Shear Strength of Partially Saturated Sedimentary Residual Soils with Respect to Soil Weathering Grades

Conference Paper · November 1998

7 authors, including:

Saravanan Mariappan
Nexus EC Sdn. Bhd., Kuala Lumpur, Malaysia .

Faisal Hj. Ali
National Defence University of Malaysia

Thirteenth Southeast Asian Geotechnical Conference, 16-20 November, 1998, Taipei, Taiwan, ROC

Shear Strength of Partially Saturated Sedimentary Residual Soils with Respect to Soil Weathering Grades

S. MARIAPPAN* **T. H. LOW*** **C. A. NEOH****
FAISAL HJ. ALI* **S. HASHIM*** **A. N. HUSSEIN****
K. ABDULLAH**

* **University of Malaya, Malaysia**
** **Public Works Dept., Malaysia**

SYNOPSIS : This paper deals with the basic behavior of partially saturated sedimentary weathered residual soils with respect to soil weathering grades. The weathering grades, covered in the study, are soils of grade VI to grade I. Shear strength determination was carried out in laboratory by using automated testing system. Minor modification was carried out to introduce matric suction to the soil samples. At the same time the concept of multistage multi suction was used to perform the testing due to the limitation of samples and time. Multistage triaxial test may also reduce the effect of soil variability, which is very often in residual soils. The collected sample and test results were categorized into stratum profiles based on changes in soil strength and weathering grades. The test procedures and typical test results are presented in this paper.

INTRODUCTION

Residual soils in Malaysia mainly consist of weathered igneous, sedimentary and metamorphic rock. The interest of this research is to study the performance of shear strength of partially saturated weathered sedimentary residual soil. As in nature residual soils are in unsaturated condition and therefore suction is an important factor to be considered in testing these soils. Suction has an important bearing on water entry, structural stability, stiffness, shear strength and volume change. The total suction, water content, solute content and how they vary with time are often the most important variables in soil engineering design.

This research attempts to find the shear strength of Malaysian weathered sedimentary residual soil with the effect of suction. To model the study a typical cut slope was adopted to perform slope stability analysis based on the shear strength results. (Figure 1. shows the slope layout). A weathering grade map was also prepared for the slope after it has been cut and selections of test sample are done based on the map. (Figure 2. shows the mapped weathering grade on the cut slope). The selected area is defined into slope sections for stability analysis.

