STUDY ON PHYSICOCHEMICAL AND HYDRAULIC PROPERTIES OF TROPICAL ORGANIC SOIL IN BEAUFORT, SABAH

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FACULTY OF ENGINEERING
UNIVERSITI MALAYSIA SABAH
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ABSTRACT

Organic soil is a difficult soil to work with in the engineering field due to its characteristics that make it unsuitable for building or highway construction. It is fragile and has low shear strength, a wide deformation range, high compressibility, and a high-water holding capacity. Due to the fact that water is always the primary factor influencing how soil properties behave, this study aims to provide an in-depth understanding of tropical organic soil properties, particularly their hydraulic characteristics, in order to facilitate a better understanding of such soils. Soil water characteristics and hydraulic conductivity are two major components of hydraulic properties. The primary goal of this research is to characterise the physicochemical and hydraulic properties of organic soil in order to establish a relationship between them. Two locations were considered: the Lumadan site and the Klias site, where organic soil samples were collected in Beaufort, Sabah. Field tests such as the von Post test and an investigation of organic soil depth were carried out at the study sites. The scope of the study includes index and chemical properties tests such as natural density, moisture content, organic matter content, fibre content, liquid limit, specific gravity, and pH tests; hydraulic properties tests such as permeability and soil-water retention characteristics; and mechanical compaction properties. The microstructural characteristics and chemical composition of the samples were also determined in this study using the Scanning Electron Microscope (SEM) and Energy-Dispersive X-ray spectroscopy (EDX) tests. As per the findings of the research, Klias and Lumadan organic soils were classified as hemic (pseudo-fibrous), with von Post scales ranging from H6 to H7, indicating a degree of decomposition in the intermediate range. The organic soil depth at Lumadan is 4.5m, while it is 4.0m at Klias. Moisture content, organic content, fibre content, specific gravity, liquid limit, and acidity results indicated that organic soil index properties varied between the Klias and Lumadan sites. The chemical composition of organic soil samples collected at both study sites also demonstrates that the elements present are influenced by the type of cultivation, groundwater level, and local climate conditions. Microstructural analysis reveals that the characteristics of organic soil samples vary slightly. Klias samples are made up of fibres and appear to be woody and porous, whereas Lumadan samples are made up of flaky granular. In terms of hydraulic properties, the average coefficients of permeability of Lumadan and Klias samples are 9.89 x 10^{-6} m/s and 9.11 x 10^{-6} m/s, respectively, indicating that organic soil has a low degree of permeability. Four models were used to describe the soil water characteristic curve. Based on the fitting analysis, the Brooks and Corey and Fredlund and Xing models were found to be the best fitted models to represent the soil water characteristic curve for organic soils in Beaufort, Sabah, with a linearity coefficient (R^2) ranging from 0.9368 to 0.9978. Organic soils demonstrate a high-water storage capacity, and even at high pressure conditions, such as 1500 kPa, the soil can still store water at a rate of 0.5 to 0.6 residual volumetric water content. Organic soil decomposition alters the hydraulic parameters significantly. In conclusion of this study, soil degradation caused by peatland drainage significantly alters the physicochemical and hydraulic properties of organic soils.

