UNSATURATED SHEAR STRENGTH BEHAVIOUR UNDER UNCONSOLIDATED UNDRAINED TESTS

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To my beloved family members

For their endless love, blessings and never ending supports

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ABSTRACT

Residual soils cover more than three-quarts of the land area of Peninsular Malaysia. Many steep slopes in these residual soils often have a deep ground water table. Above those ground water tables, the soils are in unsaturated conditions. In this study, unsaturated shear strength behavior of a tropical residual soil under different stress levels is investigated by using uncomplicated testing procedure. Existing triaxial tests use translation technique for determining unsaturated shear strength parameters but ordinary Unconsolidated Undrained triaxial tests were carried out due to lacking of the advanced testing unit in the laboratory. The Unconsolidated Undrained tests were carried out under different cell pressures at different suctions values to obtain the undrained compressive strengths of the specimens. Preliminary results of the consolidated isotropic undrained tests, show effective cohesion and effective angle of friction i.e., saturated shear strength parameters were 9 kPa and $23°$, respectively. In Unconsolidated Undrained tests, the values of apparent shear strength at high stress levels range from $66.1 - 72.6$ kPa. At low stress levels, the range of apparent shear strength values was obtained in between $53.1 - 57.5$ kPa. The value of friction angle for the highest suction pressure tested in this study (300 kPa) was determined $9.9°$. This study illustrated that there is nonlinear relationship between the apparent shear strength and suction.

ABSTRAK

Lebih daripada tiga suku keluasan tanah di Semenanjung Malaysia merupakan tanah residul . Kebanyakan cerun yang curam yang terdiri daripada tanah residul mempunyai paras air bawah tanah yang agak rendah. Oleh yang demikian, tanah yang terdapat di atas paras air bawah tanah adalah berada dalam keadaan tidak tepu. Dalam kajian ini, kekuatan ricih tanah tidak tepu untuk tanah residul tropika adalah dikaji di bawah tekanan yang berbeza dengan menggunakan prosedur ujian makmal yang tidak rumit. Walaupun ujian tiga paksi yang sediada menggunakan teknik translasi bagi menentukan kekuatan ricih tanah namun ujian tidak tersalir tidak termampat yang biasa telah digunakan atas sebab kekurangan alat ujian di makmal. Ujian tidak tersalir tidak termampat telah dijalankan di bawah tekanan sel yang berbeza dan pada nilai sedutan yang berlainan untuk mendapatkan kekuatan mampatan tidak tersalir bagi tanah yang diuji. Keputusan awalan daripada ujian pengukuhan isotropik tidak tersalir menunjukkan bacaan kekuatan ricih tepu iaitu nilai kejelekitan berkesan dan nilai sudut geseran berkesan sebanyak 9 kPa dan 23^0 masing-masing. Dalam ujian tidak tersalir tidak termampat pula, nilai untuk kekuatan ricih sebenar pada tekanan yang tinggi adalah dalam lingkungan 66.1 – 72.6 kPa. Sebaliknya, pada tahap tekanan yang rendah, lingkungan kekuatan ricih sebenar yang diperolehi adalah 53.1 – 57.5 kPa. Manakala nilai sudut geseran yang direkodkan semasa tekanan sedutan tinggi iaitu pada 300 kPa adalah 9.9^0. Kajian ini telah menunjukkan bahawa tiada hubungan yang linear di antara nilai kekuatan ricih sebenar dan nilai tekanan sedutan.

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LIST OF SYMBOLS

$\bar{A}$	-	Skempton's pore pressure parameter
$\bar{B}$	-	Skempton's pore pressure parameter
c_u	-	Total cohesion
C_{app}	-	Apparent shear strength
$c^{'}$	-	Effective cohesion
e	-	Void ratio
e_0	-	Initial void ratio
G_s	-	Specific gravity of soil
l_0	-	Initial length of the specimen
q_u	-	Undrained compressive strength
R	-	Universal gas constant
RH	-	Relative humidity
t	-	Temperature
T	-	Absolute temperature
u_a	-	Pore-air pressure
u_w	-	Pore-water pressure
$\overline{u}_v$	-	Partial pressure of pore-water vapor
$\overline{u}_{v0}$	-	Saturation pressure of water vapor
v_{w0}	-	Specific volume of water
W_s	-	Weight of solid soils in the specimen
W_T	-	Target weight of the specimen
W_w	-	Weight of water in the specimen
Δl	-	Compression of the specimen
Δu_d	-	Changing in pore-water pressure
$\Delta \sigma_d$	-	Deviator stress

