Remote monitoring of a tailings dam using the Internet of Things

Prof SW Jacobsz Pr Eng
Department of Civil Engineering
University of Pretoria
sw.jacobsz@up.ac.za

André Broekman
Department of Civil Engineering
University of Pretoria
andre@broekmail.com

Jack Basson
Department of Civil Engineering
University of Pretoria
u17029016@tuks.co.za

Rick Vandoorne
Department of Civil Engineering
University of Pretoria
rick.vandoorne@up.ac.za

Jan Vermaak
Department of Civil Engineering
University of Pretoria
jan.vermaak@up.ac.za

INTRODUCTION

Due to their size and often their remoteness, large geotechnical structures such as tailings dams are ideally suited to be observed using smart monitoring technologies. With the arrival of the 4th Industrial Revolution – and in a year characterised by unprecedented disruption and uncertainty impacting physical access for monitoring purposes – adoption of state-of-the-art Internet of Things (IoT) solutions for remote monitoring applications provides a unique, real-time view into the behaviour of these structures.

To improve understanding of the long-term pore pressure behaviour associated with the operation of a tailings dam, the Department of Civil Engineering at the University of Pretoria (UP), in collaboration with SRK Consulting and Marula Platinum, is conducting an instrumentation project to observe pore pressure (both positive and negative), moisture content and temperature at nine monitoring locations on a platinum tailings dam. The Marula Platinum Mine is situated approximately 30 km northwest of the town of Burgersfort. The mine operates a tailings dam with a footprint of 48 Ha on which deposition occurs by means of spigotting.

PORE PRESSURE AND TENSIOMETERS

It is of interest to understand the evolution of the pore pressure regime in the tailings dam associated with normal operation in terms of an unsaturated soil mechanics framework. The primary variables affecting the pore pressure regime are the tailings moisture content and the pore water suction. These are being measured using volumetric water content probes and tensiometers respectively. The UP Department of Civil Engineering has developed high-capacity tensiometers (Figure 1) capable of measuring both positive pore pressures and negative pore pressure in excess of 1 MPa (Jacobsz 2019).

The use of high-capacity tensiometers to measure soil suction has numerous advantages. Firstly, high-capacity tensiometers provide a direct suction measurement and are very well suited to the suction range typically expected within a tailings facility. Secondly, tensiometers enable continuous monitoring of soil suctions and do not require expensive and complex signal conditioning software, as is often required for commercially available suction sensors measuring suctions indirectly by recording another parameter such as relative humidity. Finally, the UP tensiometers, in comparison to other indirect suction measurement techniques, provide a high-resolution suction measurement in excess of 1 000 kPa, and have to date been tested on a gold tailings dam in Gauteng for 15 months, operating continuously.

Figure 1 Saturation and calibration of tensiometers installed within a pressure chamber

An important precaution associated with the use of tensiometers in the field include ensuring close contact between the tensiometer porous face and the soil water. This can be achieved by using a silica flour or kaolin paste on the face of the tensiometer, which serves to provide an interface between the tensiometer and the material in which suction is being measured. This measure has been successfully applied by the UP Department of Civil Engineering to measure pore water suctions in railway formations over periods exceeding 12 months. This precaution is not necessary when monitoring suctions in fine-grained materials such as tailings, because of the excellent contact which can be achieved by simply submerging the tensiometer in saturated tailings slurry during installation on a tailings dam. A further potential shortcoming of tensiometers is that they may cavitate after extended use at suctions exceeding absolute zero, or when they dry out, rendering their measurements unreliable. Cavitation can be observed easily through continuous monitoring of

Figure 2 From left: Nina Slawson (SRK), André Broekman, Prof SW Jacobsz, Jan Vermaak, Jack Basson and Emile Dempers (all from the University of Pretoria), in front of one of the DAQ units after installation (another unit is visible in the background towards the top left of the image)

the tensiometer output. When there is potential for cavitation, it is best to install tensiometers in such a way that they are readily serviceable.

