Use of CPT and CPTu for soil profiling of "intermediate" soils: a new approach

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ABSTRACT: The aims of this study were 1) to assess the applicability of the most popular correlations, used for soil type identification and soil stratigraphy description, in some Italian sites and 2) to propose a new method for identifying "intermediate" soils. CPT, CPTu data, belonging to different geological contexts, were collected from published reports or obtained from tests carried out with a Pagani penetrometer (with a Pagani piezocone for CPTu and a Begemann mechanical cone for CPT). Soil profiles have been established through borehole-logs. In addition, laboratory investigation helped in the geotechnical characterization of the soils. Classification charts proposed by Robertson et al. (1986), Robertson (1990) and Eslami & Fellenius (1997) were used in the case of CPTu's. Borehole logs were compared with soil profiles inferred from cone penetration test results. A percentage of success was calculated for each method. All the methods were not able to correctly identify "intermediate soils" i.e. soils relatively impervious like silty soils where the penetration occurs under the condition of partial drainage. A new method to improve the identification of this type of soils is proposed. The method consists in the performance of two contiguous CPTu run at different penetration rates.

1 INTRODUCTION

Cone penetration tests (CPT and CPTu) are well-established in situ test methods for site characterization. Tip resistance (qc), sleeve friction (fs) and (in the case of CPTu) the pore water pressure (u) are continuously measured during penetration. The indicated parameters are used to empirically infer soil profiling through the use of soil classification charts. Several classification charts, based on different database (Begemann 1965, Searle 1979 and Schmertmann 1978 for CPT and Robertson et al. 1986, Robertson 1990 and Eslami & Fellenius 1997 for CPTu) or non traditional approaches (Zhang & Tumay 1999, Kurup & Griffin 2006), are available in literature.

The aims of this study are:

- to assess the applicability of the most popular correlations, used for soil type identification and soil stratigraphy description, in some Italian sites;

- to develop a new method to improve the identification of mixtures of fine-grained soils having intermediate values of permeability and where the penetration mainly occurs under the conditions of partial drainage.

An existing, already published, database has been used in order to assess the validity of existing classification charts (Lo Presti et al. 2009). The main conclusions from the above mentioned paper are summarized in the next section. In addition two test sites were investigated to verify the newly proposed method, which requires the performance of two contiguous CPTu run at different penetration rates.

2 EXISTING DATABASE

CPT, CPTu data, approximately 6-23 m deep, from 9 different Italian sites, belonging to different geological contexts (lacustrine organic soils, very heterogeneous alluvial lacustrine soils, terraced alluvial soils, recent alluvial soils, alluvial fan soils, estuarine - marine soils) were collected from published reports or obtained from tests carried out with a Pagani penetrometer (TG 63-100, TG 63-200, TG 73-200) (Pagani 2009). The test equipment consists of 60° cone (piezocone for CPTu and Begemann mechanical cone for CPT), with a 10 cm^2 base area and a 150 cm^2 friction sleeve located above the cone. The filter position for pore pressure measurements is behind the cone tip (u2). CPTu were carried out at constant speed of 2 cm/s. The pushing equipment consists of hydraulic jacking and reaction system mounted on a heavy lorry with screw anchors. The thrust capacity is of 100 to 200 kN. The field data acquisition system includes analogue to digital converters. The piezocone provides values of cone resistance, sleeve friction and pore pressure every 1 cm.

Soil profiles have been established through borehole-logs. In addition, laboratory investigation helped in the geotechnical characterization of the soils. Laboratory tests included classification tests, oedometer, triaxial and direct shear tests. In some sites, penetration tests were repeated in different periods of the year (dry and wet period) and with the use of different fluids for the filter saturation (silicon oils and glycerine).

The classification charts proposed by Begemann (1965), Searle (1979) and Schmertmann (1978) were used in the case of CPTs. Classification charts proposed by Robertson et al. (1986), Robertson (1990) and Eslami & Fellenius (1997) were used in the case of CPTu's. The CPT and CPTu-based charts were predictive of soil behaviour type (SBT), since the cone responds to the in-situ mechanical behaviour of the soil and not directly to soil classification criteria based on grain-size distribution and soil plasticity (Robertson 2009).

A percentage of success was calculated as the ratio between the numbers of interval correctly classified in a soil category/total number of intervals of the soil category.