$(\Delta\sigma_d)_f$	-	Deviator stress at failure
ε	-	Axial strain
θ	-	Volumetric moisture content
θ_b	-	Volumetric water content at air entry value
θ_r	-	Residual volumetric water content
θ_s	-	Saturated volumetric water content
π	-	Osmotic suction
σ_1	-	Axial stress
$\sigma_1^{'}$	-	Effective axial stress
σ_3	-	Confining cell pressure
$\sigma_3^{'}$	-	Effective confining stress
τ_f	-	Effective shear strength
φ	-	Total suction
$\varphi^{'}$	-	Effective angle of shearing resistance
φ^b	-	Frictional resistance due to contribution of matric suction
χ	-	Chi parameter dependent on degree of saturation
ω	-	Moisture content
ω_0	-	Initial moisture content
ω_T	-	Target moisture content of the specimen
ω_v	-	Molecular mass of water vapor
$u_a - u_w$	-	Matric suction
$(u_a - u_w)_b$	-	Matric suction at air-entry value
$(u_a - u_w)_f$	-	Matric suction of the specimen at failure
$(u_a - u_w)_r$	-	Matric suction at residual
$\sigma_n - u_w$	-	Effective normal stress
$\sigma_n - u_a$	-	Net normal stress
$(\sigma_n - u_a)_f$	-	Net normal stress at failure

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

For many years, unsaturated soils were either ignored in civil engineering design and construction analysis or were approached inappropriately from the traditional framework of saturated soil mechanics. According to Lu and Likos (2004), however rapid advancement in our understanding of unsaturated soil behavior over the last 30 to 40 years has led today's civil engineer to realize that, there is now an opportunity to approach problems involving unsaturated soil on a much more rational basis.

Climate plays an important role in whether a soil is saturated or unsaturated. Water is removed from the soil either by evaporation from the ground surface or by evaporation-aspiration from a vegetative cover. These processes produce upward flux water out of the soil. On the other hand, rainfall and other forms of precipitation provide a downward flux into the soil. The difference between two flux conditions on a local scale largely dictates the pore-water pressure conditions in the soil. A net upward flux produces a gradual drying, cracking, and desiccation of the soil mass and a net downward flux eventually saturates the soil mass. According to Dan' azumi *et al*. (2010), Malaysia experiences more than 2000 mm annual rainfall with most of the annual precipitation falls during the monsoon seasons.

The microclimatic conditions in an area are the main factors causing a soil deposit to be unsaturated. Therefore, unsaturated soils or soils with negative pore-water pressures can occur in essentially any geological deposit, such as residual soil, a lacustrine deposit, soils in arid and semi-arid areas with deep ground water table, and tropical soils. Residual soils are products of the in situ physical and chemical weathering of bedrocks. These soils are commonly situated above the groundwater table. Therefore, in situ residual soils are often unsaturated in the nature (or approaching to saturation), and the pore-water pressures of them are negative relative to atmospheric conditions. This negative pore-water pressure is called matric suction. According to Rahardjo *et al*. (1995), residual soils cover more than three-quarters of the land area of Peninsular Malaysia. Many steep slopes in these residual soils often have a deep ground water table above the soils with high extra attractive force i.e. matric suction. It is well established that the stability of a natural or a cut slope in residual soils depends on the shear strength which is affected by the matric suction. The in-situ matric suction and the shear strength of soils are in turn affected by the climatic conditions, particularly rainfall distributions.

Shear strength parameters are the key input parameters in any soil stability analysis. In fact, the value for determining the shear strength parameters of a soil is required in the prediction of the stability of slopes and embankments, in the bearing capacity of foundations, and in pressures against earth retaining structures. Predicting unsaturated shear strength parameters is more significant in tropical countries, where rainfall and intense chemical weathering have resulted in the formation of such soils.

In vadose zone, the zone above groundwater table, matric suction has a strong influence on shear strength behaviour. This extra attractive force is producing extra shear strength, i.e. apparent shear strength (C_{app}) and friction angle with respect to suction (φ^b). The parameters C_{app} and φ^b are named unsaturated shear strength parameters. According to Md. Noor (2011), unsaturated shear strength parameters are not constant variables, but vary with depth and suction.

Several empirical models have also been proposed in prediction of unsaturated soil shear strength parameters, for instance by Fredlund *et al*. (1996), Vanapalli *et al*. (1996). These empirical approaches employ the soil water characteristic curve (SWCC). Laboratory works, despite of imposing extra time consuming and relatively higher expenses, are evidently providing the most appropriate mean for measuring the unsaturated shear strength parameters.

Conventional triaxial tests for unsaturated soils require modifications. The presence of air and water in the pores of soil causes the testing procedures and techniques to be more complex than those required when testing saturated soils. The modification must accommodate the independent measurement or control of pore-air and pore-water pressures .i.e. translation technique. In addition, in unsaturated soils the pore-water pressure is usually negative and can result in water cavitation problems in the measurement. In this project for predicting unsaturated shear strength parameters normal unconsolidated undrained tests were conducted due to the absence of advanced testing unit. These unconsolidated undrained tests were carried out at different confining pressures and different suctions with using Vanapalli and Fredlund (1997) formulas. This procedure is faster, cheaper and easier to conduct to the existing laboratory procedures.

