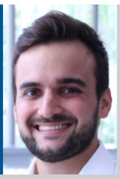
Application of unsaturated soil mechanics – two years on



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In recent years, technological advancements in the field of unsaturated soil mechanics have helped improve understanding in this field for both researchers and engineering practitioners. Gaspar & Jacobsz (2019) presented a short overview of some key principles of unsaturated soil mechanics and highlighted how measurement techniques (both in the laboratory and in-situ) are becoming increasingly available in South Africa. The purpose of this article is to present a review of the two years following that publication to illustrate the uptake of these developments in engineering practice.

LABORATORY TESTING

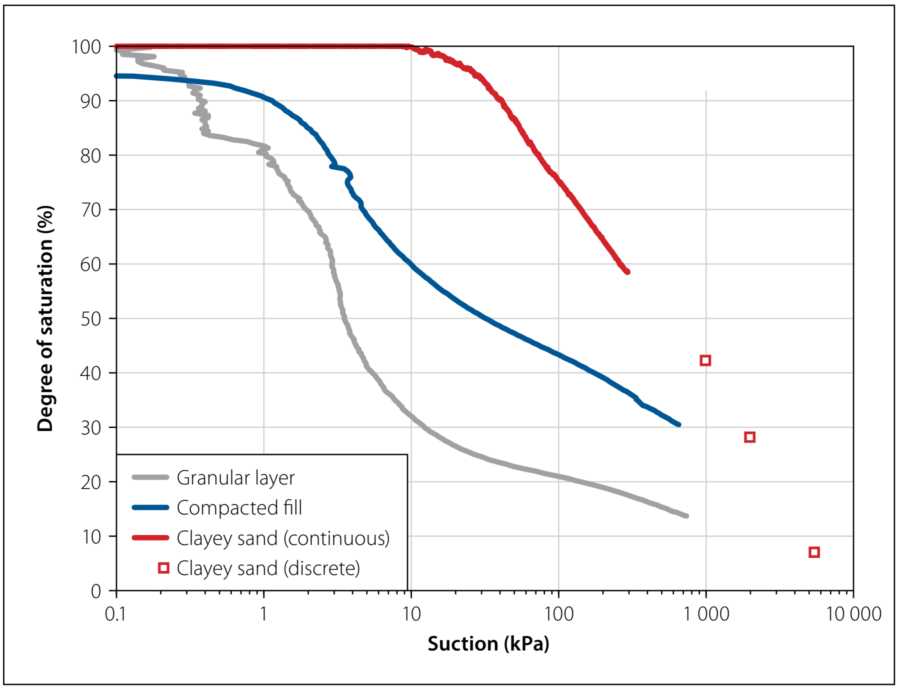

Figure 1 Typical SWRCs measured at UP unsaturated soils laboratory

The relationship between soil suction and water content, referred to as the soil water retention curve (SWRC), is often regarded as the most fundamental relationship governing the behaviour of unsaturated soils (Fredlund, 2018). Whereas conventional soil characterisation methods have long utilised, at the very least, grading curves and Atterberg limits, any application of unsaturated soil mechanics necessitates knowledge of the SWRC.

Gaspar & Jacobsz (2019) described some developments at the University of Pretoria (UP) which facilitated the measurement of the SWRC with continuous measurement of changes in water content, suction, and sample volume. Since that publication, the university has received numerous requests from various consulting firms to measure SWRCs. It has become increasingly evident that the information contained in the SWRC is particularly useful in modelling seepage problems and to assess surface infiltration and evaporation for water balance purposes.

Figure 1 illustrates the results of some typical SWRCs measured at UP. Included in this figure are measurements on two railway formation materials labelled "granular layer" and "compacted fill", as well as a measurement on a clayey sand. The measurement on the clayey sand contains a portion which was measured continuously using UP's in-house tensiometer, as well as discrete measurements in the high suction range performed using a dewpoint hygrometer.

