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Correlations between SPT and DPSH results based in energy measurements

Corrélations entre les résultats SPT et DPSH basées sur des mesures d'énergie

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ABSTRACT: Dynamic probing tests, namely in the case of the super-heavy version, are commonly used in geotechnical investigations, particularly in heterogeneous soils, stiff soils, compacted to very compacted soils and in decomposed rock. The more usual approaches to obtain the subsequent geotechnical parameters consists in transforming the N_{20} DPSH results in equivalent N_{SPT} and use the correlations established with this latter. However, the usual correlations used in our days are based in the concept of corrected SPT values, namely N_{60} and $(N_1)_{60}$, which creates an important limitation to its use in DPSH results. A research work consisting in pairs of SPT and DPSH tests executed side by side with the same equipment (hammer, anvil, rods, etc.), both instrumented with energy measurements obtained from the SPT Analyzer (PDI), was performed in the Institute Polytechnic of Guarda (IPG, Portugal) experimental site. The obtained results revealed differences between the Energy Transfer Ratios (ETR) of DPSH and SPT tests, which seems to be related with the different penetration devices (SPT sampler and DPSH cone). Departing from that it was possible to compare both the test results (N_{SPT} and N_{20}) and the respective corrected values, N_{60} or $(N_1)_{60}$. Presentation and discussion of results will be presented in the paper herein.

RÉSUMÉ: Les essais de sondage dynamique, notamment dans le cas de la version super-lourd, sont couramment utilisés dans les investigations géotechniques, notamment dans les sols hétérogènes, les sols raides, les sols compactés à très compactés et dans les roches décomposées. Les approches les plus usuelles pour obtenir les paramètres géotechniques ultérieurs consistent à transformer les résultats N_{20} DPSH en équivalent N_{SPT} et à utiliser les corrélations établies avec ce dernier. Cependant, les corrélations habituelles utilisées de nos jours reposent sur le concept de valeurs SPT corrigées, à savoir N_{60} et $(N_1)_{60}$, ce qui crée une limitation importante à son utilisation dans les résultats DPSH. Un travail de recherche consistant en des paires d'essais SPT et DPSH exécutés côte à côte avec le même équipement (mouton, enclume, tiges, etc.), tous deux instrumentés avec des mesures d'énergie obtenues à partir de l'analyseur SPT (PDI), a été réalisé dans le laboratoire expérimental site de le Institut Polytechnique de Guarda (IPG, Portugal). Les résultats obtenus ont révélé des différences entre les taux de transfert d'énergie (ETR) des tests DPSH et SPT, qui semblent être liées aux différents dispositifs de pénétration (échantillonneur SPT et cône DPSH). À partir de là, il a été possible de comparer à la fois les résultats des tests (N_{SPT} et N_{20}) et les valeurs corrigées respectives, N_{60} ou $(N_1)_{60}$. La présentation et la discussion des résultats seront présentées dans le document ci-dessous.

Keywords: SPT; DPSH; penetration resistance; energy transfer ratios; energy efficiency.

1 INTRODUCTION

Dynamic penetration tests are widely used in the geotechnical characterization of soil massifs, especially in heterogeneous, stiff/dense/compacted soils and decomposed rock, where static penetration is seriously limited. Among these, the Standard Penetration Test (SPT) is undoubtedly the more popular and common in-situ geotechnical test used worldwide, which gives it an important advantage for a successful applicability in a wide range of geo-materials. On the other hand, dynamic probing tests have the great advantage of characterizing soil profiles continuously, especially in terms of strength (ISSMFE-TC16, 1989). Within this group of tests, Dynamic Probing Super-Heavy test (DPSH) is very similar to SPT in what concerns the mode of penetration and potential energy, thus very easy to be compared with, giving access to the available SPT correlations.