1.2 Problem Statement

Several empirical models have been proposed in recent years to predict the unsaturated soil shear strength parameters. Laboratory tests, despite of imposing extra time consuming and relatively higher expenses, are evidently providing the most appropriate means for measuring the unsaturated shear strength parameters rather than empirical models.

Existing laboratory tests for determining unsaturated shear strength parameters such as consolidated drained tests and consolidated undrained tests are base on measuring pore-air and pore-water pressures .i.e. translation technique. Those procedures are difficult to conduct, complicated, costly and time consuming. This study has been proposed a simple, low cost, and quick way for predicting unsaturated soil shear strength parameters by using normal unconsolidated undrained tests.

1.3 Objectives of Study

The aim of this study is to investigate the effect of stress level on the apparent shear strength of an unsaturated tropical residual soil by using uncomplicated testing procedures. In order to achieve this aim, three objectives are outlined as follows:

1) To determine the apparent shear strength (C_{app}) from unconsolidated undrained test at different stress levels.
2) To determine the friction angle (φ^b) from unconsolidated undrained test at different stress levels.
3) To investigate the relationship between apparent shear strength and stress level of the unsaturated residual soil.

1.4 Scope and Limitation of Study

The results of this study were restricted to the soil samples collected from a slope with existence mature tropical tree acacia situated at latitude ($+1^{\circ}33^{'}32.03^{''}$) and longitude ($+103^{\circ}38^{'}38.04^{''}$). The tree located at the toe of slope in front of P16 at Faculty of Electrical Engineering Universiti Teknologi Malaysia.

In this project, several unconsolidated undrained triaxial tests using normal triaxial testing apparatus, under different cell pressures and different suctions were carried out to obtain the maximum deviator stresses of the unsaturated soil specimens. The unconsolidated undrained triaxial tests have been performed following BS 1377: part 7:1990, clause 8. The only difference was that the unsaturated soil specimens were tested in their initial water contents and suctions. For obtaining saturated shear strength parameters, consolidated isotropic undrained tests have been conducted based on BS 1377: part 8:1990, clause 7. Lack of the advanced testing unit was the limitation of this project.

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REFERENCES

Abdullah, N. H. H. B. (2011). *Empirical Correlation for Estimation of Unsaturated Soil Shear Strength.* Master of Engineering (Civil-Geotechnics), Universiti Tecknologi Malaysia, Skudai.

Aitchison, G. D. (1965). Soil Properties, Shear Strength, and Consolidation. *Proceeding of the* 6^{th} *International Conference Soil Mechanics*, 1965. Montreal, Canada, 318-321.

ASTM (2002). *Standard Test Methods for Determination of the Soil Water Characteristic Curve for Desorption Using Pressure Extractor, D6836-02.* West Conshohocken, PA, ASTM.

Bao C. G., Gong B. and Zhan L. (1998). Properties of Unsaturated Soils and Slope Stability of Expansive Soil. Keynote Lecture, *UNSAT 98,* 2^{nd} *International Conference on Unsaturated Soils,* Beijing.

Bishop, A. W. (1959). The Principal of Effective Stress. *Technische Ukebland.*106 (39), 859-863.

Bishop, A. W., and Blight, G. E. (1963). Some Aspects of Effective Stress in Saturated and Unsaturated Soils. *Geotechnique*. 13(3), 177-197.

British standards Institution (1981). *Soil Sampling, Site Investigation*. BS5930. London: British Standards Institution

British standards Institution (1990). *Consolidated-Undrained Triaxial Compression Test with Measurement of Pore Pressure*. BS1377-8. London: British Standards Institution.

British standards Institution (1990). *Determination of the undrained Shear Strength in Triaxial Compression without Measurement of Pore Pressure*. BS1377-7. London: British Standards Institution.

British standards Institution (1990). *Determination of Moisture Content*. BS 1377-2. London: British Standards Institution.

Corey, A. T. (1957). Measurement of Water and Air Permeability in Unsaturated Soils. *Proc. of the Soil Science Society of America, 21(1),7-10.*

Dan'azumi, S., Shamsudin, S., and Aris, A. (2010). Modelling the Distribution of Rainfall Intensity using Hourly Data. *American Journal of Environmental Sciences, 6*(3), 238-243.

Delage, P. (2002). Experimental Soil Mechanics. *Proceeding of* 3^{rd} *International Conference on Unsaturated Soils, UNSAT 2002,* Brazil, (3), 973-996.

