Use of TDR Probes to Measure Water Content in Pumiceous Soils

Raffaele Papa and Marco V. Nicotera

Abstract. The time domain reflectometry has become a technique commonly used in geotechnical engineering to determine soil water content of soil. The possibility to determine soil properties depends on the proper understanding of the parameters that affect the propagation of an electromagnetic pulse along the TDR wave guide. Dielectric permittivity measurements in coarse grained soils indicate that the determination of the apparent relative permittivity of this materials may be complicated by a non uniform water content distribution along the rods of the TDR probe. This problem is quite evident when pumiceous soils are of concern due to their water retention properties (very low air entry value and sharp transition from full saturation to residual saturation). In order to conceive an interpretation procedure apt to manage this complexity a specific laboratory testing programme was designed and carried out. During the tests the water content of a reconstituted pumiceous soil sample was changed by means of the negative water column technique along a number of wetting and drying cycles, and simultaneously the waveforms were registered. The soil utilized was collected from a trial field in the neighbourhood of Monteforte Irpino (Avellino, Italy).

Keywords: TDR probe, pumiceous soil, dielectric constant, soil-water content.

1 Introduction

In coarse-grained soils such as pumiceous ones, suction is difficult to measure in the field by means of tensiometers. However the complete understanding of the

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groundwater flow processes in a number of subsoil conditions, which can be encountered in geotechnical applications, may require monitoring at least the soil water content in coarse grained soil strata (NIcotera et al., 2010). Currently Time Domain Reflectometry (TDR) is prevalently used to measure the water content of fine to medium grained soils both in the laboratory and in the field. TDR is based on the measurement of the velocity of an electromagnetic wave travelling along a probe inserted in the soil. The velocity is related to dielectric permittivity of the soil, K_a, which is in turn related to volumetric water content through a suitable calibration curve. Nevertheless the correlation between the apparent relative permittivity and the soil water content may be confused by a non uniform distribution of the soil moisture along the rods of the TDR probe (Dobson et al., 1985; Regalado, 2004; Regalado et al., 2003; Tomer et al., 1999; Schneider & Fratta, 2009; Tarantino & Pozzato, 2008; Papa & Nicotera, 2011).

In this paper we will show the first results of a series of laboratory calibration tests finalised to the measurement of the water content in some pumiceous soil strata identified in the subsoil of the Monteforte trial field.

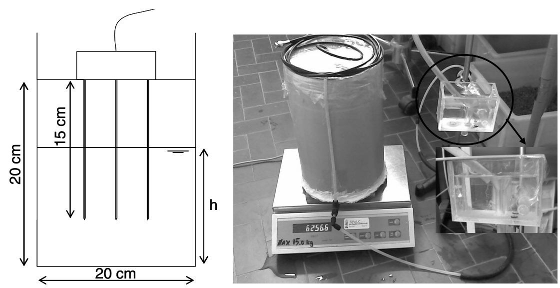
2 Material and Methods

The soil utilised was recovered from one of the pumiceous soil strata identified in the subsoil of the trial field of Monteforte Irpino; this strata was constituted of a quite uniform coarse-grained material produced by one of the main plinian eruption (Avellino eruption 3.7 ky b.p.) of the volcano *Somma-Vesuvius*. Each soil sample was reconstituted by dry pluviation inside a PVC cylindrical sampler (20cm diameter, 25cm height); the soil sample was reconstituted in four layers 50 mm thick achieving a mean value of the dry density γ_d equal to 4.70 kN/m^3 and a mean value of the porosity n equal to 0.799. A drainage grooves was machined in the base sealing acrylic cup to allow both saturation and drainage of the specimens. The drainage circuit was connected to a water reservoir and a levelling device was used to control the hydraulic head acting at the sample bottom end (see Figure 1.b); by varying the constant elevation imposed by the levelling device it was possible to vary the pore pressure applied ad the sample bottom in the range 0 to 2 kPa. A piezometric pipe was used to check the water level in the sample (Figure 1.b).

After the sample preparation a three-rod TDR probe (15 cm long) was inserted vertically into the soil sample and the total weight was recorded. The soil core was placed on an electronic balance and simultaneously a TDR reading was performed. The measurement of the electromagnetic wave velocity was carried out with TDR equipment consisting of a wave generator (Campbell Scientific TDR 100), a PDA with integrated software and a battery. The probe remained permanently inserted into the soil core during the calibration experiment.

