

A high capacity tensiometer to measure soil suction

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Abstract – A new high capacity tensiometer (HCT) have been developed at the University of Napoli Federico II (UNINA) using a design similar to that of Ridley and Burland (1993). With respect to a first prototype developed at UNINA, the new HCT is designed to be submersible, to enhance the measurements of soil suction, to make easier the calibration in the negative water pressure range and to improve the time-response of the probe. The new HCT can be accurately calibrated either for positive value of water pressure (i.e., to act as standard pressure transducer) or for measurement of negative water pressures (i.e., to work as a tensiometer). A number of free evaporation tests and matric suction measurements against preconditioned soil samples are presented in the paper and discussed in order to highlight the performances of the HCT.

I. INTRODUCTION

The main factors qualifying the performances of High Capacity Tensiometers (HCT) are the maximum value of water suction measurable avoiding cavitation and the time stability of the measurements under highly negative water pressure. The elements governing these factors are the characteristics of the measuring chamber (size, presence of irregularities on the chamber wall) its maximum attainable degree of saturation (by distilled and

de-aerated water) and the air entry value of the porous stone protecting the chamber itself from desaturation. In theory, when the measurement chamber is perfectly saturated by water, the maximum measurable suction is governed only by the air entry value of the HAVF porous stone (Ridley and Burland, 1995). In practice, instead, several experimental difficulties make HCT difficult to set in operation, highlighting the importance of its mechanical design on robustness, sensitivity, ease of saturation, speed of response and time duration of stable measurements of large suctions (Take and Bolton, 2003).

II. NEW PROTOTYPE OF HCT

The first prototype of High Capacity Tensiometer (Rojas et al., 2008) has been developed at University of Naples Federico II using a design layout similar to that initially proposed by the Imperial College of London (Ridley and Burland, 1993), with the introduction of some modifications. The instrument was composed of: an interchangeable filter cup containing a HAEV ceramic disk of 6.0 mm in height inserted into stainless steel housing; a water reservoir of 3 mm³ in volume; an integral strain-gauged diaphragm embedded in a brass housing; a vented waterproof sheathing to protect the electrical connections. The measuring chamber was inspectable and this allowed to eliminate a greater number of imperfections; one stainless steel housing was

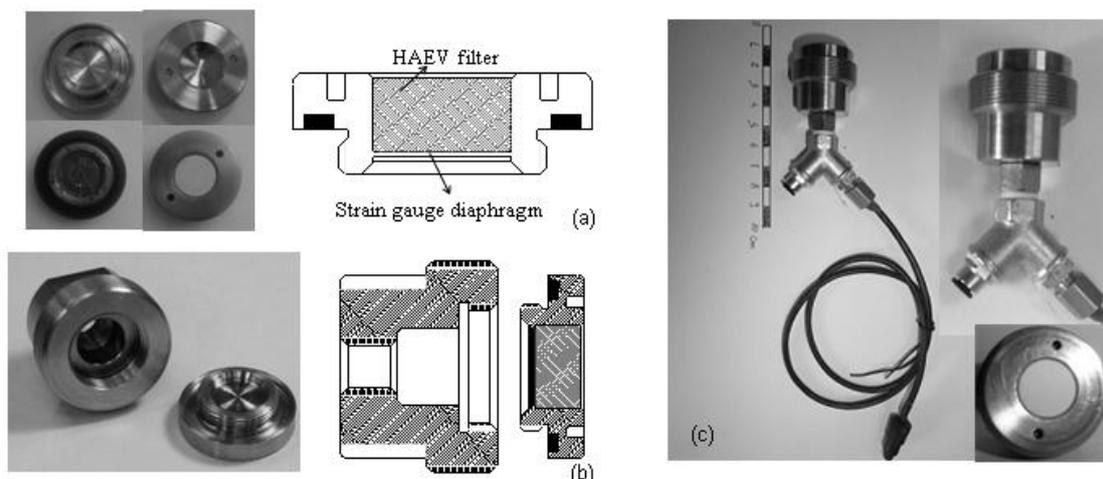


Fig. 1. New HCT.

used to hold the diaphragm and the other one was used to provide a support and isolate the electrical connectors; the shape of the filter holder permitted the HAEV disk to be easily replaced if multiple measurements were required

The main improvement of the new HCT is its mechanical design. In particular a more quick and functional assembly of components was realized (Figure 1), making the HCT less affected by setting up and measurements more stable. With respect to the first prototype, the possibility of inspecting the measuring chamber was sacrificed against different targets. The housing of the HAEV stone was carved in the same steel body housing the measurement membrane. As a consequence it was possible to eliminate any o-ring seal making the probe more prompt and eliminating some mechanical hysteresis observed in the first prototype under suction cycle. Furthermore, given the suction values of interest for practical applications, it was decided to reduce the upper bound of the measuring range to a suction of 500 kPa, making the probe more easy to saturate. This also allowed to reduce the thickness of the steel membrane deflecting under pressure and to enhance the sensitivity of the probe.

