EMPIRICAL CORRELATION FOR ESTIMATION OF UNSATURATED SOIL SHEAR STRENGTH

NOR HAFIZAH HANIS BINTI ABDULLAH

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EMPIRICAL CORRELATION FOR ESTIMATION OF UNSATURATED SOIL SHEAR STRENGTH

NOR HAFIZAH HANIS BINTI ABDULLAH

A project report 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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Bismillahirrahmanirrahim tabarakallahumma wa bihamdihi

Special dedicated to my beloved husband, mother, father, sisters and brothers...

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ABSTRACT

Most land surface in Malaysia is covered by residual soil with relatively deep ground water elevation, thus the soil presence in an unsaturated condition. Stability of slopes in such soil is governed by the shear strength of unsaturated soil, for which matric suction caused by the surface tension of the capillary water in soil pores plays an important role. The focus of this project is to study the relationship between the matric suction and the shear strength. Five empirical models are adopted to predict the shear strength of unsaturated soil by utilizing the saturated shear strength parameters and soil water characteristic curve of two soils retrieved from two sites in UTM campus i.e fine-grained (Kolej 12) and coarse-grained (Balai Cerapan). Previous studies suggested that the effect of suction is most significant within the transition zone of SWCC curves. In this case, the transition zone is 10 – 80 kPa for Kolej 12 soil and 2 – 60 kPa for Balai Cerapan soil. The saturated shear strength parameters for Kolej 12 and Balai Cerapan are (c' = 20 kPa;ϕ'= 27˚) and (c' = 22 kPa; ϕ'= 33˚) respectively. Analysis by empirical correlation also show that for fined grained soil, the shear strength increases non-linearly with suction. In this case, ϕ^b varies between 18.2 – 13.97°. On the other hand, linear increment of shear strength is depicted by coarse grained soil with constant $\phi^b$of 26.37°.

ABSTRAK

Kebanyakan tanah di permukaan bumi Malaysia diliputi oleh tanah baki, yang mana tanah baki ini mempunyai aras air bawah tanah yang dalam, sekaligus menjadikannya sebagai tanah tak tepu. Kestabilan cerun bagi tanah tersebut adalah bergantung kepada kekuatan ricih tanah tak tepu, yang mana daya sedutan yang disebabkan oleh tekanan tegangan permukaan kapilari dalam liang zarah tanah, memainkan peranan yang sangat penting. Tumpuan projek ini adalah untuk mengkaji hubungan di antara daya sedutan dan kekuatan ricih. Lima model empirikal telah digunakan untuk mendapatkan kekuatan ricih tanah tak tepu dengan menggunakan parameter kekuatan ricih tanah tepu dan lengkungan ciri tanah-air bagi dua jenis tanah yang diperolehi dari dua tapak di kampus UTM iaitu tanah butiran halus (Kolej 12) dan tanah butiran kasar (Balai Cerapan). Para pengkaji terdahulu mencadangkan bahawa kesan daya sedutan paling utama di zon peralihan dalam lengkungan ciri tanah-air. Dalam kes ini, zon peralihan adalah 10 – 80 kPa untuk tanah Kolej 12 dan 2 – 60 kPa untuk tanah Balai Cerapan. Parameter kekuatan ricih tanah tepu untuk Kolej 12 dan Balai Cerapan adalah masing-masing (c' = 20 kPa;ϕ'= 27˚) dan (c' = 22 kPa; ϕ'= 33˚). Analisis dari perkaitan empirikal juga menunjukkan bahawa untuk tanah butiran halus, kekuatan ricih meningkat secara tidak lelurus dengan daya sedutan. Bagi kes inin, ϕ^b berada di antara 18.2° – 13.97°. Namun, sebaliknya pula bagi tanah butiran kasar, yang mana peningkatan kekuatan ricih adalah lelurus dengan daya sedutan, iaitu nilai ϕ^b bersamaan dengan 26.37°.

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a	-	Suction related to the air-entry value of the soil
a_ω	-	Normalized area of water
c'	-	Effective cohesion
C_c	-	Coefficient of curvature
C_u	-	Coefficient of uniformity
$C(\psi_i)$	-	Correction factor
d_f	-	Estimated horizontal displacement at failure
d_r	-	Shearing or displacement rate
D_r	-	Relative density
D_{10}	-	Particle size for which 10% of particles are finer
D_{30}	-	Particle size for which 30% of particles are finer
D_{60}	-	Particle size for which 60% of particles are finer
e	-	Void ratio
e_{max}	-	Maximum void ratio at loosest state
e_{min}	-	Minimum void ratio at densest state
G_s	-	Specific gravity
k	-	Saturated permeability
m	-	Soil parameter related to the residual water content
n	-	Soil parameter related to slope at the inflection point
RH	-	Relative humidity
s	-	Slope of the tangent line on SWCC
S	-	Degree of saturation
t_f	-	Total estimated elapsed time to failure

t_{50}	-	Time required to achieve 50% consolidation
t_{90}	-	Time required to achieve 90% consolidation
u_a	-	Pore-air pressure
u_ω	-	Pore-water pressure
γ_b	-	Bulk unit weight
ζ	-	Slope of the linear function of SWCC
η	-	Porosity
θ_b	-	Volumetric water content at air-entry value
θ_i	-	Volumetric water content at inflection point
θ_r	-	Residual volumetric water content
θ_s	-	Saturated volumetric water content
θ_ω	-	Volumetric water content
Θ	-	Normalized water content
κ	-	Fitting parameter
ξ	-	Intercept on abscissa of SWCC
π	-	Osmotic suction
ρ_d	-	Dry density
σ_f	-	Effective stress at failure
σ_n	-	Normal stress
σ'	-	Effective normal stress
τ	-	Shear stress
τ_f	-	Shear strength of soil at failure
ϕ^b	-	Angle of shearing resistance with respect to suction
ϕ'	-	Angle of shearing resistance
χ	-	Chi parameter dependent on degree of saturation
ψ	-	Total suction
ψ_i	-	Suction at inflection point
ψ_p	-	Intercept of the tangent line on the suction axis
ψ_r	-	Suction value corresponding to residual water content
ω	-	Gravimetric water content