Since 2019, substantial improvements have been made to the laboratory equipment used to measure SWRCs. The relationship between soil suction and water content is not unique, and often exhibits hysteretic behaviour depending on whether a wetting or drying path is followed. Despite this knowledge, drying curves are generally measured regardless

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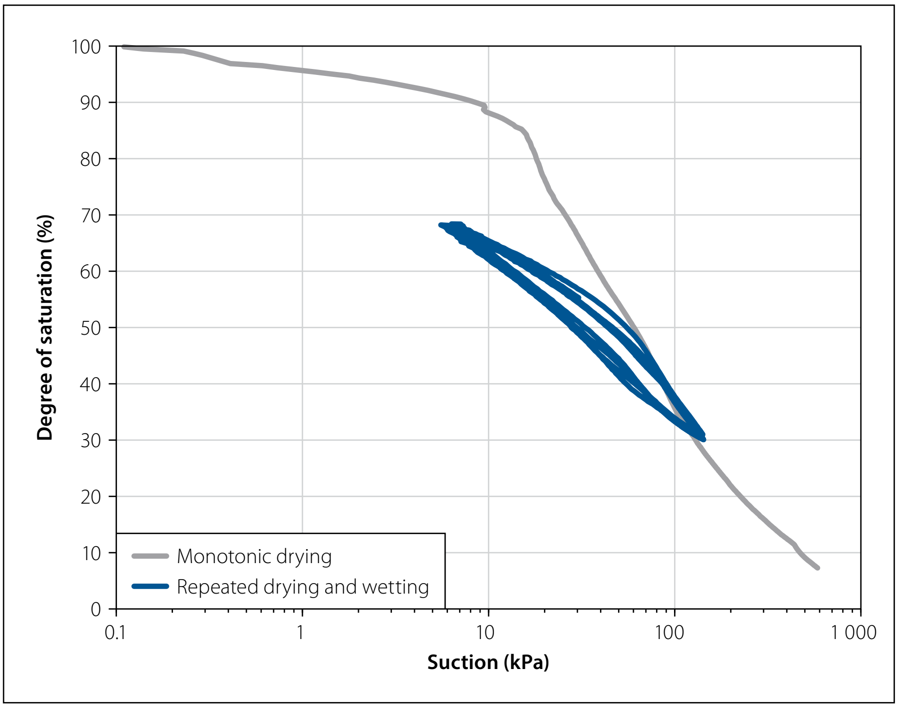

Figure 2 Drying and wetting SWRCs measured on silica flour

of application owing to the difficulties associated with measuring wetting curves. However, recent modifications by Vandoorne (2021) have extended the capabilities at UP to measure wetting curves continuously.

Figure 2 illustrates the drying and wetting curves of silica flour using this equipment. A monotonic drying curve is also presented for comparison. Figure 2 illustrates how the wetting and drying cycles were stringently controlled between suction values of 5 kPa and 150 kPa. The new SWRC apparatus allows for automatic wetting and drying cycles to be performed within specific suction ranges (provided this range falls within the capacity of the tensiometer being used).

Finally, acquisition of a new cyclic triaxial apparatus at UP has allowed for the mechanical properties of both saturated and unsaturated soils to be assessed under conditions which more closely represent that of traffic loading. Some results from this newly acquired equipment, with specific reference to railway formation materials, have recently been demonstrated by Mpye (2020).

IN-SITU MEASUREMENTS

Whereas laboratory measurements of SWRCs may be useful in the design phase, in-situ measurement of soil suction can provide a real-time indication of the performance of a structure. As stated by Toll et al. (2011), pore water pressure is the most reliable indicator of slope failure and can therefore be an extremely valuable parameter to monitor and use as a trigger value for early warning systems. Since the publication by Gaspar & Jacobsz (2019), UP has been involved with the instrumentation of several sites around South Africa, measuring both soil suction and water content.

Monitoring systems either incorporated UP's in-house low-cost tensiometers (Jacobsz, 2018) or commercially available fixed-matrix porous sensors (Tripathy, 2016; Metergroup, n.d.). The benefit of tensiometer measurements is that they can record changes in suction as small as 1 kPa almost instantaneously. Such sensors do however need to be properly saturated prior to use and may require re-saturation if cavitation of the sensor occurs due to suctions exceeding the capacity of the sensor (up to 1.7 MPa (Jacobsz, 2019)).