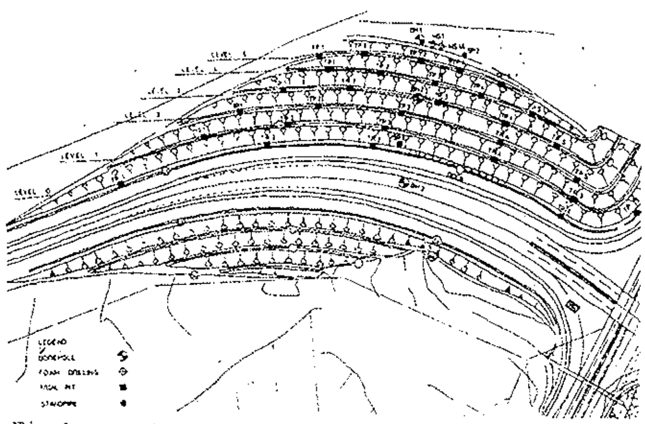

Fig.1 Slope Layout With Collected Sample Locations

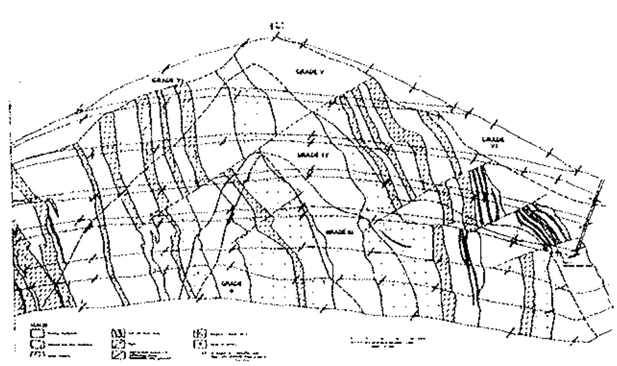

Fig.2 Geological Map Of The Cut Slope

SHEAR STRENGTH OF 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 was proposed by him in the First International Conference on Soil Mechanics in 1936. The concept and research interest on unsaturated soil developed only in 1977. Fredlund and Morgenstern made the revitalization of unsaturated soil mechanics possible. Fredlund and Morgenstern introduced the third factor of $(u_a - u_w)$ into the earlier equation of effective stress defined as (Bishop, 1959):-

$$\sigma' = (\sigma - u_a) + X(u_a - u_w) \quad \text{--------} \ (1)$$

Where σ' and σ are the effective and total stresses respectively, u_a is the pore air pressure and u_w is the pore water pressure. X is a function that depends on the saturation with value 1 to 100% and 0 for completely dry soil. The relationship between X and saturation was determined experimentally to evaluate the strength. τ, written in terms of stress state variables for an unsaturated soil and is an extension of equation used for saturated soils.

$$\tau = c' + (\sigma - u_a)\tan\phi' + (u_a - u_w)\tan\phi^b \quad \text{-----} \ (2)$$

where:

- c' = effective cohesion
- σ = total stress
- u_a = pore -air pressure
- ϕ' = effective angle of internal friction
- u_w = pore water pressure
- $(u_a - u_w)$ = matric suction
- ϕ^b = angle indicating the rate of increase in shear strength with respect to changes in $(u_a - u_w)$ when $(\sigma - u_a)$ is held constant.

The above equation assumes a planar failure envelope, the internal friction angle ϕ', remains essentially constant under saturated and unsaturated condition. The angle ϕ^b, which quantifies the effect of suction is measured from the τ Vs $(u_a - u_w)$ plot. The cohesion intercepts c_1, c_2 and c_3 due to the applied suction $(u_a - u_w)$ vary if the angle of internal friction ϕ' remains constant at different suction levels. Figure 3. shows the matric suction drawn on failure envelope.

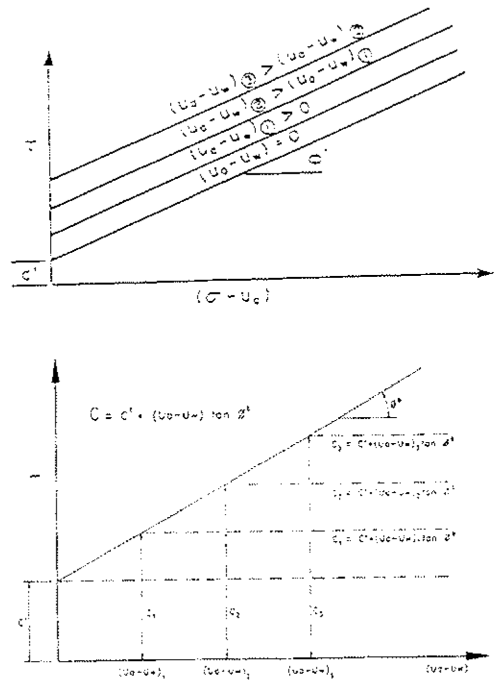

Fig.3 Matric Suction Drawn On Failure Envelope.

SOIL WEATHERING PROFILE

The residual soils at the slope were mapped for it's weathering grades. The weathering grades were categorized based on description given on Geological Society Engineering Group Working Party Report. Figure 4. shows the schematic representation of typical tropical weathering profiles.

