Penetrometer testing in residual soils from granitic rocks in the South of Portugal

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ABSTRACT: In this study, residual soils from different types of granitic rocks with distinct mineralogy, texture and soil profile, were selected in the Alentejo region in the South of Portugal. On previously selected sites, some field tests were done, including penetrometer tests, namely SPT (Standard Penetration Test), CPT (Cone Penetration Test) and Dynamic Penetrometer with conic tip DP (Dynamic Probing), such as DPL (Dynamic Penetration Light), and DPSH (Dynamic Penetration Superheavy). The data from the same type of residual soil obtained by different penetration methods are analysed; also, a comparison is made between experimental results from the same penetrometer in several residual soils. The aim of this paper is to contribute to the knowledge of the *in situ* geotechnical characterization of granitic residual soils, which are typical of regions with a temperate climate.

1 INTRODUCTION

Of all the geological materials (rocks and soils), in which site characterization is important, and sometimes decisive, residual soils are undoubtedly the ones in which this kind of characterization is fundamental. These materials exhibit peculiar properties *in situ* due mainly to the inherited characteristics of original rock, such as mineralogy and structure, that strongly influence the geomechanical behaviour of these materials.

Sampling and transporting residual soils to the laboratory frequently affects their structure, and that is the reason why site characterization becomes so important in residual soils profiles. Carrying out *in situ* tests is fundamental to the study and investigation of residual soils; this is the way of assessing their characteristics in the natural state. This applies also to the residual soils from granitic rocks.

Penetrometer tests are the type of *in situ* testing frequently used in residual soils due to the suitability of these materials, with specific characteristics related to texture, strength and deformability; besides, these tests are generally easy to carry out (Blight, 1985, 1997).

The residual soils from granitic rocks of the Alentejo region, which is in the south of Portugal, show different characteristics depending on the original rock, climatic conditions and geomorphologic aspects that prevail in their formation. Therefore, the mineralogy and texture of granitic rocks, as well as the degree of weathering, will themselves reflect the structure characteristics (microstructure and macrostructure) of the soils and, consequently, the results obtained by *in situ* tests.

The residual soils from granitic rocks in regions of temperate climate, like those that occur in Portugal, are frequently very hard and compact materials, so the penetrability of some less powerful equipment may reach only a few meters below the surface (Viana da Fonseca, 1996). Profiles of granitic residual soil in a temperate climate frequently exhibit a heterogeneous weathering, with stiff zones (rock blocks or hard soils) inside soft zones, which may make difficult, and sometimes obstruct, penetration with some of these penetrometers. On the other hand, the soft zones coincide with relict structures like discontinuities inherited from original rock, and that are the preferable ways for water circulation to promote weathering in the surroundings.

Emphasis is made about the singular character of the penetrometer tests; the results reproduce very well what happens along the borehole, but may vary strongly in a distance of a few meters due to lateral heterogeneity of residual soils from granitic rocks in this region.

2 CHARACTERISTICS OF RESIDUAL SOILS

The present paper is part of a wider study of granitic residual soils of Alentejo in the South of Portugal (Duarte, 2002) which appear in an area of about 3250 km^2 and which are shown inside the square of Figure 1. Due to the considerable vastness of the working area, the graphics of penetrometer testing concerning only four profiles of representative soils from a total of sixteen areas of residual soils, whose sites are marked on Figure 1, were selected for this paper.

