TUKS tensiometer measures to –1.7 Mega Pascal

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OVERVIEW

Tensiometers are piezometers capable of measuring negative water pressures. When the air pressure in a container partially filled with water is reduced, the water will start to boil at room temperature when the air pressure is reduced to below the vapour pressure. At sea level and typical room temperature around 25°C this occurs at about –100 kPa, and at the elevation of the University of Pretoria (about 1 400 m above sea level) at about –76 kPa. This transition from liquid into the gas phase under low pressure is often referred to as cavitation and prevents the pressure in the liquid from reducing further. However, in the small pore spaces in partially saturated soils, free water is bound by menisci which may sustain very large negative pressures (to many Mega Pascal) in the pore water without cavitation occurring. The negative water pressures result in the soil grains in contact with the water being drawn together, generating compressive forces between the grains, and because of the friction between the grains, this generates shear strength. This shear strength is often referred to as apparent cohesion and is of great significance in geotechnical engineering. In gold tailings dams, for example, consolidation is typically completed rapidly after deposition of a new layer. Then, as the tailings dry out, negative pore pressures are generated, increasing the effective stress in the tailings. This results in over-consolidation and increases the shear strength, which allows the tailings dam to be constructed using the tailings itself as a means of confinement. This is a typical method of tailings dam construction in dry climates, such as in South Africa.

Nearly all soils in South Africa and Africa occur in a partially saturated state, as the water table is typically at a significant depth below ground level. The strength of our soils is therefore very dependent on negative pore pressures. In order to study the effect of negative pore pressures on the behaviour of unsaturated soils it is necessary to measure the magnitude of these negative pore pressures. This can be achieved by various means. High suctions are measured indirectly, usually by determining the relative humidity, as there exists a fundamental thermodynamic relationship between the suction magnitude and the relative humidity in the air around the pore water. Relative humidity can, for example, be measured using dew point hygrometers or psychrometers, or by means of the widely used filter paper method (Hamblin 1981; Chandler & Guttierrez 1986).

Tensiometers have been used in agriculture for many years, as the magnitude of pore water suction affects the ease with which plants can absorb water from the soil. They have, however, traditionally been limited to the negative water pressure at which cavitation occurs, i.e. from –70 to –100 kPa, depending on the height above sea level and the ambient temperature.

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HOME-GROWN TENSIOMETERS

The high cost and difficulty to source tensiometers hamper research into unsaturated soil behaviour. We have therefore developed a low-cost tensiometer at the University of Pretoria (fondly referred to as TUKS by students and alike), with a component cost of the order of R300 per sensor, which is orders of magnitude cheaper than what can be sourced elsewhere. Similar to the Ridley and Burland sensor, the instrument comprises a high air entry ceramic filter element glued to a pore pressure sensor. The filter-sensor combination is sealed with a low water absorbent structural epoxy. The instrument, procedure for saturation and performance are described by Jacobsz (2018). Examples of tensiometers are shown in Figure 1.

In short, the saturation process involves subjecting the sensor to a high-quality vacuum and then submerging it in high-quality de-aired water. The external vacuum is released and the vacuum remaining in the ceramic filter and space between the pressure sensor and ceramic is used to draw the de-aired water into the sensor. Once the pressure registered by the sensor has returned to atmospheric, the sensor is pressurised to above the air entry value of the ceramic filter and left overnight to allow any remaining air to go into solution. The use of a vacuum allows much more rapid saturation of the sensor and significantly reduces the positive pressure required to fully saturate the sensor. An overview of the theoretical basis for this saturation procedure was presented by Take and Bolton (2003).

The performance of a tensiometer is best illustrated by allowing a fully saturated sensor to dry out in air at normal room temperature. As water evaporates from the ceramic filter, it is drawn into the pores in the ceramic where the surface tension associated with the small menisci allows negative water pressures up to the air entry value of the ceramic to develop. The maximum measuring range of the instrument is therefore limited to the air entry value, but cavitation may occur before this suction is reached. Figure 2 shows pore pressure records for two tensiometers where cavitation and air entry respectively occurred.

The original TUKS sensors comprised 500 kPa ceramics fitted to 7 bar pressure transducers. These sensors are routinely used in our laboratory to measure negative pressures to in excess of 500 kPa, as demonstrated in Figure 2.