From the analysis of the above described database the following main conclusions were drawn (Lo Presti et al. 2009):

- All classification methods allow to detect stratigraphical boundaries.
- The success rates are different.
- The classification charts are not applicable in partially saturated soils (especially fine soils) because of the soil suction which modify the effective stress state. Ap-

plication of the classification charts under these conditions leads to an overestimate of the soil grain size.
- The success rates are good for saturated homogeneous soils, particularly for soft clay or organic soils. For silty clays or soft silty sands the classification charts mis-classify the soil type.

In detail it has been possible to see that:
- CPT interpretation charts (Begemann, Schmertmann and Searle) usually identify peaty soils (78% of rate of success) but they show unsatisfying results for mixed silty soils (0-28%).
- Robertson et al. (1986) chart correctly identify 100% of organic soils, clays and sands, whereas most of intermediate soils (such as clayey silt and sandy silt) are not recognized, with percentages of success that range from 50% to 0%.
- Robertson chart (1990) shows results comparable to the previous chart.
- Eslami & Fellenius chart (1997) does not present high rates of success for mixed soils, while clay and sand shows satisfying results (rate of success up to 100%).

3 ADDITIONAL TEST SITES

CPTu were carried out at two different sites in order to verify the proposed method and more specifically to observe the influence of different penetration rates on the test results in different soil types. Therefore, two contiguous CPTu were carried out at each site using two different penetration rates (2 cm/s and 1 cm/s). The distance in plan between the standard CPTu and that carried out using a reduced penetration rate was about 1 m. A borehole was also available for each site. The distance in plan between CPTu and borehole locations is 4 m. Figures 1 to 2 compare the stratigraphy inferred from the interpretation of standard CPTu by means of Robertson (1990) chart and that obtained from borehole. The results obtained in each site with standard and reduced penetration rates are compared in Figures 3 to 6.

The site 1 corresponds to alluvial – lacustrine deposits of the Serchio River in Paganico (Lucca Tuscany). The upper layer, of variable thickness, is mainly an alluvial deposit consisting of silty sands or sandy silts and overlying the lacustrine deposit (clay and silty clay) (Fig. 1).

The compared CPTu tests reached a maximum depth of about 6 m.

The interpretation of the standard CPTu probe (Fig. 1) with Robertson chart (1990) correctly identifies “sandy silts”, “clayey silts” and “sand and gravel”; only “clayey-sandy silts” (from 2 m to 3 m) are misclassified.

The site 2 corresponds to the continental-marine sediments of the Livorno coastal plain (Tuscany), which deposited during multiple cycles of sea ingression and regression (Fig. 2).

The compared CPTu tests reached a maximum depth of about 21 m.

The CPTu was interpreted with Robertson chart (1990); we obtain a proper classification of most of the tested soils, and only intermediate soils (5.1-7.5 m and 10-10.5 m) shows unsatisfying results.