The test began with a wetting phase during which the water level from the sample bottom *h* (see Figure 1.a), was raised in four 5 cm subsequent steps from 0 cm up to 20 cm. Each increment of the water level produced an equalization process during which the water flowed into the soil sample increasing the sample weight as depicted in Figure 2a. The end of the equalization process was clearly identified by observing the diagram of the sample weight as function of the logarithm of the elapsed time. At the end of each equalization process a TDR reading was performed (Figure 3a) and the derived value of the apparent electric permittivity was compared to the mean value of the volumetric water content (see Figure 4). The wetting phase was followed by a drying phase carried out with a similar procedure (see Figure 2b and 3b) but reducing the water level up to 0 cm. Four complete wetting-drying cycles were performed in total.

a)



b)

Fig. 1. a) TDR probe installation and water level h; b) test equipment.

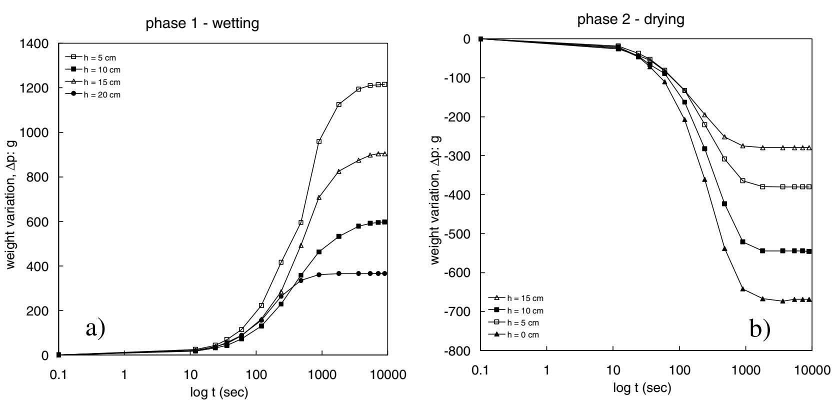


Fig. 2. Sample weight variation during equalization steps: a) wetting; b) drying.

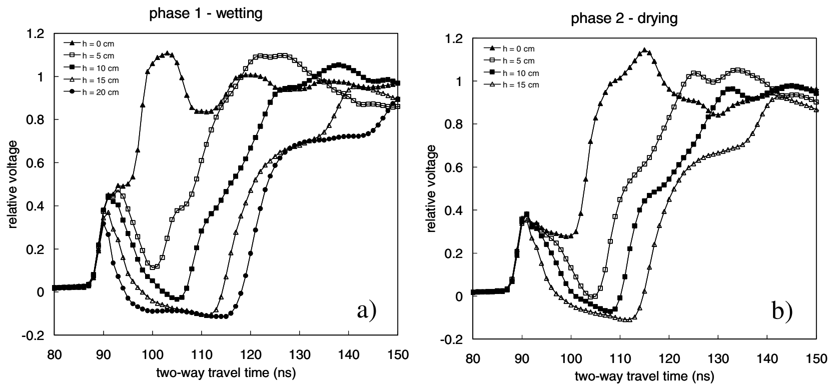


Fig. 3. Waveforms measured at the end of each equalization steps: a) wetting; b) drying.

3 Results and Discussion

The testing program was aimed to evaluate the possibility of using the TDR technique in the pumiceous soils under carefully controlled conditions.

The waveform collected along the first of four rounds of wetting-drying are shown in Figure 3. For a water level between the ends of the TDR probe (i.e. 5, 10, 15 and 20 cm), two distinct reflection were observed. The first arrival in the waveform was the signal reflection off the water level (i.e., a sudden drop in the signal amplitude) and the second arrival is the signal reflection from the tip of the TDR probe (i.e. a sudden increase in the signal amplitude). The time required for the step pulse to travel along the entire waveguide is used to measure a equivalent apparent dielectric permittivity K_a of the soil. The higher is the water level (h increases), the higher is the soil bulk permittivity and, hence the lower is the velocity at which the wave propagates into the guide (Robinson et al., 2003b).

