dengan kehadiran air bawah tanah dan kualiti jasad batuan yang rendah boleh mengakibatkan berlakunya deformasi pada terowong.

THE EFFECT OF THE ROCKMASS PROPERTIES AND GROUNDWATER INFLOW RELATED TO PERFORMANCE OF TUNNEL BORING MACHINE (TBM) AT PAHANG SELANGOR RAW WATER TRANSFER TUNNEL PROJECT (PSRWT)

ABSTRACT

Groundwater inflow into tunnels can constitute a potential hazard and an important factor influencing the performance of tunnel excavation. In this research, the results on analyses of localised jointing system are presented to study the link of groundwater inflow and the joint orientations along the 2000 meters of TBM-1 site, Karak in conjunction to the construction of Pahang Selangor Raw Water Transfer Tunnel project (PSRWT). The geology along the tunnel route is predominantly the Main Range granite batholith with a lesser extent of meta-sedimentary rocks of the Karak Formation. Structurally, TBM-1 is dominated by joints orientated at N-S, NW-SE and NE-SW direction. Faults that cross-cut the intrusive Main Range Granite rocks trending faults formed the most prominent structures in the vicinity of the Karak. Potential leakage places are identified of three main types of joints orientations; the most permeable place is parallel along the main lineament orientation, followed by perpendicular to 90 degrees to the tunnel drive direction, 45 degrees to the lineament line or combinations of both joints and crossing some of voids which creating pocket water zones. At least three sets of prominent topographic lineaments correspond to fault-zones permeability related. Based on the stereographical projection and rosette diagram analysis, the dominant orientations of joints seem to have occurred at the intersection of 3 cross-cutting trends. They are the