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Accuracy of in-situ assessment of soil density and moisture content using the non-nuclear method

Précision de l'évaluation in situ de la densité et de la teneur en eau du sol à l'aide de la méthode non nucléaire

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ABSTRACT: The in-situ determination of the conditions of the materials in the pavement and subgrade layers (density and water content) is essential in quality control. In addition to the traditional tests of the sand replacement method (density) and the oven drying method (moisture content), the nuclear method based on the gamma-densimeter device has been one of the most used due to its ease and quick operation. Non-nuclear alternative methods can be used, such as the electromagnetic method contemplated in the ASTM D7830/D7830M. The paper presents a study on the potential application of this method to quality control of earthworks, road pavement layers (unbound granular layers of base and sub-base) and subgrade. The paper describes an application of this test method to the case of soil, including a comparative analysis with other test methods, such as sand replacement and nuclear methods. The study's main results confirmed the method's feasibility and identified aspects of its practical application.

RÉSUMÉ: La détermination in situ des conditions des matériaux dans les couches de chaussée et de fondation (densité et teneur en eau) est essentielle au contrôle qualité. Outre les tests traditionnels de la méthode de remplacement du sable (densité) et de la méthode de séchage au four (teneur en humidité), la méthode nucléaire basée sur le dispositif gamma-densimètre a été l'une des plus utilisées en raison de sa facilité et de sa rapidité d'opération. D'autres méthodes alternatives non nucléaires peuvent être utilisées, comme la méthode électromagnétique envisagée dans l'ASTM D7830/D7830M. L'article présente une étude sur l'application potentielle de cette méthode au contrôle de la qualité des travaux de terrassement, des couches de chaussée routière (couches granulaires non liées de base et de sous-couche) et du sol de fondation. L'article décrit une étude sur l'application de cette méthode d'essai au cas d'un sol, comprenant une analyse comparative avec d'autres méthodes d'essai, telles que la méthode de remplacement du sable et la méthode nucléaire. Les principaux résultats de l'étude ont confirmé la faisabilité de la méthode et identifié les aspects de son application pratique.

Keywords: Density; moisture content; non-nuclear method; quality control.

1 INTRODUCTION

Compaction is a process of great relevance in geotechnical structures, such as hydraulic works (embankment dams), retaining structures (earth retaining walls) and transport infrastructures (roads, railways, and airfields construction). Compaction is fundamental for the adequate behaviour of the structures (resistance, deformability, permeability). Therefore, compaction quality control is of relevant importance and the most common procedures are based on the direct assessment of the density and water content of the compacted layers. In general, current specifications establish compaction acceptance criteria based on the maximum limit of the variation range of water content in relation to the optimum value and the minimum limit of dry density, normally expressed in terms of the degree of compaction established for maximum dry density. Those limits should consider the nature of the material, the type of application and the compaction equipment.

There are several methods that can be used to evaluate in situ density and water content. Over time, the sand replacement method, in conjunction with the determination of water content, has been considered the reference method in determining dry unit weight of soils in natural conditions or after compaction. However, other methods were developed with the aim of allowing the non-destructive in-place quality control more adjusted to the construction and continuous monitoring of the quality of roads or other infrastructure works (Wang et al., 2022), including intelligent compaction (Kumar et al., 2016, Chen et al., 2023), and artificial intelligence (Wang et al., 2022, Wang et al., 2023).

The nuclear method has been one of the most used in Portugal. This method uses a nuclear density gauge, which is a radioactive equipment composed of gamma ray and neutron sources that allows direct measurement of density and water content. However, the current licensing process for radioactive source equipment, such as the nuclear density gauge, has led to a preference for using alternative methods to control compaction. The preference for methods based on density and water content measurement has the advantage of being in accordance with the compaction control methodology contained in the specifications.

The paper describes an experimental study to validate the application of the electromagnetic soil density gauge (non-nuclear method) to the soil density and water content control, based on proficiency tests. The proficiency tests also included the sand bottle method and the nuclear method.