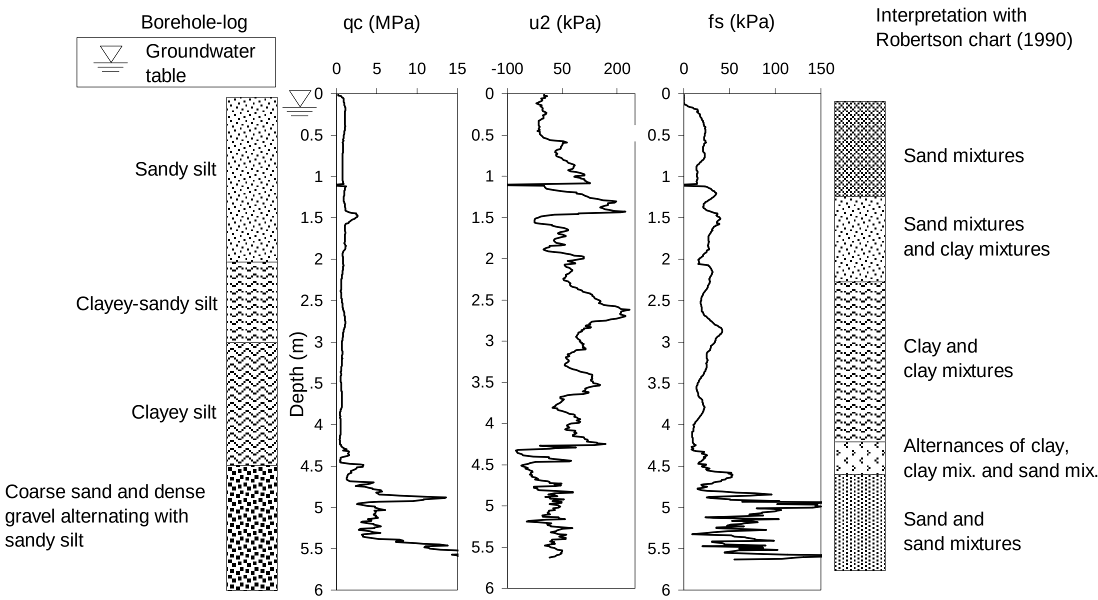

Figure 1. Site 1 (Paganico). Standard CPTu (2 cm/s) compared to a near borehole-log.

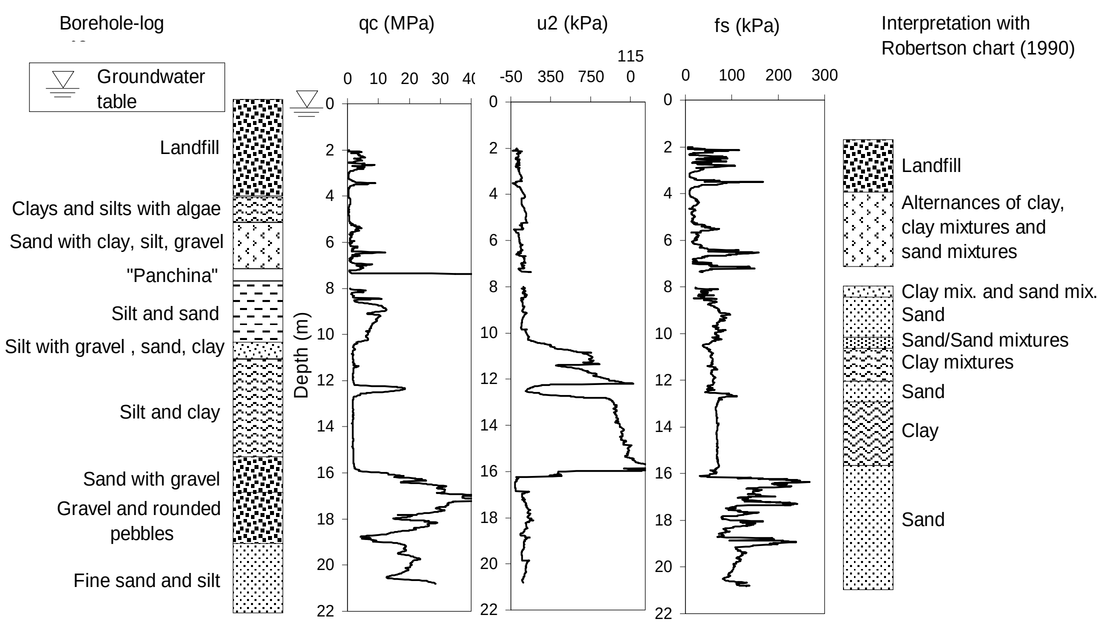

Figure 2. Site 2 (Livorno). Comparison between the CPTu carried out with the standard penetration rate (2 cm/s) and a nearby borehole-log.

4 EFFECTS OF THE PENETRATION RATE ON TEST RESULTS FOR DIFFERENT SOIL TYPES

It is possible to consider the following working hypotheses:

- for any type of soil and for the considered penetration rates (2 cm/s and 1 cm/s) it is possible to assume partial drainage conditions;
- for the standard penetration rate (2 cm/s) it is possible to simplify assuming “undrained conditions” for clays, “drained conditions” for sands and “partially drained conditions “ for intermediate soils;
- the reduced penetration rate should cause a reduction of sleeve friction and tip resistance because of creep effects. Moreover, creep effects could be responsible for an increase of pore pressure;
- the reduced penetration rate should produce an increase of tip resistance and sleeve friction when approaching the drained conditions. For the same reason it is possible to expect a reduction of pore pressure in the case of a reduced penetration rate;
- in conclusion, using a reduced penetration rate, we expect an increase of tip resistance and sleeve friction in intermediate soils, if the effects related to the drainage conditions prevails over creep effects. We also expect a reduction of pore pressure. Therefore we expect to observe effects of reduced penetration rate in sandy – clayey silts and almost negligible effects in clay and sands.

