Discussion Session 1.3 / Séance de Discussion 1.3

Laboratory techniques for unsaturated soils

Récentes mises au point dans les techniques de laboratoire pour les sols non saturés

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ABSTRACT: The theory of *unsaturated soil mechanics* is well established and accepted widely amongst geotechnical engineers and researchers. However, the movement of unsaturated soil mechanics theory into routine practice is lagging the theoretical developments, due in large part to the perceived, and often real, difficulties in property determination. Unsaturated soil properties are nonlinear functions of the stress state variables, and there are many difficulties associated with measuring soil suction and sample volume change for unsaturated soils. Therefore, the task of implementation of unsaturated soil mechanics into practice is greatly affected by the quality and availability of laboratory data, the availability of quality testing equipment suited to geotechnical applications, and the ease and speed of testing. A panel of experts considered and discussed the recent developments and future needs for laboratory testing of unsaturated soils and a summary of their experiences and recommendations is presented herein. Available methodologies for determination of soil suction and the soil-water characteristic curve are reviewed, techniques for volume change measurement are presented, and attention to stress/wetting path is identified as essential to quality test results.

1 INTRODUCTION

A panel of experts from the TC6 Committee on Unsaturated Soils was assembled for Discussion Session 1.3 on recent developments in laboratory testing of unsaturated soils. The session was held in conjunction with the XVth International Conference on Soil Mechanics and Geotechnical Engineering. Prof. Geoffrey Blight (South Africa) chaired the session, and the discussion was led by Prof. Delwyn Fredlund (Canada). Panelists included Prof. Altay Birand (Turkey), Prof. Pierre Delage (France), Prof. Harianto Rahardjo (Singapore), and Prof. Simon Wheeler (U.K.). The session was well attended, with lively audience participation in discussions at the close of presentations by panelists. The main topics of the presentations and discussions were unsaturated soils testing equipment, measurement and control of soil suction, volume change measurements for unsaturated soils, and the importance of stress/wetting path in unsaturated soil testing.

Soil properties are needed for determining soil volume change, shear strength, and seepage for geotechnical and geoenvironmental problems. The unique aspects for unsaturated soils include the nonlinearity of properties and costly and time-consuming laboratory testing.

2 EQUIPMENT USED TO MEASURE THE SOIL WATER CHARACTERISTIC CURVE

As discussed by Prof. Fredlund, traditional geotechnical equipment is designed to measure soil response (e.g. shear strength, volume change, and pore pressure) to a total stress change. To apply unsaturated soils theory, it is also necessary to track water content or suction changes. Because it is difficult and time consuming to obtain the entire soil property function over the range of suction values of interest, many researchers have developed methods for estimating unsaturated soil properties from knowledge of the soil-water characteristic curve (SWCC) and saturated soil properties. Additionally, the SWCC is a limiting boundary of the overall volume-mass constitutive surfaces. Thus the soil-water characteristic curve has become one of the most important relationships in unsaturated soil mechanics.

Available devices for SWCC measurement include the Tempe cell and pressure plate and pressure membrane devices. For geotechnical applications some modifications to pressure plate devices and triaxial cells have been made to allow SWCC measurement. For soil suction below 1500 kPa a pressure plate device is appropriate for determination of matric suction. For suctions above 1500 kPa total suctions may be determined using vapor phase equilibrium with salt solutions. In determining the SWCC, it is important to recognize that hysteresis related to wetting and drying can be significant. Prof. Fredlund therefore recommends for determination of the SWCC that the sample be saturated first so desorption curves are determined. He also remarked that manufactured equipment for determination of the SWCC was developed for agricultural purposes and that for geotechnical applications a wider range of suction and tracking of stress level and volume change is needed. Testing of one specimen at a time and ability to control stresses and measure volume and water content change are important.

Geotechnical engineers must also focus attention of how much accuracy is needed for the problem at hand. There may be many applications where estimations of the SWCC from grain-size and Atterberg limits are sufficiently accurate. The benefit of estimating unsaturated soil property functions include reduced time and cost of soil testing while maintaining appropriate accuracy for design.