2 METHODOLOGY

2.1 Equipment

One of the non-nuclear methods for measuring wet density and water content is the electromagnetic method which is based on the use of electromagnetic impedance spectroscopy device. The electromagnetic properties of the soil are evaluated for certain frequencies through changes induced in the electromagnetic field and which can be correlated with density and water content. Figure 1 shows an electromagnetic gauge (SDG 200 from TransTech Systems). The equipment consists of the following main components: the circular sensor (1) located at the base of the equipment and where the induction and electromagnetic field measurement electrodes are located; the unit where the internal circuits, batteries and the infrared temperature measuring device are located (2); the interface display for reading, managing, and storing measurement results (3). The equipment also consists of a handle for transport and operation (4). As shown in Figure 1, during measurement the equipment is supported on the ground surface. Electromagnetic equipment has the advantage of controlling compaction based on the measurement of density and water content in a simple and quick way. Another advantage of electromagnetic equipment is related to the exemption from licensing, which has contributed to the greater interest in using this equipment to control compaction to the detriment of the nuclear method. The non-nuclear method is included in the ASTM D 7830/D 7830 M.

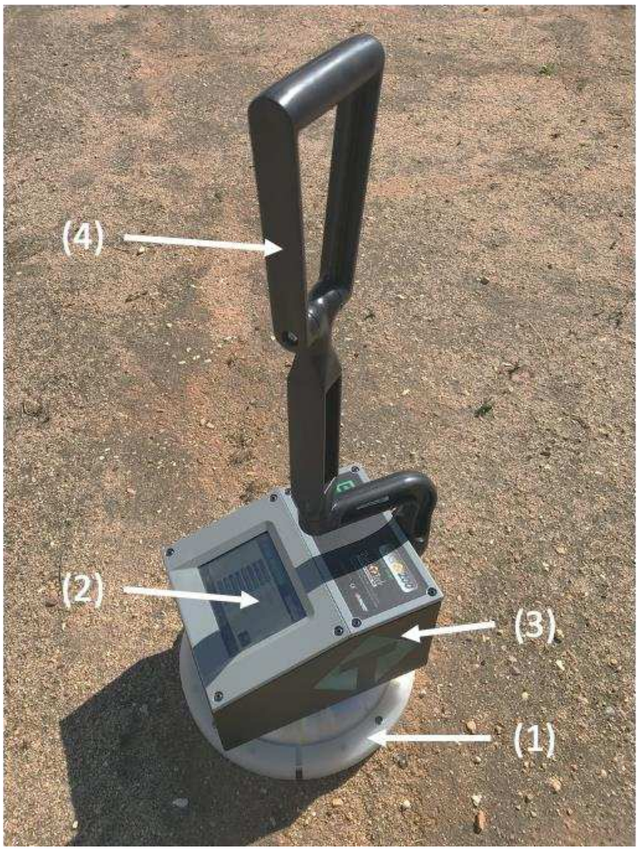

Figure 1. Electromagnetic gauge.

2.2 Proficiency tests

The Association of Accredited Laboratories of Portugal (RELACRE), representative of Portuguese laboratories at EUROLAB, has more than two decades of experience in organizing proficiency tests in the context of construction and building materials (tests of soils, aggregates, bitumen, bituminous mixtures, and concrete). Since 2010, RELACRE has also organized proficiency tests relating to in-place tests carried out on pavement and sub-grade layers (Neves et al., 2013). The proficiency tests follow the methodology of the ISO/IEC 7043 standard.

In 2022, a proficiency test was carried out including the following test methods related to quality compaction control based on dry density and water content:

- Determination of "in situ" density by the nuclear method considering measurements at the surface (backscatter mode) and at a depth of

200 mm (direct transmission mode) of wet density and water content, according to ASTM D 6938.
- Determination of "in situ" density by the sand replacement method, using a sand cone apparatus, according to LNEC E 204 (Portuguese specification based on ASTM D 1556 and ASTM D 1557).

The proficiency test was carried out in a compacted soil. The local was sectioned into three large zones and each zone was divided into nine test points. The zones and points were selected to guarantee homogeneity of state conditions (density and water content). The distance between test points was at least three meters. The soil was a clayey sand (SC) with the properties listed in Table 1 (grain size distribution and plasticity).

Table 1. Properties of the soil.