Figures 3 and 5 show the variation of qc, fs and u2 experimentally observed in the case of CPTu carried out at reduced penetration rate in the two sites. Variations are expressed as percentages and are computed after the application of a moving point average based on 10 values. Some extreme values are probably due to local soil heterogeneities. Some systematic increase or decrease of the measured values enable us to draw preliminary conclusions.

More specifically the slower probe carried out at Paganico shows (Figs 3 and 4):

- from 0 to 2 m a decrease of pore pressure (-138 %) and an increase of tip resistance (30 %) and sleeve friction (40 %), as expected in sandy silts;
- from 2 to 4.5 m negligible variations of resistances (7-9 %) and pore pressures (3%), probably related to the presence of clayey-silty soils (Fig.1);
- from 4.5 to the end of the probe strong differences of qc, fs and u2 between the standard probe and the slower probe. Those changes are not due to the different penetration rate but to local lithological heterogeneities.

In the Livorno site the comparison between the two penetrometric tests highlights the following intervals (Figs 5 and 6):

- from 5 to 10 m (borehole log: intermediate soils) there is an increase of tip resistances (43 %) and sleeve frictions (46 %) whereas pore pressures decrease (-129 %);
- from 10 to 15 m (borehole log: clayey soils) the variation of qc (2 %), fs (-4%) and u2 (18 %) seems negligible, as expected;
- from 15 m to the end of the probe (borehole log: sandy soils) the differences between probes are probably due to local lithological differences.

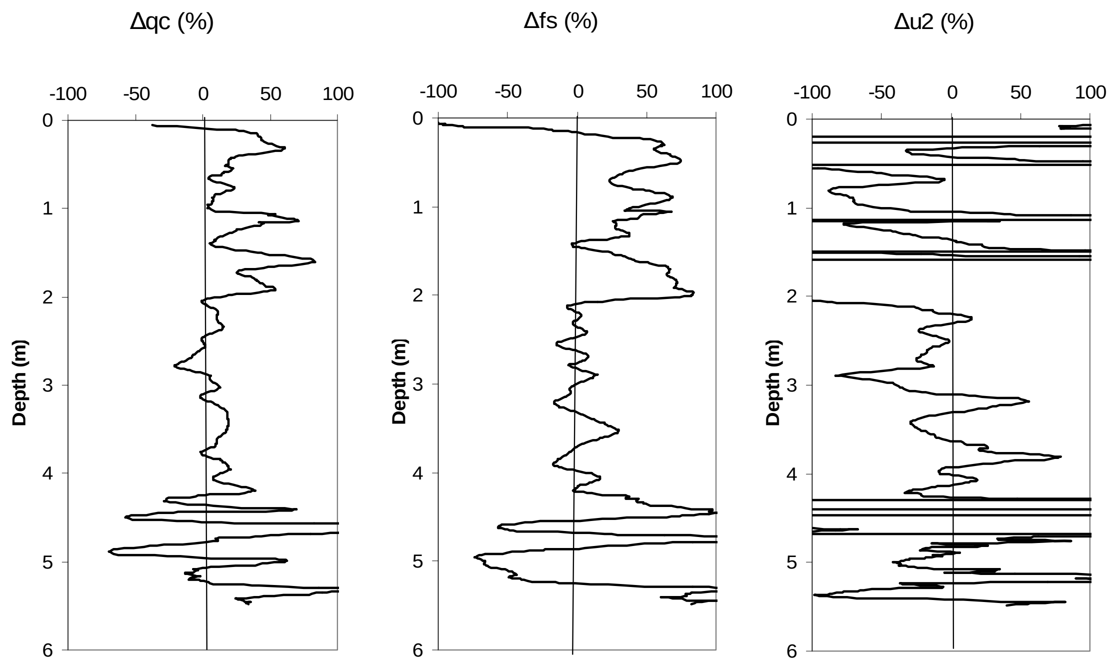

Figure 3. Site 1 (Paganico). Variations of qc, fs and u2 between 2 cm/s and 1 cm/s expressed as percentages.

