GEOPHYSICAL CHARACTERIZATION OF WEATHERED SEDIMENTARY ROCK MASS FOR SURFACE EXCAVATION PURPOSE

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DEDICATION

In the name of Most Kind and Merciful Allah the Almighty

This thesis is specially dedicated to:

My dearest parents, my pillar of strength, *Mohd Akip Tan Bin Abdullah* and *Sabariah Binti Yassin*, who gave me the world, support me all the way, endless love, belief and encouragement through the years.

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ABSTRACT

An accurate and reliable assessment of ground condition is one of the critical aspects in surface excavation work. This issue become more complex when dealing with heterogeneous ground material with various weathering stages. Seismic velocity and electrical resistivity method are among the common tools used to assist the understanding of the subsurface condition. This study aims to investigate the application of the seismic refraction and resistivity method together with the geotechnical assessment for the purpose of surface excavation work. The study was carried out at Iskandar Puteri, Johor namely Legoland (LEGO), SILC Site 1 (SILC 1), SILC Site 2 (SILC 2) and SILC Site 3 (SILC 3). The sites are underlain by a thick residual soil and interbedding of sandstone and shale from various weathering states. The geophysical surveys that were carried out on the same outcrops were then compared. The classification of rock mass was carried out by adopting Rock Mass Rating (RMR) and Q-system. The field results indicate RMR range from 0 to 69 and Q-value of 0 to 16.883 specifies weak to fair rock. Joint spacing was attained with value of 0 – 1.95 m. The laboratory tests were carried out on 144 – 156 samples for dry density, moisture content, point load test and slake durability. Point Load Strength (Is_{50}) for the samples ranges from 0 – 6.889 MPa indicates very weak to strong rock. Laboratory evaluation indicates the rock quality deteriorates with increase of weathering. Trial excavation was carried out on 19 panels using Komatsu PC300 - 6. Four boreholes that were drilled then correlated with five resistivity and four seismic velocity profiles. Resistivity value for residual soil indicates value of less than 1000 Ωm. Meanwhile for slightly weathered sandstone and shale 1500 Ωm – 12000 Ωm, moderately weathered zone ranges from 370 Ωm – 5000 Ωm, highly weathered of 100 Ωm – 3000 Ωm and completely weathered with 30 Ωm – 2000Ωm. Boulder was detected with resistivity value of 5000 Ωm – 12000 Ωm. Besides that, seismic velocity for residual soil shows value of less than 750 m/s, slightly weathered zone of 1500 m/s – 3000 m/s, highly weathered zone of 100 m/s – 2000 m/s and completely weathered zone with velocity of 500 m/s – 1500 m/s. Boulder was not able to be detected. Resistivity survey provide more reliable results in sensing lithology and saturated zone. Field assessment quantified that when RMR less than 40 and Q less than 1 is dominated by completely weathered shale is categorized as easy excavation (> 400 m^3/h). On the other hand, moderate excavatability (100 m^3/h – 400 m^3/h) yielded when 40 < RMR < 60 and 1 < Q < 10 which consists of highly/moderately weathered sandstone/shale and completely weathered sandstone while hard excavation (< 100 m^3/h) was observed when 60 < RMR < 70 and 10 < Q < 20 which includes slightly weathered sandstone/shale. The result showed that both Q and RMR exhibit a trend of higher value of rating and commensurate with seismic and resistivity value. The findings of this study contributed the development in excavatability assessment by proposing the resistivity and seismic velocity index for interbedded sedimentary rock mass. The proposed scheme of resistivity and velocity index based on tropically weathered sedimentary rock mass with respect to excavation performance is significant advanced compared to existing assessment.