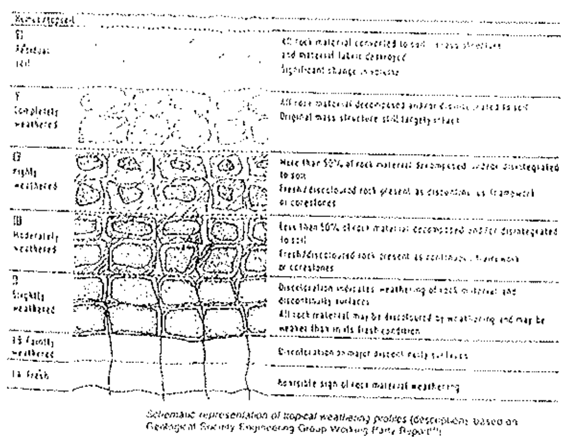

Fig.4 A Schematic Representation of Tropical Weathering Profiles.

The site geological map illustrates the estimated boundary of each weathering grade. The map also draws out the fault and soil boundaries. (Refer Figure 2.)

METHOD OF SOIL SAMPLING

Undisturbed block samples were collected from the site at every berm level at various locations. The collected samples at every berm level were categorized to their weathering grade based on site geological map. The stratum profiles at every sample location were categorized based on site geological map and laboratory test results.
Block samples were collected from the site in boxes made of metal plates measuring 200x200x200 mm. After choosing a suitable location to sample, the topsoil of about 300mm was removed using lightweight shovels. Trenches were dug all around the soil mass of about 250x250x250mm. Sides of the soil mass are 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.

LABORATORY TEST

Triaxial Test Setup for Partially Saturated Soil Test

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 5. 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.

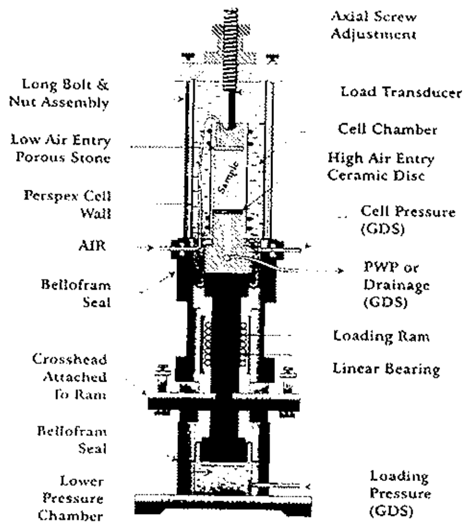

Fig.5 Details of Typical Bishop-Wesley Cell

High air entry disc was used to separate soil samples with the water compartment underneath. The function of the high air entry disc is to separate the air and water. Air could only pass through the ceramic disc when the air pressure exceed 15 bar. 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.

Diffused Air Volume Indicator (DAVI) 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 can be determined when there is no infinitesimal changes of water volume during suction equilibrium stage. The diffused air volume measurement should be performed once or twice a day or more frequently when high pressures are used. The measured water volume changes should be adjusted in accordance with the diffused air volume.

Computer Controlled Testing

The triaxial test setup used for testing was fully computerized. 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.

The computer controlled system and the versatile cell was equally adapt to carry out classical as well as advanced tests. It enables output from the transducers to be automatically logged by the computer. A microprocessor collects the data automatically at prescribed intervals. The data were transmitted by the controlling microprocessor for recording, processing and production of results, which could be displayed on the screen or tabulated or plotted by a printer.

The computer can control the test itself according to specified conditions by using data fed back from test measuring devices, by processing it and transmitting to a pressure controller which make instant adjustments to the applied pressure by means of stepper motors. Equation representing the desired stress path and tests, together with other instructions and specified limitations (such as maximum rate of strain, or maximum permissible) are incorporated in the computer software. The Consolidated Drained (CD) triaxial strength tests with suction stabilization normally runs for days, this arrangement enables the test to be performed continuously with data collection left unattended. Figure 6. shows the full layout of computerized triaxial testing for unsaturated soils.