Dorsey, N. E. (1940). *Properties of Ordinary Water-Substances.* Amer. Chemical Society. Mono. Series. New York: Reinhold, 673.

Edlefsen, N. E. and Anderson, A.B.C. (1943). *Thermodynamics of Soil Moisture.* Hilgardia. 15(2), 31-298.

Fredlund, D. G. (1996). *The Emergence of Unsaturated Soil Mechanics*. The Foutrh Spencer J. Buchanan Lecture, College Station, Texas: A & M University Press.

Fredlund, D. G. (2006). Unsaturated Soil Mechanics in Engineering Practice. *Journal of Geotechnical and Environmental Engineering,* ASCE, 132(3), 286-321.

Fredlund, D. G., and Morgenstern, N. R. (1977). Stress State Variables for Unsaturated soils. *J. Geotech Engrg. Div*., ASCE, GT5, 103, 447-466.

Fredlund, D. G., and Rahardjo, H. (1993). *Soil Mechanics for Unsaturated Soils*. New York: John Wiley & Sons, Inc.

Fredlund, D.G., and Xing, A. (1994). Equations for the Soil-Water Characteristic Curve. *Canadian Geotechnical Journal*. (31), 521-532.

Fredlund, D. G., Morgenstern, N. R., and Widger, R. A. (1978). The Shear Strength of Unsaturated Soils. *Canadian Geotechnical Journal.* 15, 313-321.

Fredlund, D. G., Xing, A., Fredlund, M. D., and Barbour, S. L. (1996). The Relationship of the Unsaturated Soil Shear Strength to the Soil Water Characteristic Curve. *Canadian Geotechnical Journal.* (32), 440-448.

Gan, J. K. M., and Fredlund, D. G. (1996). Shear Strength Characteristics of Two Saprolitic soils. *Canadian Geotechnical Journal. 33*(4), 595-609.

Gitirana Jr, G. de F. N., and Fredlund, D. G. (2004). Soil-Water Characteristic Curve Equation with Independent Properties. *Journal of Geotechnical and Geoenvironmental Engineering.* 130 (3), 209-212.

Irfan, T. Y. (1988). Fabric Variability and Index Testing of a Granitic Saprolite. *Proceeding of* 2nd *International Conference on Geomechanics in Tropical Soils*, Dec. 12-14, Singapore, 1, 25-35.

Khallili N. and Khabaz M. H. (1998). A Unique Relationship for the Determination of the Shear Strength of Unsaturated Soil. *Geotechnique.* 48(5), 681-687.

Lu, N., and Likos, W. J. (2004). *Unsaturated Soil Mechanics*. New York: John Wiley & Sons.

Leong, E.C. and Rahardjo, H. (1997). Permeability Functions for Unsaturated Soils. *Journal of Geotechnical and Geoenvironmenal engineering.* 123 (12), 1118-1126.

Md.Noor, M. J. (2011). *Understanding Rainfall-Induced Landslide*. Universiti Teknologi Mara, Shah Alam: UiTM Press.

Paddy, J. F. (1969). Theory of surface tension. *Surface and Colloid Science*, 1, Wiley Interscience, Toronto, Canada.

Rahardjo, H., Lim, T. T., Chang, M. F., and Fredlund, D. G. (1995). Shear Strength Characteristic of a Residual Soil. *Canadian Geotechnical Journal.* (32), 60-77.

Richards, B.G. (1965). Measurement of the Free Energy of Soil Moisture by the Psychrometric Technique using Thermistors. *Moisture Equilibria and Moisture Changes in Soils Beneath Covered Arteas.* Butterworth, Australia, 39-46.

Roslan, S. M. B. (2012). *Effect of Changing Suction on Shear Strength of Unsaturated Soil.* Master of Engineering(Civil-Geotechnics), Universiti Teknologi Malaysia, Skudai.

Terzaghi, K. (1936). The Shear Resistance of Saturated Soils. *Proceedins of 1st International Conference of Soil Mech.Found. Eng.* Cambridge.1, 54-56.

Vanapalli, S. K., and Fredlund, D. G. (1997). Interpretation of Unsaturated Shear strength of Unsaturated Soils in terms of Stress State Variables. *Proceedings of the* 3rd *Brazilian Symposium on Unsaturated Soils*, Tacio de Campos, Vargas, 35-45.

Vanapalli, S. K. and Fredlund, D.G. (2000). Comparison of Different Procedures to Predict unsaturated Soil Shear Strength. *Advances in Unsaturated Geotechnics,* ASCE, 195-20.

Vanapalli, S. K., Fredlund, D. G., Pufahl, D. E., and Clifton, A. W. (1996). Model for the Prediction of Shear Strength with Respect to Soil Suction. *Canadian Geotechnical Journal.* (33), 379-392.