ABSTRAK

KAJIAN TENTANG SIFAT FIZIKOKIMIA DAN HIDRAULIK BAGI TANAH ORGANIK TROPIKA DI BEAUFORT, SABAH

Tanah organik adalah tanah yang sukar untuk diusahakan dalam bidang kejuruteraan kerana ciri-cirinya yang menyebabkan tanah tersebut tidak sesuai untuk pembinaan bangunan atau lebuh raya. Ia bersifat rapuh dan mempunyai kekuatan ricih yang rendah, julat ubah bentuk yang besar, kebolehmampatan yang tinggi, dan kapasiti pegangan air yang tinggi. Disebabkan fakta bahawa air sentiasa menjadi faktor utama yang mempengaruhi bagaimana sifat tanah berkelakuan, kajian ini bertujuan untuk memberikan pemahaman yang mendalam tentang sifat tanah organik tropika, terutamanya ciri hidrauliknya, untuk memudahkan pemahaman yang lebih baik tentang tanah tersebut. Ciri-ciri air tanah dan kekonduksian hidraulik adalah dua komponen utama sifat hidraulik. Objektif utama kajian ini adalah untuk mencirikan sifat fizikokimia dan hidraulik tanah organik untuk mewujudkan hubungan antara mereka. Dua lokasi telah dipilih iaitu tapak Lumadan dan tapak Klias, tempat sampel tanah organik dikumpul di Beaufort, Sabah. Di tapak kajian, ujian lapangan seperti ujian von Post dan penyiasatan kedalaman tanah organik telah dijalankan. Skop kajian termasuk ujian sifat indeks dan kimia seperti ketumpatan semula jadi, kandungan lembapan, kandungan bahan organik, kandungan gentian serat, had cecair, graviti tentu, dan ujian pH; ujian sifat hidraulik seperti kebolehtelapan dan ciri pengekalan air tanah; dan sifat pemadatan mekanikal. Ciri-ciri mikrostruktur dan komposisi kimia sampel juga ditentukan dalam kajian ini menggunakan ujian Mikroskop Elektron Pengimbasan (SEM) dan Spektroskopi X-ray Penyebaran Tenaga (EDX). Hasil daripada kajian ini, tanah organik Klias dan Lumadan dikelaskan sebagai hemik (berserabut pseudo), dengan skala von Post antara H6 hingga H7, menunjukkan tahap penguraian dalam julat pertengahan. Kedalaman tanah organik di tapak Lumadan ialah 4.5 m, manakala Klias pula 4.0 m. Kandungan lembapan, kandungan organik, kandungan gentian serat, graviti tentu, had cecair, dan keputusan keasidan menunjukkan bahawa sifat indeks tanah organik berbeza antara tapak Klias dan Lumadan. Komposisi kimia sampel tanah organik yang dikumpul di kedua-dua tapak kajian juga menunjukkan bahawa unsur-unsur yang ada dipengaruhi oleh jenis penanaman, paras air bawah tanah, dan keadaan iklim tempatan. Pemeriksaan mikrostruktur mendedahkan bahawa sampel tanah organik menunjukkan sedikit variasi dalam ciri-cirinya. Sampel Klias terdiri daripada gentian serat dan kelihatan seperti berkayu dan berliang, manakala sampel Lumadan terdiri daripada berbutir berkeping-keping. Bagi sifat hidraulik pula, purata pekali kebolehtelapan bagi sampel Lumadan dan Klias ialah masing-masing 9.89 x 10^{-6} m/s dan 9.11 x 10^{-6} m/s menunjukkan tahap kebolehtelapan yang rendah. Empat model telah digunakan untuk menerangkan lengkung ciri air tanah. Berdasarkan analisis pemasangan, model Brooks dan Corey dan Fredlund dan Xing didapati merupakan model yang paling sesuai digunakan untuk mewakili keluk pengekalan air tanah bagi tanah organik di Beaufort, Sabah dengan pekali linearity (R^2) iaitu antara 0.9368 hingga 0.9978. Tanah organik menunjukkan kapasiti penyimpanan air yang tinggi walaupun dikenakan tekanan yang besar seperti 1500 kPa, tanah masih boleh menyimpan air pada kadar 0.5 hingga 0.6 kandungan air isi padu sisa. Parameter hidraulik diubah dengan ketara oleh penguraian tanah organik. Sebagai kesimpulan kepada kajian ini, degradasi tanah yang disebabkan oleh saliran tanah dengan ketara mengubah sifat fizikal dan hidraulik tanah organik.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

$>$	-	Greater Than
$<$	-	Less Than
$\geq$	-	Greater Than or Equal to
%	-	Percentage
θ	-	Volumetric Water Content
θw	-	Volumetric Water Content
θv	-	Residual Water Content
θi	-	Measured Volumetric Water Content
$\theta' i$	-	Modeled Volumetric Water Content
θ_r	-	Residual Volumetric Water Content
θ_s	-	Saturated Volumetric Water Content
e	-	Void Ratio
°	-	Degree Sign
ψ	-	Soil Suction
σ	-	Width of the Pore Radius Distribution
ρ	-	Bulk Density
ϕ	-	Angle of Internal Friction
λ	-	Pore Size Index
ρ_w	-	Density of Water
w	-	Moisture Content
wi	-	Weighting Aspect
u_a	-	Matric Suction
D_{10}	-	Sieve Size for 10% Passing
D_{50}	-	Sieve Size for 50% Passing
a	-	Fitting Parameters of SWCC
A	-	Permeameter Cross-Section
Al	-	Aluminium
Al^{3+}	-	Aluminium Ion
Au	-	Augite
c	-	Cohesion

