Comparison of Nuclear Gauge Density-meter and Sand Cone Test Results on Clay and Shale Soils

A. Santos-Ferreira
Lisbon, Portugal.

C. Santos, C. Rocha and M. Cabral
Lisbon, Portugal.

ABSTRACT: Different types of soils may present different variations in field trials and laboratory tests. This paper outlines a comparison between nuclear gauge density-meter and sand cone test, used in two types of soils materials: clay and shale. The analysis is based on direct values obtained by each method for the dry density and water content, and also, in both cases, using the degree of compaction, and the deviation of water content, applying the Hilf method. A case of a compaction control of a heterogeneous embankment, executed in same condition for both materials, in order to heighten a waste installation will be used as example. Considering the materials analyzed, it can be concluded that the values obtained from the nuclear gauge density-meter are more approximate to the values obtained in laboratory in the case of shale material. However, it can be considered that, in the case of the clay material, the difference is not so great when compares the two methods.

1 INTRODUCTION

Nowadays, both nuclear gauge density-meter and sand cone tests are common methods for compaction control of embankment layers. Since it is more traditional, the later method gathers more significant field experience and results confidence among the geotechnical community, whereas it is a more laborious and time consuming technique. On the other hand, the first method requires sophisticated but easier to handle equipment and it is a quick way to acquire field test results, although it should be operated only by qualified technicians, to assure a critical acceptance of the obtained values.

Regarding the inherent advantages and limitations, the accuracy of the results obtained by each method is a relevant subject of discussion.

So, following a previous comparative study under the referred topic regarding arkoses soils in Santos-Ferreira *et al* (2014), the present analysis concerns the test results obtained in clay and shale materials gathered during the construction works of the heightening of a tailing dam, in Aljustrel mining complex, south of Portugal. As the national dam authority does not accept nuclear gauge results for compaction control, it is aimed, with this study, to establish a reliable methodology of correction of the referred method measurements, so it can be used in a consistent way, following previously research by Santos-Ferreira *et al.* (2014) and Maregesi (2012).

2 METHODOLOGY

For this investigation, the compaction control results of a heterogeneous embankment executed to heighten a tailing dam were considered. In the referred project, the core and the upstream and downstream shells were comprised of clay and shale soils, respectively, and both zones were executed under the same conditions. Additionally, the compaction control of each embankment layer was accomplished by nuclear gauge density-meter and sand cone test methods, in the same emplacements to assure representative results for comparison purposes.

2.1 *Execution of Tests*

The performed analysis was based on values gathered by nuclear gauge density-meter and sand cone test methods for the wet density and water content. For each test point, a nuclear gauge density-meter test was carried out; exactly at the same location, a sand cone test was then executed, and enough soil was collected so it could be possible to rectify the values by the Hilf method. This was particularly interesting for the construction work itself, as to get reliable values for the degree of compaction, although Hilf corrections for the water content were also used in this analysis. All the nuclear gauge density-meter tests were carried out with the direct test, with the source of radiation at 25cm depth.

This study included the testing of two soils, a medium plasticity clay soil and a shale soil, as follows: (i) 95 pairs of test results of the core clay materials and (ii) 87 pairs of test results obtained on the shells construction materials (i.e. shale soils).

2.2 *Test correction procedure*

In order to adjust the nuclear gauge density-meter measurements, it is usual to find the mean error (shift coefficient) of the nuclear gauge density-meter readings and add or subtract the readings from the sand replacement method test results (wet density and moisture content). Anyway, as in the field it is a common procedure to use the degree of compaction for the acceptance criteria of embankment layers, it is often used the Hilf method to rectify the sand cone test values and so to solve the geotechnical properties of soils variability problem.

In this paper, the Hilf method is applied mainly in the moisture content correction. So, it was considered, for the sand cone method, the moisture content as determined by the oven method and the wet density attained in the field; the moisture content was then corrected by the Hilf method and so it was obtained the dry density by the sand cone method, corrected by the Hilf method.

It is object of this study to establish the relation, and ascertain its reliability, of the dry density by the nuclear gauge density-meter and the sand cone test results, corrected by Hilf method.