Both SPT and DPSH tests consist in the blow count needed for the penetration of a standard element by means of an impact produced by a hammer falling from a certain height. The hammer and falling weight are similar in these two tests, thus generating the same potential energy, while the main difference is related with the equipment that firstly penetrates the soil, namely a SPT 45 cm normalized sampler and a DPSH cone with diameter similar to the SPT sampler. Furthermore, SPT tests are performed inside a borehole previously drilled until the depth of each test (typically performed every 1.0-1.5 m), while DPSH is penetrated directly from the surface without need of a borehole, thus generating continuous profiles. The results of both tests correspond to the number of blows to penetrate a length of 30 cm (N_{SPT}) and 20 cm (N_{20}), respectively representing SPT and DPSH tests.

Given the similarity between both tests, it is of great practical interest to obtain DPSH normalized parameters identical to the SPT, opening an access to the most updated SPT correlations.

The International Geotechnical Society (ISSMFE, 1989) has established a reference value of 60% of the theoretical free fall of 474 J, E_{60}, for comparisons among tests performed by different equipment. The corresponding N value is designated as N_{60} and can be obtained from Eq. 1 as:

$$N_{60} = N \frac{E}{E_{60}} \quad (1)$$

where N corresponds to the energy E, which has to be known. The energy is to be obtained below the driving head (ISSMFE, 1989).

The more recent procedures and available correlations from SPT results, require the SPT normalized parameters, N_{60} and $(N_1)_{60}$ (Robertson et al., 1983, Seed et al., 1985, Skempton, 1986), represented by the Eq. 1 to Eq. 4. Thus, DPSH results should be represented by similar parameters. In the following sections an experimental frame performed in the Institute Polytechnic of Guarda (IPG), Portugal, experimental site under this subject is presented and discussed. The N_{60} and $(N_1)_{60}$ parameters are defined by the following equations:

$$N_{60} = C_E * C_R * C_B * C_S * N_{SPT} \quad (2)$$

$$C_E = \frac{ER_r}{60} \quad (3)$$

$$ER_r = \left(\frac{E_R}{E_P}\right) * 100 \quad (4)$$

$$(N_1)_{60} = C_N * N_{60} \quad (5)$$

where C_E represents the correction factor related with the energy transmitted to the rods, C_R and C_B the corrections related with the length of the rods and the diameter of the borehole, C_S the correction factor related with the liner, C_N the correction factor related with the overburden stress in granular soils, ER_r the energy ratio transferred to the rods, E_R the energy effectively transferred to the rods and E_P the potential energy of the hammer falling from a specific height.

More detailed information on the SPT normalized parameters can be easily found in the referenced bibliography.

2 EXPERIMENTAL WORK

The experimental frame related with this work was performed in the IPG experimental site, which has been used in the several studies related with in-situ tests in residual soils. The local geology corresponds to the residual soils, which are the result of the chemical weathering of Guarda granitic formation where the experimental site is located. Detailed information can be found in several available publications (e.g. Ávila Martins et al., 1963; Rodrigues, 2003; Cruz, 2010).

The experimental frame consisted in the execution of pairs of DPSH/SPT tests performed side by side, following the procedures recommended in Eurocode 7-Geotechnical design, part 3. A PDI SPT Analyzer equipment (1999) was used to measure the energy delivered to the rods of each DPSH and SPT blow and both tests were performed with the same equipment characterized by a 63.5 kgf hammer falling from 0.75 m height, which correspond to 476.3 J. The same rods were used in the execution of both tests, bore holes were performed without introducing casing and liners were not used in the SPT sampler. The blow frequency was the same in both tests (23 to 25 blows per minute). For comparing purposes, the number of blows considered in each test were taken at similar depths and the DPSH number of blows (N_{20}) was transformed (N_{30}), multiplying the earlier by 1.5, in order to have comparable lengths of determination.

After the execution of tests, the obtained field results were object of statistical treatment to analyse the energy efficiency and then globally compared in what concerns to the energy efficiency, field results at the same depth ranges and normalized parameters. The normalized SPT parameters followed the current procedures (expressed by eq. 1 to 3), while for DPSH similar correction factors were applied except for the borehole diameter correction, which was discarded since the test is not executed inside a borehole.

The granitic residual massif under study consistently reveals an increase of the penetration resistance with depth, which is well represented both by SPT and DPSH tests, although with different evolution rates (Figure 1).