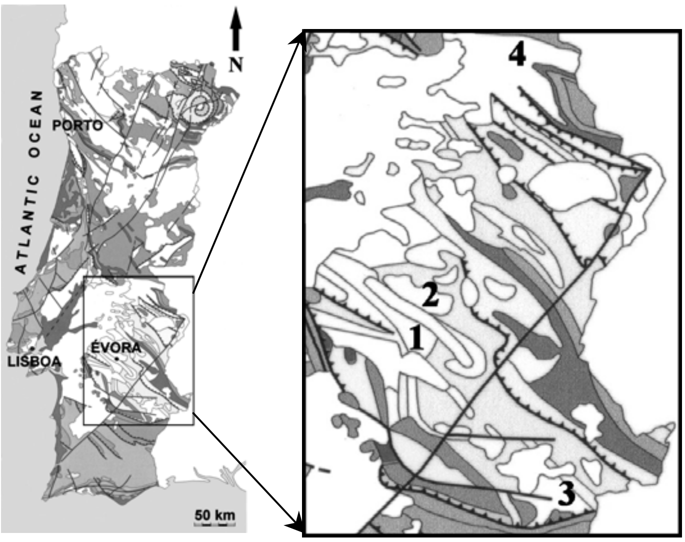

Figure 1 - The granitoid rocks in the South of Portugal. Selected sites: 1 - Évora; 2 - Arraiolos; 3 - Pias; 4 - Marvão.

The granite from Marvão, post-orogenic, is calc-alkaline, light grey, of medium to coarse grain, porfiroid, and it is located in a mountainous region; its residual soil is a white or sometimes grey-yellowish sand, which is visible in profile with a thickness of 12 m.

The granite from Pias is located 200 Km to the south of the granite from Marvão, in a flat area; it is a hercynic, calc-alkaline granite, of medium to coarse, light grey grain, biotitic; the profile of residual soil, with an approximate thickness of 8 m, is homogeneous but, with some joints inherited from parent rock, it exhibits a white silty sand.

The quartz diorite from Évora is biotitic, dark grey, of medium grain, resulting in a medium to fine, dark grey silty sand with a thickness of 8 m.

The quartz diorite from Arraiolos is of medium grain, dark grey, because of magnesium iron minerals; the profile with 5 m of thickness, with many rock blocks, consists of sand-silt, brown-yellowish soils.

A summary of the general characteristics of the tested soils is presented in Table 1 for a better understanding of the results obtained. Details of geological and geotechnical data can be found in Duarte (2002).

3 SITE INVESTIGATION

3.1 *Available data*

A summary of DPL (Dynamic Penetration Light) testing in residual soils from granitoid rocks of the region is presented in Figure 2, in which N is the number of blows obtained in the DPL testing. Test equipment characteristics are presented in Table 2.

From the analysis of the data obtained in 79 testings using light penetrometers, it can be observed that this type of penetrometer rarely surpasses the 2.5 metres of depth in this kind of residual soil from granitoid rocks. It is also clear that the great majority of testing reaches 60 blows or more in a depth between 1 and 2 metres approximately.

The above-mentioned testing, from several places, sometimes separated by hundreds of kilometres, clearly reveals the limited penetrative power of the DPL in the aforesaid soils. The thickness of these residual soils goes far beyond the depth reached by this method, stopping quite far from the bedrock and its progress is prevented, not only by the existence of erratic residual blocks of rock, but mainly by the high frictional resistance and reduced deformability intrinsic to these residual soils.

Table 1 - General characteristics of the tested soils.

RESIDUAL SOIL	w_o (%)	γ_d (KN/m^3)	PARTICLE SIZE (mm)			w_L (%)	I_P (%)	CLASSIFICATION		γ_s (KN/m^3)	e_o	ϕ (o)
			< 2.00	< 0.425	< 0.075			USCS	A.A.S.H.T.O.			
Évora	8.5	16.08	94.94	57.32	27.62	42	6	SM	A-2-5	26.87	0.671	32
Arraiolos	8.0	16.87	95.30	54.40	22.60	28	2	SM	A-2-4	26.38	0.564	35
Pias	16.8	16.28	68.60	33.84	17.67	42	15	SM	A-2-7(0)	26.09	0.602	30
Marvão	9.2	15.59	84.72	42.95	17.05	33	2	SM	A-1-b	26.28	0.686	33