ABSTRAK

Penilaian efektif berkaitan profil sub-permukaan bumi merupakan aspek kritikal dalam penilaian kerja pengorekan. Isu ini menjadi semakin kompleks dalam zon yang rencam tahap luluhawanya. Kaedah seismik dan keberintangan elektrik merupakan prosedur yang sering digunakan untuk memahami profil sub-permukaan. Kajian ini bertujuan menilai keupayaan kaedah geofizik sebagai salah satu cara penilaian sub-permukaan sebelum kerja pengorekan sebenar dilakukan. Kajian ini dijalankan di Iskandar Puteri, Johor, melibatkan empat tempat kajian iaitu Legoland (LEGO), SILC Site 1 (SILC1), SILC Site 2 (SILC 2) dan SILC Site 3 (SILC 3). Kawasan kajian diliputi oleh tanah baki dan batu pasir yang berselang-lapis dengan syal daripada tahap luluhawa yang berbeza. Survei geofizik dijalankan pada singkapan yang sama dimana pengkelasan batuan dijalankan. Klasifikasi jasad batuan dikelaskan dengan ‘Rock Mass Rating (RMR)’ dan ‘Q-system’ mendapati nilai RMR berjulat 0 – 69 manakala Q ialah 0 hingga 16.883 menunjukkan batuan jenis lemah hingga kuat. Nilai jarak antara ketakselanjaran berjulat antara 0 – 1.95 m. Ujian makmal melibatkan 144 – 156 jumlah sampel untuk setiap ujian ketumpatan kering, kandungan kelembapan, kekuatan beban titik dan pemeroian batuan. Indeks titik beban (Is_{50}) berjulat antara 0 ke 6.889 MPa menunjukkan tahap kekuatan berbeza. Penilaian di makmal menunjukkan kualiti batuan menurun apabila tahap luluhawa meningkat. Ujian pengorekan langsung menggunakan Komatsu PC300 - 6 dijalankan pada 19 panel. Lima profil keberintangan dan empat profil halaju seismik dikorelasikan dengan empat lubang bor. Nilai keberintangan tanah baki adalah kurang daripada 1000 Ωm. Manakala batu pasir dan syal terluluhawa sedikit menunjukkan julat 1500 Ωm – 12000 Ωm, batuan yang terluluhawa sederhana berjulat 370 Ωm – 5000 Ωm, terluluhawa tinggi adalah 100 Ωm – 3000 Ωm dan batuan yang terluluhawa lengkap menunjukkan nilai 30 Ωm – 2000 Ωm. Batu tongkol pula dapat dikesan dengan nilai 5000 Ωm – 12000 Ωm. Sementara itu, nilai halaju seismik bagi tanah baki adalah kurang daripada 750 m/s, batuan terluluhawa sedikit 1500 m/s – 3000 m/s, terluluhawa sederhana 500 m/s – 3000m/s, terluluhawa tinggi 100 m/s – 2000 m/s dan zon terluluhawa lengkap 500 m/s – 1500m/s. Batu tongkol tidak dapat dikesan melalui kaedah seismik ini. Survei keberintangan memperlihatkan hasil yang lebih baik dalam mengenalpasti litologi dan zon lembap. Penilaian di lapangan membuktikan bahawa RMR yang kurang daripada 40 dan Q kurang daripada 1 didominasi oleh tanah baki dan syal terluluhawa lengkap, dikategorikan sebagai pengorekan mudah (> 400 m^3/jam). Pengorekan sederhana (100 m^3/jam – 400 m^3/jam) apabila $40 < RMR < 60$ dan $1 < Q < 10$ melibatkan batu pasir/syal yang terluluhawa tinggi/sederhana. Pengorekan sukar dicerap apabila $60 < RMR < 70$ dan $10 < Q < 20$ melibatkan batu pasir/syal yang terluluhawa sedikit. Hasil kajian ini menyumbang terhadap kemajuan penilaian kebolehkorekan dengan menambah nilai keberintangan dan halaju seismik pada batuan sedimen yang berselang-lapis. Skema nilai keberintangan dan halaju seismik yang dicadang berdasarkan tahap luluhawa batuan sedimen berluluhawa tropika dengan menilai prestasi pengorekan adalah signifikan berbanding dengan penilaian sedia ada.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2-D	-	Two-Dimensional
3-D	-	Three-Dimensional
ASTM	-	American Society for Testing and Materials
BHP	-	Brake Horse Power
CBR	-	California bearing ratio
DC	-	Direct current
EISR	-	Excavation Index for Sedimentary Rock
GPR	-	Ground Penetrating Radar
HP	-	Horse Power
ISRM	-	International Society for Rock Mechanics
JKR	-	Jabatan Kerja Raya
JMG	-	Jabatan Mineral & Geosains
Lbs	-	Pound
LEGO	-	Legoland
P-wave	-	Primary Wave
Q-system	-	Rock Mass Quality
Qr	-	Field Production Rate
RM	-	Ringgit Malaysia
RMR	-	Rock Mass Rating
RQD	-	Rock Quality Designation
RR	-	Rippability Rating
S-wave	-	Secondary Wave
SAS	-	Signal Averaging System
SE	-	Specific Energy
SH	-	Schmidt Hammer
SiLC	-	Sourtern industry Logistic Cluster
SILC 1	-	SILC Site 1
SILC 2	-	SILC Site 2
SILC 3	-	SILC Site 3
SPT	-	Standard Penetration Test

