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LABORATORY STUDY OF DIFFERENT FIELD SYSTEMS FOR MEASURING SOIL MATRIC SUCTION

ETUDE EN LABORATOIRE DE DIFFERENTS SYSTEMES DE MESURE EN CHANTIER DE PRESSIONS INTERSTITIELLES NEGATIVES

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SYNOPSIS: Laboratory equipment consisting of a large vertical cylinder has been built. The cylinder can be filled with any type of soil and the water level in the soil can be controlled so that the water conditions can be studied at both the steady-state and transient state. The equipment is used for studying the behavior of different instruments designed to measure soil matric suction in field conditions. After an initial series of tests revealed shortcomings in the calibration of some of the instruments studied, a null-type pressure cell has been built to perform a more accurate calibration. The investigation, which is performed both at steady-state and at transient state, should result in better understanding of the measuring instruments and recognition of their accuracy and general response to fluctuations in the matric suction.

INTRODUCTION

The increased involvement of geotechnical engineers in environmental problems calls for better knowledge of soil behavior in the zone situated above the groundwater table, the vadoze zone. Even traditional problems such as slope stability and groundwater flow require the same knowledge when encountered in fine-grained materials such as silts and clays, where the capillary zone may reach a significant height above the water table. The presence of a capillary zone influences the groundwater and soil conditions in different ways, for example by raising the upper boundary of the flow surface to the limit of the capillary fringe or by affecting the strength characteristics of the soil.

One of the characteristics of the vadoze zone is that the pore water pressure is lower than the atmospheric pressure. This relative negative pressure is called matric suction ψ_m and is due to the reduction in the relative humidity created by a curved air-water interface in the pores.

The matric suction is equal to the difference in pressure in the air and water phases, and is obtained from the following equation (Fredlund and Rahardjo, 1988):

$$\psi_m = u_{air} - u_{water}$$

or

$$\psi_m = u_a - u_w \qquad (1)$$

which can be reduced to

$$\psi_m = - u_w \qquad (2)$$

if the pressure in the pore air is equal to the atmospheric pressure.

In order to study and possibly model the behavior of unsaturated soils, negative pore water pressures must be measured. The quality of the predictions to be made is greatly influenced by the quality of these measurements. Therefore, an investigation was started at Chalmers University of Technology and the Swedish Geotechnical Institute to study the behavior of some of the most common instruments available. This investigation, which is performed both at steady-state and at transient state, should result in better understanding of the measuring instruments and recognition of their accuracy and general response to fluctuations of the matric suction.

INSTRUMENTS USED IN THE INVESTIGATION

Many different instruments have been developed for the measurement of matric suction (Fredlund and Rahardjo, 1988). Some of these instruments perform indirect measurement of the matric suction, i.e. the measurement is not made on the suction itself, but on a parameter which is directly related to it; the suction is thereafter obtained from a calibration curve. Other instruments perform direct measurement of the suction. In the present investigation, a total of four instruments were chosen, two in each group.

The thermal conductivity and electrical conductivity sensors (Figs. 1a and 1b) measure indirectly the matric suction using the relation between the suction, the water content and the respective conductivity. Both instruments are built in porous blocks. For measurements performed with the thermal conductivity sensor, a controlled amount of heat is generated and the increase in temperature in the block is measured. In the case of the electrical conductivity sensor, an electric signal of a given intensity is sent to the block and the electrical resistivity is observed. Both the difference in temperature and the electrical resistivity depend on the water content of the blocks, which is directly controlled by the matric suction in the surrounding soil. The matric suction can therefore be evaluated from a calibration curve, usually provided by the manufacturer, in which the relation between the suction and the two measuring parameters mentioned above is established.

The tensiometer and the BAT piezometer (Figs. 1c and 1d) measure the pore water pressure directly, thanks to the contact through a porous element between the pore water and the water in the measuring system. If the pore air pressure is equal to the atmospheric pressure, the value measured with these two instruments is equal to the matric suction. Both systems are designed on the same basic principle, the only difference being the point of measurement, which is located at ground level for the tensiometer and directly at filter tip level for the BAT piezometer. The value measured is the matric suction in the soil at the level of the porous element.