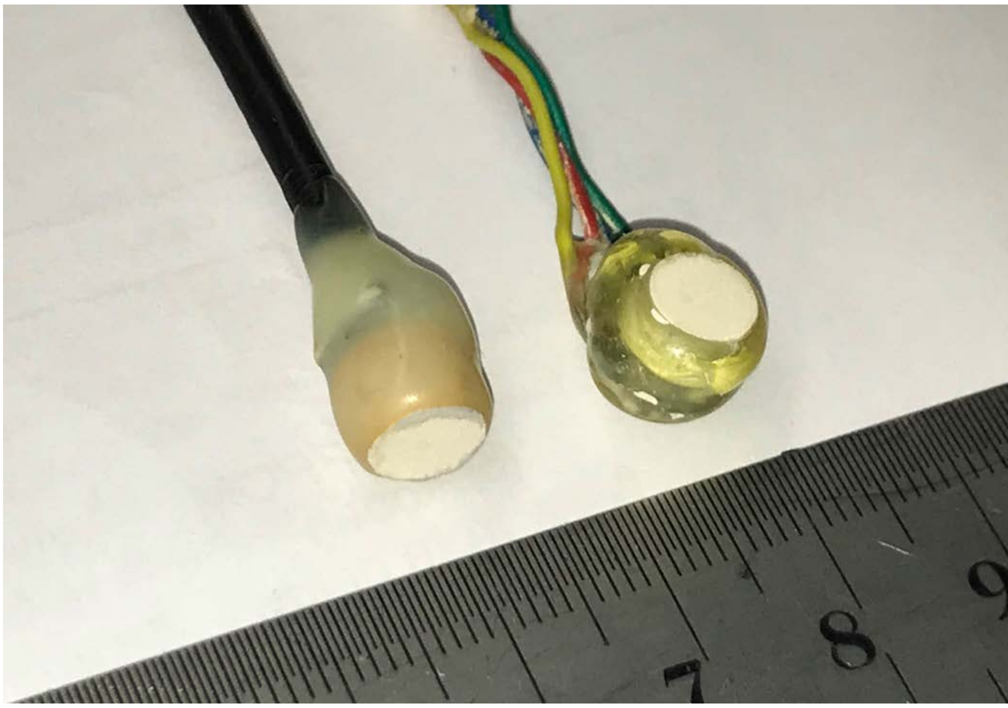


Figure 1 TUKS low-cost tensiometers

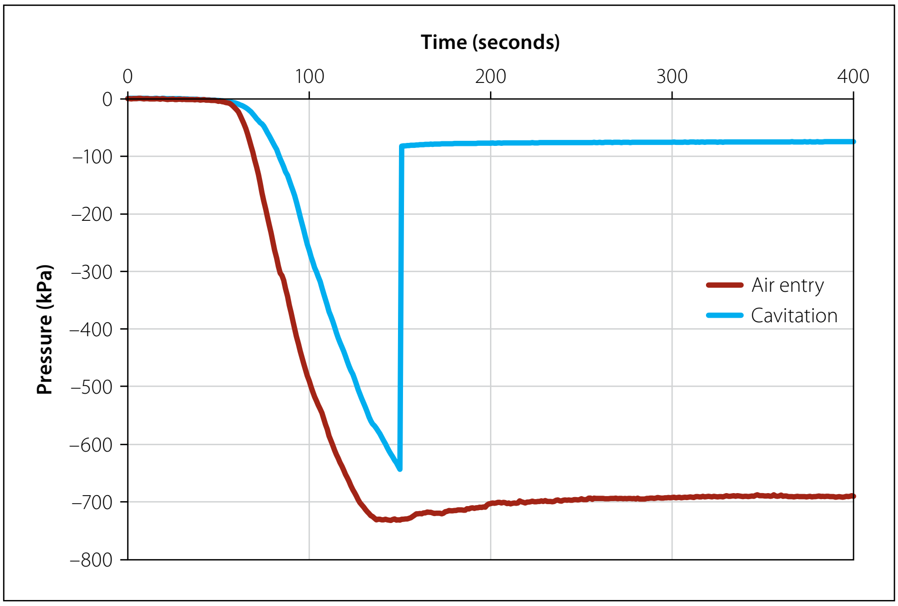


Figure 2 Tensiometer performance under cavitation and air entry respectively

The instruments are equally capable of measuring positive pressures. They are saturated in the laboratory in a conventional triaxial cell.

Recently a more robust sensor was developed using a stainless steel housing in which the ceramic filter and pressure sensor can be mounted. The new high-capacity tensiometer is presented in Figure 3. Compared to the previous sensor, which was of somewhat variable shape because of the outside comprising unconfined structural epoxy, the regular shape and sturdy construction of the new sensor allow it to be mounted in a specially developed pressure vessel so that it can be saturated at high pressures of up to 3 MPa. A number of tensiometers comprising pressure sensors with a rated capacity of 12 bar, and ceramics with an air entry value of 15 bar were built and successfully saturated and subjected to a dry-out test, as described before. The performance is illustrated in Figure 4, showing that the sensor, costing less than R300, was capable of reaching a suction value of 1 697 kPa before cavitation occurred.