SPT-N - Standard Penetration Test N-value
SV - Seismic velocity
UCS - Uniaxial Compressive Strength
UTM - Universiti Teknologi Malaysia
Vs - Versus

LIST OF SYMBOLS

α - Alpha

ρ_a - Apparent resistivity

β - Beta

cm - Centimetre

δ_R - Change in resistance

δ_A - Cross sectional area

I - Current

θ_{ic} - Critical angle of incidence

° C - Degree Celcius

ft/s - Feet per second

θ_i - Incidence angle

R_{oj} - Joint orientation

R_{dj} - Joint spacing

MPa - Megapascal

m - Metre

m^3 - Metre cube

mm - Millimetre

Ω - Ohm

% - Percentage

I_s - Point load strength index

ΔV - Potential difference

Q - Practical excavation rate

θ_r - Refracted angle

δL - Resistance length

R - Resistivity

s - Shear

Id_2 - Slake durability second cycle

C_1 and C_2 - Two current electrodes

P_1 and P_2 - Two potential electrodes

p - Value of compressional

V_p - Velocity of P-waves / Seismic wave velocity

V_s - Velocity of S-waves

V_1 - Velocity of first layer

V_2 - Velocity of second layer

V - Voltage

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

Detailed and reliable assessment of ground condition is one critical aspect in excavation work in order to do a proper ground evaluation. This issue become more fascinating when dealing with heterogeneous zone and intricate weathering stages (Bolton *et al.*, 2010; Hakan and Palmstrom, 2011; Edy Tonnizam *et al.*, 2017). The application of geophysical method widely applied in excavation work by seismic technique lead to the use of others method such as electrical resistivity to ease the site investigation (Soupios *et al.*, 2007; Abidin *et al.*, 2011). The complexity of subsurface conditions and various underlying materials with disreputable mechanical properties often unfavorable for the constructions. This can give rises to difficulties particularly in impending progress or increasing the hazardous nature of the excavation works. Sufficient information of the subsurface features can assist the construction process efficiently.

Disagreements in excavation method are common problems in construction especially the existence of hard material. This hard material primes to complications because its properties often too weak to be blast and too strong to be excavated by conventional method (Mohd For, 1995; Kavvadas, 1998; Kanji, 2014). This problem is particularly acute in tropical region given that thick profile of weathered zone is encountered. In relation to this, there is essential for the development of technology related to the excavation works that is needed for site investigation by adding geophysical methods as a tool. However, the most significant factor in evaluating the excavation assessment are the weathering profile, rock nature and its properties. The complexity of subsurface conditions, existences of boulders, cavities, faults, discontinuities such as bedding, joint, foliation and the inhomogeneity of rocks prominently influence the excavation performances. Geomechanical properties of both intact rock and rock mass is theoretical thought to be great aspect for excavatability of rock includes weathering grade, strength and discontinuities. Field and laboratory test for instance rock strength, rebound test, durability test and wave velocity are often applied to determine its mechanical properties in order to evaluate its excavatability.