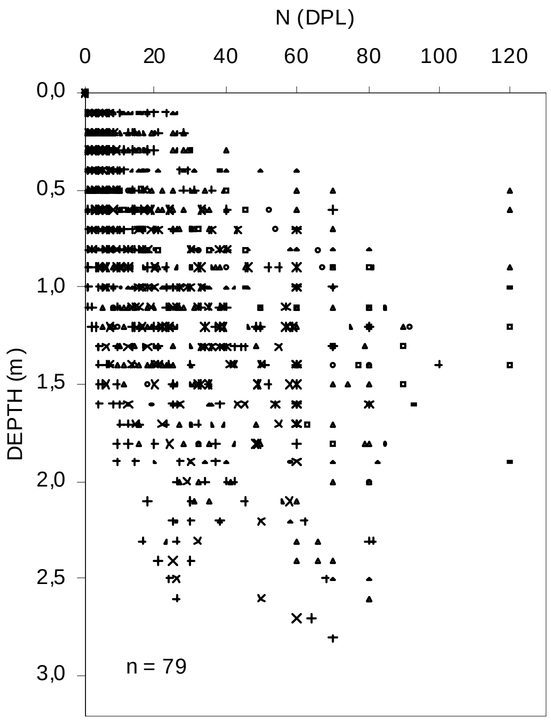

Figure 2 - Results of the DPL testing in granitic residual soils from Alentejo.

Three hundred and seventy-nine testings were made during the project phase of the A6- highway, which intercepts the eruptive massif of Évora and its residual soils (Figure 3). As far as the variation in the value of SPT in relation to depth is concerned, it can be easily observed that in the first 3 metres of depth, in almost half of the testings, values superior to 50-60 N were obtained; in 28% of the cases, values inferior to 30 N were obtained (loose to medium compact soils) and in the remaining 24% of testings, results between 30 and 50 N_{SPT} were obtained (compact soils). From this depth on, the great majority of testings (90% of the cases) produced results superior to 50-60 N_{SPT}, which correspond to very compact formations.

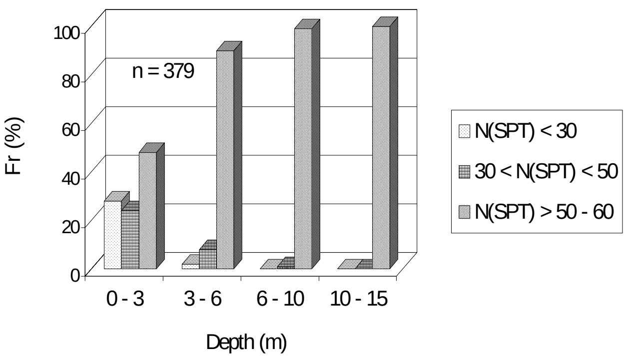

Figure 3 - Variation of N_{SPT} with the depth in granitic residual soils from Alentejo.

Table 2 - Test equipment characteristics

Designation	DPSH	DPL
Hammer mass (kg)	63.5	10
Fall height (cm)	75	50
Cone section (cm^2)	20	7
Rod mass (kg)	5.1	2.0
Cone angle (degree)	90º	60º
Rod diameter (cm)	3.2	2.2
Number of blows for standard penetration	N_{20}	N_{10}

3.2 *Results and analysis*

The site investigation started with the DPL, because it is the simplest, the quickest and the most easily transportable. The SPT, DPSH and CPT testings were performed with equipment constructed by Pagani, model TG 63-100, according to the suggested procedures of ISSMFE.

3.2.1 *Residual soil from Évora quartz diorite*

In the vast area of residual soils from the granitic massif of Évora (500 Km^2), a site was selected where the testings represented in Figure 4 were done. It can be verified that the depth reached by two tests with light penetrometer was of 2 metres. The SPT reached 60 blows at 2.5 metres and the DPSH at 5 metres, twice the previous depth, but stopping before the estimated thickness for the residual soil of this profile, which is of approximately 8 metres.

It is clear that the DPL testing is more sensitive to the heterogeneity than the DPSH testing, and that can be justified by the bigger energy of impact, intrinsic to this last testing, which allows it to surpass the obstacles more easily. On the other hand, the evolution of the two DPL testing with at depth is somewhat different; in spite of the precaution of doing all the testings near each other, with a distance between them of usually 0.5 m and a maximum of 1 m, the enormous heterogeneity verified on the horizontal plane in these profiles of residual soils should be pointed out.

The increasing resistance observed at 3 m in the DPSH, shows that in these soils it is advisable to go on with the testing, because this high resistance is a localised phenomenon and it does not reproduce the resistance of the matrix of the soil, because immediately afterwards, there is a sudden break in the resistance, which reveals a more homogeneous behaviour until the end of the testing.

