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Application of TDR technique for compaction control of engineered fills

L'application de la technique de TDR en contrôle du compactage des remblais

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ABSTRACT: The new procedure for compaction control of engineered fills is presented in the paper. The proposed procedure is based on the Time Domain Reflectometry (TDR) technique, a versatile method for the non-destructive measurement of the compacted soil moisture content. The test results obtained confirm the usefulness of a new procedure, its an operator-safety and environmental friendliness.

RESUME: La nouvelle procédure du contrôle du compactage de sols á grains fins on a présenté dans l 'article. La procédure proposée s 'appuie sur la méthode de la spectroscopie par réflexion (TDR), classée parmi les méthodes non destructives de désignation de teneur en eau volumétrique des sols. Les essais faits jusqu 'á présent pour des sols choisis, présentés dans l 'article ont confirmé l 'utilité de la méthode pour le contrôle du compactage des constructions en terre, leurs sécurité pour les ouvriers et leurs comportement amical envers le milieu naturel.

1 INTRODUCTION

Construction Quality Control and Assurance (CQC/CQA) of engineered fills is provided by observation of filling operations and in situ testing, required to document the soil densities obtained. The standard procedure of compaction tests used is relatively simple, however it takes time, mainly for drying specimens to obtain moisture contents. On most construction jobs, the amount of time required for performing the tests is unacceptable; hence, many short-cut methods have been used.

The new procedure for rapid compaction control of fine-grained soils is presented in this paper. The proposed procedure is based on the time-domain reflectometry (TDR) technique. The soil dielectric constant obtained with the use of reflectometric method is directly related to the volumetric water content (Topp et al. 1980). Over the past ten years, the TDR-technique is widely performed in agricultural research (Topp & Davis 1985; Dalton & Genuchten 1986) and in environmental monitoring. The TDR principle is also very well suited for the measurement of the soil moisture content in civil engineering, for instance in the construction of highways (Brown 1996), railroads, airfields, canals, levees and earth dams. The TDR tester makes it possible to read directly the volumetric water content in the full range of moisture on many depths of compacted soil layer simultaneously and it does not need to be individually calibrated for particular types of soil. The presence of the probes installed in the soil does not disturb the water distribution in the soil.

The proposed procedure was applied for determination of the optimum moisture - maximum dry density relationships of the various fill materials, mainly fine-grained soils and ash. The test results obtained and description of the procedure used are presented in the paper.

2 THE PROPOSED RESEARCH PROCEDURES

It is proposed to apply time-domain reflectometry system to perform control field research into the compaction of earth engineering objects. The method permits rapid (10-30 seconds) determination of volumetric water content of the compacted soil.

In the TDR measurement, volumetric water content (θ_{TDR}) is determined from the soil dielectric constant (ε). The dielectric constant may be calculated as based on the measurement of the electromagnetic wave propagation rate in the soil (v), using the following formula: $\varepsilon = (c/v)^2$, where c is the speed of light in vacuum. The principle of the reflectometric measurement (Fig. 1) consists in the introduction of a symmetrical transmission line section (probe) in the form of two parallel, uninsulated metal bars, with one end connected through another transmission line (feeder) with the electric voltage pulse generator, to the being investigated capillary/porous medium. Voltage distortion caused by the fed electromagnetic pulse leads to pulse propagation towards the probe. Over a time period of t_1 it reaches the probe input and propagates forward in the soil, reaching probe end at t_2. Fig. 1B shows the pulse images and its reflections shown on the screen of an oscilloscope connected to the feeder. Measurement of time $t = t_2 - t_1$ and knowing probe length (L), enables calculation of ε and the soil water content, which is a linear function of ε. The probe measurement zone (i.e. volume in which measurement takes place) comprises a soil cylinder with height equal to the length of electrodes (bars) and diameter equal to three times the bar spacing.

The following two procedures are proposed to investigates the degree of soil compaction in an earth engineered fills.

PROCEDURE 1

The field TDR tester measures water content of the compacted soil in volume percent (θ_{TDR}). A soil sample of known volume (V) and undisturbed structure is taken during the field test, its weight (W_1) is determined as the total of dry soil weight (m_s) and water weight (m_w). The value of dry soil density (ρ_d) required to calculate the degree of compaction is determined from the following formula:

$$\rho_d = (W_1 - 0.01\ \rho_w\ \theta_{TDR}\ V)/V = W_1/V - 0.01\ \rho_w\ \theta_{TDR} \qquad (1)$$

The degree of soil compaction is determined once ρ_{dmax} is known from the Proctor test.