In the meantime, borehole drilling is the most conservative implemented method to acquire subsurface profile and its engineering properties. To establish the requisite number of boreholes, apply at site is difficult and it is bond directly to relative costs of the project. The result obtain from drilling methods does not offer continuous and detailed information of the entire studied area. The samples were taken from a range of depths depends on the subsurface for an amount of distinct points. Drilling only provides representative samples of the site. In tropical region country as Malaysia, inappropriate site investigation and lack of precise ground information lead to non-efficient construction in excavation works, failure and damage of building structure, road and cut slope.

Besides that, effective excavation require precise interpretation of different characteristic for thick weathering profiles typically contains of a numeral of sub classifications or weathering state produced by the weathering of surface rocks in tropical climates. Therefore, by implementing a method that can deliver information of the entire area of the unpredicted ground condition, the site investigation problems can be reduced. Hence, geophysical methods are appointed as a non-destructive technique for the site investigation engage with geotechnical work due the limitations in providing continuous and precise information by borehole method.

Along with that, ground information could be obtained through geotechnical and geophysical methods. Several studies on the application of geophysical methods in engineering and environment purpose are executed all over the world with different geological setting and target definition. The application of geophysics in civil engineering implement the principles and methods of physics in the measurement of subsurface characteristics and properties. The methods are used to determine ground properties and profile for the engineering and development purposes. Note that the important aspect in all geophysical methods is that they are non-invasive and non-destructive. Geophysical approaches play a significant role in the possession of such knowledge; it provides helpful and cost effectives information about subsurface features at the required level of spatial resolution and target definition. Geophysical methods comprise resistivity, seismic, ground penetrating radar, gravity and magnetic to measure ground. The methods that have progressive growth are electrical resistivity imaging or geo-resistivity and seismic refractions method. The techniques can produce continuous image of subsurface profile with a measurement that provides an improvement in accurate and sufficient information for heterogeneous ground.

The combinations of geotechnical and geophysical discipline can be beneficial in classifying the depth of rock layer, detecting voids, cavities and boulders in subsurface works. Since the early application of seismic refraction method to determine depth to bedrock at 1930s, geophysical methods have been discovered as one of the dependable practices for geotechnical evaluation (McDowell *et al.*, 2002; Anderson *et al.*, 2008; Mahvelati *et al.*, 2018). The greatest verdict when applying the method in early stage of site investigation work is that able to discard other site investigation technique and shortlist those with potential values for improving the overall effectiveness of site investigation in term of cost and time consuming. This study focuses on the use of resistivity survey and seismic refraction methods in the study area and the result are then correlate with the geotechnical result and potential relation between the parameters are studies to get better interpretation in term of geophysics and engineering.

1.2 Problem Statement

The problems of geological variation, structural complexity, heterogeneous zones and unpredictable weathering states are some examples in the tropics ground condition that lead to difficulties in site clearing earth excavation work. Assessment of rock mass properties are significant, primarily in the pre-construction stage and are a consequence of the geological understanding based on field investigations and the experienced interpretation of accessible results. Regardless of the intricacy and difficulty in determining the engineering properties of rocks, in order to diminish rock engineering dispute and assign reliable values to them. The state of weathering from the parent rock to the ground surface reflects rock mass weathering profile. It is significantly altered the geotechnical behaviours of rocks. The degree of weathering illustrates the disintegration of the parent rock with depth.

Researchers have made continuous efforts in developing the method for characterisation or description of this weathered profile. The variations of weathering profile from different location, due to rock type and structure, topography and rate of erosion because of regional climate variation, particularly rainfall, are amongst the struggles in attaining broad perception from which to view the weathered profile. Guidance in different engineering purposes of existing rock mass classification essentially convey the development in enhancing the properties considered for excavation assessment. Most classification emphasis on the application in tunneling work. Concerning about weathered rock, the problems of structural complexity of the parent rock, unpredictable variable due to wide range of properties, heterogeneity, anisotropy and major changes in degree of weathering lead to difficulties in the method of excavation in engineering design.

Characterization of rock masses has to some extent been developed by some of the existing classification systems but few of them are of a general character as they are mainly directed towards a specific engineering function or design. In geotechnical engineering applications, the geophysical methods could be beneficial because there are many chambers for improvement and development to cater the engineering purposes. There is a need for better documentation and correlation of geological and geophysical for each grade of weathering profile for surface excavation purposes in order to adopt accurate and economical method in the construction.