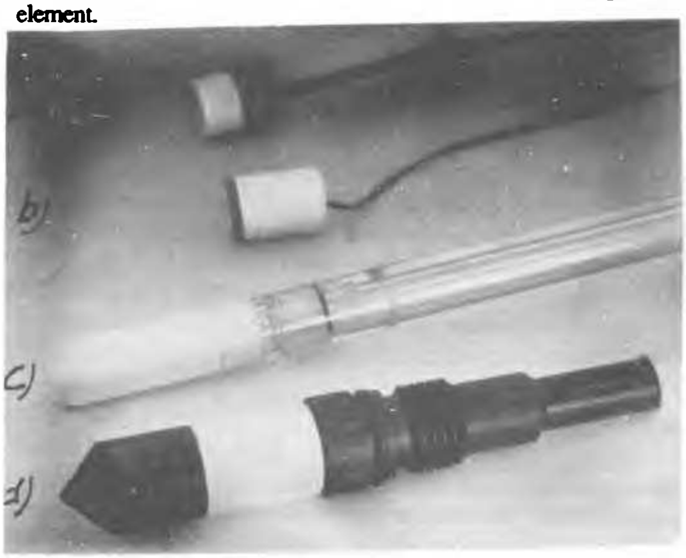

Fig. 1. Field measuring instruments used in the investigation.

LABORATORY INVESTIGATION - PHASE I

Equipment Developed

To perform the first phase of the study, new laboratory equipment was built at Chalmers University. The equipment consists of a large cylinder 1000 mm in diameter, which can be raised to 1.6 m height by the addition of 400 mm rings, Fig. 2. A water reservoir situated on the outside of the cylinder is in contact with the bottom of the cylinder through three porous plates 100 mm in diameter. The water level in the cylinder can therefore easily be controlled by varying the level of the water reservoir.

The cylinder can be filled with any type of soil to perform different types of studies. In the present case, where the properties of instruments for measuring negative pressure are investigated, the soil used should be relatively fine-grained so that a certain capillary zone will develop above the groundwater level. The instruments can be installed at any level in the soil specimen and the water level can be adjusted to a given level to study the properties of the instruments in steady-state conditions. The water level can also be altered more or less rapidly to perform similar analysis of the properties at transient state.

Tests Performed

One series of tests has been performed with the first laboratory equipment. This initial series aimed mainly at checking the operation of the equipment and the data acquisition system, as well as making a preliminary evaluation of the measuring characteristics of the different instruments. The soil used in these tests was a fairly uniform fine sand.