The waveforms were collected and analysed to determine the equivalent value of the apparent relative dielectric permittivity and subsequently the experimental values of K_a were plotted as function of the corresponding imposed water level h (Figure 4a). The observed hysteresis shown by the relationship between the water level and the apparent relative dielectric permittivity (Figure 4a) could mainly be ascribed to the hysteretic feature of the pumices water retention behaviour; hydraulic hysteresis was indeed quite evident in the relationship between the water level (i.e. the applied matric suction) and the mean value of the volumetric water content (see Figure 4b). Nevertheless hysteresis persisted even in the experimental relationship between the apparent relative dielectric permittivity and the mean value of the volumetric water content. As a consequence it seemed that the mean value of the soil water content could be correlated to the mean value of the apparent dielectric permittivity only with a limited accuracy. This limitation was likely produced by the non uniform distribution of the water content along the TDR probe; two different distributions of water content could indeed corresponds to the same travelling time of the step pulse along the rods. However a different interpretation procedure taking into account the complete waveform must be considered in order to achieve a higher accuracy.

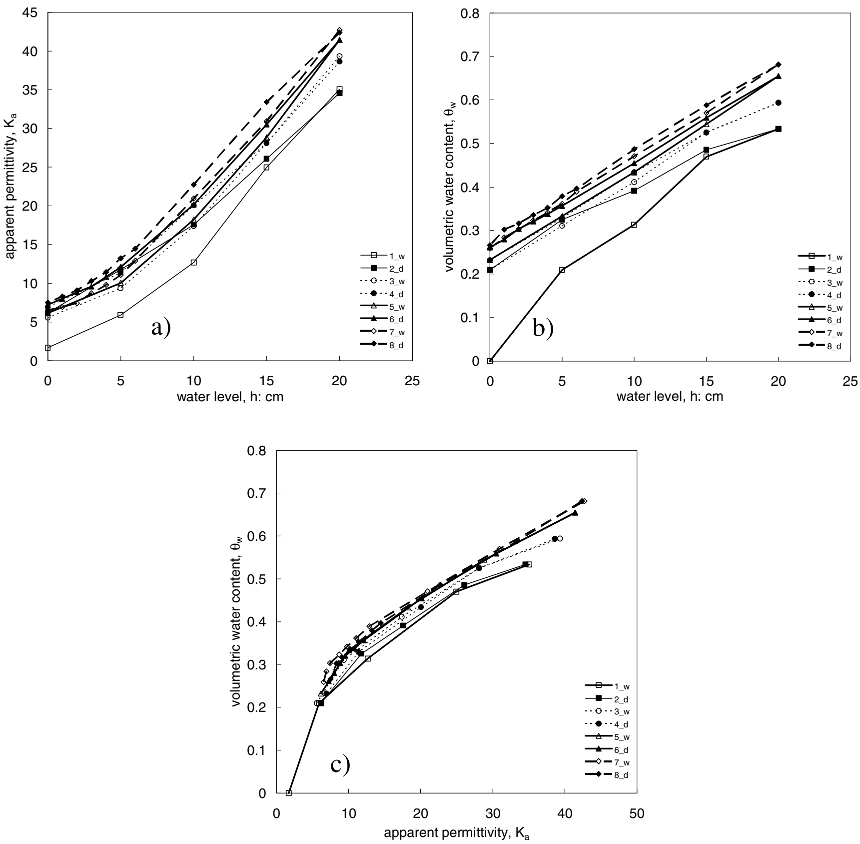


Fig. 4. Variation of apparent dielectric permittivity with water level. a) increasing value of K_a with increasing of wet-dry cycles; b) relationship between volumetric water content and water level variation for different cycles; c) relationship between volumetric water content and apparent dielectric permittivity for different cycles.

4 Concluding Remarks

In the paper the first results of a series of lab calibration tests finalised to the measurement of the water content in a pumiceous soil stratum by means of a TDR probe were presented. The observed hysteresis between the water level and the apparent relative dielectric permittivity could mainly be due to the hydraulic hysteretic behaviour of the pumices. This effect was quite evident in the relationship between the water level and the mean value of the volumetric water content. Nevertheless a calibration curve correlating the mean value of the soil water content to the mean value of the apparent dielectric permittivity was identified. However the correlation was scattered due to the non uniform distribution of the soil moisture along the rods of the TDR probe and a different interpretation procedure taking into account the complete waveform must be considered in order to achieve a higher accuracy.

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