PREDICTION OF BEARING CAPACITY OF BORED PILE SOCKETTED IN LIMESTONE OF VARYING ROCK QUALITY DESIGNATION

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A dissertation submitted in partial fulfillment of the

requirements for the award of the degree of

Master of Engineering (Civil – Geotechnics)

Faculty of Civil Engineering

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July 2011

I declare that this dissertation entitled "Prediction of Bearing Capacity of Bored Pile Socketted in Limestone of Varying Rock Quality Designation" is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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This thesis is dedicated to my beloved wife, family and friends

ACKNOWLEDGEMENT

I would like to take this opportunity to express my deep and sincere gratitude to my supervisor, Assoc. Prof. Mohd For Mohd Amin, a dedicate lecturer in Faculty of Civil Engineering for his encouragement and expert advice, regarding the planning, processing in order to complete this dissertation. The ideas and concepts have had a remarkable influence on my entire project in this field. And also I must appreciate from Dr. Nurly Gofar for her effectual helps in editing this project.

During this work I have collaborated with many persons for whom I have great regard, and I wish to extend my warmest thanks to all those who have helped me with my work in the Faculty of Civil Engineering in Universiti Teknologi Malaysia, especially Assoc. Prof. Ir. Azman Kassim.

I owe my loving thanks to my parents and my wife who always, pray for my success in everyday life. Without their encouragement and understanding it would have been impossible for me to finish this work.

Thank you very much

ABSTRACT

Reliable design of cast in-situ micropiles depends greatly on data pertaining to the properties of the rock mass, which include Rock Quality Designation (*RQD*) and modulus of deformation. However, this data are difficult and costly to acquire for it requires direct measurement on the rock mass. Consequently, the design of micropiles is often based on semi-empirical method. This study is aimed at establishing relevant correlations between properties of rock mass and selected parameters for the design of micropile socketed in limestone. Data used for the correlations are properties of limestone in Pandan Indah, Kuala Lumpur. For natural material like rocks, anisotropy and discontinuity may lead to variations of its properties. Consequently, it often requires a large number of field data to ensure reliability of correlations. It also noted that the use *RQD*, to describe the discontinuous nature of limestone, is not that reliable. Despite of these constraints, this study has shown the existence of some forms of correlations between design parameters of piles and characteristics of the rock mass. Correlation exists between mobilised skin frictions (*FS*) and *RQD*. Rock with lower *RQD* tends to induce a higher *FS*. A good correlation exists between *RQD* and in-situ deformation modulus (E_m) obtained from Pressuremeter test. This implies that *RQD* value can be used for estimating E_m of in-situ limestone. Further verification shows that for rock with *RQD* $<$ 25 %, the value of E_m drops as much as 99 % (compared to intact modulus (E_i)). Similar behavior is observed on the effect of *RQD* on the dynamic modulus and Poisson's ratio. With regard to the material properties of limestone, it is found that its Uniaxial Compression Strength (*UCS*) is about 26 times its Point-load index strength (I_S), and Tensile strength (T_S) is less than one-tenth of the *UCS*. More field data is essential to improve the reliability of the established correlations.

ABSTRAK

Kebolehgantungan rekabentuk cerucuk mikro tuang di-situ amat bergantung pada data mengenai sifat-sifat massa batuan di tapak, dan data ini merangkumi nilai *RQD* dan modulus perubahanbentuk. Walaubagaimanapun data ini sukar dan mahal untuk diperolehi kerana ia memerlukan pengukuran secara terus ke atas batuan di tapak. Oleh yang demikian rekabentuk cerujuk mikro selalunya berasaskan kepada kaedah separa empirikal. Kajian ini bertujuan untuk mewujudkan beberapa korelasi di antara sifat-sifat massa batuan di tapak dan beberapa parameter penting bagi rekabentuk cerucuk mikro dalam batukapur. Data yang digunakan bagi mewujudkan pertalian ini adalah sifat-sifat batukapur di Pandan Indah, Kuala Lumpur. Bagi bahan semulajadi seperti batuan, ciri anisotropi dan ketakselarasan boleh menyebabkan wujudnya variasi dalam sifat sampel. Oleh yang demikian bagi batuan, ianya memerlukan bilangan data di tapak yang lebih banyak bagi memastikan ketepatan korelasi yang diwujudkan. Pemerhatian juga menunjukkan penggunaan nilai *RQD* bagi menggambarkan ketidakselaran jasad batuan adalah kurang sempurna. Di samping kekangan yang dihadapi, kajian ini telah berjaya membuktikan wujudnya beberapa bentuk pertalian di antara parameter rekabentuk cerucuk dan sifat-sifat massa batuan di tapak. Wujud pertalian di antara geseran kulit yang digerakkan (*FS*) dan *RQD*. Batuan yang mempunyai nilai *RQD* yang lebih rendah akan mengaruhkan nilai *FS* yang lebih tinggi. Pertalian yang baik wujud di antara *RQD* dan modulus perubahanbentuk (E_m) di tapak, yang diperolehi dari ujian Pressuremeter. Ini membuktikan bahawa nilai *RQD* boleh digunakan bagi menganggarkan nilai E_m bagi batukapor di lapangan. Penelitian lanjut menunjukkan bagi batuan dengan nilai *RQD* < 25 %, nilai E_m nya menurun hampir 99 % (dibandingkan dengan modulus tak terusik E_i). Ciri-ciri yang hampir sama dilihat dari segi kesan *RQD* ke atas modulus dinamik dan nisbah Poisson. Dari segi sifat bahan batukapur, didapati nilai *UCS* nya adalah 26 kali lebih besar dari I_S, dan nilai T_S pula kurang dari 1/10 nilai *UCS*. Bilangan data di tapak memainkan peranan yang penting dalam memastikan ketepatan pertalian yang telah diwujudkan.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE

CHAPTER	TITLE	PAGE

LIST OF TABLES

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE

FIGURE NO.	TITLE	PAGE

LIST OF APPENDICES

LIST OF SYMBOLS

α	-	Rock socket reduction factor with respect to q_{uc}
A_b	-	Pile base area
A_S	-	Pile shaft area
B	-	Footing width in cm & Pile diameter
β	-	Reduction factor with respect to the rock mass effect
c	-	Cohesion
D	-	Diameter of socket & Depth of pile base below rock surface
δ	-	Opening of joint in cm
E	-	Young's Modulus
E_i	-	Elastic Modulus of intact rock
E_{id}	-	Deformation modulus of intact rock material
E_P	-	Pile Modulus
E_r&E_m	-	In-situ Rock Modulus (Mass Rock Modulus)
E_{rd}	-	Deformation modulus of in-situ rock mass
E_s	-	Secant Modulus
E_t	-	Tangent Modulus
f_b	-	Unit base resistance for the bearing layer of soil
F_b	-	Partial Factor of Safety for Base Resistance
F_g	-	Global Factor of Safety for Total Resistance
f_S	-	Unit shaft resistance for each layer of embedded soil
F_S	-	Partial Factor of Safety for Shaft Resistance
FOS	-	Factor of Safety
FS	-	Mobilised Skin Friction
G	-	Modulus of rigidity (Shear Modulus)
g	-	Acceleration due to gravity, 9.8m/sec^2

γ	-	Effective density of rock mass
h	-	Depth of socket in rock
i	-	Number of soil layers
I_S	-	Point-load index strength
ν	-	Poisson's ratio
MRF	-	Mass Reduction Factor
Nc & $N\phi$ & $N\gamma$	-	Bearing capacity factors
N_d	-	Depth factor
N_j	-	Empirical coefficient depending on the spacing of discontinuities
q_a	-	Allowable safe bearing pressure
Q_{ag}	-	Allowable geotechnical capacity
Q_{bu}	-	Ultimate base capacity
q_C	-	Average uniaxial crushing strength of intact rock material
Q_{su}	-	Ultimate shaft capacity
q_{uc}	-	Unconfined compressive strength (*UCS*) of intact rock
ρ	-	Density of limestone, g/cm^3
R^2	-	Coefficient of Determination
RMR	-	Rock Mass Rating
RQD	-	Rock Quality Designation
S	-	Spacing of joint in cm
SBP	-	Safe Bearing Pressure
t	-	Ton
T_S	-	Tensile strength
UCS	-	Uniaxial compressive strength
V_F	-	Field compression (primary) wave velocity, m/s
V_L	-	Laboratory compression (primary) wave velocity, m/s
V_P	-	Compression (Primary) wave velocity, m/s
V_S	-	Shear (Secondary) wave velocity, m/s
Ψ	-	Socket roughness

CHAPTER 1

INTRODUCTION

1.1 Background

Most problems in rock engineering and construction involve either the strength of the in-situ rock mass or the compressibility of the rock mass. For purposes of design it is necessary to represent, in equations of engineering mechanics the corresponding numerical values representing an appropriate in-situ property. Strength values and modulus values determined from laboratory testing of intact rock cores are recognized as not being directly applicable to the in-situ rock mass because of the scale effect.

