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Determination of shear strength parameters of unsaturated sedimentary residual soils for slope stability analyses

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ABSTRACT: Weathered granite, sedimentary and metamorphic rocks are the main types of residual soil in Malaysia. In natural state the soil above ground water level are in unsaturated condition. Major parts of residual soils in Malaysia are in unsaturated state, therefore studies have to be done in order to understand the influence of soil suction on shear strength of these residual soils. Soil suction has important influences on water entry, structural stability, stiffness, shear strength and volume change, which are an important variables in soil engineering design.

Shear strength determination was carried out on unsaturated sample using specially modified apparatus. At the same time the concept of multistage multi suction is implemented in order to eliminate soil variations. Discussion in the paper covers the modification of testing equipment, method of sample collection, details of multi stage test procedure and test results.

INTRODUCTION

Residual soils are product of the in-situ weathering of igneous, sedimentary and metamorphic rocks. They occur in most countries of the world but the greater areas and depths are normally found in tropical humid areas such as Malaysia. Residual soils in Malaysia mainly consist of weathered igneous or sedimentary rock. The interest of this research is to study the shear strength of partially saturated weathered sedimentary residual soil.

Various soil samples were collected from slope at locations of different soil weathering grades. Figure 1.0 shows the description given by Geological Society Engineering Group for residual weathering grade. Figure 2.0 shows the cut slope layout with soil sampling locations. Figure 3.0 indicates a map was proposed by him in the First International Conference on Soil Mechanics in 1936. Fredlund and Morgenstem introduced the third factor of (ua - uw) into the earlier equation of effective stress: -

x = c' + (a - ua) tan <>' + (ua- uw)tan<t)b ----- (1)

where:

c' = effective cohesion
a = total stress
ua= pore -air pressure
0' = effective angle of internal friction
uw= pore water pressure
(ua- uw) = matric suction
())b = angle indicating the rate of increase in shear strength with respect to changes in (ua- uw) when (a - ua) is held constant.

of weathering grades on the cut slope. Due to the variation in soil profiles, the focus is only on weathered sand stone material.

UNSATURATED SOILS

The principal and fundamental research on unsaturated soil mechanics started in 1962 by Jennings and Burland in Imperial College. At that time much interest was on Terzaghi's (1923) principle of effective stress for saturated soil which

The above equation assumes a planar failure envelope, the internal friction angle 0', remains essentially constant under saturated and unsaturated condition. The angle 0b, which quantifies the effect of suction, is measured from the T Vs (ua - uw) plot. The cohesion intercepts Ci, C2 and C3 due to the applied suction (ua - uw) vary if the angle of internal friction 0' remains constant at different suction levels. Figure 4.0 shows the matric suction drawn on failure envelope.

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--Humus / Topsoil

'• VI Residual Soil

-•V Completely Weathered

i®IV Highly Weathered

III Moderately Weathered

II Slightly Weathered

lB Faintly Weathered

1A Fresh

Figure 1.0 : A schematic representation of tropical soil weathering profiles.

BH1 -

Figure 2.0 : Slope layout with sampling locations

| | Massive Sandstone

Sides of the soil mass were then trimmed slowly and carefully to fit the sample box size. The box was then fitted to the specimen with the bottom cap opened. The whole soil mass with the box in place were dug and removed. The top cover was placed and sealed with paraffin to prevent moisture lost. All the boxes were carried with care to the laboratory and kept in constant temperature humidified room.

The sample from the block sample was removed using specially fabricated split-mould sampler. During extrusion of sample, silicon oil was applied to the sampler to reduce friction. During sampling the sampler was pushed into the block sample by using hydraulic jack, cutting it to the required diameter. Finally the extruded sample will be cut to the required thickness. Figure 5.0 illustrates the split sampler.

Four numbers of such split samplers were pushed into the sample at the same time in order to obtain 4 soil samples. The samples were used to perform two multistage multi suction tests, one multistage CIU test and one for soil water characteristics curve.

(Of ^ *2*

Uy)2 > (Ua~ UwH

f V l > °
0

(<r-Ua)

C = c’ + (ug- %)

C3= c'+(ug- u^taru^

b p c'+Cug- uw)3tan<(>,“

“l

|c3

("a" <Ma~ °vp2 ^ 3 (%” V

Figure 4.0 : Matric suction drawn on failure

Figure 3.0 : Geological map of the cut slope

SOIL SAMPLING

Undisturbed block samples were collected from the site in boxes made of metal plates measuring 200x200x200 mm. After choosing a suitable location, the topsoil of about 300mm was removed using lightweight shovels. Trenches were dug all around the soil mass of about 250x250x250mm.

envelope

TEST SETUP AND PROCEDURE

Bishop-Wesley triaxial cell set was modified to carry out the test on suction induced soil specimens. The top cap of the triaxial cell was modified to provide inlet for air pressure applied at the top of specimen. Suction was applied by controlling the pore air and pore water pressure. The layout of the modified triaxial setup is shown in Figure 6.0. Axis

translation technique (Hilf, 1956) was used to apply soil suction to the specimens. A 15 bar high air entry disc was sealed on a modified base pedestal. This allowed the air and water pressures to be controlled during the application of deviator stress in order to maintain the constant matrix suction throughout the test.

However, with time pore air may diffuse through the water in the high air entry discs and appear as air bubbles in the water compartment below the disc. Therefore the water compartment was fabricated to facilitate flushing of the diffused air bubbles on a periodic basis.