Properties		Values
Percent passing (Sieve size, mm)	19.0	100
	9.5	98
	4.75	96
	2.00	84
	0.850	53
	0.425	29
	0.250	21
	0.106	17
	0.075	16
Liquid Limit, LL (%)		27
Plasticity Index, PI (%)		11

Seven laboratories participated in the evaluation of wet density and water content using the nuclear method. Each laboratory carried out measurements in three randomly chosen locations: one test point in each zone. At each test point, measurements were taken first at the surface (backscatter) and then at depth (direct transmission). In both operating modes of the nuclear equipment, three measurements were taken at the test site, characterized by a reading time of sixty seconds, with an interval of three minutes between successive measurements. Each laboratory carried out a total of nine measurements of wet density and water content. In the case of the sand replacement method, five laboratories participated and followed a similar procedure to the nuclear method. They carried out a test in each of the three zones, for a total of three measurements of wet density.

In addition, the non-nuclear method was also used in the organization of the proficiency test. Three measurements of wet density and water content were carried out with the electromagnetic gauge. Measurements of the nuclear method were carried out at the surface (backscatter).

3 RESULTS AND DISCUSSION

Figure 2 presents the mean of the values measured by all laboratories for each parameter of the nuclear method and the sand replacement method. Neves et al. (2013) concluded that, in general, the wet density measured at depth (direct transmission) tends to be higher than the wet density value measured at the surface (backscatter). The same authors also found that measuring wet density at depth is the closest to the sand replacement method. The results presented in Figure 2 confirm those conclusions. It was also observed that the standard deviation was smaller in the direct transmission mode. These results reinforce the recommendation of using the direct transmission mode to measure wet density. In relation to water content: the measurements were similar in both modes of nuclear gauge operation: 2,7% (direct transmission) and 3,0% (backscatter).

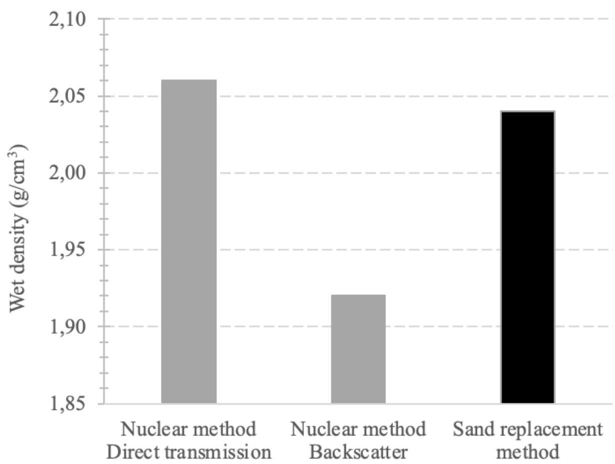

Figure 2. Comparison of wet density measurements.

Regarding the comparison between nuclear and non-nuclear methods, Table 3 presents the values of wet density and water content (mean and standard deviation, SD, of three measurements). The values measured by the non-nuclear method resulted from correction of the equipment in accordance with the manufacturer's methodology. The correction procedure is based on knowledge of the material's identification properties (granulometry and plasticity) and their comparison with values established by the manufacturer for standard samples. For each type of material, correction factors for wet density and water content (offset) are established, which are added to the measured values to obtain the corresponding final values. From the analysis of Table 2, it appears that the corrected values obtained in the non-nuclear method are practically coincident with the values from the nuclear method (backscatter).

Table 2. Comparison of nuclear and electromagnetic methods.

Test	Parameter	Mean	SD
Nuclear method (backscatter)	Wet Density (g/cm^3)	1.927	0.003091
	Water content (%)	2.57	0.0471
Non-nuclear method	Wet Density (g/cm^3)	1.927	0.002974
	Water content (%)	2.57	0.0471

4 CONCLUSION

The paper presented a study on the application of the electromagnetic method to control the compaction of clayey sand, in comparison with the nuclear method. The study was carried out as part of a proficiency test that included the nuclear method and the sand replacement method. The study allowed to conclude that the values of wet density and water content measured by nuclear and non-nuclear (after correction) methods were practically coincident. The study also highlighted the importance of correcting the values measured by the electromagnetic equipment, in accordance with the procedure established by the manufacturer and considering the main properties of the soil (granulometry and plasticity). In addition, the study also provided a comparison between the nuclear and the sand replacement methods. The wet density measurement at depth through the nuclear method was the closest to the sand replacement method.

These conclusions provide confidence in the use of the electromagnetic method to control soil compaction, as an alternative to the nuclear method. However, it will be desirable to validate this study by applying the non-nuclear method to other compacted soils for different conditions (density and humidity).

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