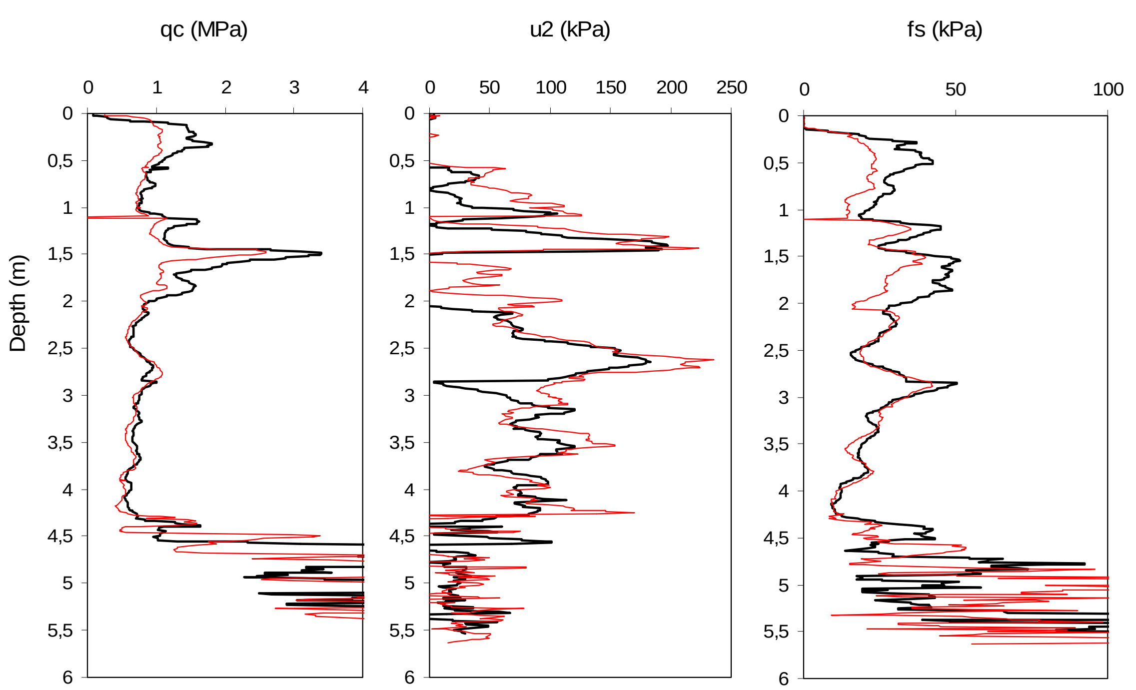

Figure 4. Paganico. Comparison of the standard rate (red line) and the slower rate (black line).

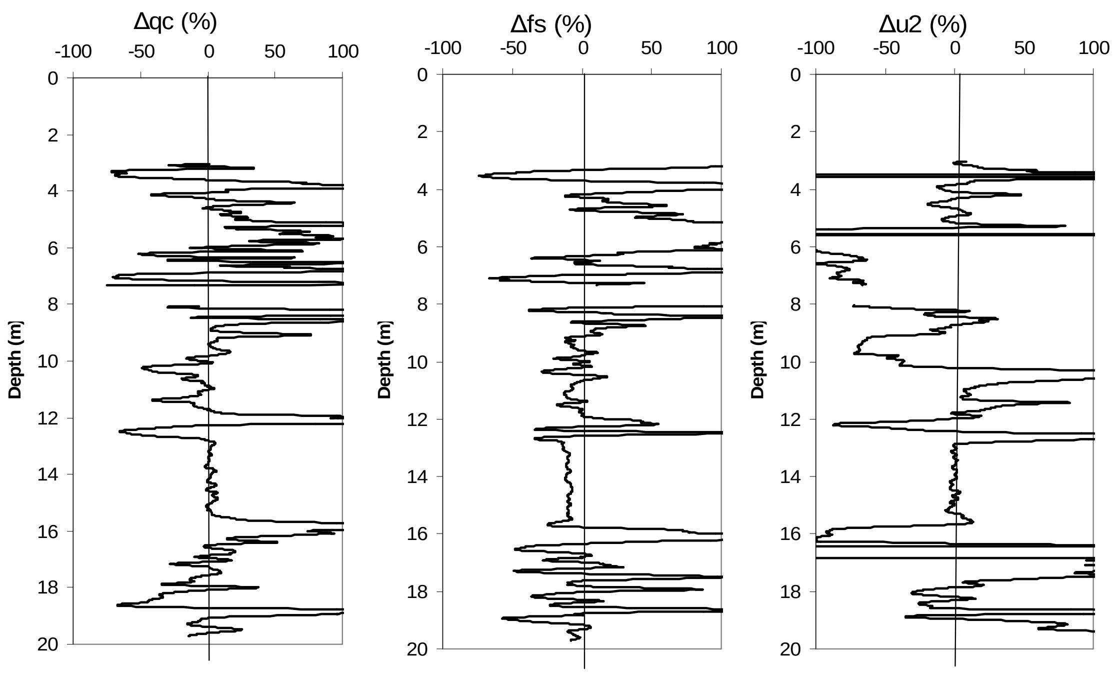

Figure 5. Site 2 (Livorno). Percentage variation of qc, fs and u2 between 2 cm/s and 1cm/s.