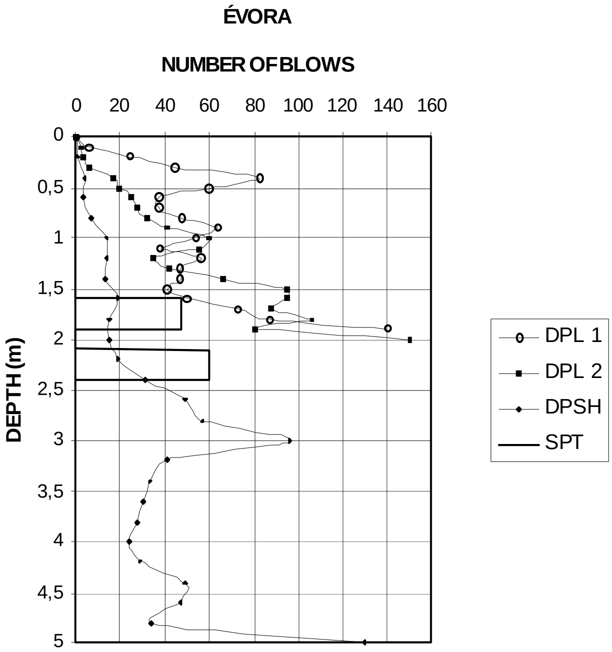

Figure 4 - Results of the tests with dynamic penetration in the residual soil of Évora quartz diorite.

3.2.2 *Residual soil from Arraiolos quartz diorite*

The maximum depth attained by the DPSH test on the quartz diorite residual soil of Arraiolos, was of 3m (Figure 5), which is in accordance with the thickness of the soil observed at the site of the testing, approximately 4 m. It has to be stressed that, in all the surrounding area, the sudden transition from residual soil to sound rock, rock massif or blocks with a diameter bigger than 2 m is clear.

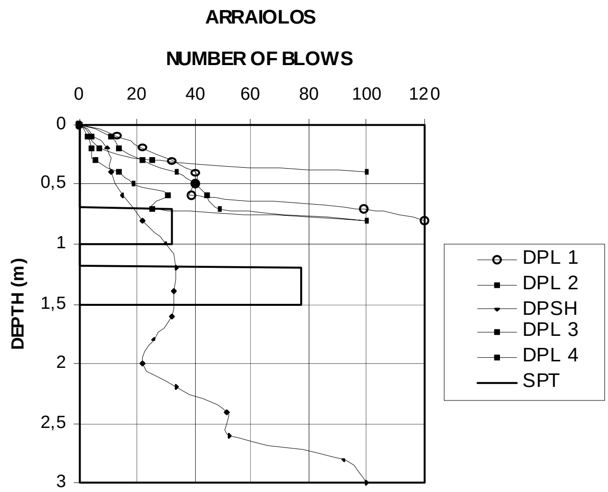

Figure 5 - Results of the dynamic penetration testing in the quartz diorite residual soil of Arraiolos.

The results of the DPL testing confirm the lateral heterogeneity of the profile, though they indicate a bigger vertical homogeneity compared to the residual soil of Évora quartz diorite. The SPT surpassed the 60 blows for a depth that is of about half the one reached by the DPSH.

3.2.3 *Residual soil from Pias granite*

On top of the slope of the residual soil from Pias granite, it was possible to do three DPL testings, two DPSH testings (Figure 6) and one CPT testing (Figure 7). As can be seen through the respective digrams, the testing with light penetrometers, as well as the CPT, stopped at a depth inferior to 1.5 m, which is frequent in this type of residual soil, while more powerful methods like DPSH reached 7.5 m.