C	-	Carbon
Ca	-	Calcium
$\mathbf{Ca^{2+}}$	-	Calcium Ion
Cl	-	Chlorine
D	-	Soil Water Diffusivity
Fe	-	Iron
$\mathbf{FeS_2}$	-	Pyrite
fit	-	Fitted values
$\mathbf{h_b}$	-	Air Entry Value of the Soil
hj	-	Measured Heads at Measuring Tips 1 and 2
hm	-	Capillary Pressure Head
Hg	-	Mercury
i	-	Numbers; 1, 2, 3, …
j	-	Parameter vector
K	-	Potassium
$\mathbf{K^+}$	-	Potassium Ion
K	-	Soil Hydraulic Conductivity Function
K	-	Number of Estimable Parameters (Degrees of Freedom)
$\mathbf{k_h}$	-	Coefficient of Horizontal Permeability
$\mathbf{k_v}$	-	Coefficient of Vertical Permeability
kr	-	Relative Permeability
$K(\psi)$	-	Unsaturated Hydraulic Conductivity Function
Ks	-	Saturated Hydraulic Conductivity
L	-	Distance between the Two Piezometer Measuring Tips
m	-	Fitting Parameters of SWCC
Mg	-	Magnesium
$\mathbf{Mg^{3+}}$	-	Magnesium Ion
MW	-	Pore Water Pressure
n	-	Porosity
n	-	Fitting Parameter of SWCC
N	-	Nitrogen

N	-	Number of soil-water characteristic data values
Na	-	Sodium
Na^{+}	-	Sodium Ion
NH^{4+}	-	Ammonium Ion
O	-	Oxygen
obs	-	Observed values
P	-	Phosphorus
Pf	-	Decimal Log of Tension
Q	-	Flow Rate
Rb	-	Rubidium
S	-	Saturation Level as Fraction
S	-	Degree of Saturation
S_e	-	Effective Saturation
S_r	-	Saturation
Si	-	Silicone
Ti	-	Titanium
W	-	Tungsten
Zr	-	Zirconium

LIST OF ABBREVIATIONS

AASHTO	-	American Association of State and Highway Transportation Officials
AEV	-	Air Entry Value
AI	-	Artificial Intelligence
AIC	-	Akaike Information Criterion
ASTM	-	American Society for Testing and Materials
BC	-	Brooks and Corey
BS	-	British Standard
BSE	-	Backscattered-Electron
BS EN ISO	-	British Standard European Norm International Organization for Standardization
CBR	-	California Bearing Ratio
CEC	-	Cation Exchange Capacity
CREAM	-	Construction Research Institute of Malaysia
CU	-	Consolidated Undrained
EDX	-	Energy-Dispersive X-Ray Spectroscopy
EVAC	-	Evacuated
FAA	-	Federal Aviation Administration
FC	-	Fibre Content
FX	-	Fredlund and Xing
GBNN	-	Genetic Based Neural Network
GHG	-	Greenhouse Gas
GP	-	Genetic Programming
Gs	-	Specific Gravity
HCl	-	Hydrochloric Acid
KEP	-	Kampung Endap, Kota Samarahan
KFR	-	Klias Forest Reserve
KHFR	-	Kampung Hindian Forest Reserve
LL	-	Liquid Limit
LOI	-	Loss on Ignition

MARDI	-	Malaysian Agriculture Research and Development Institute
MC	-	Moisture Content
MDD	-	Maximum Dry Density
MMT	-	Montmorillonite
M1, M2	-	Matang areas 1 and 2, Sarawak
OC	-	Organic Content
OMC	-	Optimum Moisture Content
PNFR	-	Pulau Nabahan Forest Reserve
PNpt	-	Parit Nipah in Batu Pahat, Johor
R^2	-	Coefficient of Determination, R-squared
SEM	-	Scanning Electron Micrographs
SOC	-	Soil Organic Carbon
SWCC	-	Soil Water Characteristics Curve
SWRC	-	Soil Water Retention Curve
UCS	-	Unconfined Compressive Strength
UNDP	-	United Nations Development Programme
UPVC	-	Unplasticized Polyvinyl Chloride
USDA	-	United States Department of Agriculture
USCS	-	Unified Soil Classification System
UTHM	-	Universiti Tun Hussein Onn Malaysia
VG	-	van Genuchten

CHAPTER 1

INTRODUCTION

1.1 Introduction

Peatland is a massive terrestrial ecosystem that contains huge amounts of carbon (C). Peatlands cover only 3% of the world's land area, which is 4,000,000 km^2, storing 550 gigatons of carbon in peat (Parish *et al.*, 2008). According to the Malaysian Department of Environment and the Ministry of Energy, Science, Technology, Environment, and Climate Change (Peatland Fire Prevention Programme to Mitigate Haze in Malaysia, 2019), peat soils cover approximately 2.56 million ha (roughly 7.74 percent) of Malaysia's total land area.

