Performances of Two High Capacity Tensiometers

Claudio Mancuso, Marco V. Nicotera, and Raffaele Papa

Abstract. Two High Capacity Tensiometers (HCT) have been developed at the University of Napoli Federico II (UNINA) using a design layout similar to that of Ridley and Burland (1993). One of the HCT includes a O-ring sealing and a high air-entry value disk (HAEV) to protect a water-saturated measurement chamber from desaturation. The second one eliminates the O-ring in the attempt to enhance the time-response and improve the mechanical design for the calibration in the "negative" pressure range. Two different pre-conditioning devices have been developed to water-saturate the HAEV and the measurement chamber. The HCT may also be calibrated in the same chamber by applying positive values of water pressure to the first prototype, and positive value of air pressure, to the second prototype, for 'negative' calibration. 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 two HCTs.

Keywords: HCT, suction measurement, unsaturated soils, calibration, evaporation tests.

1 Introduction

The main factors that qualify the performance of a High Capacity Tensiometer (HCT) are the measurement duration and the maximum value of suction reached

Claudio Mancuso
Università di Napoli Federico II, Napoli, Italy
e-mail: mancuso@unina.it

Marco V. Nicotera
Università di Napoli Federico II, Napoli, Italy
e-mail: nicotera@unina.it

Raffaele Papa
Università di Napoli Federico II, Napoli, Italy
e-mail: rafpapa@unina.it

prior to cavitation. The elements that govern these factors are strongly linked: the measuring chamber (size, absence of superficial irregularities on the chamber wall, level of saturation); the porous stone (at least 5 bar AEV, perfect saturation); the materials used to manufacture the instrument. It has been shown by Ridley & Burland (1993) that the maximum sustainable suction of a HCT is strictly a function of the air entry value of the ceramic disk provided the ceramic disk is adequately saturated. If this is not the case, there are other sub-experimental factors that make the tensiometer difficult to set-up. Therefore, the mechanical design of HCT plays a crucial role because it influences its robustness, sensitivity, ease of saturation, speed of response and the sustainability of large suction measurements (Take & Bolton, 2003).

2 First Prototype of UniNa 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 & Burland, 1993), with the introduction of some modifications. The instrument was composed of (Fig. 1): 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 mm^3 in volume; an integral strain-gauged diaphragm embedded in a brass housing; a vented waterproof sheathing to protect the electrical connections.

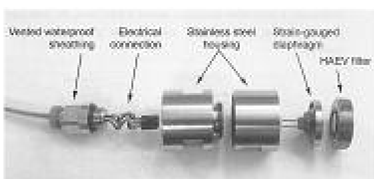

Fig. 1. First prototype of Unina High capacity tensiometer, (Rojas et al., 2008).

The measuring chamber was inspectable and this allowed to eliminate a greater number of imperfections; one stainless steel housing was 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 strain-gauge measurements were acquired through a bridge amplifier static strain indicator and stored in a digital data logger. The strain gauge was connected to the acquisition system through appropriate input terminals.

The saturation procedure used for the first prototype was in part based on the information provided by Take & Bolton (2003). In particular, a conditioning system was designed to calibrate and pre-pressurize the HCT. The system developed, Fig.2a, allowed the combined application of high temperatures and vacuum pressures, in order to improve the effectiveness of the drying phase of the porous stone and also of the measuring chamber. The conditioning procedure consisted of the following phases: application of vacuum with simultaneous heating, chamber c2, to improve the porous stone drying (16 hours); submersion of HCT with deaired water (4 hours); c2 chamber filling and application of a pressure of 800 kPa (72 hours).

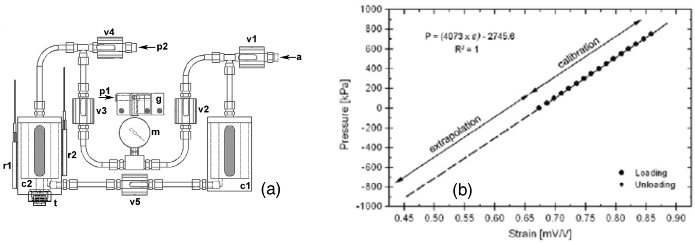

Fig. 2. a) Saturation system; b) tensiometer calibration curve (Rojas et al., 2008).