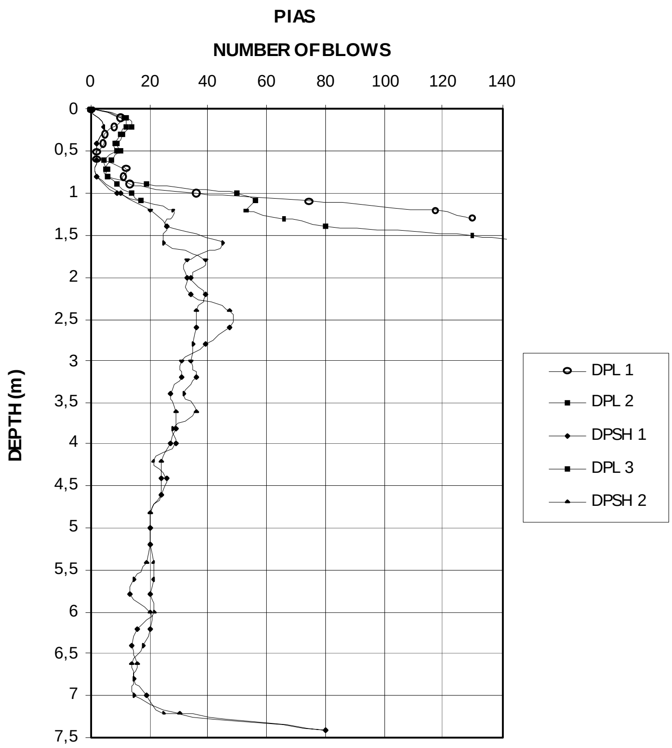

Figure 6 - Results of the testing with dynamic penetration in the residual soil from Pias granite.

The two DPSH tests reflect a certain vertical and horizontal homogeneity of resistance *in situ* of the residual soil from Pias granite, which is in accordance with the textural, physical and mechanical characteristics of these soils (Table 1). It cannot be forgotten that they are mainly sand-silt, sometimes sand-clayed soils, with a significant percentage of fine, due to a complete alteration of the feldspars. This explains its soft and friable aspect, which is related to the low resistance verified mainly at depths between 4 and 7 m, where subhorizontal joints can be observed in the slope, around which the soil appeared quite damp.

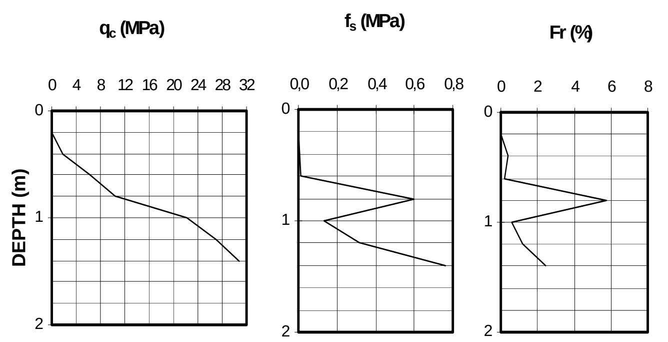

Figure 7 - Graphics of the testing with static penetration in the residual soil from Pias granite.

3.2.4 *Residual soil from Marvão granite*

In the slope of a granitic residual soil from Marvão, it was possible to apply the four penetrometric methods planned for this site investigation, with a maximum of 0.5 m distanced between them, thus allowing a comparative analysis between different methods.

The depth reached by the different methods (at the biggest of all the testing sites) is due mainly to the characteristics of the sandy-silt residual soil forming a vertical and lateral homogeneous profile concerning granularity, with the exception of some oblique discontinuities (Duarte *et al*., 2000).

From the analysis of Figure 8, it can be concluded that, with the superheavy penetrometer, a greater depth can be reached, almost double the one achieved by a light penetrometer, in this kind of soil. On the other hand, this last testing is very susceptible to the heterogeneity of the ground, which is the result of the presence of small fragments of rock, “relic joints” filled with materials, with a different resistance, etc.

In the SPT testing, in spite of using the same hammer as in the DPSH testing, the standard split-spoon sampler (Terzaghi sampler) has got a less penetrative power than the DPSH cone, offering a bigger lateral resistance, so there is a bigger dissipation of energy due to the drill rods and sampler. The difference verified between the two testings increase with the depth.

CPT testing (Figure 9) is very sensitive to granular soils, and the depth reached is limited by the more resistant zones, which is common in these profiles. The anchorage of the machine is difficult in these residual soils. However, the advance of the CPT in depth produced very similar results to those of the DPL testing, even at the same depth.