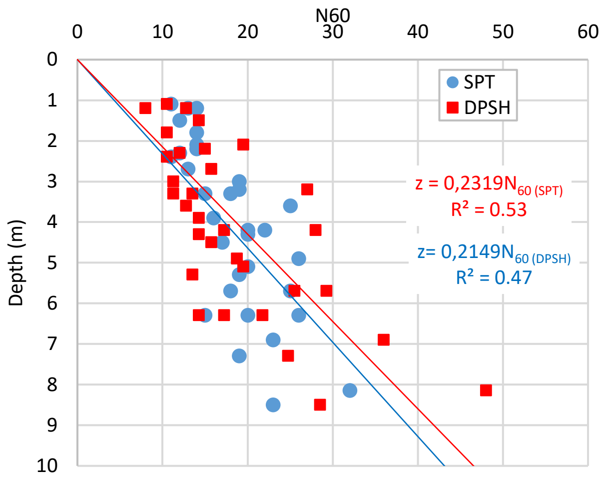

Figure 1. Evolution of penetration resistance with depth in the SPT and DPSH tests.

Compairing directly the global results of N_{20} with N_{SPT}, obtained at equivalent depths, it becomes obvious the (expected) lower blowcount of N_{20} (Figure 2), which is naturally justified by the different lenghts of penetration.

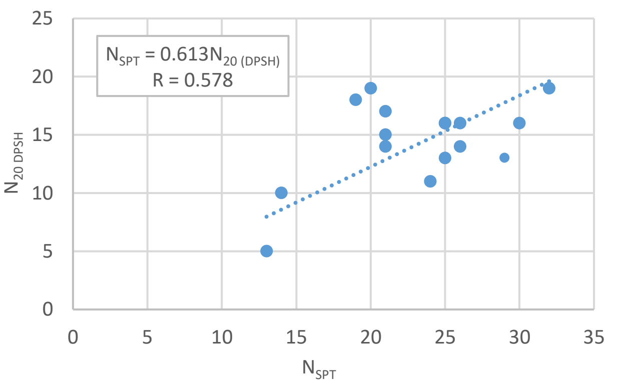

Figure 2. Relation between the penetration resistance N_{SPT} and N_{20}.

On the other hand, the experimental transmitted energy (ETR) results measured by the SPT Analyzer reveal that the delivered energy is not the same in each test (Figure 3), which can only be adressed to the different tip equipments (SPT sampler and DPSH cone) since all the other equipments are the same. In fact, the superficial contact area of the DPSH conic tip with the ground is constant the whole test (155.0 cm^2), while the area of SPT sampler varies according to a penetration length of 15 to 45 cm with internal and external contact with the ground (405.3 cm^2 a 1215.8 cm^2). The normalization of ETR by the N_{30} and N_{SPT} values seem to produce a more robust correlation between both tests (Figure 4).

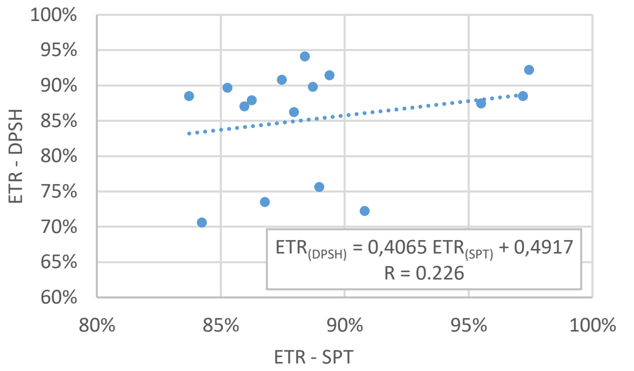

Figure 3. Relation between transmitted energy (ETR) in SPT and DPSH tests.

