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A PRACTICAL APPROACH TO DETERMINE THE TEMPERATURE CORRECTION FOR EC-5 MOISTURE SENSORS EMBEDDED IN VERTOSOL

* Rajitha Shehan Udukumburage[1] and Les Dawes[2]

[1,2] Science & Engineering Faculty, Queensland University of Technology, Australia

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ABSTRACT: Expansive soils are predominant in arid and semi-arid regions, and they are highly moisture sensitive. The investigation of the climate-ground interaction of expansive soils is extremely important to understand the hydro-mechanical responses of such soils. During the past decade, the low cost and simple methods to reliably monitor the soil volumetric water content have been popular among geotechnical practitioners. As a result, EC-5 moisture sensors have been widely used in agricultural and scientific projects due to the minimized salinity and textural effects on the final volumetric water content readings. The changes in soil volumetric water content profile can be effectively monitored using soil-specifically calibrated EC-5 sensors. However, due to the temperature sensitivity of EC-5 sensors, a suitable correction factor is essential to determine the actual volumetric water content of the expansive soil. In this study, the authors present a practical and straightforward approach to calibrate EC-5 sensors incorporating the temperature effect. This simple calibration approach enhances the accuracy of the EC-5 moisture profiling and eventually leads to safe decision-making of geotechnical practitioners.

Keywords: Unsaturated soil, Soil moisture, Temperature correction, EC-5 moisture sensors

1. INTRODUCTION

Unsaturated soil behaviour and the soil properties are significantly dependent on the soil moisture conditions [1-5]. Therefore, it is imperative to identify accurate methods and instrument to investigate the moisture variations in soil profiles [1-8]. These investigations include laboratory-based element tests, model tests and field-based investigations. The moisture sensitivity of expansive clays are considerably greater compared to non-reactive soils and hence, much attention has been given to these soils lately [3-12].

Expansive soils are widely distributed in arid and semi-arid regions in the world [9-10]. The surface soils in Queensland, Australia consists of more than 40% of these reactive soils. The swell-shrink characteristics of expansive soils when subjected into alternate wet-dry cycles have caused severe repercussions for the light-weight structures founded on these clays [11-12]. Therefore, the geotechnical practitioners and researchers have identified the importance of the climate-ground interaction in expansive soils and investigated their behaviour under field and laboratory conditions during the past 2 decades [9-15]. Based on the current research, the variations in soil moisture causes changes in soil suction which eventually results in surface and sub-soil movements in expansive soil strata [9-11], [16-17]. Therefore, it is utmost important to determine the changes in soil moisture profile to investigate the expansive soil behaviour under different climatic conditions [9,10,16].

Monitoring of the soil water content in expansive soils has been conducted based on both destructive and non-destructive methods; however, the non-destructive methods are widely accepted due to minimum disturbance to long-term in-situ monitoring [18-20]. The radioactive non-destructive methods such as gamma-ray attenuation and neutron scattering have been mostly avoided due to possible health hazards. As a result, the non-destructive methods based on the dielectric constant of the media have been trending during the past decade to monitor the volumetric water content profile in expansive clays [21-24]. EC-5 moisture sensors can be identified for its wide application in research as non-destructive, dielectric sensors based on capacitance principle. The simplicity, cost and the ability to take point measurements due to small size have been beneficial for geotechnical practitioners when compared to the other commercially available options [26-30].

According to Decagon, EC-5 sensors use 70 MHz frequency which minimizes the textural and salinity effects [9,10,16,17]. The volumetric water content measurement of EC-5 sensors depend on the surrounding soil volume of the probes. The change in volumetric water content in expansive clays occurs due to the volume changes in both the surrounding soil and water [9,10,30,31]. Therefore, additional considerations for embedment and calibration of EC-5 sensors are required. Generally, these sensors capable of measuring the volumetric water contents of saturated soils up to 60%; however, is highly dependent on the soil [11,12,16,19,21,23].