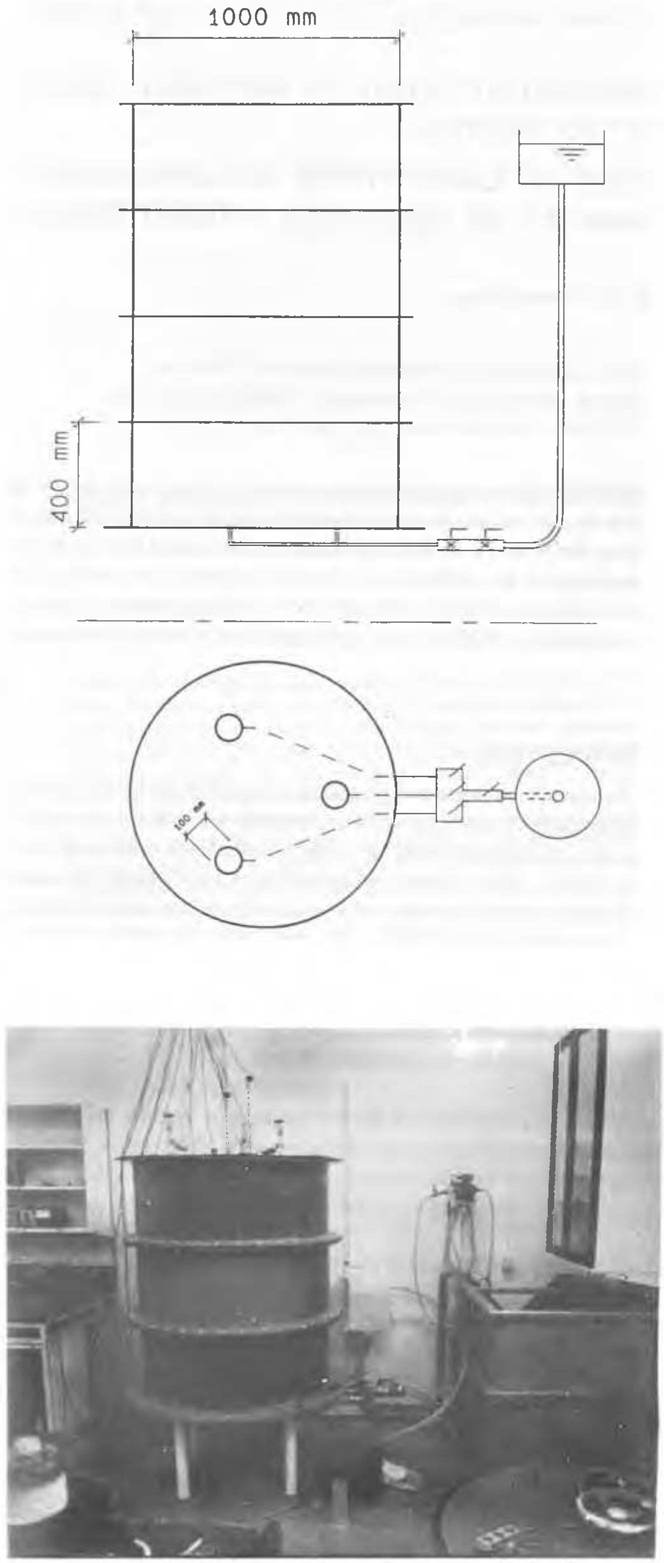

Fig. 2. Laboratory equipment used to control the accuracy and response of the field measuring instruments. Schematic (top) and during operation control test (bottom).

This soil was chosen in order to be facilitate changing the water level in the cylinder without having to wait too long for stabilization of the water conditions and recording of the steady-state. In order to obtain a fairly homogeneous density in the whole soil specimen, the water level was gradually increased so that the soil was continuously covered by about 20 cm of water. The soil specimen was raised to a total height of 1.2 m.

A total of eleven instruments were installed and recorded during this initial series. One instrument of each type described above was installed at two different levels for comparison. In addition, two gypsum blocks with electrical conductivity sensor and one BAT piezometer were installed, respectively in the upper, middle and lower parts of the soil cylinder.

After building up the soil specimen and installing the instruments, the water level was kept at the top of the cylinder for a certain time in order to obtain a reliable measurement of the initial value. Thereafter, the water level was rapidly lowered about 25 cm and kept at this level for about one day, this operation being repeated twice for a total lowering of 75 cm. Measurements were performed every 30 minutes on all instruments during the entire period.

The results obtained in these measurements where first interpreted without any correction. They showed clearly that the calibration performed by the manufacturers of the conductivity sensors is not accurate enough for these instruments to be used in the pressure domain studied. The inaccuracy is especially important regarding the zero-value, i.e. the value registered when the porewater pressure is zero, or equal to atmospheric pressure. In order to eliminate the error caused by uncertain initial values, the calibration parameters of the conductivity sensors were adjusted so that a correct value of the water level was registered in the first part of the test, when the soil cylinder was completely submerged. Thereafter, the interpretation of the measurements was made according to the manufacturers' calibration curves. The measurements made with tensiometers and BAT piezometers did not require any correction.