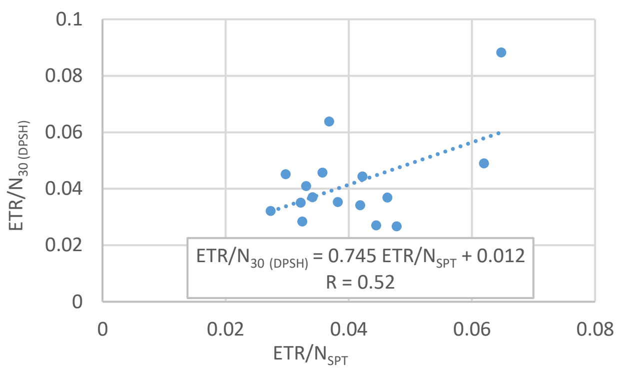

Figure 4. Relation between the ETR/N_{SPT} of SPT and ETR/N_{30} of DPSH tests.

The different obtained delivered energies seem to be related with the differences of contact areas, suggesting that higher contact generate a more efficient form to transfer to the soil the available energy generated by each blow. Figure 5 represents the mean ETRs obtained in the first, second and third 15 cm penetration phases of SPT tests and seems to corroborate the previous explanation, since the contact area of the SPT sampler with the soil is increasing with penetration.

As consequence, the comparison of normalized parameters instead of the simple blowcounts of each test is much more reliable, which is clearly proved by the diagram of Figure 6. Being so, if all the correction factors are applied, the normalized parameters obtained by both tests are equivalent, thus the available modes of correlation for SPT tests can be equally applied to DPSH tests. In the case of DPSH the C_B

factor (related with the diameter of borehole) should be considered equal to 1, while the remaining are applied as in the case of the SPT test.

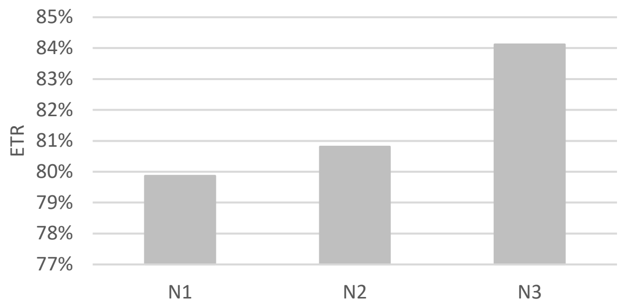

Figure 5. Evolution of ETR in the SPT tests.

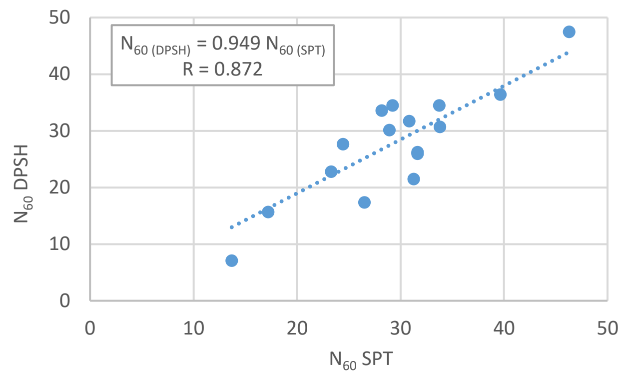

Figure 6. Relation between the N_{60} of SPT and $(N_{30})_{60}$ of DPSH tests.

3 CONCLUSIONS

The experimental frame presented herein clearly revealed that the energy efficiency is higher in the case of the SPT test than in the case of DPSH, which seems to be related with the higher contact area of the SPT sampler with the soil compared with the DPSH cone-soil contact. The higher the contact area the higher the energy efficiency. The comparison between normalized blow counts showed that the ratio between test results is basically equivalent. As consequence of the present findings, if the field work is performed with hammers of known (measured, calibrated) energy efficiencies (as it should) it is possible to obtain DPSH normalized parameters (considering C_B =1) that can be used in the current correlations settled for SPT tests. Naturally, this is a limited experience within certains strength and depth ranges, as well as in very specific geologic environment, and so the study should be enlarged to other geo-materials with other strengths and different test depths to validate this conclusions. For the time being, local calibration with 1 or 2 pairs of SPT-DPSH tests will allow to evaluate the sustainability of the findings presented herein.

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