Axial Screw Adjustment

Long Bolt?
&Nut Assembly*

Load Transducer

Low Air Entry Porous Stone

Cell Chamber

High Air Entry Ceramic Disc

Perspex Cell

Figure 7.0 : Diffused air volume indicator

Diffused Air Volume Indicator (DAVI as shown in Figure 7.0) was used to measure the amount of air that diffused through the ceramic disc and accumulated under ceramic disc. The recorded volume change during testing could indicate the suction equilibrium in the specimen. Suction equilibrium of the specimen could determine when there were no infinitesimal changes of water volume during suction equilibrium stage. The diffused air volume measurement was performed once or twice a day or more frequently when high pressures were used. The measured water volume changes were adjusted in accordance with the diffused air volume.

Multistage triaxial set up was adopted due to the limited specimens and to eliminate the effect of the soil variability.

Multistage multi suction, shear test was chosen in which, the <(>b value be determined based on known value of <))’. According to the unsaturated soil mechanics theory (D.G. Fredlund, H. Rahardjo, 1993), the (t)’ for different matric suction is the same for a particular soil sample. A multistage CIU triaxial test was conducted to obtain the <J) value. The test procedure for the multistage multi suction shear test is as follows:-

i. The specimens was sampled and mounted in the modified triaxial setup with filter paper at the bottom of the sample. (This is to prevent the fine clay material from blocking the fine

Wall
Air
Bellofram
Seal
Crosshead
Attached t<
Ram
Bellofram
Lower Pressure ..
Chamber jjp——————
^Cell Pressure
PWP or
Drainage
Loading Ram
Linear Bearing
A ssure

Figure 6.0 : Modified triaxial setup

pores in the high air entry disc).

ii. Suction equilibrium and consolidation was carried out before the shearing process. Matric suction equilibration is generally attained in about one week or more.

iii. After consolidation the sample was sheared at a constant rate.

iv. Just before peak shear stress the axial force was immediately released until no significant shear

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resisting force, allowing the sample to recover elastically.

v. For the second stage of multi suction multistage shear test, the matric suction was increased to another higher suction value. Suction equilibrium had to be carried out first according to steps 2.

vi. The matric suction was increases for every shearing stage.

vii. Since the (()' is assumed the same for every suction value, the failure envelope can be obtained for every stage. The <j)b value was found based on the relationship between effective cohesion and the suction.

viii. This multi stage multi suction shear test can actually reduce the number of samples used and time in order to obtain the shear strength parameter of the unsaturated soil.

The triaxial test setup used for testing was fully computerized (as shown in Figure 8.0). This setup uses three pressure controllers for cell, back and lower chamber and a digital pressure Interface to measure and maintain pore water/air pressure respectively.

.TriaxiaJ Cell

D igital Press
Volume Contro.

^ . . D igital Pressure
Printer/ Interface
Plotter

Figure 8.0 : Computerized triaxial testing for unsaturated soils

TEST RESULTS AND DISCUSSIONS

Figure 9.0 : Stress - strain curve for multi suction - multistage test at berm 4

Figure 10.0 : Suction stabilization plot at TP5 level 1

Principal Stress (kPa)

Figure 11.0 : Mohr circle plots for multistage CIU test

From the CIU test results, friction angle of 26° and 33° were obtained for sample at grade IV and grade III. Using the friction angle (<j)'), parallel lines are plotted to obtain effective cohesion for various **suction, shown in Figure 12.0 and Figure 13.0.**

Two sets of test results are presented here for discussions. The sample were collected at TP5 Level 1 (weathering grade IV) and Berm 4 (weathering grade III). Both samples were collected from the sandstone zone. A typical test results of :

1. stress-strain curve for multi suction multistage,
2. plots of continuous water volume change during suction consolidation,
3. mohr circle plots for multistage CIU test results,

are shown in Figure 9.0, 10.0 and 11.0 respectively.

Figure 12.0 : Mohr circle plots for multi suction multistage test at TP5 level 1

Principal Stress (kPa)

Figure 13.0 : Mohr circle plots for multi suction multistage test at berm 4

The effective cohesions obtained are then plotted with matric suction to determine the value of (f)b (angle indicating the rate of increase in shear strength with respect to changes in (ua - uw)) in Figure 14.0 and Figure 15.0. From the above plots the contribution of suction in shear strength reduces when the suction value gets higher.

In addition to the above tests, soil-water characteristic curves were also determined for both laboratory and field tests. A typical plot of soil water characteristic curve at berm 4 (soil of grade IV) is shown in Figure 16.

Many more samples will be tested in the future to verify these test results. In the final part of this research work, stability analysis of the slope will be conducted at various sectional profiles to determine the changes in factor of safety caused by suction.

Matric Suction (kPa)

Figure 14.0 : Matric suction drawn on failure envelope for sample at TP5 level 1

Moisture Content (%)

k Laboratory * Field Results

Figure 16.0 : Combination of field and laboratory soil-water characteristic curve for berm 4

CONCLUSION

The proposed multi-stage triaxial testing procedure to evaluate the rate of increment in shear strength <|)b concerning matric suction is possible provided that 6' is assumed to be constant at all suction level. Furthermore triaxial test on unsaturated soil specimens using multi-stage technique will greatly reduces the sample or soil variation and disturbances.

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Figure 15.0 : Matric suction drawn on failure envelope for sample at Berm 4