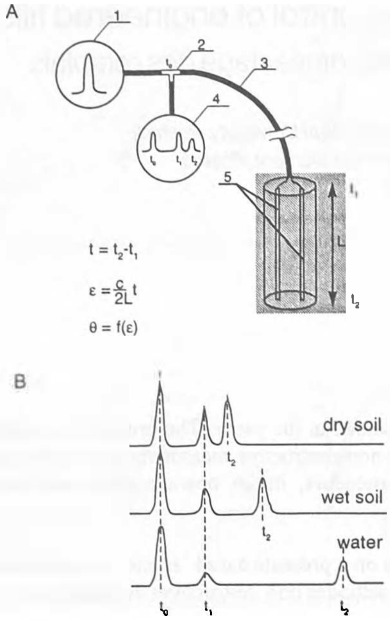

Figure 1. Principle of water content measurements by TDR technique; A-main components of reflectometer (1-oscilloscope screen, 2-T-connection, 3-feeder, 4-oscillogram, 5-bars), B - oscillograms.

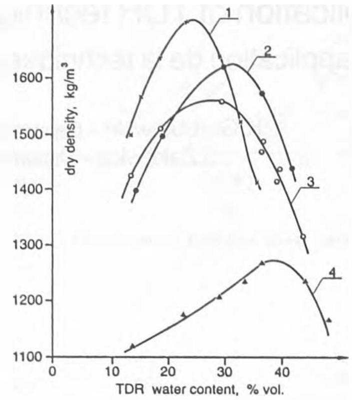

Figure 2. Compaction curves obtained with using TDR technique; 1, 2 and 3 - number of soils tested (silty clays), 4-ash.

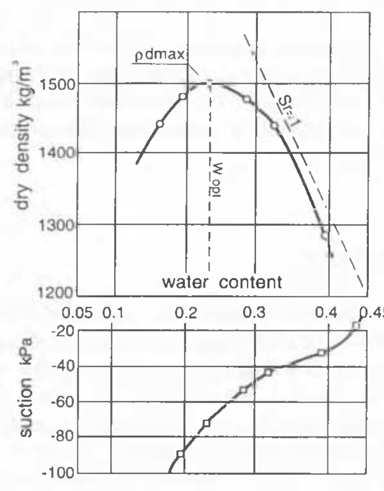

Figure 3. Nomograph for compaction control of clay.

PROCEDURE 2

This procedure requires laboratory determination of two curves for the tested soil: the modified compaction curve (dependence between ρ_d and θ_{TDR}) and the soil retention curve (dependence between θ_{TDR} and matrix suction $h_s = u_a - u_w$, where u_a and u_w are, respectively, air and water pressure in the soil). The soil retention curve may be determined using a modified Proctor apparatus (Garbulewski et al. 1994). A nomograph allowing determination of soil compaction and the required volumetric water content has been presented in fig. 3. Control field tests involve use of the TDR tester to determine volumetric water content and the tensiometer to determine matrix suction; with subsequent use of the nomograph to assess soil compaction.

3 RESULTS OF INVESTIGATIONS

Compaction measurements using the TDR tester were made for three selected, CH-type soils and ash. The tested materials were compacted in the Proctor apparatus using normal energy and volumetric water content was determined using a miniature laboratory probe. The probe consisted of two 0.8 mm diameter 53 mm long parallel meter bars spaced 5 mm apart. The volumetric water content value appeared in the computerized recording system after some 30 seconds.

Test results presented in the form of modified compaction curves (Fig. 2) allow to easily determine maximum values of dry soil densities of the tested soils and ash, as well as the ranges of permitted volumetric water content values. The water content was verified during field measurements using a TDR tester equipped with probes made as metal bars 2 mm in diameter and 100 mm long, spaced 16 mm apart. The field tester has a switch permitting testing of soil with high organic content.

Compaction tests in the modified Proctor apparatus were made for a clay with very high clay fraction content. The nomograph received from the compaction and retention tests has been presented in fig. 3.

4 CONCLUSIONS

1. Application of the TDR technique to determination of volumetric water content has been proposed as a method for performing control tests of earth engineered fills, particularly of the being in-built soil moisture content at which the best compaction is obtained.
2. Two procedures presented in this paper may be applied to determination of soil compaction. Procedure 1 is more easy to use and requires the use of available on the market TDR testers (laboratory and field versions). Procedure 2 requires the TDR tester to determine the modified compaction curve and, additionally, the determination of soil retention at various compactions.

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