The tensiometer was then calibrated in the chamber c2 by varying pressure p2 from 0 to 800 kPa. The response of the HCT during the loading unloading process showed a linear response without appreciable hysteresis (Fig.2b). The calibration curve in the negative pressure range was extrapolated from the calibrated positive range (Fig.2b). A this point the instrument was ready and further tests were performed to verify its ability to rapidly and efficiently measure high suction values. These tests will be described later along with the new prototype.

3 New HCT Prototype

The main changes of the new HCT essentially concern the mechanical parts. In particular a more quick and functional assembly of components was realized (Fig.3). In this way, the HCT performance were less affected by setting up procedures and resulted more easily constructable.

The possibility of inspecting the measuring chamber was sacrificed to achieve different goals (Fig.3). The housing for the porous stone was machined in the same metal body that was used to manufacture the sensitive membrane; as a consequence it was possible to eliminate the O-ring seal that likely gave rise to some mechanical hysteresis affecting the response of the first prototype along a suction cycle. Moreover it was decided to reduce the upper bound of the measuring range to 500 kPa; this upper bound was considered a good compromise accordingly to the suction values expected in laboratory and in situ for possible future applications. Hence the membrane thickness was reduced to achieve an adequate sensitivity as compared to the new measuring range (Fig.3). Obviously the 1.5 MPa AEV filter was substituted with a 500 kPa AEV; this resulted in a faster and easier saturation of the device.

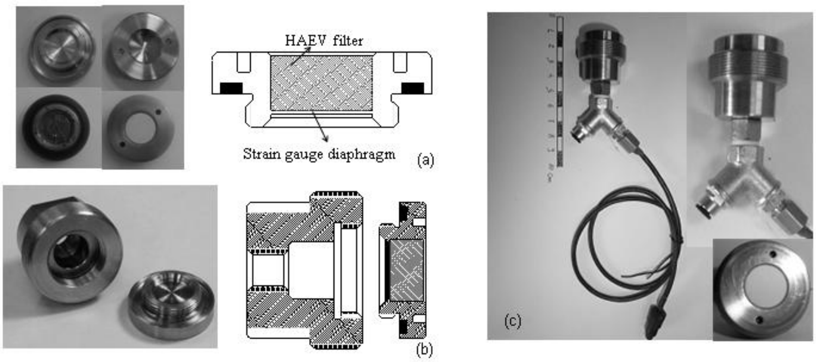

Fig. 3. Second prototype of Unina high capacity tensiometer. a) strain gauge diaphragm; b) total body; c) HCT assembled.

If compared with the first prototype, significant modifications to the external structure may be noticed (Fig. 3c). In particular there is vent for the application of air pressure to the back of the membrane, through which the back chamber of the instrument can be pressurized in order to perform calibration in the "negative pressure range". Therefore under these conditions the membrane is deflected in the same direction of suction measurements and then the calibration is obtained directly without the need of extrapolating it from the calibration in the positive pressure range. Another visible change is the presence of a thread outside the body of HCT to allow easy, installation into other equipment.

4 Experimental Procedures

In addition to the mechanical improvements also the system of saturation and the conditioning procedure were changed. The new device for saturation was smaller and capable of reaching pressure values much higher than the previous one (about 2.0 MPa). This device was also cheaper and easier to be assembled. As regards the modifications to the procedure of saturation, they were related to various issues and in particular:

- the initial phase of heating was eliminated, since it seemed to produce irreversible deformation of the resin used for gluing the strain gauge on the deformable membrane;
- the pressurization to saturate the HAEV disk 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 behind the membrane; thereby during pressurization (72 hours) the membrane was subjected to a differential pressure of about 500 kPa; therefore, its deformations are kept in the elastic range;

- pressurization cycles were repeated for the purpose of deflecting the diaphragm in both directions in order to minimize any hysteresis in its response.

5 HCT Calibration and First Results

The calibration of the HCT was performed initially by progressively increasing the water pressure in the measuring chamber (calibration for positive water pressure) and subsequently by rising air pressure in the posterior chamber (calibration for positive air pressure).

The diagram in Fig. 4 shows that the instrument response was perfectly linear and, moreover, that the calibration curve was independent of the sign of the diaphragm deflection. This result confirms that, with the design adopted, it is possible to extrapolate the calibration performed in positive pressure to negative pressures without making significant errors.