The correlation between the nuclear gauge reading and the sand replacement methods is equal to 1 (one) only when the fitted equation is:

$$y = x \quad (1)$$

In Equation (1), "y" is either the wet density as determined by sand replacement method or moisture content as determined using oven dry method, and "x" is either the nuclear gauge density or moisture content readings. So, in order to use a single "shift coefficient" for adjusting the nuclear gauge readings, the slope of the best-fit line must be equal or very close to unit (one); this means the line must be parallel with the perfect fit equation of "y=x", i.e. with an equation in the form of:

$$y_0 = x+C \quad (2)$$

Where ***C*** is constant value, which is equivalent to the shift coefficient.

Due to the soil variability and to the different soils mineralogy, it is rare to achieve this kind of perfect correlation, and usually the fitted equation is more likely in form of:

$$y_1 = mx+C \quad (3)$$

So, the error term (***k***) for the regression model is:

$$k = y1\text{-}y = mx+C\text{-}x = (m\text{-}1)x+C \quad (4)$$

This error term represents a "multiple shift coefficients" to be used for adjusting the nuclear gauge density or moisture readings (Maregesi, 2012).

The procedure for the analysis of the set of tests performed was, for each soil:

i. The regression line for the wet density for the sand cone test and nuclear gauge density-meter results was established;
ii. The regression line for the moisture content for the nuclear density-meter and oven determination results was established;
iii. The oven moisture content determination for the sand cone test was corrected by the Hilf method, and a new regression line regarding these values and the nuclear gauge density-meter values was established;
iv. The equation established in iii) was used, applying the described method, as well as the equation (4) to correct the moisture content obtained with the nuclear gauge density-meter;
v. In the same way, the wet density obtained by the nuclear density-meter was corrected;
vi. The wet density obtained by the sand cone test was corrected by the Hilf method;
vii. With the corrected moisture contents (corrected as exposed) and the corrected values of the wet density, it was possible to establish the rectified regression line for the dry density for the sand cone test and nuclear gauge density-meter.

3 TEST RESULTS

3.1 *Clay materials*

According to the methodology described in section 2, Figs. 1 to 3 present the results obtained for the clayey soil.

In Fig. 1 is represented the wet density for the sand cone test and nuclear gauge density-meter, without any correction; Fig. 2 presents the moisture content for the nuclear gauge density-meter, related with the same result for the sand cone test, corrected accordingly with the Hilf method; in Fig. 3 it is presented the relation, for both tests, of the dry density, with the correction of the sand cone test by Hilf method, and for the nuclear gauge density-meter with the correction presented in point vii, of section 2.2.

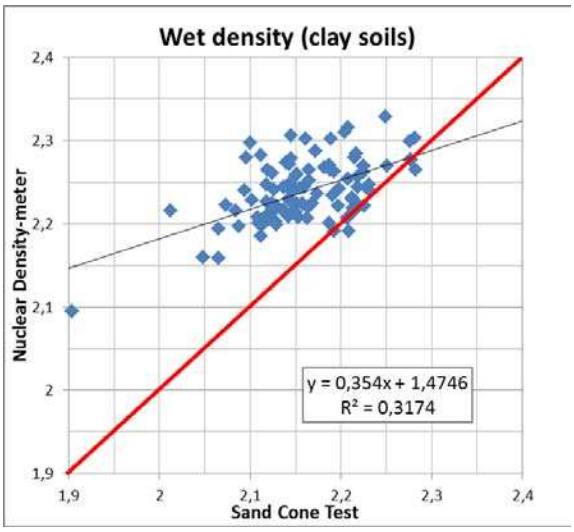

Fig. 1 Nuclear density-meter vs sand cone tests results for the wet density in clay soils.