In Malaysia, agriculture and oil palm plantations account for more than 60% of the total peatland area (Miettinen *et al.*, 2016). Sarawak has the most peat soils in Malaysia, accounting for 64.27 percent of total peatland area, with 1,645,585 hectares, followed by Peninsular Malaysia (714,156 ha, or 27.89 percent), and Sabah (200,600 ha, or 7.83 percent). Only 18 percent of peat soil remains beneath peat swamp forest in Sabah, despite more than 70 percent canopy cover. The peat soil in Malaysia is depicted in Figure 1.1.

Tropical peats that are water-saturated and largely degraded with organic material are typically found at lower elevations. Peat soil is an organic soil with a higher value of organic content generally more than 75% (Moayedi and Mosallanezhad, 2017). In addition, peat soil in Malaysia has a water content ranging from 250% to 985.40% (Adnan Zainorabidin and Habib Musa Mohamad, 2017a). Due to its high moisture content, high compressibility, and low shear strength values ranging from 5 to 20 kPa, peat is a deliberately inappropriate soil for sustaining foundations in its natural form.

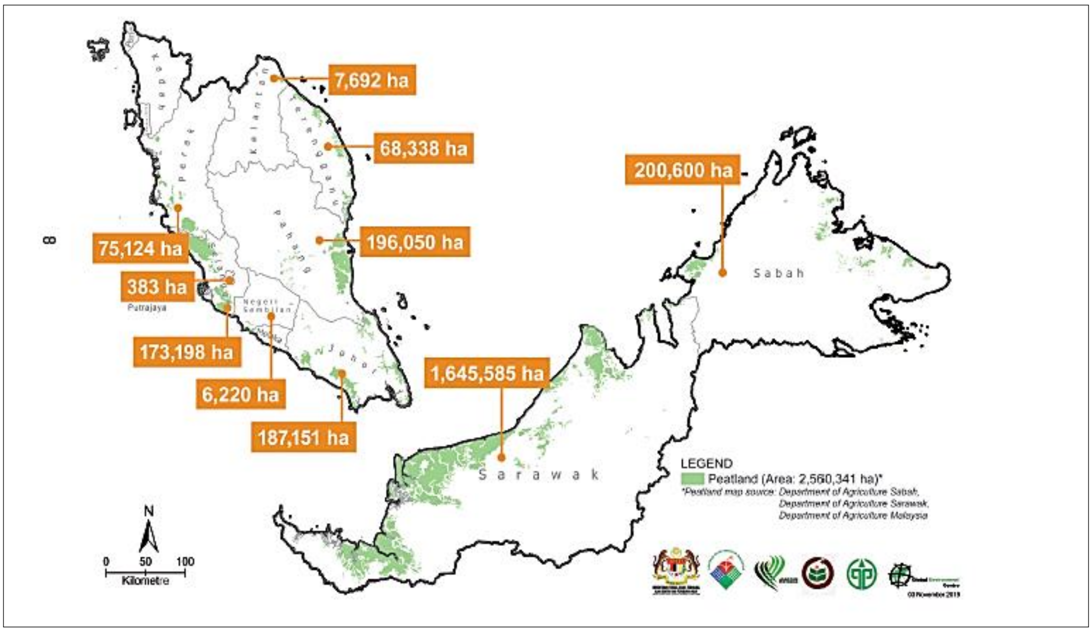

Figure 1.1 : Distribution of peatland in Malaysia

Source : Peatland Fire Prevention Programme to Mitigate Haze in Malaysia (2019)

According to Rahgozar and Saberian (2016), peat soil has high permeability, porosity ratio, compressibility, and consolidation settling while having low pH, bulk density, bearing capacity, shear strength, and plasticity. Peat has a unique property in that the pore produced when it accumulates with fibrous materials allows water to resist and remain in the particles, resulting in high water content. Sina Kazemian *et al*. (2011a) discovered that the in-situ void ratio of fibrous peats is relatively high because very compressible and bending hollow cellular fibres generate an open, entangled network of particles and the high initial water content.

Soil hydraulic properties include soil moisture retention and hydraulic conductivity (coefficient of permeability). Under equilibrium conditions, the soil water characteristics curve (SWCC) or water retention curve, defines the functional interactions between soil water content (w, θ_w, S_r) and matric potential. It is one of the essential characteristics of unsaturated soils that has been discovered to change with matrix suction and investigate soil water storage. The soil-water