EC-5 sensors are mostly soil-specifically calibrated for volumetric water content without incorporating the temperature effect due to the complexities involved in expansive soils [31-34]. This study presents a simple and practical approach to determine the temperature correction function for a given expansive clay. These findings may be useful for geotechnical practitioners and researchers to soil specifically calibrate EC-5 sensors maintaining high accuracy and thereby obtain a reliable moisture profile for their project-related decisions.

2. RESEARCH SIGNIFICANCE

EC-5 moisture sensors are highly used in research and industrial applications due to their simplicity and relatively low cost. The significance of this study is to introduce a practical approach to determine the temperature correction for EC-5 moisture sensors embedded in expansive clays to improve the accuracy of the output.

3. TEST MATERIAL

Natural expansive grey clay collected from Sherwood, Queensland, in Australia was used in this study. These grey Vertosol soils are widespread in the south-east Queensland region and representative of subsoil conditions in Brisbane. Infiltration in these soils is moderate-to-low and known for swell-shrink responses due to climate changes [36]. For laboratory model and element tests, 250 kg (dry soil mass) of expansive grey Vertosol was extracted and carefully transported to Queensland University of Technology (QUT) with in-kind support from 'The SoilTesters'.

The basic soil classification of the test material was conducted according to Australian Standards (AS 1289.3. 6.3, 2003; AS 1289.3.5.1, 2006; AS 1289.3.4.1, 2008; AS 1289.3.1.1, 2009a; AS 1289.3.2.1, 2009b; AS 1289.3. 6.1, 2009c). The grain size distribution of the test material was obtained from the combination of sieve and hydrometer analyses. It contains 77.3% fines (particles finer than 75 microns) and 50.2% of clay (particles finer than 2 microns). Other basic properties of the clay, including liquid limit (LL), plasticity index (PI), linear shrinkage (LS), and the specific gravity were determined in accordance with Australian Standard test methods, and they are 67%, 37.2 %, 13.4%, and 2.68, respectively [29-34]. The soil is classified as CH (Clay of High Plasticity) according to the Unified Soil Classification System