The benefits of fixed-matrix porous sensors are that they do not require any preparation before being used on site and require no maintenance after installation. Interestingly, preliminary tests have shown no significant difference in the response time of these sensors versus tensiometers. However, laboratory tests have shown that these sensors are not as accurate as tensiometers, and show appreciable hysteresis (Vandoorne, 2021). Furthermore, the fixed-matrix porous sensors suffer in low suction environments as they cannot measure suctions less than approximately 9 kPa. Unlike tensiometers, fixed-matrix porous sensors are also not able to measure positive pore water pressure. Despite these limitations, these sensors can offer valuable information on seasonal changes in suction.

Figures 3 and 4 illustrate the measurement of soil suction within tailings storage facilities in two regions of South Africa, using tensiometers. From both figures it can be seen that tensiometer measurements respond sharply to tailings depositions and rainfall events. What is perhaps more important in this result is the longevity of the low-cost tensiometers used. Figure 4 illustrates that after a period of two years, the tensiometers continue to function. Such a result is comparable with some of the longest studies involving the measurement of suction in the field (Mendes et al. (2008); Toll et al. (2011); Toll et al. (2012)).

It is worth noting that at no point during the measurement period did pore water pressure move into the positive range. Soil suctions can contribute positively to slope stability but are hardly ever measured. Consequently, their variation over time is poorly understood. Recognising this observation, it may be worth considering the routine use of tensiometers on tailings dams, augmenting or even replacing more routinely used instrumentation such as piezometers. Replacing piezometers with tensiometers is, in principle, feasible as tensiometers can also measure positive pore pressures. The addition of tensiometers to tailings dam monitoring systems would provide significant additional data on the pore pressure regime at very little additional cost.

In addition to measurements on tailings storage facilities presented in Figures 3 and 4, Figure 5 illustrates measurements beneath a railway formation using both tensiometers and fixed-matrix porous sensors. A three-month period is

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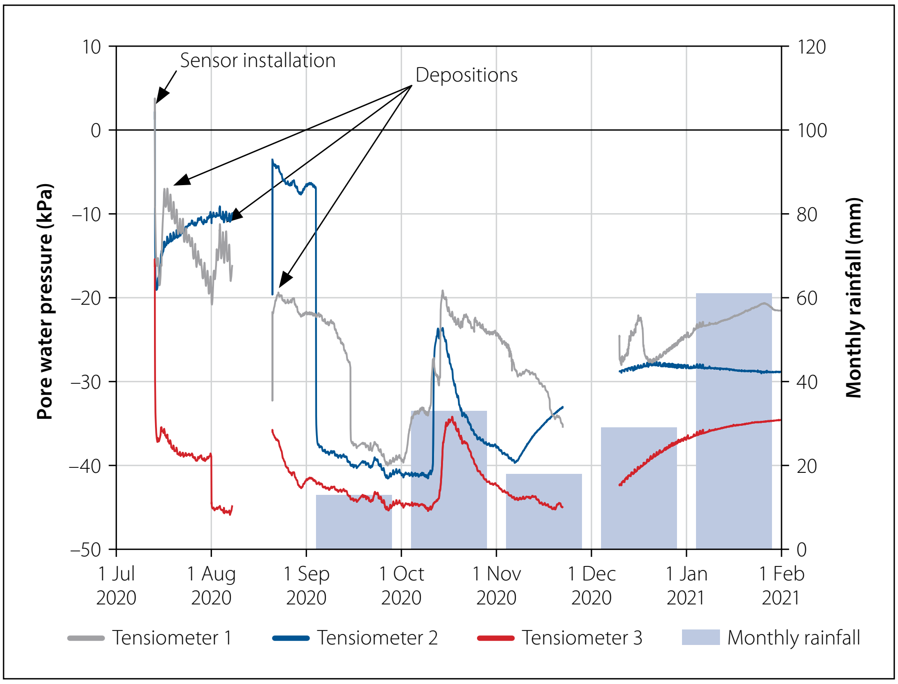

Figure 3 Suction measurements in a platinum tailings storage facility over a period of approximately 8 months

shown. At the start of the measurement period, a limitation of the fixed-matrix porous sensor can be see seen as these sensors have a measuring limit of –9 kPa. It is also clear that the fixed-matrix porous sensor is less sensitive to changes in matric suction than the tensiometer. It is, however, evident that both sensors measured similar trends and provide useful information of seasonal variations in soil suction.

