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Calibration procedure for a Time Domain Relectometry (TDR) apparatus to measure volumetric water content in pyroclastic soils.

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Calibration procedure for a Time Domain Relectometry (TDR) apparatus to measure volumetric water content in pyroclastic soils.

Summary

This technical report describes an experimental procedure to calibrate a Time Domain Reflectometry (TDR) system to measure volumetric water content in pyroclastic soils. The TDR technique is based on the measure of dielectric constant of a soil to estimate its volumetric water content.
Even thought the well known experimental tests performed by Topp et al. (1980) evidenced as the variation of dielectric constant in a soil is closely connected to the change of its water content, other authors (Regalado et al. 2001, Regalado et al. 2003, Roth et al. 1992, Tomer et al. 1999, Weitz et al. 1997) have showed that for a volcanic soil other factors as porosity, bulk density and surface area can affect the variation of soil dielectric constant. For this reason the authors suggest to perform always an appropriate calibration phase before use TDR.
As the TDR technique will be employed in the experimental test performed with lisimeter to investigate the water retention curve of pyroclastic soils, the calibration of TDR apparatus is necessary to estimate the correct relationship between the variation of water content and the related change of the idro-mechanical behaviour of the soil.

Keywords: seepage, lisimeter, Time Domain Reflectometry, calibration procedure.

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Introduction

The Time Domain Reflectometry (TDR) is one of the most useful and common techniques used to estimate volumetric water content in a soil. This technique allows to determine the permittivity (dielectric constant ε_c) of a material from wave propagation, measuring the velocity of the wave motion v_P along the rods of the TDR probe (see fig. 1). Known the velocity it is possible to determine the dielectric constant of soil from the following equation:

$$V_P = c/\sqrt{\varepsilon_s} \tag{1}$$

where c is the velocity of light and ε_s is the dielectric constant of the material in which the TDR probe has been put in.

The measure of the water content by using the TDR technique is based on the assumption that the variation of the dielectric constant in a soil ε_s, is strictly connected to the variation of soil moisture as the dielectric constant of water ε_w is greater than ε_s (see table 1).

Table 1

dielectric constant of air	ε_a	1
dielectric constant of soil	ε_s	3÷5
dielectric constant of water (20°C)	ε_w	82
dielectric constant of water (25°C)	ε_w	78.5

Many authors, first of all Hoekstra and Delaney (1974), and Topp et al. (1980), verified that for different types of soils there is a strong relationship between their permittivity and their water content, whereas the permittivity is independent of soil density, texture, temperature, and salt content.

Analyzing their experimental results Topp et al. (1980) determined also a polynomial equation which links the volumetric water content θ ($\theta=V_w/V$, where V_w is the volume of the water into the soil and V is the total volume of soil), to the dielectric constant ε_s measured with the TDR technique:

$$\theta = -5.3 x 10^{-2} + 2.92 x 10^{-2}\, \varepsilon_s - 5.5 x 10^{-4}\, \varepsilon_s^2 + 4.3 x 10^{-6}\, \varepsilon_s^3 \quad (2)$$

The equation (2) is well known as Topp's equation. The value of the volumetric water content θ estimates with the (2) can be affect by an error of $\Delta\theta = \pm\, 0.02 m^3/m^3$.
A large number of measures made on different soils have showed the effectiveness of this equation, so it was usually used in almost all the applications where the TDR technique is employed. In these case the procedure followed to calibrate the TDR apparatus (fig. 1), is made to take in account only the geometric configuration of probe, in particular its size and the spacing of rods, but also the effect of the cable length on the shape of waveform reflection. Nothing is mentioned about the properties of the soils.

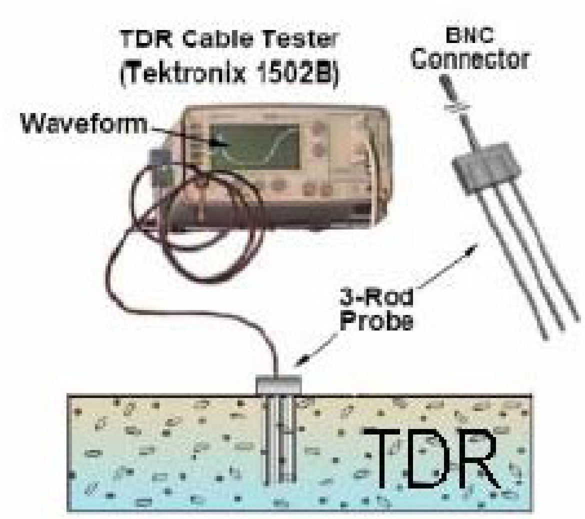

Figure 1. TDR apparatus.

