Time Domain Transmissiometry for Measurement of Soil Moisture and Bulk Electrical Conductivity

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Abstract: Time domain transmissiometry (TDT) is a viable and economical alternative to time domain reflectometry (TDR). Digital TDT sensors that communicate via the SDI-12 protocol and have the measurement electronics embedded directly within the sensor head are gaining increased popularity for monitoring soil moisture and bulk soil electrical conductivity. To evaluate the performance of commercially available TDT sensors, the travel time and amplitude of the broad band microwave frequency step-pulse was measured in sands with varying moisture contents and bulk ECs. While the sensors performed very well in moderately conductive soils, limitations for highly conductive soils as well as for soils with very low water contents and electrolyte concentrations have been experienced. An empirical relationship between the maximum slope of the TDT waveform and the bulk EC was developed to improve measurement capabilities in soils with low moisture contents and electrolyte concentrations.

Keywords: Time domain transmissiometry (TDT), Apparent permittivity, Bulk electrical conductivity

1. Research background

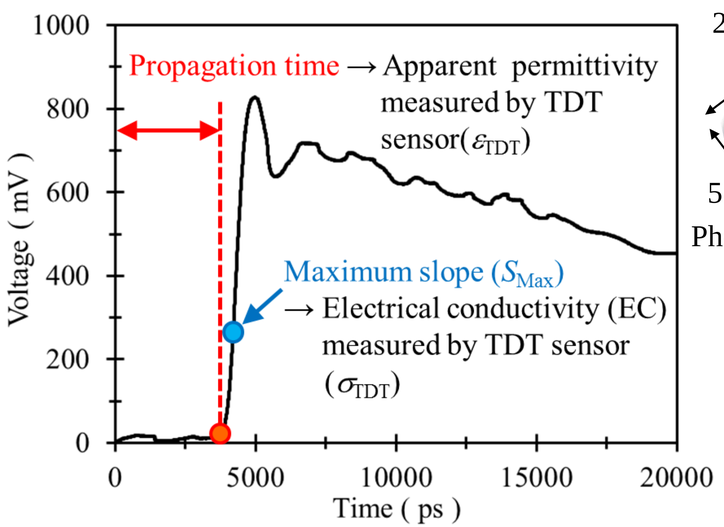


Fig.1 A TDT waveform.

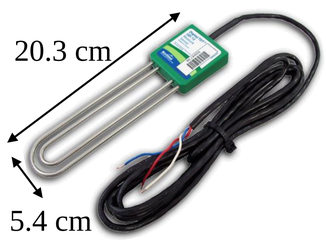


Photo1 A digital TDT sensor. (Model number : ACC-SEN-SDI)

Photo2 The experimental site.

Technical problem of bulk EC measurement

The lack of sensitivity for low-conductive soils with low moisture contents and electrolyte concentrations.

The aim of present study is to evaluate the performance of commercially available TDT sensors and to present an empirical relationship between the maximum slope of the TDT waveforms (S_{Max}) and the bulk soil EC.

2. Experimental method

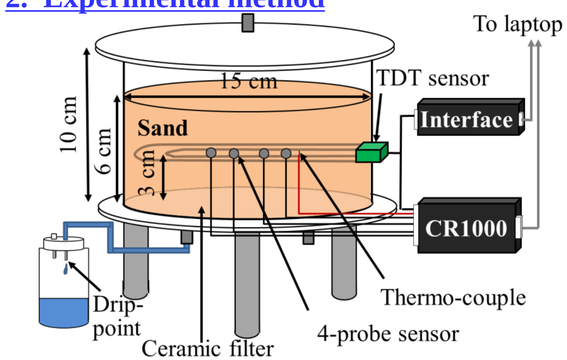


Fig.2 Schematic of the experimental setup.

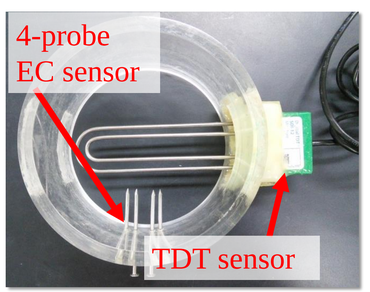


Photo3 TDT sensor and 4-probe sensor.

Material under test: Toyoura sand mixed with NaCl solutions

EC of NaCl solutions(σ_w): 0.1, 5.0, 10.0, 19.9 dS m^{-1}

Measured data sets: Volumetric water content (θ)

TDT waveforms, Apparent permittivity (ε_{TDT}), Bulk EC (σ_{TDT}), Maximum slope (S_{Max}) } TDT sensor

