Evaluation a volumetric water content sensor to be used for compacted filtered iron ore tailings.

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Abstract. The use of compacted landfills for filtered tailings has grown to replace dams. Considering that this is a structure that must remain in the unsaturated condition, it is necessary to monitor the flow pattern and water retention in these landfills. The use of sensors for the automatic monitoring of volumetric water content is a fundamental tool for use in the field. Sensors that use the technique called FDR (Frequency Domain Refractometry) emit an electromagnetic signal that, associated with the ability of materials to store electrical charge, allows the determination of the so-called dielectric constant. The dielectric constant relates the capacitance of the material to the capacitance of the air. As the dielectric constant in air is, by definition, equal to 1 and of the water, at 20 degrees Celsius, equal to 80, materials with a range proportion of air and water have variable dielectric constant values, considering the dielectric constant of minerals being constant. Many commercial sensors already come with a calibration curve that is based on typical soils (quartz and feldspar). However, in the case of iron mining tailings, in addition of having a very different mineral composition from the soils normally founded, there is the possibility that the presence of very fine particles could alter the dielectric constant of the liquid. In this way, it is essential to obtain a specific calibration curve, taking into account not only the material, but also the density of it. The sensor used in the present study is the TEROS 12. The results obtained for the sensor calibration in the case of iron ore tailings, demands a specific calibration to be performed for the material and each density to be used. The process used for the calibration and the equations obtained are presented in this paper.

1. Introduction

The piles of filtered tailings have been used as an alternative to the deposition system in dams. This is not only a result of increased safety, but also contributes to the reuse of water. Despite being a safer and environmentally better alternative, the filtered tailings stacking system still lacks more detailed studies on the behavior of infiltration water or even the capillary rise. The porous characteristic of these systems and the variable and/or constant presence of water generate problems that can jeopardize the safety of the landfill. In this way, the definition of the water retention characteristics and its flow process associated or not with climatic processes is of paramount importance.

Field monitoring of volumetric moisture content, associated or not with suction measurement, can make an important contribution to the assessment of landfill behavior and safety.

Dry stacking of tailings can reach heights of over 200 m. The monitoring of possible processes of variation in water content must be followed over time to ensure the unsaturated condition in the sections that are thus defined in the project. Remembering that saturation is one of the triggers for liquefaction. Just to make clear the application of water content monitoring in practice, Figure 1a illustrates the execution of a pile of filtered tailings, and Figure 1b schematically presents what could be instrumentation niches for monitoring suction and water content. moisture. Numerical flow analyzes considering climatic conditions should be used to predict behavior.

For this, robust sensors are needed that allow measurements to be carried out with sufficient accuracy to monitor whether the field behavior is in accordance with the concepts of the projects. In other words, it is critical to understand how the material behaves in terms of varying degrees of saturation, and this can be done by measuring the volumetric moisture content. An option to this is to use the TEROS 12 sensor, manufactured by the company Meter Instruments ([2]).

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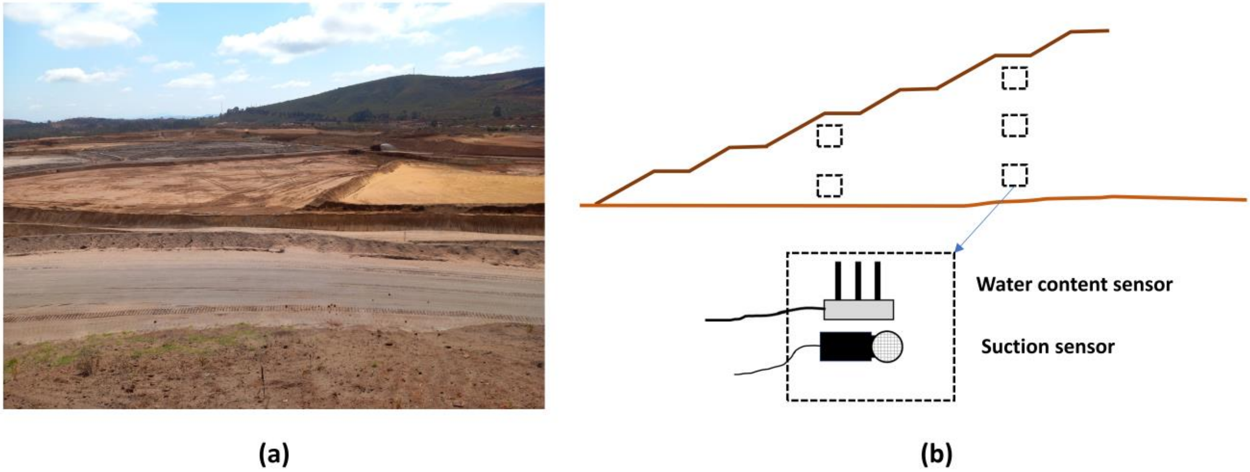