The results of the measurements after correction are presented in Fig. 3. As can be seen from these results, the tensiometers and BAT piezometers respond directly to the fluctuations in the water level, and show good agreement with each other. The measurements performed with the thermal conductivity sensors show a large scattering and no visible sign of reaction to the water level fluctuations. The values obtained with the electrical conductivity sensors are much less unstable than those recorded with the thermal sensors, but they do not show a correct response to the lowering of the water level. In some cases, a total increase (!) in pore pressure was observed. The underlying cause of the behavior of the conductivity sensors is probably the fact that these instruments were primarily developed for measuring higher values and do not have good accuracy in the pressure domain studied so far. However, the inaccuracy may also result from the fact that the calibration performed by the manufacturer of the two conductivity sensors is not accurate enough to be used in the pressure domain encountered in this investigation and should therefore be performed with better precision for low pressures.

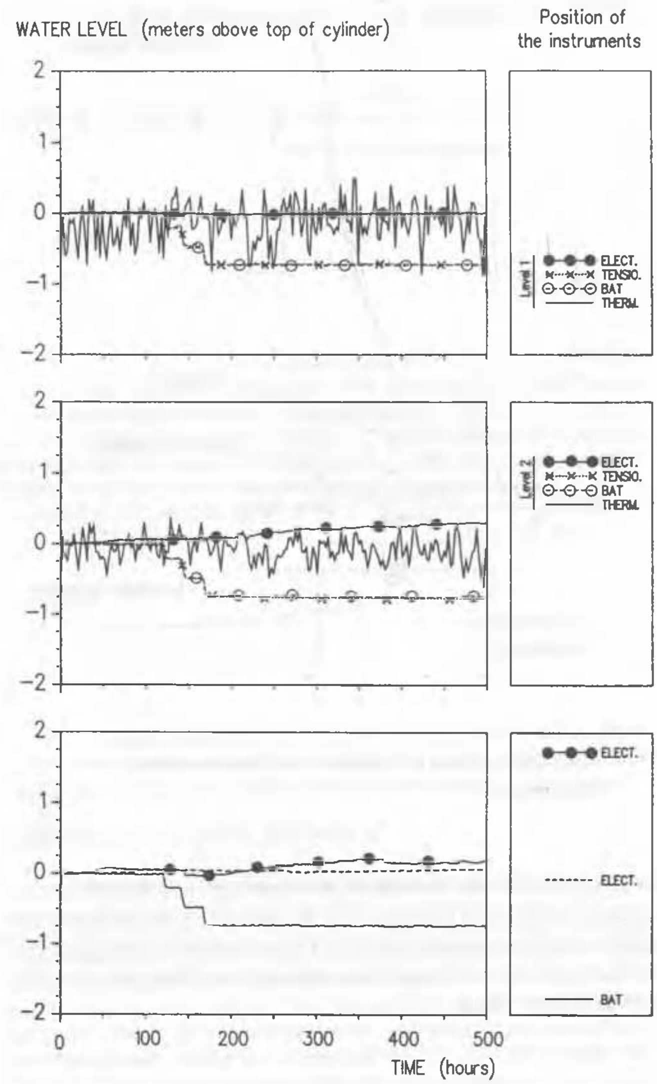

Fig. 3. Measurements performed during control tests.

LABORATORY INVESTIGATION - PHASE II

Equipment Developed

A second set of laboratory equipment was built in order to perform a more accurate calibration of the thermal and electrical conductivity sensors. This equipment consists of a pressure cell based on the axis-translation technique (Hilf, 1956) also called a Null Type Pressure Cell, Fig. 4. The cell is 400 mm high and has a diameter of 150 mm.

At the bottom of the cell is a water reservoir in contact with the air in the cell through a porous plate with an air entry value of 300 kPa. The water pressure is measured with a pressure transducer located at the bottom of the reservoir. The water reservoir is carefully saturated and two communication lines are used to flush any air and to keep the reservoir fully water-saturated.

