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

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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
\( \bar{u}_v \) - Partial pressure of pore-water vapor
\( \bar{u}_{v0} \) - 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
\( \Delta l \) - Compression of the specimen
\( \Delta u_d \) - Changing in pore-water pressure
\( \Delta \sigma_d \) - Deviator stress
\((\Delta \sigma_d)_f\) - Deviator stress at failure
\(\varepsilon\) - Axial strain
\(\theta\) - Volumetric moisture content
\(\theta_b\) - Volumetric water content at air entry value
\(\theta_r\) - Residual volumetric water content
\(\theta_s\) - Saturated volumetric water content
\(\pi\) - Osmotic suction
\(\sigma_1\) - Axial stress
\(\sigma'_1\) - Effective axial stress
\(\sigma_3\) - Confining cell pressure
\(\sigma'_3\) - Effective confining stress
\(\tau_f\) - Effective shear strength
\(\varphi\) - Total suction
\(\varphi'\) - Effective angle of shearing resistance
\(\varphi^b\) - Frictional resistance due to contribution of matric suction
\(\chi\) - Chi parameter dependent on degree of saturation
\(\omega\) - Moisture content
\(\omega_0\) - Initial moisture content
\(\omega_T\) - Target moisture content of the specimen
\(\omega_v\) - 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 ($\phi^b$). The parameters $C_{app}$ and $\phi^b$ 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 ($\phi^b$) 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°33′32.03″) and longitude (+103°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.
REFERENCES