Fig 1. (a) General view of a dry stack under construction (b) schematic illustration of possible instrumentation niches.

Because it is a relatively new instrument and there is still little research developed specifically with the TEROS 12 sensor. Mokarighahroodi and Shukla [3] evaluated the sensor's performance in clayey soil, and found that the values measured with the sensor are in accordance with the real values. Thus, they conclude that the TEROS 12 sensor can monitor clayey soils with reasonable accuracy. Narayanan & Sathian [4] evaluate the behavior of the TEROS 12 sensor in lateritic soil for three different densities and conclude the importance of determining a specific calibration. It is observed in the results obtained by Narayanan & Sathian [4] that for values of volumetric water content above 30%, the calibration equation becomes nonlinear. Peranić & Arbanas [5] also demonstrate the importance of performing a specific calibration. In this case, sand and mixtures of sand with kaolin were tested.

2. Teros 12 sensor

The present study uses the TEROS 12 humidity sensor. The sensor (see Figure 2) uses an electromagnetic field to measure the dielectric permittivity of the environment, providing a 70-MHz oscillating wave to the sensor rods, which carry, as a capacitor, according to the dielectric characteristics of the medium. The charging time is proportional to the dielectric characteristics of the material which includes the volumetric water content of the soil. The sensor is compact for field use. In addition to determining volumetric moisture content, TEROS 12 measures soil temperature and electrical conductivity. More details about the sensor can be obtained in the manual made available by the manufacturer ([2]).

The sensor and its data acquisition system already include a calibration that converts the reading taken into volumetric moisture content. The equation provided by the manufacturer is presented below.

$$\theta = 0.0388*(RAW) - 69.56 \quad [1]$$

The equation is generic for most soils, but must be verified for situations where the material where the sensor is to be used has mineral characteristics different from the soils usually found in nature. In addition, it is important to check if there is any variation in relation to the dry density of the soil.

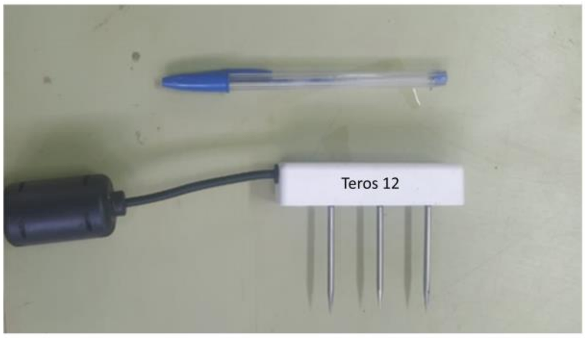

Fig. 2. Volumetric water content sensor, TEROS 12.

3. Materials used for the tests

The materials used for testing and calibration were uniform fine sand and two iron mining tailings. One of the tailings used, called Abóboras, is itabirite and comes from the Pico Mine, located in the municipality of Itabirito in MG. The other tailings, called Cianita, are flotation tailings from the Vargem Grande Mine, located in the municipality of Nova Lima, also in the state of MG.

Studies by X-ray diffraction carried out by Jesus ([1]) showed that the Abóboras tailings are composed of quartz and hematite, with goethite, muscovite and kaolinite, minerals that occur in smaller proportions. The waste called Cyanite is composed exclusively of quartz and hematite, with hematite equivalent to 10.9% of its composition.