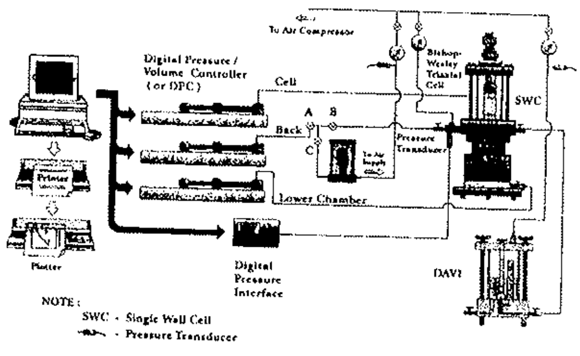

Fig.6 The Full Layout Of Computerized Triaxial Testing For Unsaturated Soil.

Test Procedure

Multistage triaxial set up was carried out due to the limited specimens and the effect of the soil variability, which is often high in residual soils are also eliminated.

Multistage multi suction, direct shear test could assist in overcoming soil variability problem. In this case, the ϕ^b value could be determined as well as ϕ'. According to the unsaturated soil mechanics theory (D.G. Fredlund, H. Rahardjo, 1993), the ϕ' for different matric suction is the same for a particular soil sample. In this case, a multistage triaxial test need to be conducted in order to obtain the ϕ' value. After the multistage test, another sample was set up to carry out the multi suction multistage test. The test procedure is as follows:-

1. The specimens are 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 pores in the high air entry disc).

2. Suction equilibrium and consolidation were carried out before the direct shearing process. Matric suction equilibration is generally attained in about one week or more. Stress conditions associated with the first stage of loading are applied and the sample is allowed to consolidate.

3. After the consolidation the stresses are maintained while the sample is sheared at a constant rate.

4. At peak shear stress the axial force is immediately released until no significant shear resisting force, allowing the sample to recover elastically.

5. For the second stage of multi suction multistage direct shear test, the matric suction is increased to another higher suction value. Suction equilibrium has to be carried out first according to steps 2.

6. In this case, the matric suction increases for every shearing stage.

7. Since the ϕ' is the same for a difference suction value, the failure envelope can be obtained for a single peak value for every

multi stage shearing. With the difference apparent cohesion, the ϕ^b value also can be found.

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

TEST RESULTS AND DISCUSSIONS

Typical test results of multistage triaxial test are presented here. Results of sample at TP5 level 1 (Refer Figure 1.) which falls on massive sandstone area is used for discussion.

Typical results of stress-strain curve for multi suction multistage are plotted in Figure 7. Corresponding to that, a plot of continuous water volume change with time during consolidation process is plotted in Figure 8. The volume change increases when the applied normal load increases. The reduction in volume change shows water is drained from the soil specimen. From the plot it shows that a significant amount of water has been removed from the specimen at the lower suction values relative to higher suction.

Mohr circles for drain tests for various suctions are also plotted in Figure 9. This plot shows a clear increment of net normal stress with higher suction. Using the friction angle ϕ' of 26^0, parallel lines were plotted to obtain effective cohesions for various suctions in Figure 9. These values were plotted with matric suctions in Figure 10 to determine the value of ϕ^b. From the plot the variation is not linear with suction but the initial gradient can be taken as the value of ϕ^b i.e.24.7^0, for lower range of suction.

It clearly indicates that the influence of suction on shear strength (equation 2) is becoming lower when the suction value gets very high.

Much 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.

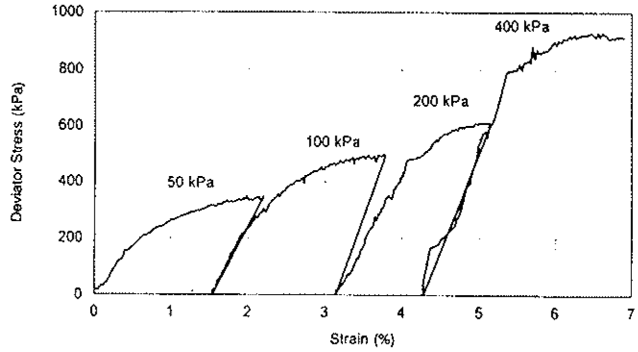

Fig.7 Stress – Strain Curve For Multi suction – Multistage Test At TP5 Level 1.