CONCLUSIONS

Two years ago, Gaspar & Jacobsz (2019) highlighted the importance of unsaturated soil mechanics and illustrated how its application in practice had become significantly more accessible. Industry's response to these developments was overwhelmingly positive, leading to further research on the subject, as well as its implementation in practice. Improvements

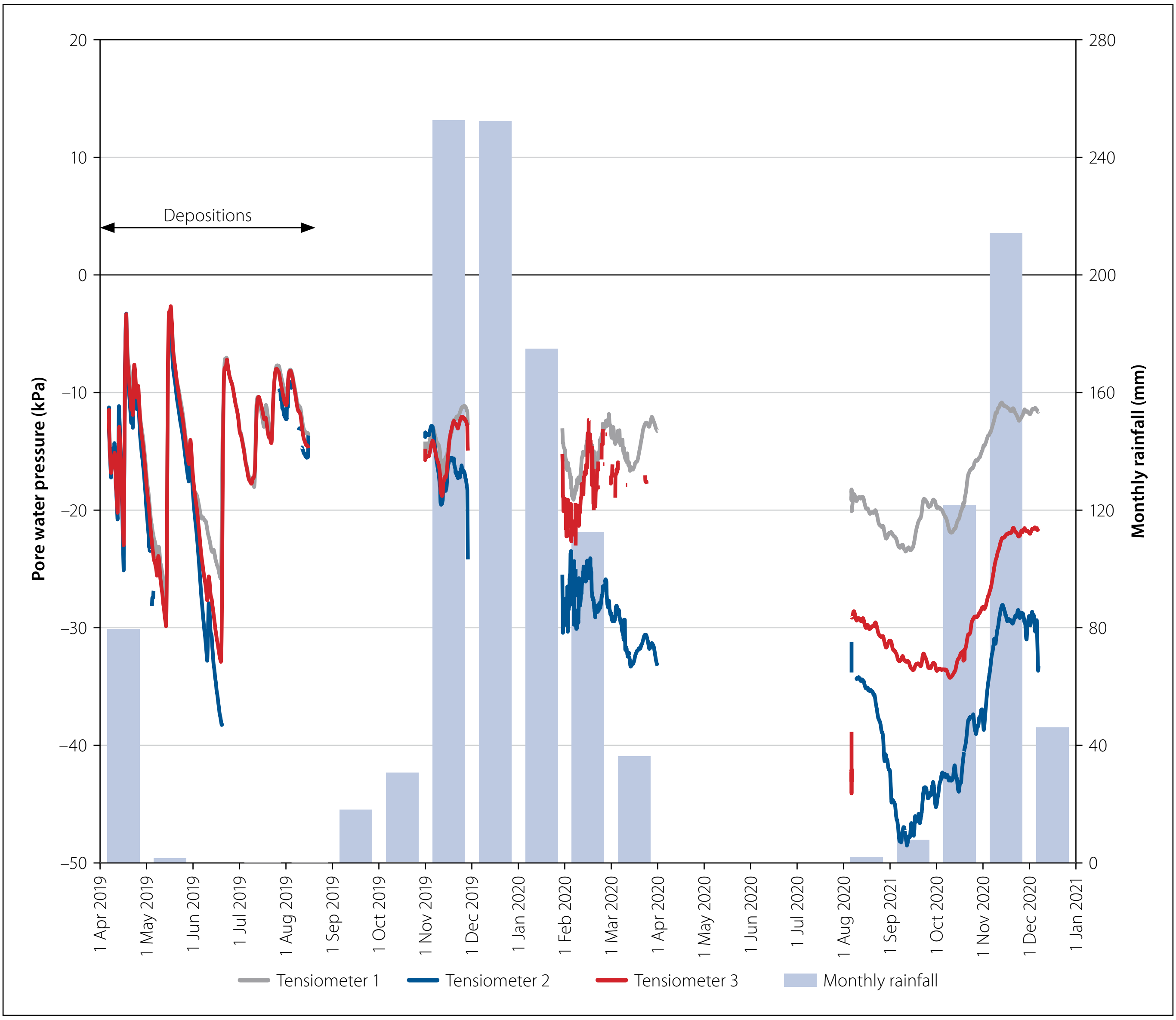

Figure 4 Suction measurements in a gold tailings storage facility over a period of approximately 2 years