The compaction (standard Proctor) parameters and the specific gravity of the two tailings are presented in Table 1

Table 1 Compaction parameters and specific gravity

	ρ_{d-max} (g/cm^3)	w_{opt} (%)	G_s
Aboboras	2.04	12.6	
Cianita	2.015	10.8	

4. Testing Method

The points for verification and determination of the calibration equations were obtained using a PVC mould, where the materials were compacted with a previously established density and water content. Figure 3 shows the sensor positioned on an already compacted layer, and the compaction process of the subsequent layers. A similar procedure was adopted for tests performed with fine sand.

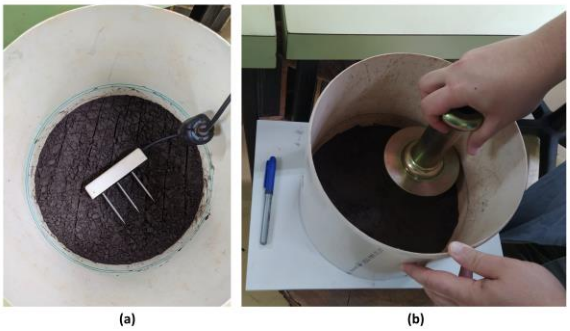

Fig.3 - Procedure adopted for compaction with the sensor.

5. Evaluation of the sensor

It was verified how the sensor behaved in relation to the readings taken in the air, in dry sand, dry tailings, in a solution with tailings, and in pure water. The tailings solution aimed to verify if water with excess material in suspension could change the sensor reading, in relation to pure water. Figure 4 presents the results obtained.

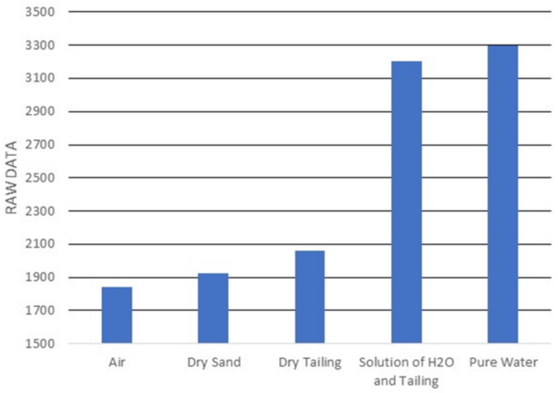

Fig. 4. Sensor response for different media

The readings for air, dry sand and tailings provided low values as expected, but indicated a slightly higher value for dry tailings compared to dry sand. When comparing the value of pure water with the solution of water and tailing, a reduction in the value recorded by the sensor was observed. This difference can affect the calibration.

In Figure 5 all the data obtained for the different materials and densities are presented. The original manufacturer's calibration is also shown.

It is observed that the data obtained with the fine sand are very close to the manufacturer's original calibration curve. However, the data for the tailings are all to the right of the original calibration.

It can also be observed that there is a tendency to have values further to the right (higher Raw data values) for higher density. However, it seems to be within the accuracy range of the sensor. Note that two points obtained with the Cyanite tailings, with a density of 2.01 g/cm³, are located between the other points.