III. EXPERIMENTAL PROCEDURES

Based on the experience gathered with the first prototype, also the system and the procedure for the initial saturation of the measurement chamber were adjusted. The new device for saturation was cheaper and easier to assemble, smaller and capable to reach pressure as high as 2.0 MPa – by counterbalancing such high pressure on the back of the measurement chamber,

excessive deflection and plastic deformations of the measurement membrane are avoided. The new saturation procedure achieve various targets: an initial phase of heating of the probe was eliminated since suspected to cause irreversible deformation of the glue connecting the strain gauge to the measurement membrane; as previously stated the saturation of the HAEV stone and the water reservoir was performed by applying a positive water pressure of about 1.3 MPa in the measuring chamber and an air pressure of about 800 kPa on its back - a maximum differential pressure of about 500 kPa was then achieved during the 72 hours duration of the first saturation stage of the probe; pressurization cycles were repeated for the purpose of deflecting the diaphragm in both directions and improving the saturation of the HAEV and the water reservoir.

IV. HCT CALIBRATION AND FIRST RESULTS

As schematically indicated in Figure 2, the calibration of the HCT can be performed either increasing the water pressure in the water saturated measuring chamber (calibration for positive water pressure) or by pressurising the back portion of the transducer (calibration for positive air pressure). The data in Figure 2 show a linear response independent of the direction of the diaphragm deflection, confirming the symmetric design adopted for the steel diaphragm make possible to extrapolate the calibration from the positive to the negative range.

The HCT ability to measure sudden suction changes is demonstrated in Figure 3, showing the response to several free evaporation stages up to prescribed suction values (lower than the theoretical AEV of the filter) followed by steps in which the atmospheric water

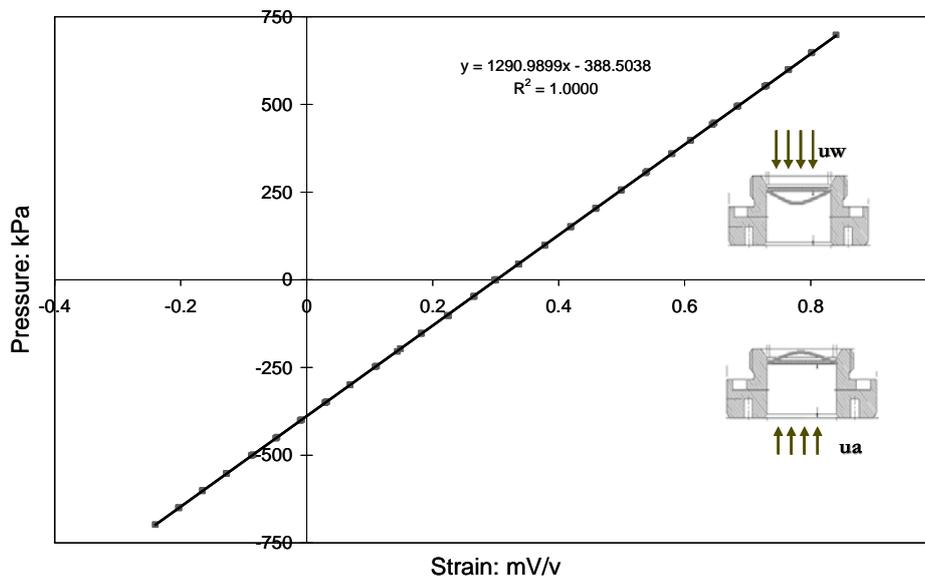


Fig. 2. Calibration curve of new HCT.