EXCITING RESEARCH POSSIBILITIES

This sensor opens up many research possibilities. Due to the high air entry

Figure 3 Two new high-capacity tensiometers and the saturation equipment

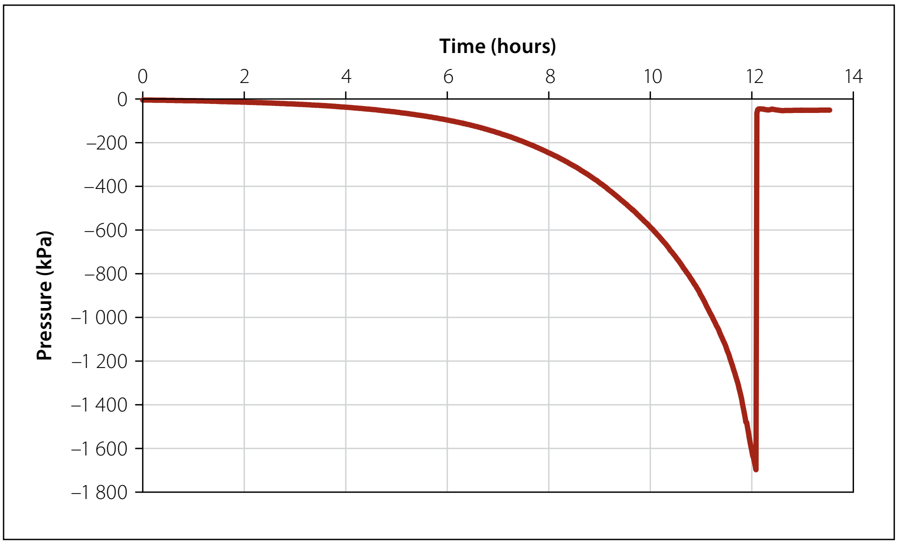
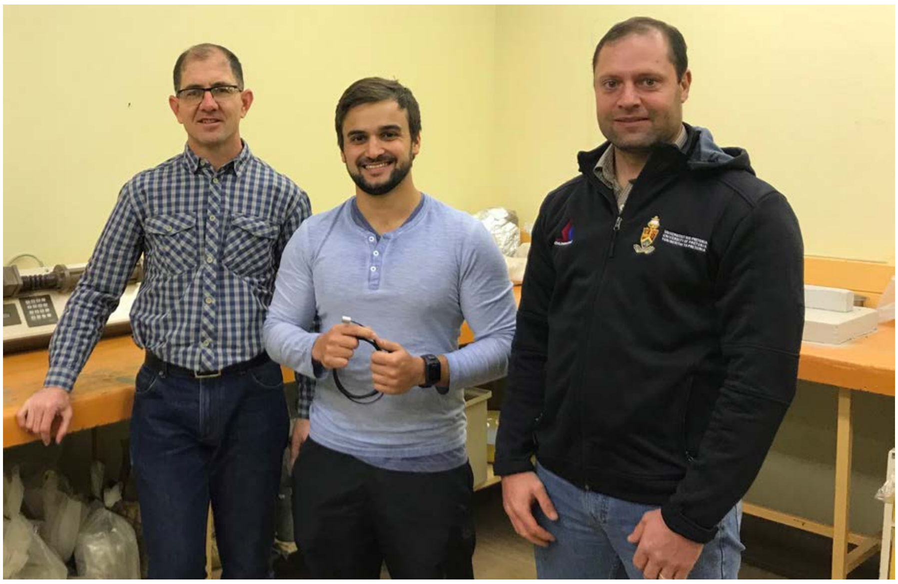


Figure 4 Performance of high-capacity tensiometers during a dry-out test, measuring to a negative pore pressure of 1 697 kPa before cavitating



The TUKS team who developed the new tensiometer, from left: Prof SW Jacobsz, study leader, Tiago Gaspar, PhD student, and Jan Vermaak, the technician from the geotechnical laboratories who manufactured the tensiometer and equipment for saturation

value it will not desaturate easily and should therefore be suitable for use in field applications. One potential example could be a study of suction generation during repeated deposition and drying cycles on tailings dams, as this will allow the role of over-consolidation associated with drying and desiccation in strength gain to be studied. Another example is the study of seasonal suction cycles in road and railway embankments to understand seasonal variation and the effect of climate change on slope stability.
The sensors are also routinely used in our laboratory to measure gravimetric soil water retention curves of soils by measuring suctions in soil samples as they dry out. By placing these samples on a scale as they dry, the suction and water content can be related. This information is required for stability analyses when working with models using unsaturated soil properties. □

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