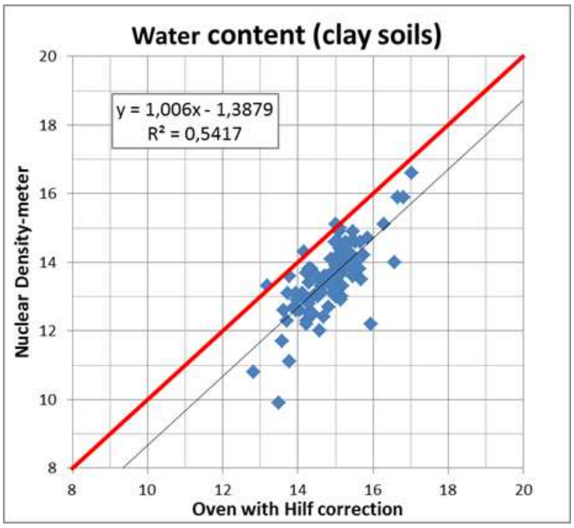

Fig. 2 Nuclear density-meter *vs* sand cone tests results for the water content in clay soils.

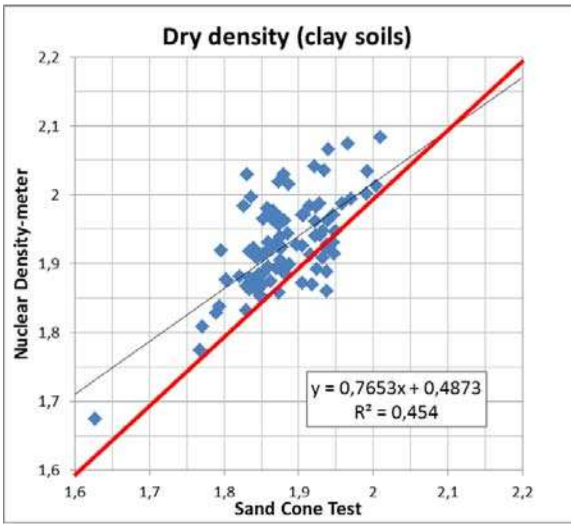

Fig. 3 Nuclear density-meter *vs* sand cone tests results for the dry density in clay soils with corrections.

3.2 *Shale materials*

For the shale soils, namely the construction materials of the zoned tailing dam shells, the comparative analysis is presented in Fig 4 and Fig 6.

In Fig. 4 is represented the wet density for the sand cone test and nuclear gauge density-meter, without any correction; Fig. 5 presents the moisture content for the nuclear gauge density-meter, related with the same result for the sand cone test, corrected accordingly with the Hilf method; in Fig. 6 it is presented the relation, for both tests, of the dry density, with the correction of the sand cone test by Hilf method, and for the nuclear gauge density-meter with the correction presented in point vii, of section 2.2.

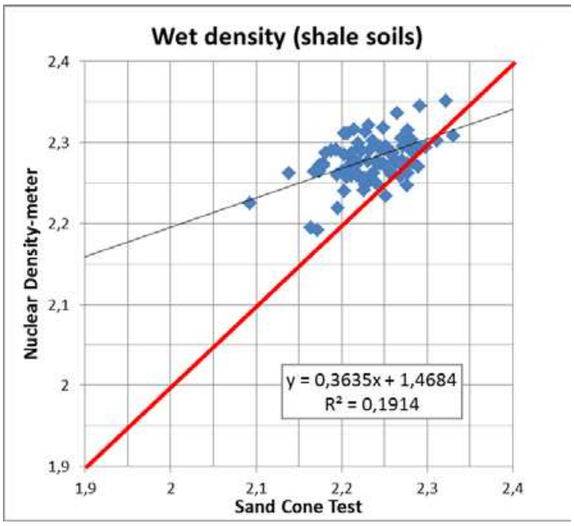

Fig. 4 Nuclear density-meter *vs* sand cone tests results for the wet density in shale soils.

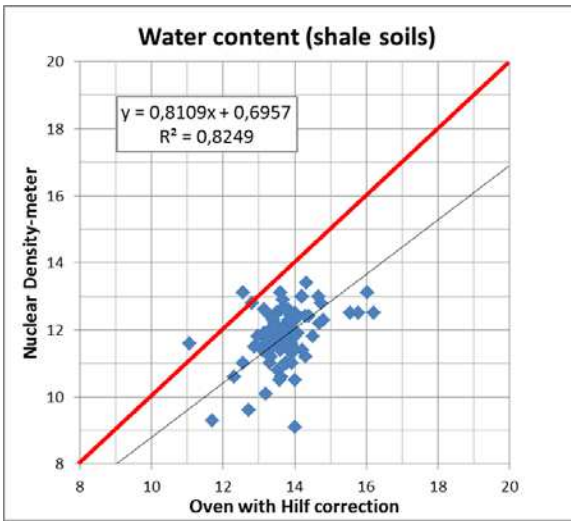

Fig. 5 Nuclear density-meter *vs* sand cone tests results for the water content in shale soils.