Presence of joints in rock mass has rendered it to be discontinuous in nature. Expressed in terms of Rock Quality Designation (RQD), this discontinuous to nature makes a rock mass to behave differently than intact rock samples used in laboratory tests. Some forms of reduction on the properties must be applied as intact rock is usually stronger than a discontinuous rock. In bored pile design, the mass properties of the rock mass are the essential input parameters. The socket skin friction for instance, is estimated using the rock mass properties (e.g. in-situ modulus and *RQD*) and the related pile and rock socket dimensions. Surface roughness and strength of the socket wall (main contributor to the skin friction) are difficult to quantify as they depend on rock strength, *RQD* and method of drilling. It is due to the intricate interactions between the pile and the surrounding rock mass that the design of a bored pile is semi-empirical and relies greatly on established correlations. Despite these interacting factors, certain components which dictate the pile behaviour can be quantified through laboratory and field tests. The measured properties can be established in the form of correlations and used for predicting conditions of rock mass and consequently, to assess whether the design of bored pile in this rock is acceptable.

Hence it is thought that if the corresponding values for the in-situ rock mass are known (e.g. safe bearing pressure and in-situ modulus) then, correlation between intact and mass properties could be recognized. Some correlations exist between mobilised skin friction and *RQD* of the surrounding rock. It is also found that joints (i.e. *RQD*) dictate the in-situ modulus of limestone, and consequently, correlation exists between *RQD*, intact and in-situ modulus (Barton *et al*., 1974; Waltham, 2002; Singh and Goel, 1999). However, these in-situ properties must be measured in the field using relevant methods such as Pressuremeter tests which have been carried out at the project site. Without any related and viable number of field data, it may be difficult to ascertain useful correlations, even though the laboratory data is abundant.

1.2 Problem Statement

Reliable design of a bored pile relies greatly on data pertaining to properties of rock mass surrounding the pile socket. However, these properties such as skin friction, in-situ modulus are difficult and costly to acquire for it requires direct measurement on the in-situ rock. When such data is lacking, the design is often based on semi-empirical method. Unfortunately, this method may lead to some level of uncertainty on whether a pile is over- or under-design. It is thought that there are means to verify the reliability of the design approach. For instance, if characteristics of the pile and properties of the in-situ rock can be correlated to certain level of reliability, then this correlation can be used to verify suitability of the design. In addition, correlation between intact and mass properties of a rock can be used to predict the characteristics of its in-situ mass, and this information is vital for proper design of bored pile.

1.3 Objectives of Study

This study is aimed at establishing some correlations between properties of intact rock and in-situ rock, with specific focus on design of bored pile in limestone. In achieving the aim, following objectives are set forth:

1) To identify and to establish relationships between selected intact (material) properties and discontinuous (mass) properties of limestone, with focus on laboratory properties like compressive strengths and compression (primary) wave velocity.
2) To verify current approach in designing micro piles in limestone and criterion used in validating the geotechnical capacity of the pile (e.g. mobilised skin friction) and the condition of rock (e.g. *RQD*).
3) To identify and to establish correlations between designs criterion of pile and mass properties of in-situ rock, with focus on mobilised skin friction and *RQD*.
4) To establish correlations between selected rock mass properties (in-situ modulus of deformation and Poisson's ratio) and its discontinuous state (*RQD*), particularly those correlations relevant to design of micro pile in rock.

1.4 Methodology

To achieve the desired goals, the following steps are adopted. Compilation of related notes and reports on bored pile design, rock mass and rock material properties that are important for design approach. Appropriate material properties of limestone through various laboratory tests and characterisation of intact rock samples was collected. Field data (provided by Unit Geoteknik Jalan, Jabatan Kerja Raya Malaysia, and other parties and contractors involved in the site investigation work and field tests) which include site investigation report, static axial compression load tests and Pressuremeter test was compiled too. And finally analysis of data to establish suitable correlations for verifying reliability of existing practice on micro pile design, and for predicting in-situ conditions of limestone rock mass was done.

1.5 Scope of Study

This study was carried out on Limestone bedrock in Pandan Indah, Kuala Lumpur. Data used was related rock properties obtained from laboratory tests and field tests in that site. Field data provided by Unit Geoteknik Jalan, Jabatan Kerja Raya Malaysia, and other parties and contractors involved in the site investigation work and field tests obtained from laboratory tests. These field performance tests were included trial shafts and in-situ assessment (Pressuremeter test) on limestone bedrock. Weakening effects in expressing the discontinuous nature of limestone is due to presence of joints only, effect of weathering and cavities were not considered. The correlations established are used as guides for checking the performance and reliability of micro pile socketed in limestone. Others correlations were proposed to relate typical material and mass properties of limestone.