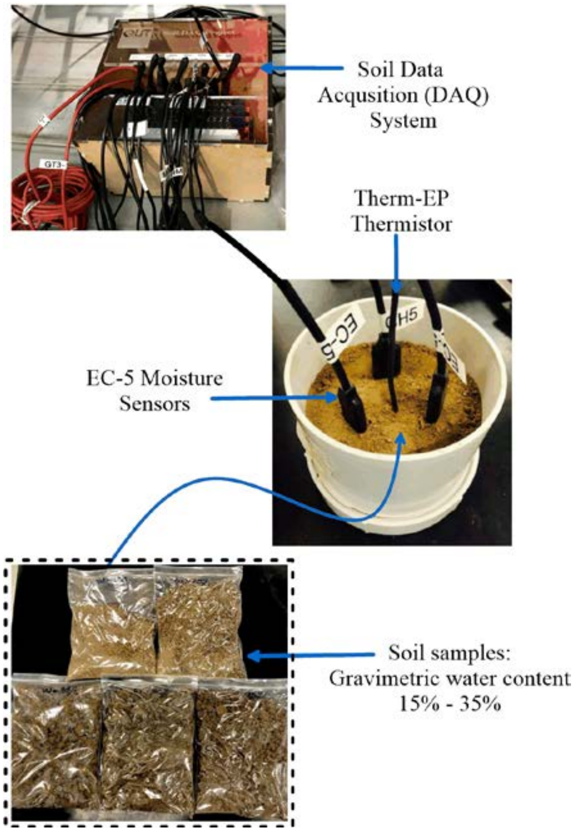

Fig.1 EC5 moisture sensor calibration and data acquisition

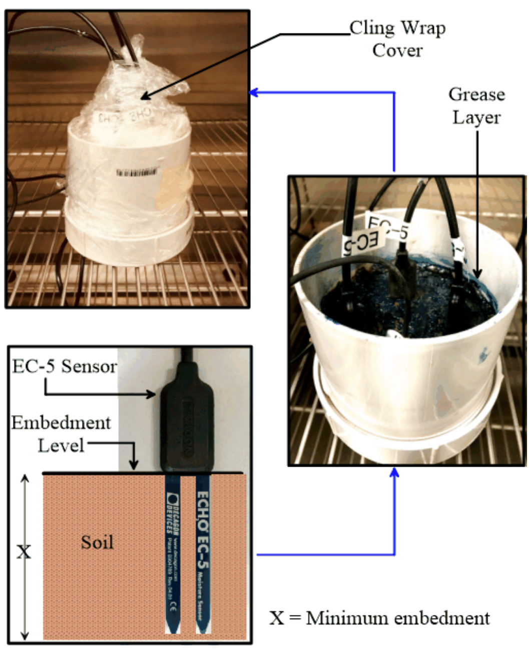

Fig.2 EC5 moisture sensor embedment in expansive soil

(USCS). The compaction properties (MDD = 1.75 g/cm^3, OMC = 18%) were determined from the modified proctor compaction test. X-ray diffraction (XRD) analysis carried out on the test material identified smectite minerals, which predominantly contribute to the expansive nature of the soil.

3. METHODOLOGY

EC-5 sensors are ideal for measuring soil moisture content in localized areas due to the small sensor length (50 mm) and its small area of influence. These sensors need to be properly calibrated for the temperature variations to obtain a precise representation of the sensor output due to the moisture variations within the range of 0-60% vwc. The independence to salinity and soil texture accompanied with low-cost build-up makes EC-5s preferable to use in research subsequent to rigorous soil-specific calibration, resulting in 1-2% accuracy.

In this study, soil samples of five different known gravimetric moisture contents (i.e. 15%, 20%, 25%, 30% & 35%) were statically compacted to achieve dry density of 1.2 g/cm^3. The entire sensor body of EC-5 sensors were embedded on the compacted soil as shown in fig. 1. The minimum sample height for the sensor calibration was maintained more than that of sensor body (i.e. 50 mm) to ensure the entire area is contacted by the soil to obtain a precise correlation between volumetric water content (%) and the sensor output voltage as shown in fig. 2.

Since EC-5 moisture measurements are susceptible to temperature, temperature correction factors were developed by measuring soil moisture at different temperatures. Calibrated temperature sensor (Therm-EP) was embedded to acquire the temperature variation throughout the measuring duration. Soil moisture was maintained constant during the experimentation by applying a thick grease layer on the topsoil surface. The final gravimetric moisture content of the soil was measured by oven drying the test sample to make sure the moisture is successfully maintained. Likewise, the same procedure was adopted for all the moisture contents to derive a correlation between the volumetric water content (%), temperature (°C), and the sensor voltage output (V).

4. RESULTS & DISCUSSION

The results of this study investigate the volumetric water content variations of grey Vertosol at different temperature conditions. Fig.3 illustrates the variation of EC-5 moisture sensor responses under controlled temperature variation inside the environmental chamber. Relative humidity inside the chamber was maintained at a reasonable value of 60% during the investigation. The experimental results indicated a significant variation of dielectric responses of EC-5 moisture sensors (vwc) when the temperature varies from 15°C to 33°C during heating and cooling cycles.

The volumetric water content of grey Vertosol at a given soil temperature can be derived with respect to 20°C. Equations (1) and (2) demonstrate the representative calibration equation for EC-5 moisture sensor.