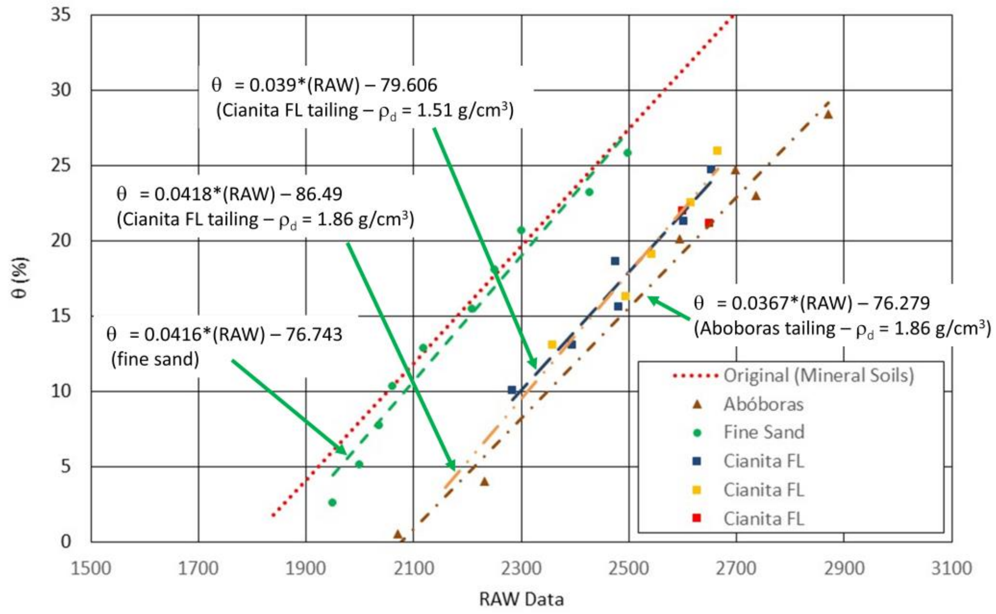

Fig. 5. Calibration data and equations for each test performed.

Figure 6 shows the relationship between the actual volumetric moisture content and the value read by the sensor. The equality line representing the association between the readings is displayed when using the manufacturer's equation.

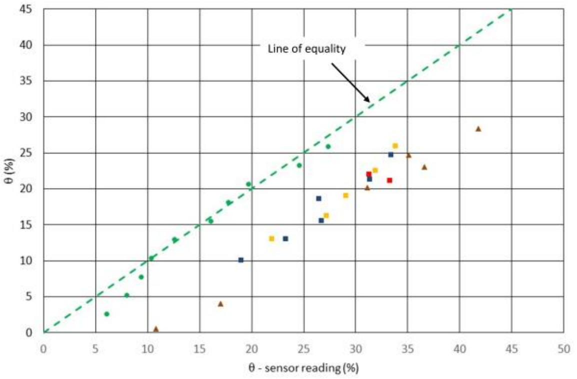

Fig. 6. Relation between the volumetric water content values read by the sensor and the actual ones.

In this way, it is clearly stated that, when using the original calibration for the tailings, an error of approximately 20% (gross) will occur.

Considering that no clear differences were detected between the two tailings tested and that the difference in density was small, a single equation was defined for the tailings. The following equation was obtained with all the experimental points of the tailings, independently of the used density, and can be used for the tested tailings.

$$\theta = 0.037^*(RAW) - 75.354 \qquad [2]$$

Figure 7 presents the general equation obtained for the tested tailings and the original manufacturer's calibration. Also indicated in the figure is the approximate range of water content between the volumetric water content related to the optimal gravimetric water content of the standard Proctor, and the saturation volumetric water content value (which is the porosity of the material). In practice, it should be possible to identify the eventual trajectory of humidity that leads to saturation. It is important to get more points in the region of interest.

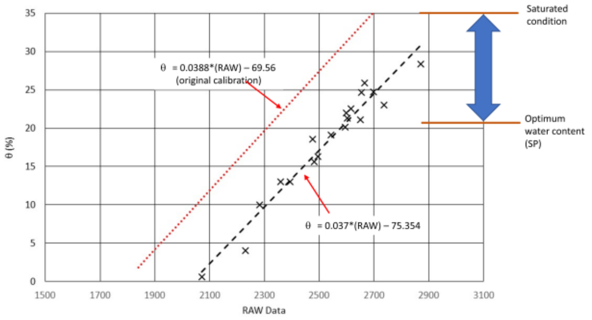

Fig. 7. Calibration curve determined using all points obtained.

Tests performed only with the rods inserted into the material seem to indicate different values than those obtained with the sensor completely buried in the ground. Thus, it is suggested that the sensor be calibrated in the same way as it will be used.

6. Conclusions

Based on the studies carried out in the laboratory, it was possible to define the following conclusions:

- The TEROS 12 manufacturer's original calibration curve is valid for sandy soils;
- The manufacturer's calibration curve is not valid for iron ore tailings that contain a large amount of hematite;
- A variation of the calibration equation was detected as a function of material density;
- Even with the observed variation, it is possible that, within certain limits, a single calibration equation for the tailings can be established;

Acknowledgment

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