Other experimental testing carried out by different authors demonstrated that the variability of dielectric constant in volcanic soil can be influenced by other factor, because of their considerable amount of organic substance and lower relative densities.

Tests performed on these kind of soils demonstrated that the Topp's equation undervalues the real value of water content θ.

This discrepancy can be related to:

- the mineralogy of soil (Regalado et al. 2001);
- density (Regalado et al. 2003, Weitz et al. 1997, Tomer et al. 1999);
- specific surface (Regalado et al. 2003, Weitz et al. 1997, Tomer et al. 1999);
- amount of organic substance (Topp et al. 1988, Roth et al. 1992).

in particular the difference between the Topp's and the correct value increases as the real θ increases (see fig. 2, the results of Regalado et al. (2001)).

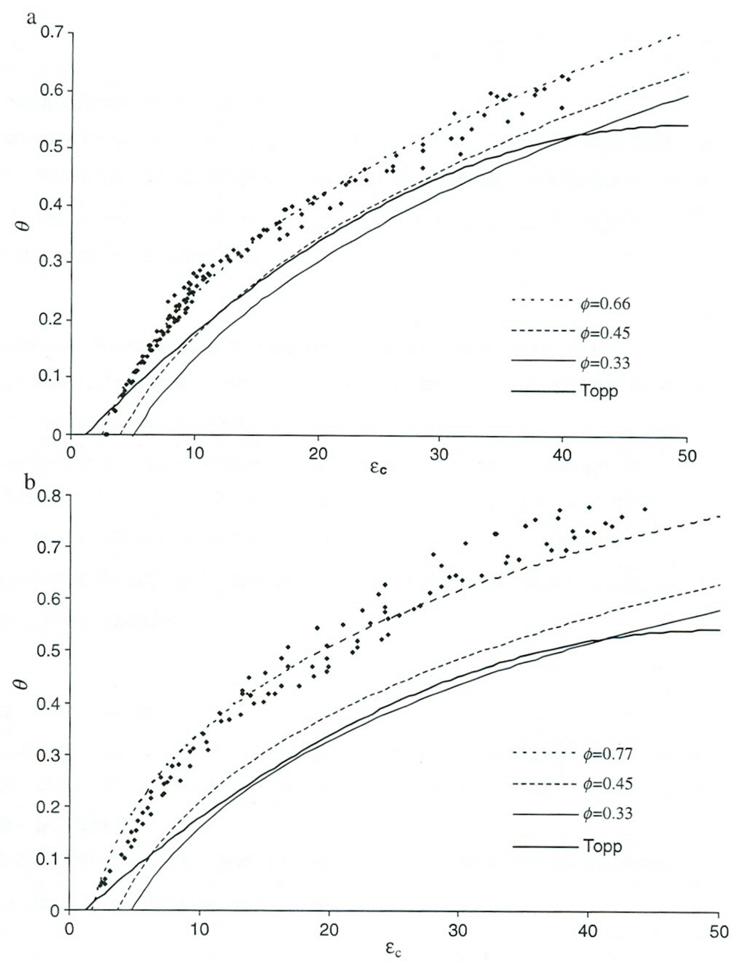

Figure 2. Data obtained by Regalado et al. (2001) to evaluate the effect of the soil density on the variability of dielectric constant in a soil.

All the experimentation mentioned above (Regalado et al. 2001, Regalado et al. 2003, et al. 1997, Tomer et al. 1999, Weitz et al. 1997), have been carried out testing volcanic soils.

Considered that, a calibration procedure has been followed to determine the relationship between the dielectric constant and water content for the pyroclastic soil employed in the lisimeter experimentation.

This technical report describes the calibration procedure and showed the first obtained results.

1_ Experimental procedures

The lisimeter will be used to estimate the water retention curve (i.e. water content against suction), on a large sample of pyroclastic soils in environmental or in quite controlled conditions, using small tip Soil Moisture tensiometers and TDR probes to measure soil suction and water content respectively.

The soil tested is a volcanic ash, made of non plastic silty sand with gravel, pumiceous stones, (see fig. 3).