INSTRUMENTATION HARDWARE

Since 2017, the Department of Civil Engineering has been developing several instrumentation solutions suited to unique research applications and requirements (Broekman & Gräbe 2019; Steyn & Broekman 2020). These solutions combine the fields of traditional civil engineering, electronic engineering, information technology and computer science, collectively referred to as *Civiltronics*. For this project, a low-cost data acquisition (DAQ) system was developed, combining both the popular Arduino and Pycom family of microcontrollers at a cost of less than a third of an equivalent commercial system. The harsh and remote operating environment at Marula Platinum Mine requires long-term battery-powered operation and low-power wireless communication abilities. The implementation of microcontrollers enables reliable operations alongside remote data collection capabilities in the form of Sigfox (2020). Sigfox operates alongside existing cellular communication infrastructure, negating the need to deploy dedicated hardware on the site to establish internet connectivity. Even though each message payload is limited to 12 bytes, with a maximum message capacity of 140 uplink messages per day per device, all the sensor data and the battery charge level can be encoded within a single message and relayed to the SigFox backend. This data is subsequently retrieved as an aggregated CSV file and decoded, yielding the original calibrated sensor measurements with adequate resolution. In the event of a loss in communications or poor signal coverage, the original data can still be retrieved from the non-volatile storage in the form of an SD card.

The instrumentation hardware was assembled, tested and calibrated by Jack Basson, a final-year civil engineering student at UP; this research project forms part of Jack's final-year research project. Jack, working under the supervision of Prof SW Jacobsz, was assisted in the development of the system by André Broekman and Rick Vandoorne, both PhD students at UP Civil Engineering (Figure 2). The team was assisted by UP Civil Engineering technician, Jan Vermaak.

The electronics, power supply and antenna are secured in a waterproof casing (Figure 3). Watertight cable glands provide the required seal between the sensor lead wires and the instrumentation. The DAQs were preconfigured with all the necessary sensor wiring prior to installation on the tailings dam to eliminate any wiring errors. The tensiometers were transported to the site in a water vessel filled with de-aired water to ensure that they remained saturated during transit from the laboratory (where they had been saturated) to the point of installation.

INSTALLATION

A total of three DAQs were constructed, each monitoring three tensiometers and three water-content sensors (which also measure temperature). The tensiometers and water-content sensors were installed together in the same locations. The three DAQs are separated by a distance of approximately 130 m on the tailings dam – the first located adjacent to the outer wall near the edge of the beach, the second halfway to the pond and the third immediately adjacent to the pond (Figure 4). For DAQ 1, adjacent to the edge of the beach, the sensors were installed at a depth of 0.25, 1.4 and 2.8 m. In the case of both DAQ 2 and DAQ 3, all the sensors were installed at a depth of 250 mm at