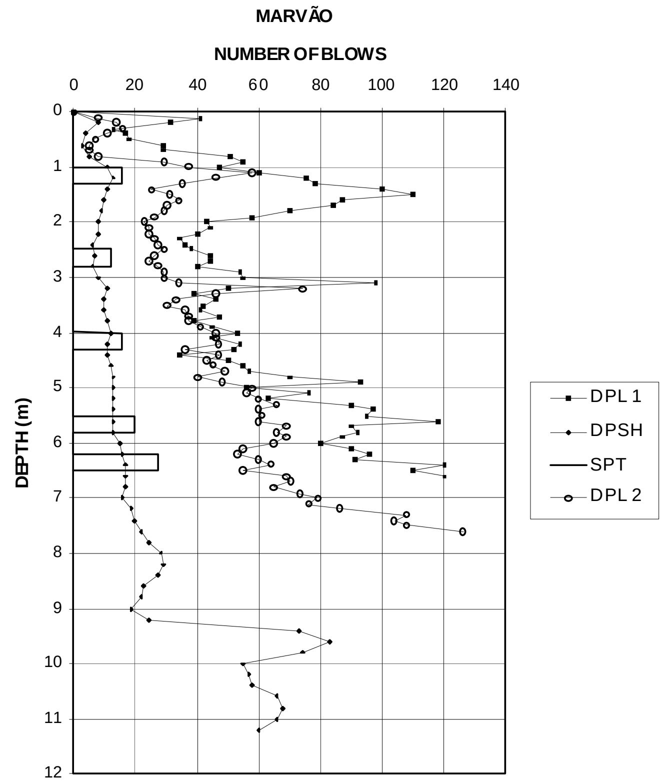

Figure 8 - Results of the testing with dynamic penetration in the residual soil from Marvão granite.

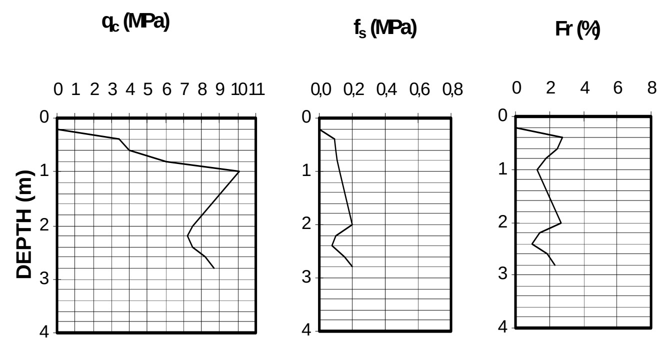

Figure 9 - Results of the testing with static penetration (CPT) in the residual soil from Marvão granite.

4 CONCLUSIONS

From the penetrometer testing in areas of residual soils from granitic rocks, typical of regions of temperate climate, the following can be positively established:

i) it is clear that there is a bigger sensitivity to heterogeneity by the DPL, compared to the DPSH, which can be explained by the bigger impact energy of the latter, which allows it to surpass the most resistant zones more easily;

ii) the variety of values concerning the testing performed with the same penetrometer is due to the great horizontal heterogeneity in these profiles of residual soils from a temperate climate;

iii) these testings give occasional results in quite heterogeneous areas, which will be investigated; it is not advisable to make general considerations from the few occasional testings in profiles and soils that are typically heterogeneous;

iv) with the superheavy penetrometer (DPSH), depths can be reached almost double those achieved by the light penetrometer; however, the DPL testing is much more sensitive to the heterogeneity of the ground, such as small fragments of rock, and “relic joints” filled with materials of a different resistance;

v) in SPT testing, in spite of using the same hammer as in DPSH testing, the standard split-spoon sampler (Terzaghi sampler) has got a less penetrative power than the DPSH cone, and it offers a bigger lateral resistance, so there is a greater dissipation of energy due to the drill rods and sampler; the difference between the two testings increases with depth; the SPT is much slower, because it is necessary to take the sampler after each testing at a certain depth;

vi) the CPT is very sensitive to granular soils, and the depth reached is limited by the more resistant zones, as usually happens in soils resulting from the alteration of granite;

vii) in short, the DPSH has proved to be the most suitable for testing penetration into residual soils from granitic rocks, because more than achieving a greater depth, it can provide a continuous record of the resistance to penetration.

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