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Simultaneous measurement of penetration resistance and soil water content

A sensor system for real-time measurement in the penetrometer

For the simple and area-covering measurement of soil compaction, a double sensor based on dielectric and mechanical variables was developed in Bonn and built as a prototype for laboratory measurements. The geometric form of the sensor meets the ASAE standard for penetrometer cones. The sensor provides the signals in real time when penetrating into the soil. The signals enable the soil water content and penetration resistance as a measure of soil bulk density to be deduced. Laboratory tests were carried out with a prototype. Use on the field is planned.

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Keywords

Cone index, soil moisture, soil bulk density, dielectrics

Since [1] presented an empirical formula for the description of the relation between soil moisture and the dielectricity of moist soil, a large number of measuring methods based on the dielectric properties of soil for the determination of the soil water content have been studied. Under laboratory conditions, these methods provide sufficiently accurate results. In field use, however, they are imprecise [2]. The unreliable values in field use are mainly caused by dielelectricity not only being dependent upon soil moisture, but also on soil bulk density. A conventional way of determining soil bulk density is the measurement of penetration resistance with the aid of penetrometers. This technique provides direct results in the form of the cone index, which is defined as penetration resistance force in relation to the cross-sectional area of the standardized cone and closely correlates with soil bulk density, though it is also influenced by the kind of soil and the soil water content [2; 3]. Therefore, the proposal has been made to measure soil moisture θ and soil bulk density ρ simulaneously [4].

The goal of this development work is the combination of both measuring principles in a sensor system which is termed hygro-penetrometer. The sensor system is intended to provide signal pairs in real time, which will enable penetration resistance and soil moisture to be analyzed and are intended to be used for the mapping of the bulk density of soil used for agriculture in a range of soil moisture and soil bulk density of 10 to 40% and 1.0 to 1.7 kg l^{-2} respectively. Using a suitable measuring set-up, the soil water content and the bulk density of soil samples were measured under laboratory conditions.

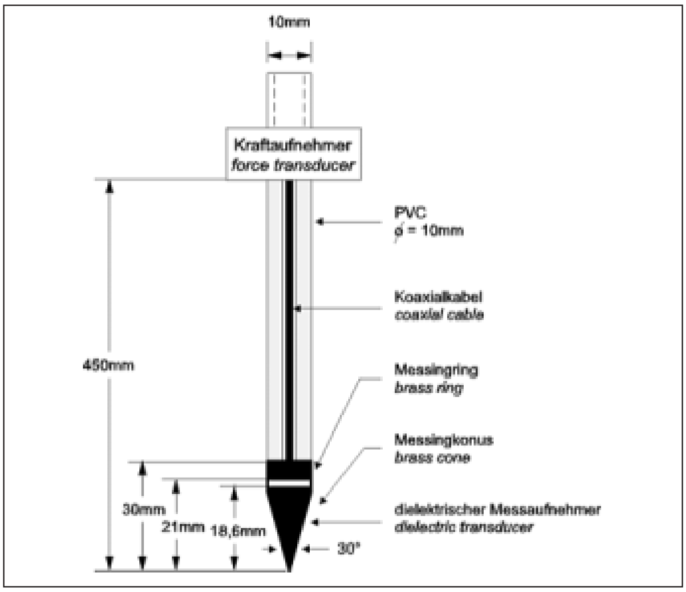

Fig. 1: A sensor system consisting of two transducers for the cone index and the soil water content

Measuring Principle

Figure 1 shows the outlines of the design of the sensor system, which consists of the penetrometer rod with a cone standardized according to ASAE [5] and the impedance sensor. The dielectric transducer consists of a brass cone and a brass ring, which is embedded at the end of the rod slightly above the cone. The penetrometer is equipped with an electric drive for penetration into the soil and a force transducer. The force transducer used is an HM-C9B/500N with a maximum measuring range of 500 N. Maximum vertical movement is 420 mm.

In most cases, penetration resistance increases with an increasing silt- and clay content, decreasing soil moisture, growing penetration depth into the soil and growing soil bulk densities [6, 7, 8]. It is assumed that the signals of the dielectric sensor and the force

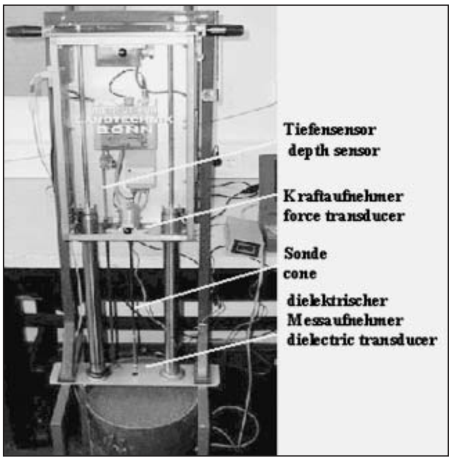

Fig. 2: Photo of the sensorsystem

transducer can be described as a function:

$$S_{Dielektrik} = f_1(\theta, \rho, \alpha) \quad (1)$$

and

$$S_{Kraft} = f_2(\theta, \rho, \alpha) \quad (2)$$

$S_{Dielectric}$: output signal of the force transducer

S_{force}: output signal of the dielectric transducer

θ: volumetric water content of the soil

ρ: soil bulk density

α: coefficient for adaptation to different kinds of soil

With the selection of the soil, α is determined. If α is constant, two unknown variables remain in each equation. These are the volumetric water content and soil bulk density. Furthermore, a necessary condition which guarantees that no linear correlation between the two equations exists must be taken into account. If there is a dimensionless constant C so that

$$f_2(\theta, \rho, \alpha) = C f_1(\theta, \rho, \alpha) \quad (3)$$

a large number of solutions exist for equations 1 and 2, and one pair of the dual sensor results becomes identical. For this reason, the dielectric transducer was designed such that the following condition is met:

$$(\theta^{\uparrow} \cup \rho^{\uparrow}) \rightarrow S_{Dielectrics}^{\uparrow} \quad (4)$$

The properties of the force transducer are known as follows:

$$(\theta^{\downarrow} \cup \rho^{\uparrow}) \rightarrow S_{force}^{\uparrow} \quad (5)$$

As the required result, both output sensors are linearly independent, and it can be expected that the value pairs represent penetration resistance and soil moisture.

Realization of the Experiments and Results

For the trials, soil from the experimental field „Messdorferfeld" in Bonn-Endenich was used. Soil samples having different volumetric water contents were filled into seven cylindrical plastic containers in a range between 0 and 42.5 $m^3\ m^{-3}$, i.e. between an absolutely dry and a saturated moisture condition. The containers were 400 mm tall and had a diameter of 340 mm. The soil samples consisted of clayey loam with the following texture: 36% clay, 53% silt, and 11% sand.

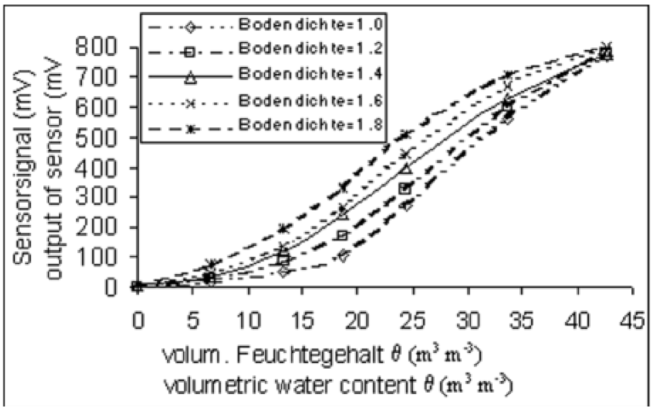

Fig. 3: Influence of soil bulk density on the signal of the dielectric sensor as a function of the volumetric soil water content

Figure 3 shows a group of curves for different soil bulk densities which describes the correlation between volumetric soil moisture and the signal of the dielectric transducer. Another result of the trial series is shown in *figure 4*, which contains a three-dimensional course of the curves for the correlation between volumetric soil moisture, soil bulk density and penetration resistance for the selected soil type. The curves show that the course of penetration resistance matches the theoretical considerations. However, the driest sample (near θ = 0) does not always exhibit the maximum value of penetration resistance. This phenomenon has already been described in reference [3]. Two aspects are stated as the main reasons: the influence of the soil water content on soil bulk density would have to be taken into account, and cohesive interaction between the soil and the cone surface changes significantly if either the soil water content or soil bulk density (in a dry condition) change. Therefore, it must be assumed that penetration resistance measured as the cone index can be found in many different combinations of cohesion and friction.

Summary and Conclusions

A dual sensor for the simultaneous and real-time measurement of penetration resistance and soil moisture was developed and tested under laboratory conditions. It must be emphasized in particular that the moisture sensor is significantly cheaper than TDR transducers. The results of the laboratory tests indicate that the dual sensor is also well suited for field use. Future studies will focus on calibration for different kinds of soils and the development of a model for the interpretation of the processes under the cone tip as well as the influence of soil bulk density and soil water content with regard to universal application. Moreover, the mathematical solution algorithms for the measuring principle of the dielectric transducer are intended to be optimized.

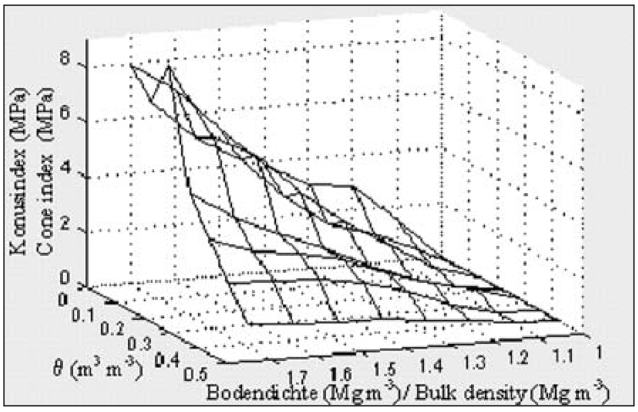

Fig. 4: Soil penetration resistance (cone index) over soil bulk density and the volumetric soil water content θ

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