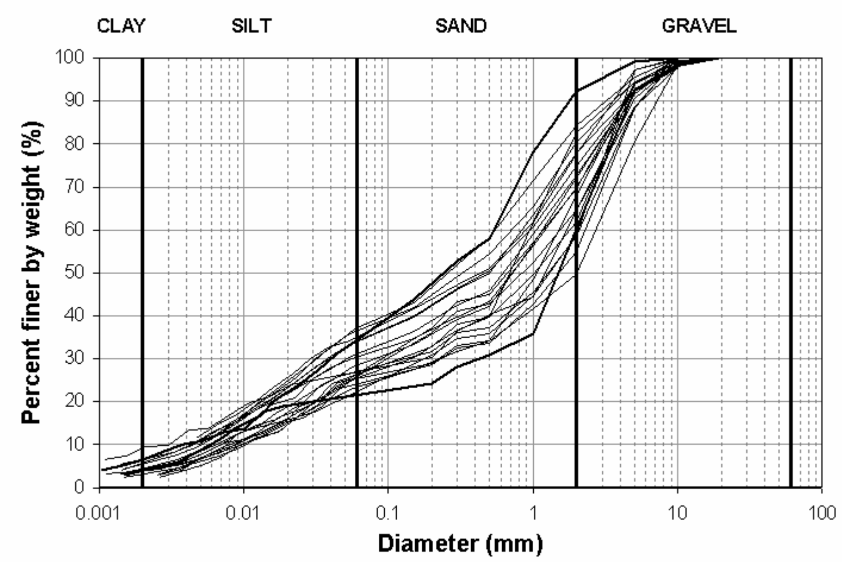

Figure 3. Soil grading.

It is similar to the pyroclastic soil layers which cover the slopes of the Campania region where flowslide events occurred. These layers were formed during eruptions of Somma-Vesuvius volcano taken place over the last ten thousand years. The thickness of the layers changes along the slope. It reaches a maximum value of 1.5÷2.0 m, but usually it is about 1 m. The natural water content ($w=P_w/P_s$, where P_w is the weight of the water into a specify volume of the soil and P_s the weight of the same soil once it is dried), of these soils was slightly greater than 30% during rainy period; the density measured in situ indicated high value of porosity, greater at the top of the hill.

The TDR system used in this experimentation has a time domain reflectometer with N. 8 TDR 3-rod probes connected to it. Each probe is 30 cm long has a cable length of 8 m. The measures were collected every five minutes by a data logger CR1000 (Campebell Scientific).

The calibration procedure is carried out using samples of pyroclastic soil reconstructed in cylindrical formers 50 cm long. The formers consists of a PVC pipe with a diameter of 20 mm glued on a plate of Plexiglas to close one of its opening. The sizes of the formers have been chosen to avoid any interference of the wave propagation inside the soil around the TDR probes.

The samples have been made using the wet tamping compaction technique. With this method the soil characterized by a constant water content has been compacted in eight layers 5 cm thin, to obtained a sample with a fixed density and an uniform moisture.

Two different densities (γ_d) have been chosen: 0.94 g/cm^3 and 0.80 g/cm^3 which correspond to a high porosity of 65% and 70% respectively.

Samples with different water content have been made for both the porosity considered. A TDR probe has been put in each sample. All the measured have been carried out for a time sufficient to verify the sample moisture did not change during measurement. Moreover, for the same reason, the water content of sample has been checked before and after each TDR measure.

2_ First results

Until now six measures have been made on sample reconstructed with the characteristic indicated in table 2, where n is the porosity, w is the water content, γ_d the weight of the dried soil per unity of volume; γ the weight of the wet soil per unity of volume, S_r the degree of saturation and θ_w the volumetric water content.

Table 2

n (%)	w (%)	γ_d (g/cm^3)	γ (g/cm^3)	S_r (%)	θ_w (%)
65.00	26.10	0.94	1.18	37.67	24.48
65.00	35.49	0.94	1.27	51.22	33.29
65.00	38.31	0.94	1.30	55.29	35.94
70.00	26.10	0.80	1.01	29.98	20.99
70.00	35.49	0.80	1.09	40.77	28.54
70.00	38.31	0.80	1.11	44.01	30.80

To avoid loss of water the measures have been performed in a chamber with a fixed temperature of 20°C and. For the same reason, once the TDR probes have been put in, the top surface of the samples has been covered with a flexible thin plastic sheet. The TDR system has measured for a time not less than 1000 min (about 17 hours) for each sample to evaluate water content variation during measurement.

The fig 4 showed the comparison between the real value of volumetric water content θ and the values of θ obtained with TDR technique using both the Topp's equation and Regalado equation.

Respect to the first data obtained, the values of θ calculated using the Topp's equation underestimate the real ones, while the equation proposed by Regalado seems to fit better the effective value of θ.