Figure 3 DAQs and sensors preconfigured in the laboratory

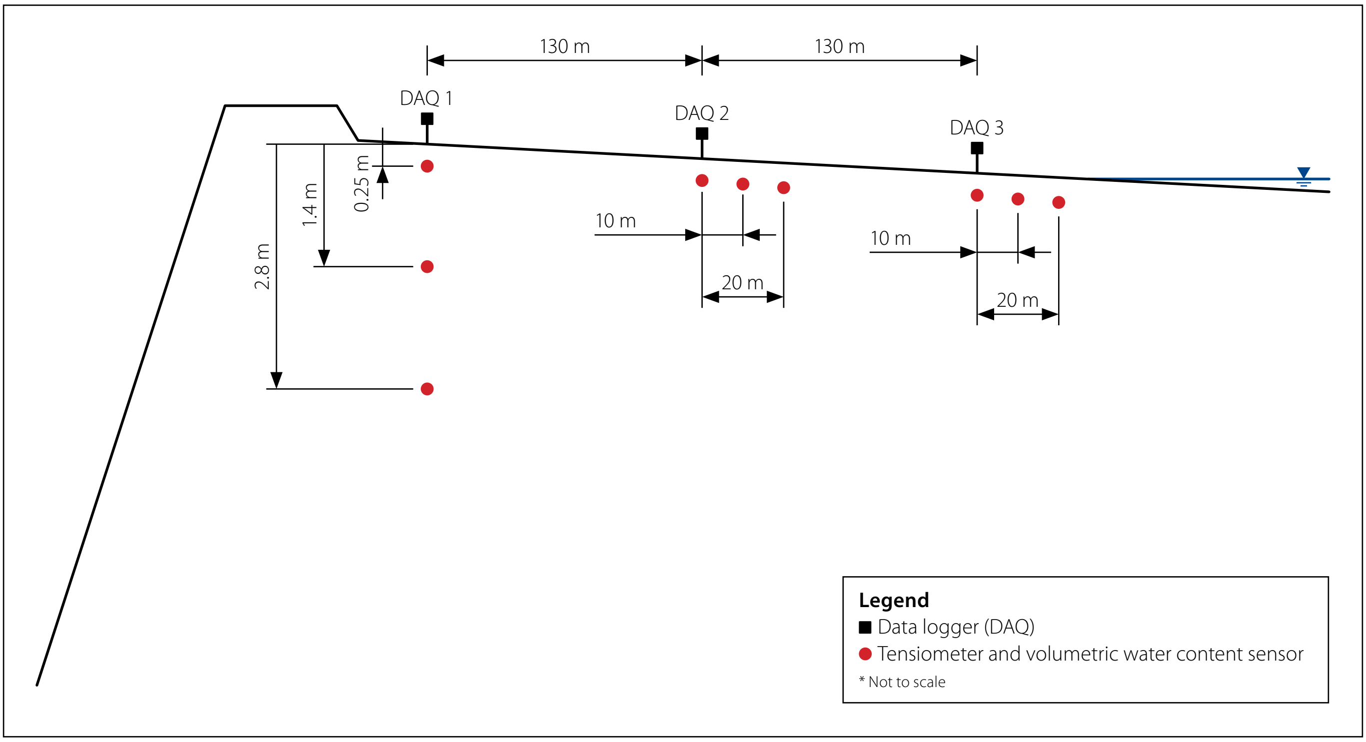

Figure 4 Idealised cross-section illustrating the sensor and data logger locations (not to scale)

distances of approximately 1, 10 and 20 m away from the DAQ. For every cable, a redundant length of approximately 3 m was reserved to accommodate the eventual rise in elevation of the tailings, such that the DAQ could be raised over time without applying strain to the sensor cables. The DAQs were mounted on galvanised-steel poles measuring 2 m in length, using rigid brackets (Figure 5). Alternating markings on the pole delineate intervals of 250 mm to assist visual monitoring of the rate of rise of the tailings over time. To install the sensors, holes were augered by hand to the appropriate installation depth in the tailings.

Careful consideration was given to the installation procedure of the tensiometer sensors to prevent cavitation and damage. The augered holes were first filled with a small amount of water to prevent drying and cavitation during the installation and backfilling process. This was followed by transferring the tensiometer from the water vessel to a secondary water-filled container and positioning it close to the hole. The tensiometer was rapidly, but carefully, lowered down the augered hole, settling into the freestanding water at the bottom. The installation of the water-content sensor followed thereafter. There was no need to keep the sensor saturated. Finally, the hole was carefully backfilled with dry tailings (by hand) to surface level. This process was repeated for all the sensors, regardless of installation depth.

MONITORING

During the installation process, data was recorded at a frequency of one reading every minute to document the zero reading of all the sensors. Thereafter, all three DAQs were configured to record and transmit data every hour, which is also the logging rate over the course of the monitoring period. This will continue until either the battery charge has depleted, or the system is turned off. Based on laboratory testing conditions, the rechargeable lithium ion batteries are expected to operate for six to eight weeks at a logging rate of once per hour. A secondary set of batteries and SD cards is kept on site, serving to keep the DAQs operating continuously by replacing both components periodically. The battery voltage is monitored remotely to determine when the components should be replaced.

Figure 7 illustrates the tensiometer sensor measurements from one data acquisition unit over the first ten-day period after the installation of the sensors. Pore pressure equilibration following the installation and the deposition of new tailings on 15 July is clearly reflected in the data. Since the installation of the DAQs, the sensor measurements have been transmitted reliably using Sigfox to remotely monitor and interpret the data from anywhere where internet access is available.