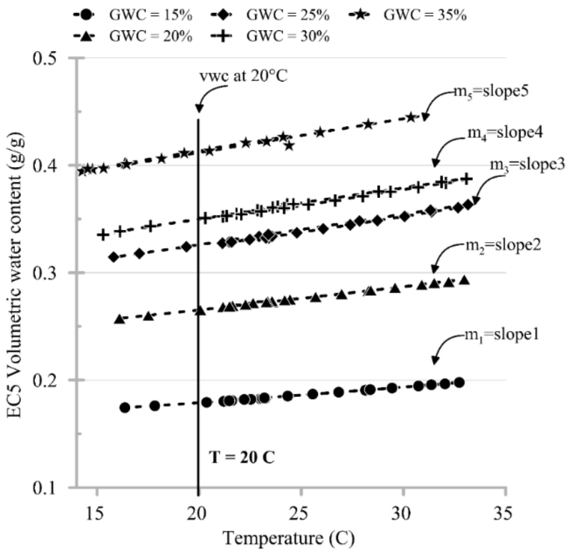

Fig.3 EC5 moisture sensor responses with temperature variations

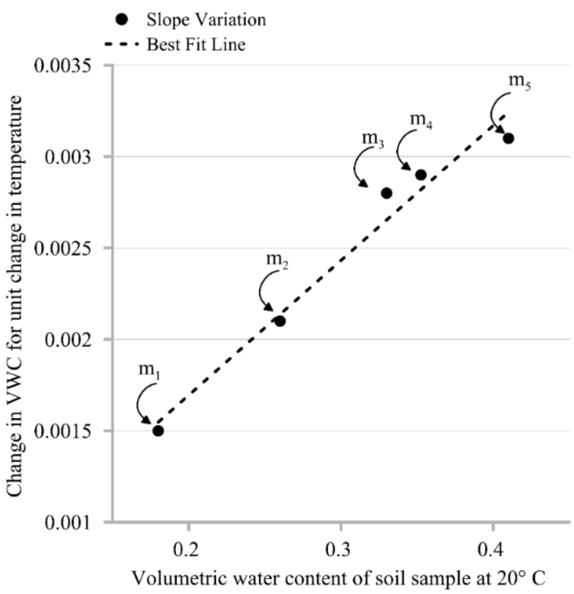

Fig.4 Sample slope variation with respect to the volumetric water content at reference temperature

$$\boldsymbol{\theta_T = \theta_{20} - \varepsilon_T(m, \Delta T)} \quad (1)$$

$$\boldsymbol{\theta_T = (1.383 \times A_{EC5} - 1.0868) - [m \times (T - 20)]} \quad (2)$$

Where;

$\boldsymbol{\theta_T}$ = Volumetric water content at T°C temperature

$\boldsymbol{\theta_{20}}$= Volumetric water content at 20°C temperature
$\boldsymbol{\varepsilon_T(m, \Delta T)}$ = Temperature correction factor
m = Change in volumetric water content for unit change in temperature corresponds to volumetric water content of sample at 20° C

The temperature calibration was conducted with respect to T = 20° C and 'm' value for Equation (3) can be determined from Fig. 4 provided that volumetric water content of the soil at 20°C is known. Equation (3) presents the statistical relationship obtained between the 'volumetric water content of soil at 20°C' and 'change in vwc for unit change in temperature' that can be used to derive Equation (4); temperature calibrated volumetric water content of EC5.

$$\mathbf{m = 0.0074 \times \theta_{20} + 0.0002} \quad (3)$$

$$\theta_T = (1.383 \times A_{EC5} - 1.0868) - [\{0.0074 \times \theta_{20} + 0.0002\} \times (T - 20)]$$

$$\theta_T = (1.383 \times A_{EC5} - 1.0868) - [\{0.0074 \times (1.383 \times A_{EC5} - 1.0868) + 0.0002\} \times (T - 20)] \quad (4)$$

Where;

A_{EC5} = Sensor voltage output from Soil DAQ

5. CONCLUSIONS

The climate-ground interaction of expansive clays is imperative to monitor and understand the soil responses due to climate variations. The volumetric water content of expansive soils has been identified as one of the critical parameters to investigate the stress state variables (i.e. soil suction and displacement) in such soils. The use of EC-5 moisture sensors to monitor the changes in volumetric water content profile has become popular due to the low cost and simplicity of the sensors. However, the use of these sensors for expansive soil investigations requires the incorporation of temperature calibration. The complexities involved in the current calibration methods have restricted the use of these low-cost sensors.

This study introduced a practical and straightforward approach to calibrate EC-5 sensors by incorporating the temperature effect accurately. The method has been successfully validated for grey Vertosol and can be used to soil specifically calibrate any EC-5 sensor embedded in expansive clays. This approach enhances the applicability of low-cost EC-5 moisture sensors to accurately monitor the volumetric water content profile in expansive soils. Consequently, the quality of the data acquired can be maintained at a reliable state for the end-user's decision-making (i.e. geotechnical practitioners). As a result, the quality of the geotechnical application and eventually, the safety of human lives may be improved.

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