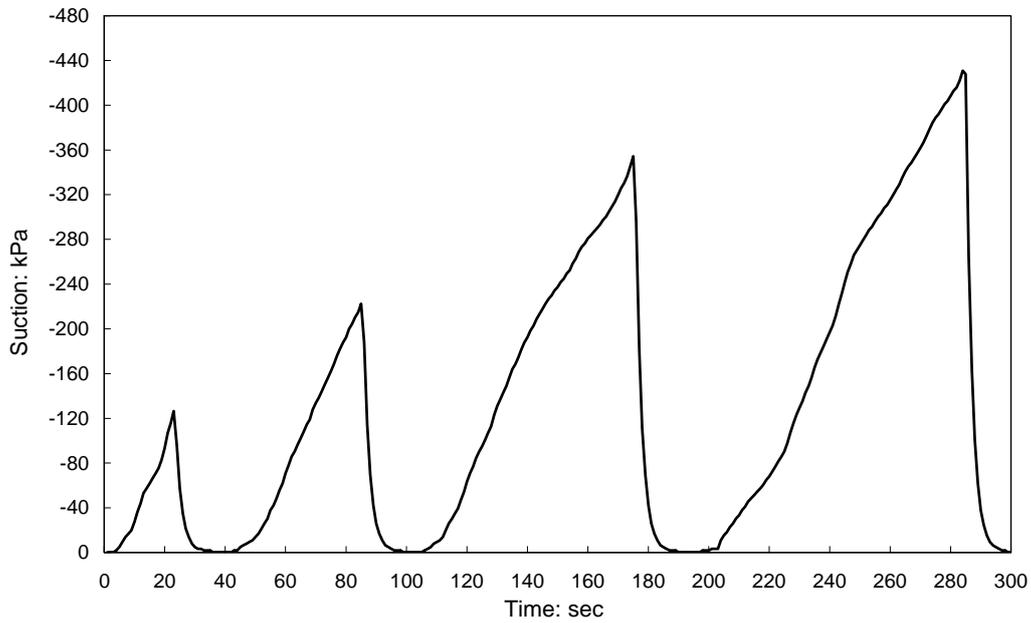


Fig. 3. Evaporation tests of new HCT.

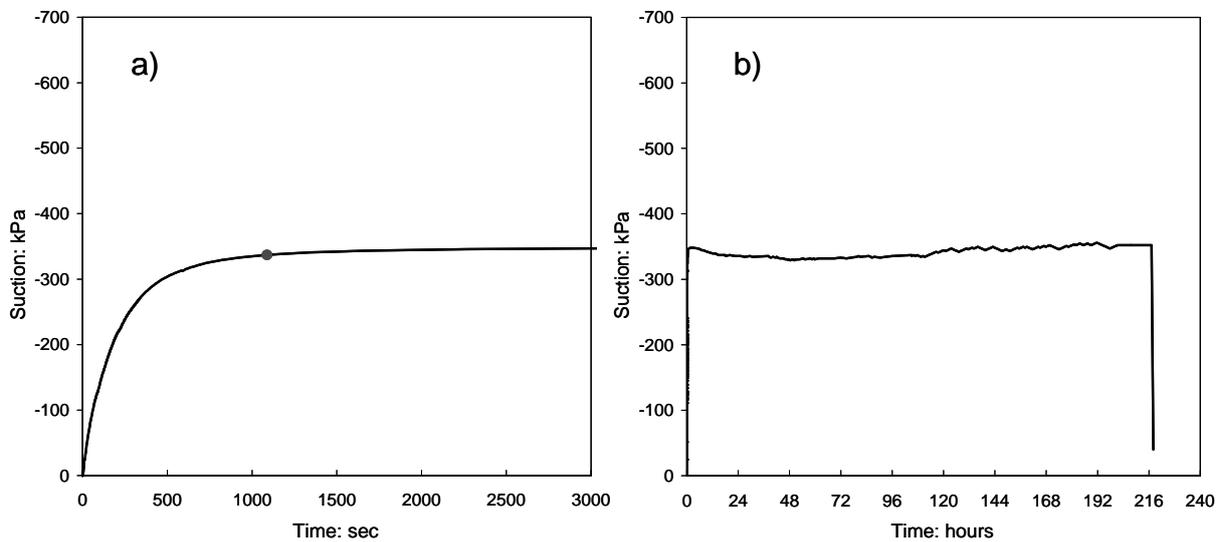


Fig. 4. Long time suction measurement on soil sample.

pressure was applied to the measurement chamber by submerging the tensiometer tip in a small water reservoir. This demonstrate that the new saturation procedure provide excellent results, as just 7-8 sec. are required for

the equalization to the pressure in the small water reservoir (almost null), regardless of the initial suction. Data here not shown, also demonstrate that the maximum suction causing cavitation was always greater than the

theoretical AEV of the stone protecting the measurement chamber.

Long lasting measurements were performed to detect the time stability of the tensiometer to high suction. Figure 4 shows the measurements collected connecting the HCT to a specimen of silty-sand in which a suction of about 320 kPa was generated by the axis translation technique. A thin layer of the soil paste was used to improve the contact between the soil sample and the HCT. During the measurement the sample remained isolated to avoid large suction changes associated with the environmental conditions. In Figure 4a, the equalization time (evaluated according to Oliveira and Marinho, 2008) is about 1100 seconds. As demonstrated in Figure 4b, the measurement remains stable for about 10 days after which it was interrupted due to an electrical shutdown of the power supply.

V. FUTURE DEVELOPMENTS

The results obtained show satisfactory performance of the new prototype in terms of promptness and stability of measurement, encouraging its future use in various possible applications both in the laboratory and in-situ for geotechnical and agronomy applications.

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