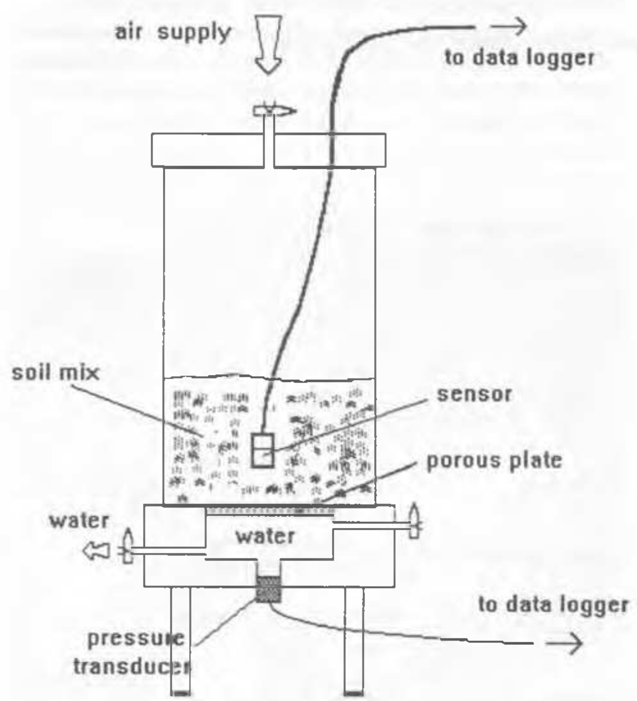

Fig. 4. Pressure cell used to calibrate the field measuring instruments.

Air is supplied to the cell through the upper part and the pressure is controlled with an air regulator. The air pressure is measured on the supply line with a pressure transducer. In the present investigation, three pressure cells were built in order to accelerate the calibration process of the instruments, Fig. 5.

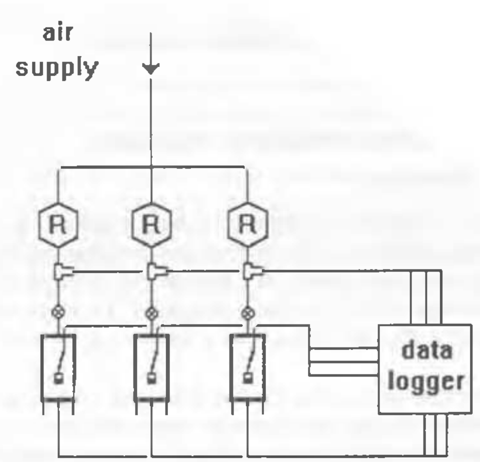

Fig. 5. Schematic of the installation of the three pressure cells.

Tests Performed

In order to check the correct function of the pressure cells, an initial series of tests was performed in which the cells were used to measure the pore pressure in soil specimens taken on a silty slope. The values obtained were then compared with measurements performed in the field at approximately the same levels as the soil samples.

After this series of tests, which confirmed the correct function of the apparatus and the data acquisition system, the calibration of six thermal conductivity sensors was started. The calibration was performed by introducing the sensors in a silty material placed in the cells. The pressure in the cell was thereafter increased stepwise and the water was allowed to leave the soil through the porous plate before passing out of the cell through a burette connected to the water reservoir. At each step, the pressure was kept constant until no more water left the cell and a stabilization of the pressure registered by the sensors was reached.

The calibration performed shows that the values registered by the sensors fluctuated significantly and therefore the mean value of a number of measurements should be used instead of a single point measurement. The calibration also showed that the use of a curve from linear regression is not accurate enough when the values are close to zero. The calibration parameters should instead be chosen according to the range of pressure in which the measurements are to be performed.

CONCLUSIONS

The first series of tests performed in the laboratory equipment consisting of a large vertical cylinder has showed clearly that an accurate calibration of the thermal and electrical conductivity sensors is necessary if these instruments are to be used for measurements in the zone located immediately above the groundwater table. Since the pore pressure in this zone is generally only slightly lower than the atmospheric pressure and this zone is often fully saturated, the accuracy of these instruments is closely related to the accuracy of the calibration. Therefore, calibration parameters should be chosen according to the pressure range in which the instruments are to be used.

The first step of this ongoing investigation also showed that tensiometers and BAT piezometers appear to be reliable for measurement of variations of the pore pressure in the vadoze zone. After calibration of all the thermal and electrical conductivity sensors, the investigation will resume and several series of tests similar to those presented above will be performed using different types of soil. These tests will hopefully lead to better understanding of the operation, accuracy, limitations and fields of utilization of the instruments studied.

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