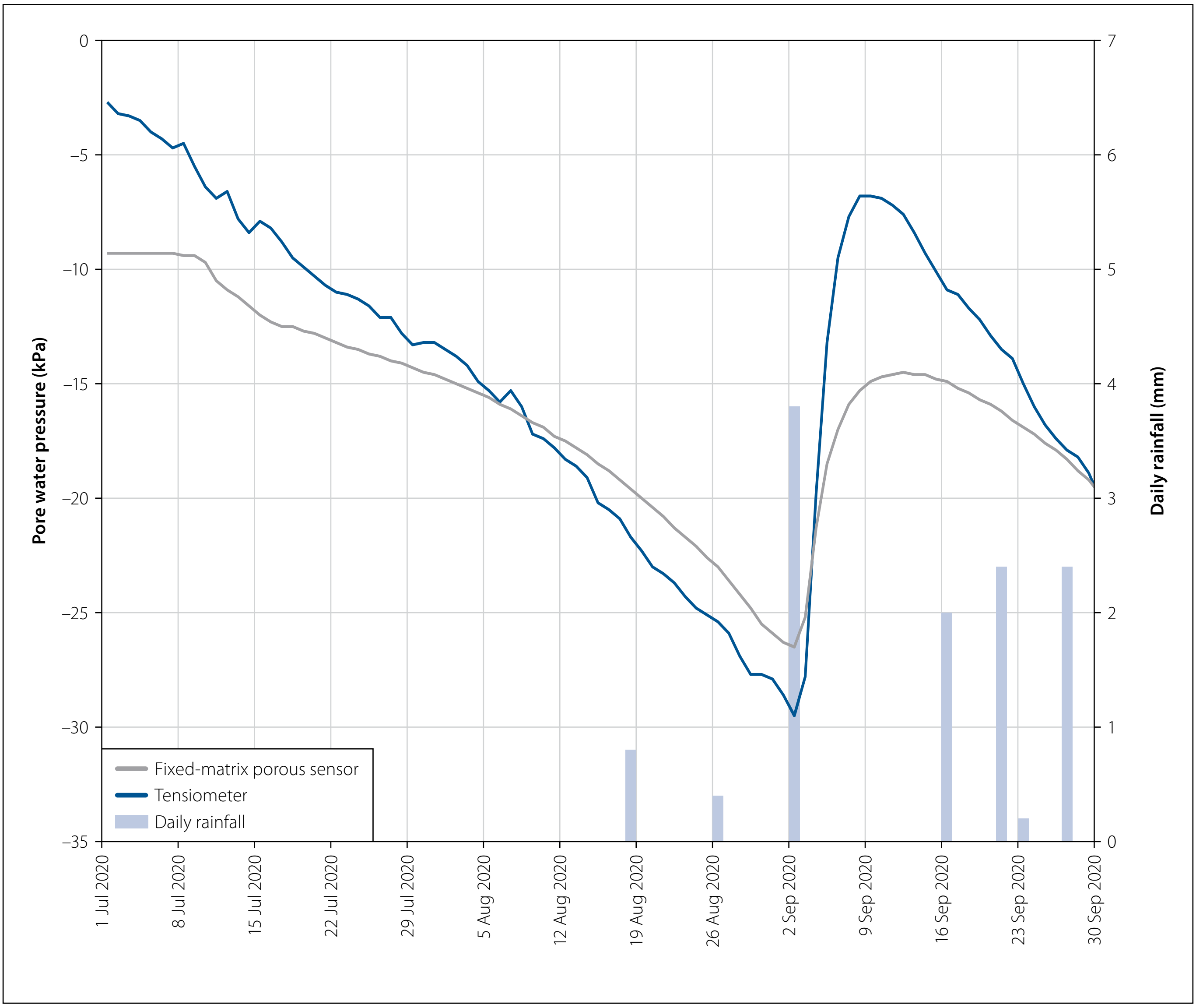

Figure 5 Suction measurements beneath a railway formation using both tensiometers and fixed-matrix porous sensors

in laboratory testing have facilitated proper characterisation of unsaturated soils, while data from field studies demonstrate that measurement of negative pore water pressure can now be added to routine monitoring systems. Considering the performance of the sensors discussed and their associated costs, it appears that the hinderances to the application of unsaturated soil mechanics in practice are rapidly falling away.

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