Bulk EC (σ_0) } 4 - probe sensor

3. Results and discussion

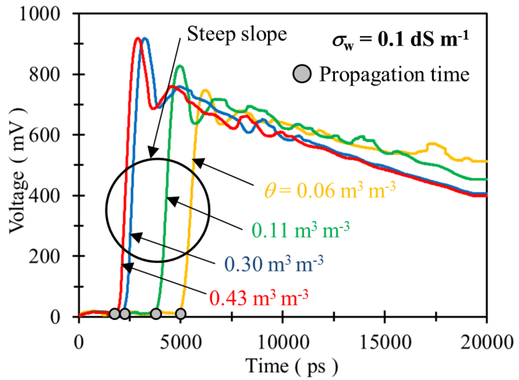
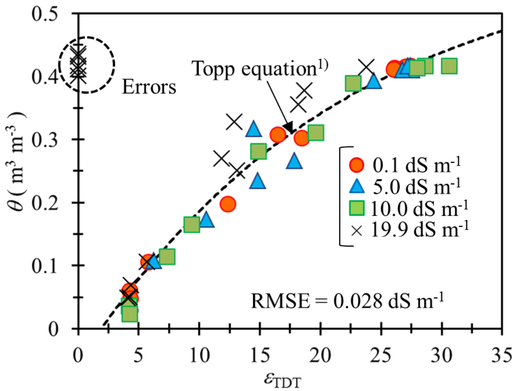
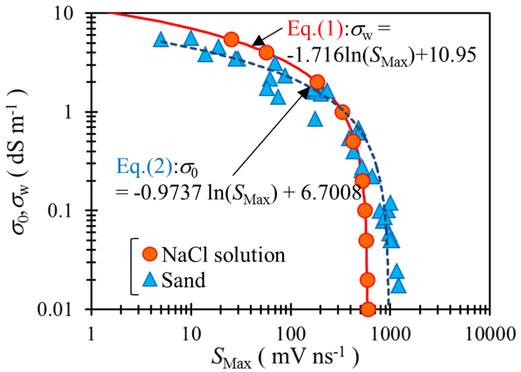


Fig.2 TDT waveforms for sands in different moisture conditions.



- ε_{TDT} obtained distributed near the Topp equation[1)].
- Analytical errors due to signal loss observed in extremely high-conductive conditions.

Fig.4 Volumetric water content (θ) for apparent permittivity measured by TDT sensor (ε_{TDT}).



- S_{Max} measured by the TDT sensors.

vs.

σ_0 measured by the 4-probe sensor.

An empirical relationship: Eq.(2)

Fig.6 Bulk electrical conductivity measured by the 4-probe sensor (σ_0) for Maximum slope (S_{Max}).

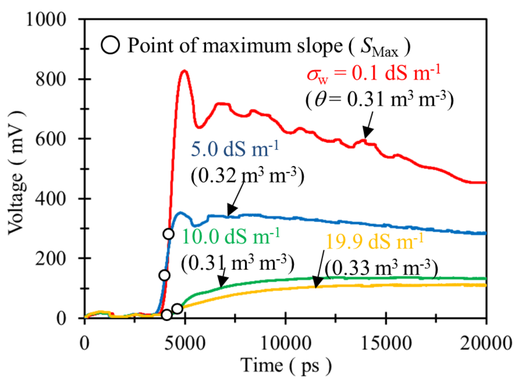
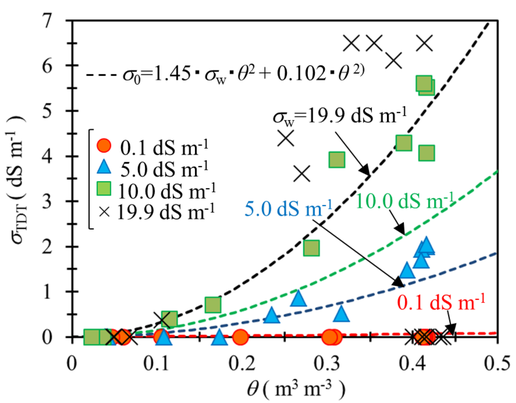


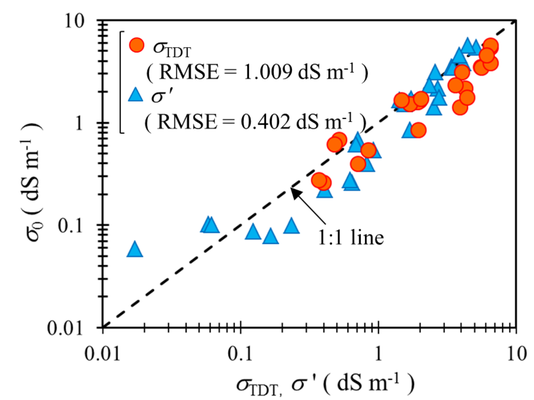
Fig.3 TDT waveforms for sands with different electrolyte levels.

- Amplitude decreased with increase in σ_w.



- Analytical errors due to signal loss in 19.9 dS m^{-1}.
- Lack of sensitivity in 0.1 dS m^{-1} and 5.0 dS m^{-1}.

Fig.5 Bulk electrical conductivity measured by the TDT sensor (σ_{TDT}) for volumetric water content (θ).



- σ' modified by applying the Eq.(2) distributed near the 1:1 line.
- Sensitivity of EC measurement can be improved.

Fig.7 Bulk electrical conductivity measured by the 4-probe sensor (σ_0) for bulk electrical conductivity measured by the TDT sensor(σ_{TDT}, σ').

4. Conclusion

An empirical relationship between the maximum slope of the TDT waveform(S_{Max}) and the bulk EC was developed to improve measurement capabilities in low-conductive soils with low moisture contents and electrolyte concentrations.

References 1)Topp et al. 1980. electromagnetic determination of soil water content: measurement in coaxial transmission lines. Water Resour. Res. 16: 574 - 582., 2) Inoue M and Shiozawa S. 1994. Measurement of electrical conductivity in soil columns by the Four-electrode method and its application. Journal of the Japanese society of soil physics. 70: 23-28.