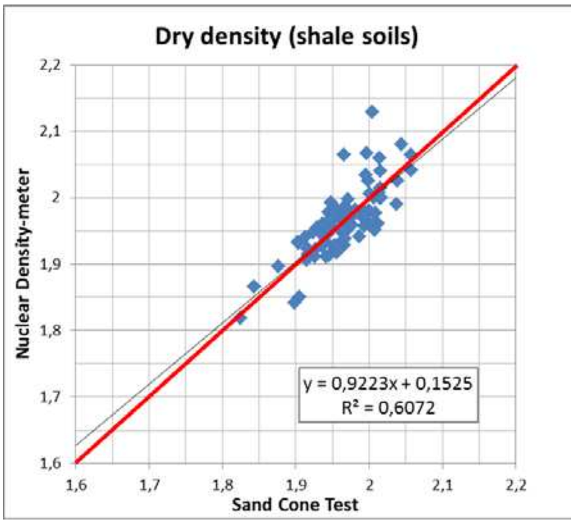

Fig. 6 Nuclear density-meter *vs* sand cone tests results for the dry density in shale soils.

4 RESULTS AND DISCUSSION

4.1 *Clay materials*

The comparative analysis of the obtained values by nuclear gauge density-meter and sand cone test for the wet density, in clay soils, without any correction, is presented in Fig 1. In this figure, for the referred parameter, the nuclear gauge tends to attain higher values than the sand cone test in the studied soils, possibly due to the higher compaction level of the surface layer and to the way of measuring of the gamma particles. Anyway, the correlation between the two sets of results is low, as shown by a coefficient of correlation of 0.56 and a coefficient of determination (R^2) of only 0.32.

Comparing the results for the moisture content (Fig. 2) by the nuclear gauge and the values for the sand cone test corrected by the Hilf method, the coefficient of determination is higher, i.e., R^2 = 0.54, with the regression line parallel to the y=x line, and with a correlation coefficient of 0.73.

When the correction method presented in section 2.2 is applied (Fig. 3), the correlation of the dry density values obtained by the two tests presents a R^2 = 0.45, and a correlation coefficient of 0.67.

4.2 *Shale materials*

The comparative analysis of the values obtained by nuclear density-meter and sand cone test for the wet density, in shale soils, without any correction, is presented in Fig 4. Considering the Fig 4, for the referred parameter, the nuclear density-meter tends to attain higher values than the sand cone test in the tested soil, as it occurred with the clay soil. Anyway, the correlation between the two sets of results is lower for the shale as the attained coefficient of correlation is 0.44 and the coefficient of determination (R^2) is only 0.19.

Regarding the results for the moisture content, Fig. 5, obtained by nuclear density-meter and the sand cone test corrected by the Hilf method, the resultant coefficient of determination is higher, i.e. equals to 0.82, with the regression line quasi parallel to the y=x line, and with a correlation coefficient of 0.90.

When the correction method presented in section 2.2 is applied to the shale soil (Fig. 6), the correlation of the dry density values obtained by the two tests presents a R^2= 0.61, and a correlation coefficient of 0.78.

5 CONCLUSIONS

The methodology proposed for the correction of the field data and the correlation of the nuclear gauge density-meter test with the sand cone test show that, after correction, a dispersion of the values usually inferior to 2% can be attained. Anyway, the higher number of nuclear gauge density-meter tests that is possible to carry out in a site allows a much interesting statistics results analysis, with no loss of final precision.

Nevertheless, further studies should go on, in several types of soils, to ascertain the importance, in the nuclear gauge density-meter testing method, of the nature of soil, grain size and reliability of field testing results. Probably part of the inadequate results should be due to human error, not fully identified, for example, the misdetection of larger soil particles which influence the nuclear gauge readings.

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