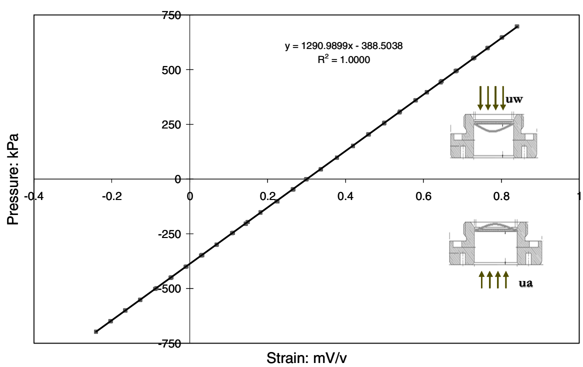

Fig. 4. Calibration curve of new HCT.

The HCT ability to measure rapid suction changes was investigated by means of cyclic evaporation tests. Fig. 5 shows several evaporation tests, consisting in free evaporation stages up to prescribed suction values (i.e. lower than the nominal filter AEV) and stages in which the water pressure inside the chamber was reduced to the atmospheric value by submerging the tensiometer tip in a water reservoir. The new adopted saturation procedure provided excellent results. In fact, few seconds (about 7-8 s) were enough to reach zero suction regardless of its initial value. The maximum value of suction measured up to cavitations was always greater than 500 kPa (nominal filter AEV about 500 kPa).

Long lasting measurements were conducted to estimate the response time of the tensiometer and to verify its ability to sustain high suction for a long time. The results are showed in Fig. 6. The equalization time of the tensiometer was examined by using silty-sand samples. Matric suction of about 350 kPa was generated in the sample of this material by using a modified Wissa oedometer working under 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.

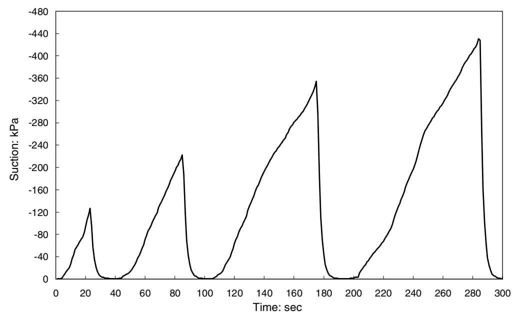

Fig. 5. Evaporation tests of new HCT.

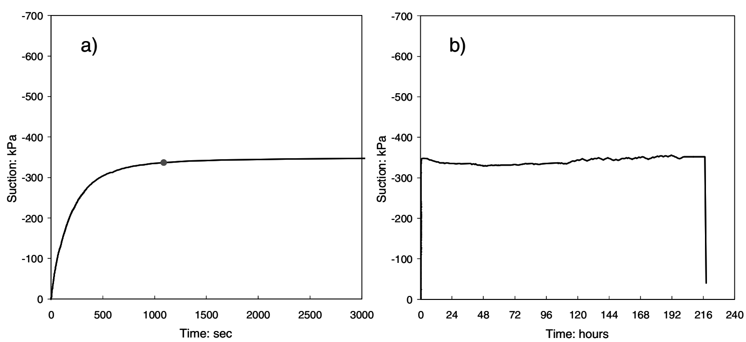

Fig. 6. Long time suction measurement on soil sample.

As it can be observed in Fig. 6a, about 1100 seconds were needed for the measurement to equalize (the response time was evaluated according to the procedure suggested by Oliveira and Marinho, 2008). The measurement remained stable for about 10 days (Fig. 6b), after which it was interrupted due to an electrical failure in the laboratory.

6 Conclusions and Future Developments

The results obtained from preliminary testing show satisfactory performance of the new prototype in terms of readiness and stability of measurement and seem very promising for future use of the instrument in the laboratory and in the field.

References

Oliveira, O.M., Marinho, F.A.M.: Suction equilibration time for a high capacity tensiometer. Geotechnical Testing Journal 31(1), 1–5 (2008)

Ridley, A.M., Burland, J.B.: A new instrument for the measurement of soil moisture suction. Geotechnique 43, 321–324 (1993)

Rojas, J.C., Pagano, L., Zingariello, M.C., Mancuso, C., Giordano, G., Passeggio, G.: A new high capacity tensiometer: first results. In: First European Conference on Unsaturated Soils, Durham, July 2-4 (2008)

Take, W.A., Bolton, M.D.: Tensiometer saturation and the reliable measurement of soil suction. Geotechnique 53(2), 159–172 (2003)