Looking at the distribution of the real θ data on the plane (ε_c, θ), it seems to suggest that for the same value of ε_c the volumetric water content θ decreases with porosity. Anyway the difference from $\theta_{65\%}$ and $\theta_{70\%}$ is not so great, so it should be possible to interpolate all the data with the same curve. Anyway it is necessary to investigate other values of water content and porosity, lower than those used until now, to check the role of soil density on the variability of dielectric constant in a pyroclastic soil..

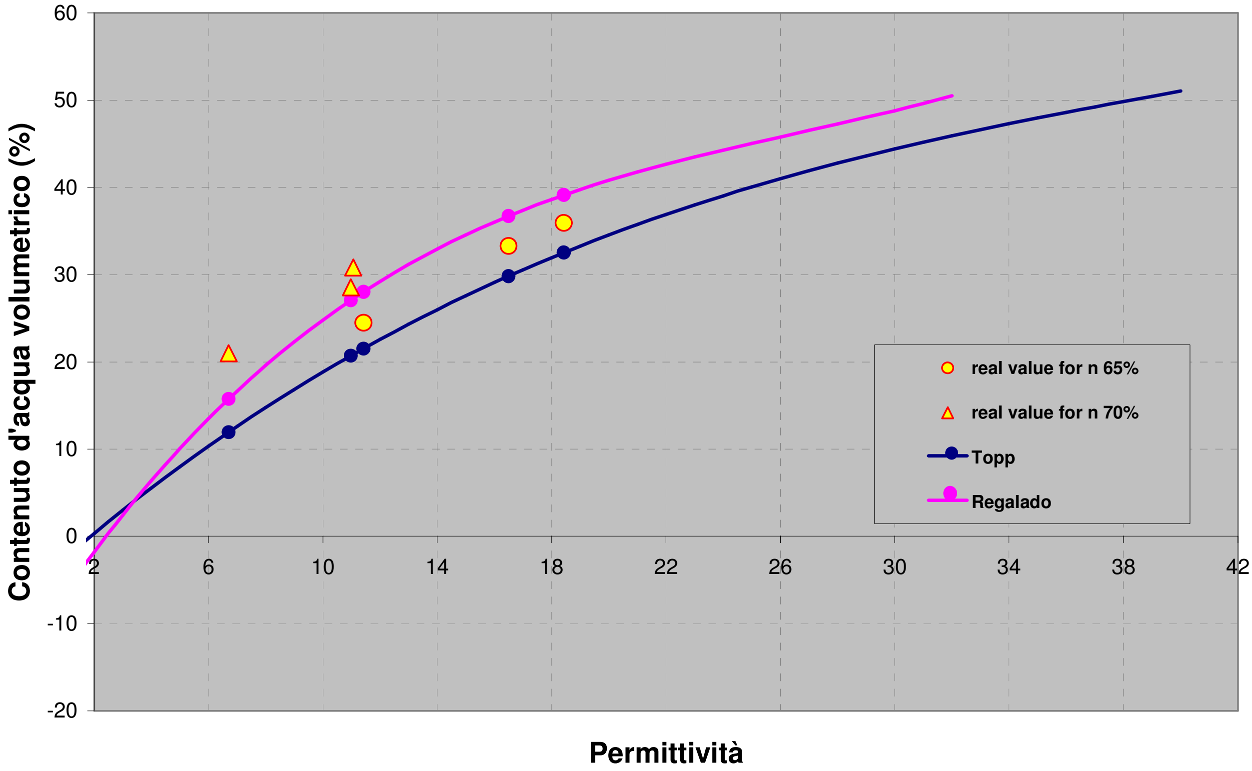

Figure 4. Comparison between the real value of volumetric water content θ and the values of θ obtained using the Topp's equation and Regalado's equation.

Conclusion

A calibration procedure was employed to verify the effectiveness of the Topp's equation to estimate the volumetric water content θ in pyroclastic soil by using the time domain reflectometry (TDR) technique.

Samples with different density and water content have been reconstructed to investigate the effect of the large porosity which characterizes this kind of soils.

The TDR system employed is made of N. 8 three-rods probes connected to a reflectometer. A data logger collects the data measured every five minutes.

The first data obtained have showed as for high value of porosity the θ calculated using the Topp's equation underestimates the effective ones. On the contrary the equation proposed by Regalado et al. (2003), seems to fit better the same data.

Other measures performed in samples with different water content and lower porosity could give a more accuracy to determine the more suitable relationship between dielectric constant and volumetric water content for pyroclastic soil.

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