3 SOIL SUCTION MEASUREMENT

Measurement of the SWCC involves direct measurement of soil suction using devices such as the pressure plate. There are also indirect methods for determination of soil suction. One such method is the use of the Methylene Blue Test as discussed by Prof. Birand. The test involves saturating the clay minerals with methylyne blue to cover all available clay particle surfaces. The Methylene Blue Value (related to the amount of methylene blue absorbed) has been correlated with clay content and swell potential. New studies presented by Prof. Birand show that the soil suction also correlates with the Methylene Blue Value.

Prof. Delage addressed the osmotic principle for determination of suction and suction control in laboratory testing. For these tests, the soil specimen is separated from a Polyethylene Glycol (PEG) solution by a semi-permeable membrane. Suction may be determined through correlation with the PEG concentration in water. The osmotic suction controlled tests avoid the application of air pressure inside of the specimen and can provide a relatively simple and inexpensive method for SWCC determination. The process can be applied to consolidometer and direct shear testing with relative ease. Applications to triaxial testing are somewhat difficult compared to axis-translation methods. In using the osmotic suction principle in laboratory testing precautions must be taken due to membrane fragility and possible bacterial attack of the membrane.

The osmotic method compared well with other suction measurement techniques such as tensiometer, axis translation, and psychrometer. Given the possible advantages of the osmotic method for suction determination, Prof. Delage suggested future research in the areas of purification and stability of PEG and refinement of calibration curves.

4 VOLUME CHANGE MEASUREMENTS FOR UNSATURATED SOIL TESTING

One of the most challenging aspects of unsaturated soil testing is the measurement of sample volume in triaxial tests. The problems arise due to the compressible air phase in the specimen, preventing the simple use of outflow and inflow of specimen water used for volume change determination in saturated soil testing. In spite of the difficulties, volume change must be measured to monitor changes in void ratio, degree of saturation (by combining with measurements of water inflow/outflow from the specimen), and to calculate changes in cross-sectional area for determination of deviator stress. Prof. Wheeler presented four possible methods for measuring the volume change of unsaturated soil specimens during triaxial testing: 1. Measurement of axial and radial strains directly on the soil specimen, 2. Measurement of the flow of water into the triaxial cell, 3. Measurement of air inflow/outflow into the sample, and 4. Measurement of the specimen profile using laser techniques or image analysis of digital photographs. Prof. Wheeler recommended Method 1 for tests examining soil behavior at small strains, whereas Method 2 was recommended for testing involving shearing to failure or large strains. He suggested that Method 4 could provide high quality results, but is likely restricted to the research environment at the current time. Method 3 was not recommended. It was suggested that the typical accuracy required for volume change measurements is $0.4 cm^3$ (0.5% volumetric strain) for 38 mm triaxial specimens.

5 IMPORTANCE OF STRESS/WETTING PATH IN UNSATURATED SOIL TESTING

The importance of stress path to geotechnical laboratory testing and property determination has long been recognized. For unsaturated soils, however, two stress state variables are important to soil behavior: the net normal stress and the matric suction. For this reason, both net normal stress path and suction (wetting) path are important in unsaturated soil testing. The importance of stress/wetting path was clearly revealed by Prof Rahardjo's presentation of testing methods and test results from studies designed to evaluate the failure condition of unsaturated soils under infiltration. The studies focused on rainfall induced slope failure, and modified direct shear and triaxial equipment were used to follow field stress and wetting paths appropriate to the field. The matric suction was controlled using the axis-translation technique. The results indicated that failure due to infiltration is marked by an excessive deformation rate of the soil. Some significant matric suction appears to be present in the soil at failure, indicating an unsaturated condition may typically exist at the time of failure for field conditions.

6 SUMMARY

Improved methods for testing and estimating unsaturated soil properties are necessary for the wide scale implementation of unsaturated soil mechanics into practice. Advances in unsaturated soil testing have been made through the use of new technology and the adoption of testing equipment from the discipline of agriculture. Remaining challenges include measurement or control of soil suction, volume change determination, and availability of suitable geotechnical testing devices for unsaturated soil property determination.