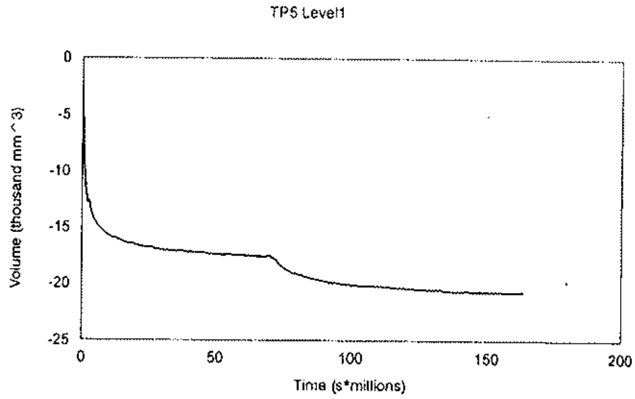

Fig.8 Suction Stabilization / Consolidation Curve (50kPa, 100kPa, 200kPa, 400kPa), TP5 Level 1.

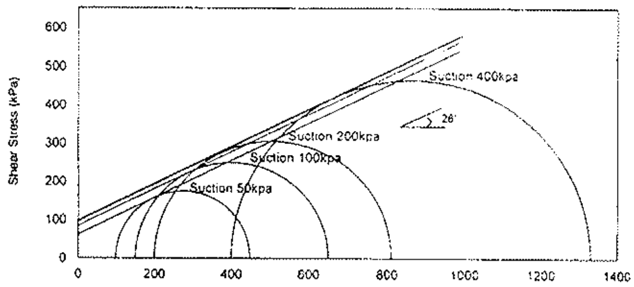

Fig.9 Mohr Plot For CD Test Of Various Suction At TP5 Level 1 (Multisuction – Multistage).

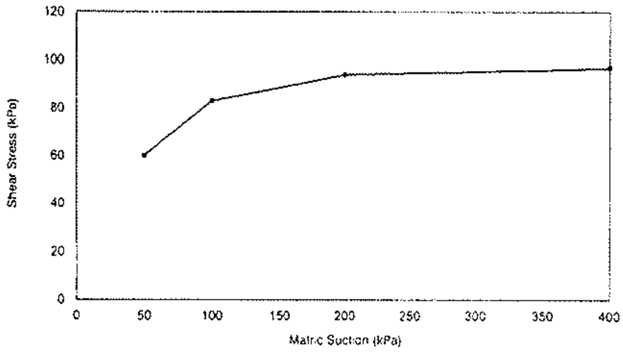

Fig.10 Shear Strength Vs Suction At TP5 Level 1.

CONCLUSION

The proposed multi-stage triaxial testing procedure to evaluate the rate of increment in shear strength ϕ^b concerning matric suction is possible provided that ϕ' 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.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Road Section of Public Works Department of Malaysia and Malaysian Government R & D Department (IRPA) for providing the research grant.

REFERENCES

Affendi A., (1996). Field and laboratory study on unsaturated residual soils in relation to slope stability analysis. Ph.D. Thesis. University of Malaya, Malaysia.

Affendi A, Faisal A. & Chandrasegaran S, (1994) Triaxial shear tests on partially saturated undisturbed residual soil. Geotropika, Malacca, Malaysia.

Bishop, A.W., (1959). "The principle of effective stress," Lectured in Oslo, Norway, printed in Teknish, Ukefland, Vol.106, No.39, pp. 359-383

David Y.F. Ho, Del G. Fredlund,, (Jan 1982). Increase in strength due to suction for two Hong Kong soils. Proc, ASCE Geotech. Conf. Eng. and Construction in Tropical and Residual Soils (Honolulu, HI), pp. 263-295.

D.G. Fredlund, H. Rahardjo,(1993). Soil mechanics for unsaturated soils, John Wiley & Sons.

Low Tian Huat, Soenita Hashim, Faisal H. Ali. (1997). Shear strength of Undisturbed partially saturated residual soils. Geotropika, Johor, Malaysia. pp 69-81.