$(u_a - u_w)$	-	Matric suction
$(u_a - u_w)_b$	-	Matric suction at air-entry value
$(u_a - u_w)_f$	-	Matric suction in the specimens at failure
$(u_a - u_\omega)_r$	-	Matric suction at residual
$(\sigma_n - u_a)$	-	Net normal stress with reference to air pressure
$(\sigma_n - u_\omega)$	-	Effective normal stress

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Rainfall-induced slope failures are common geotechnical hazards in Malaysia. Every year, there are innumerable small to catastrophic slope failures that cumulatively impose great impact to the society. The high occurrences of the slope failures in Malaysia can essentially be attributed in part to two major factors, i.e. the intense and frequent downpours, and the natural characteristics of residual soil.

The average annual rainfall amount in Malaysia is considerably high of more than 2000 mm with most of the annual precipitation falls during the monsoon seasons (Dan'azumi *et al*., 2010). In general, the monsoon rainfall can be characterized by long duration and high daily rainfall intensity, while the typical tropical rainfall has short duration (less than one day) and high hourly rainfall intensity. The slope failures are usually triggered by the precipitation regimes, represented by either a short and intense rainstorm or a prolonged light rainfall, depending on the characteristics of the potentially unstable material.

Residual soil, which is the product of intense weathering of granite or sedimentary rocks in tropical climate, covers 75% of the land surface in Malaysia. The residual soil is naturally in an unsaturated condition because the ground water elevation is relatively deep (Rahardjo *et al.* 1993). Stability of slope in such soils is notably governed by the shear strength of unsaturated soil, for which suction plays an important role. High degree of saturation induced by rainfall infiltration will diminish the matric suction; hence reducing the shear strength of unsaturated soils.

Recent studies of unsaturated soils shear strength has gained widespread attention among researchers due to increasing concern towards understanding the shear strength behaviour with regard to matric suction. Numerous physical and theoretical models have been developed in the past 50 years owing to the needs to predict the highly complex shear behaviour of unsaturated soil. Experimental works, despite of imposing extra time consuming and relatively higher expenses, are evidently providing the most appropriate mean for measuring the shear strength of unsaturated soils. Mostly adopted measuring devices are direct shear box and triaxial cell with several modifications to implement the effect of suction on soil samples (Gan *et al.* (1988), Rahardjo *et al*. (1995), Taha *et al*. (2000), and Mohamed *et al*. (2006)).

In the absence of laboratory data, several empirical models have also been proposed as an alternative tool in prediction of unsaturated soil shear strength, for instance by Fredlund *et al*. (1996), Vanapalli *et al.* (1996), Oberg and Salfors (1997), Khallili and Khabaz (1998) and Bao *et al.* (1998). These empirical approaches employ the soil water characteristic curve (SWCC), which is a fundamental hydraulic property of unsaturated soil relating the volumetric water content (θ_ω) to matric suction (ψ), and saturated shear strength parameters in developing their models. Soil water characteristic curve can be established using laboratory works or can be predicted using empirical model.

This project deals specifically with empirical model to predict the shear strength of unsaturated soil as a function of matric suction by making use of saturated shear strength parameters and soil water characteristic curve. The saturated shear strength parameters were obtained from consolidated-drained direct shear test and parameters related to soil water characteristics curve were collected from existing data. Five empirical models were adopted for the prediction of shear strength under different suction values. The results were then analyzed and several merits and drawbacks are discussed.

1.2 Aim and Objectives of Study

The aim of this project is to predict the unsaturated shear strength of tropical residual soil obtained from two different sites at Universiti Teknologi Malaysia campus with respect to suction. Several empirical models gathered from literature were adopted. To achieve this aim, several objectives are outlined as below:

1) To obtain saturated shear strength parameters of the soil samples by direct shear test under consolidated drained (CD) condition.

2) To study the relationship between shear strength and suction by utilizing soil water characteristic curves.
3) To predict the shear strength of the corresponding soil in unsaturated condition by empirical methods.

1.3 Scope and Limitation of Study

The results are restricted to soil collected from two sites at Universiti Teknologi Malaysia campus where the soil water characteristic curve of the soil has been tested in the previous research. Direct shear test under consolidated drained condition will be performed following ASTM D3080-04 procedure to get the saturated shear strength parameters. Empirical procedures proposed by Fredlund *et al*. (1996), Vanapalli *et al.* (1996), Oberg and Salfors (1997), Khallili and Khabaz (1998) and Bao *et al.* (1998) are utilized in this project. Following that, parameters required in the empirical model will be extracted from the soil water characteristic curve. Finally, the predicted shear strength using empirical model will be compared with available laboratory data.