IN CLOSING

To our knowledge this project marks the first research project to include

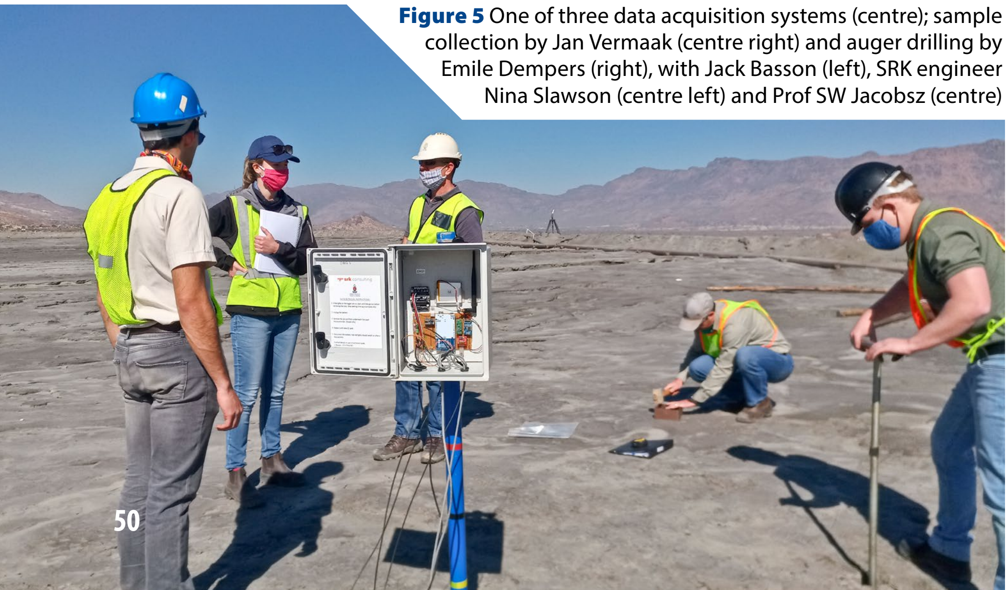

Figure 5 One of three data acquisition systems (centre); sample collection by Jan Vermaak (centre right) and auger drilling by Emile Dempers (right), with Jack Basson (left), SRK engineer Nina Slawson (centre left) and Prof SW Jacobsz (centre)

Figure 6 Installation methodology: pole installation (top left), tensiometer transfer from water vessel (top right), installation of tensiometer (bottom left) and backfilling (bottom right)

state-of-the-art IoT technology to address long-term, remote monitoring requirements to observe the full pore pressure regime of a tailings dam. The technology reduces the need to collect data manually and can be economically scaled for more cost-effective monitoring. The team gratefully acknowledges the support and funding received from SRK Consulting and Marula Platinum. □

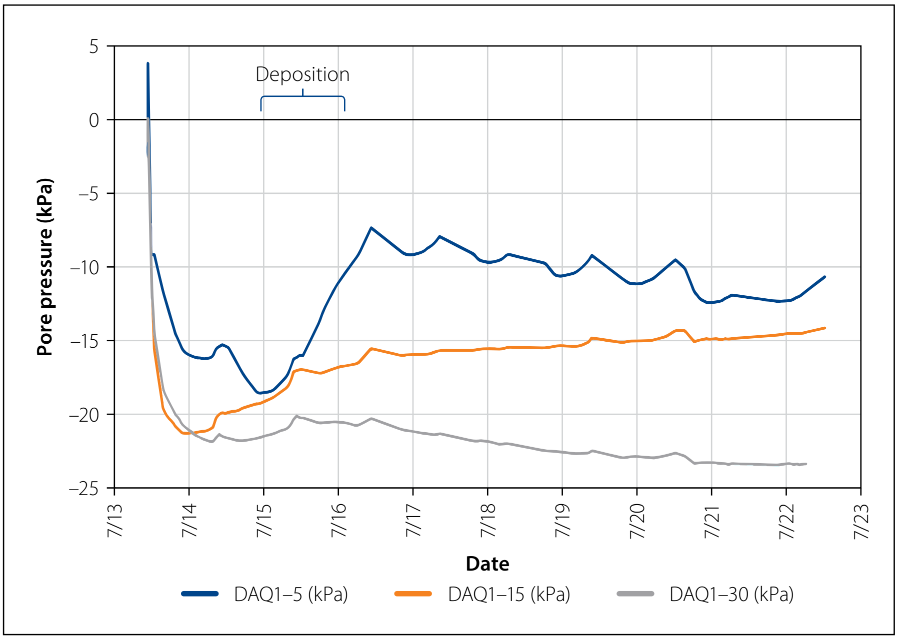

Figure 7 Tensiometer sensor measurements recorded and transmitted by DAQ 1

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