1.3 Aim and Objectives

This study aims to investigate the geophysical characteristic of subsurface profile that affecting the performance of surface excavation. In order to obtain reliable and accurate information on subsurface materials for excavation purposes, this study embark on the following objectives:

i. To characterize the rock mass and geophysical index using resistivity value and seismic refraction velocity based on state of weathering.
ii. To evaluate and correlate the resistivity and seismic refraction value for sandstone and shale with respect to surface excavation.
iii. To propose a surface excavation classification based on resistivity value and seismic refraction velocity for tropically weathered sandstone and shale.

1.4 Research Scope

The study basically focuses on evaluating resistivity imaging and seismic data as a geophysical tool to map the subsurface profile in non-bedded and bedded rock mass area at few construction sites mainly in Johor Bahru. Special attention is provided in determining resistivity value and seismic velocity of various weathering grade of rock mass and evaluating them with their physical and mechanical properties related to excavation. The study comprises of geophysics field measurement and rock mass observation as well as laboratory testing in a way to investigate any possible correlation between the resistivity value and seismic velocity with the excavation performance in bedded sedimentary rock mass. Resistivity apply pole-dipole array for the assessment of geophysical survey, while seismic velocity adopted in this study is the primary wave (P). Two outcrops dominated by bedded sedimentary rock mass were studied. The geophysical results were validated with existing borehole data. The findings were then synthesized based on identified significant field observation, physical and engineering properties of materials with resistivity value and seismic velocity for the purpose of surface excavation works. Lastly, an inclusive resistivity value and seismic velocity with engineering properties as one of the indirect assessment tools in excavation assessment for tropically weathered rock mass was proposed.

1.5 Novelty and Significant of Study

The economic grow is taking important part in a developed country as in Malaysia. This study contributes to a cost efficient and improved performance of excavation for construction purposes in a variety of materials, particularly in bedded sedimentary rock mass. Resistivity value and seismic velocity for ground material is very advantageous as it increases the interpretation accuracy of investigation site. Besides that, heterogeneity issues on rock mass always a dispute during the construction process, lead to the delay and cost expansion.

A more comprehensive classification should available to ease the assessment of excavation process in order to enhance the economy by the development and effective implementation of geotechnical characterization. Tropical region is characterised by complex subsurface issues such as heterogeneities of ground, thick weathering profile, decrease of strength due to moisture and unclear interface boundary between soil and rock. Subsurface investigation may involve large area and deeper regions of the ground. By comprehending geophysical method in excavation assessment, the cost entail for total investigation work can be effectively sufficient besides saving time consumption on the processes.

Geophysical method covered survey of large areas hence the number of boreholes drilling to investigate the subsurface condition can be diminished. A critical point or location of the borehole drilling will do to impact the geophysical data by relating its properties to the pseudo section inspected. Marrying the geophysical and geotechnical way of assessing ground could provide a simplified new option for surface excavation. By understanding of the ground characteristic cater by seismic and geophysical method, site investigation either for excavation purpose or preliminary design stage could be enhance. Various geophysical method can be applied based on the priority in different ground conditions such as rock type and strength.

By grasping resistivity and seismic velocity of tropically weathered sandstone and shale for excavation purposes, the correlation between both rock mass and geophysical resistivity and seismic velocity with excavation performance are established. The most common available excavatability chart by Caterpillar (2007) was modified with new range of seismic velocity for tropically weathered sandstone and shale, besides disseminate the excavation performances into three classes which are easy (> 400 m^3/h), moderate (100 m^3/h to 400 m^3/h) and hard (< 100 m^3/h). The resistivity chart for excavation was proposed in addition to the new seismic velocity chart, with reverence to excavation performances for both sandstone and shale. The findings of this study contributed the development in excavatability assessment by proposing the resistivity and seismic velocity value for tropically interbedded sedimentary rock mass. The proposed scheme of resistivity and velocity index based on tropically weathered sedimentary rock mass with respect to excavation performance is extensively advanced compared to existing assessment.

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