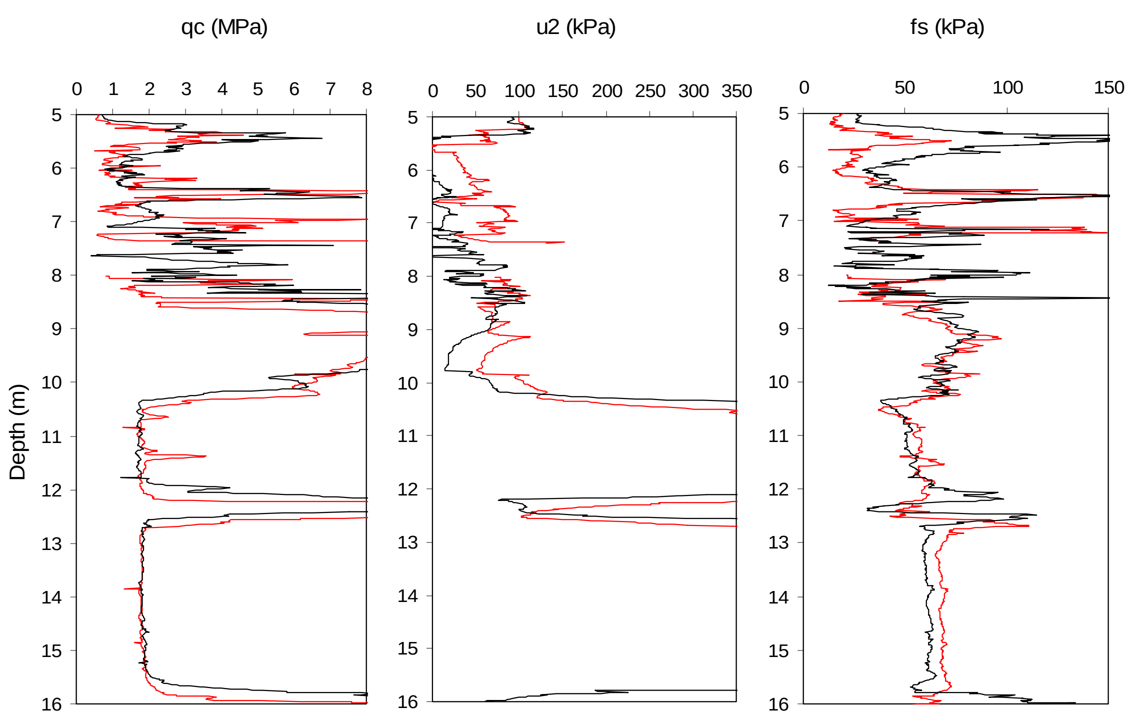

Figure 6. Livorno. Comparison between the slower rate (black line) and the standard rate (red line).

5 PROPOSED METHOD AND CONCLUSIONS

The problem of misclassification of intermediate soils (silt, clayey silt, sandy silt,…) generally can be solved with dissipation tests (Robertson 1990) which can significantly aid in identifying soil behaviour type, but dissipation tests are often time-consuming.

Based on the results of this study we propose a new and faster experimental approach, based and the execution of two contiguous CPTu probes with different penetration rates. The first probe will be carried out at the standard penetration rate (2 cm/s), while the other at a slower speed (1cm/s).

Even though a partially drained penetration will continue to occur at the lower penetration rate, based on the results shown in the previous section we expect that:

- in “intermediate” soils both sleeve friction and tip resistance will increase, while the pore pressure will decrease;
- in “clay” and “sand” the above effects will not appear.

Therefore it will be possible to identify the “intermediate” soils by comparing, at an appropriate scale, the results of the two tests.

In practice it seems more useful to consider the comparisons of sleeve friction and pore pressure than that concerning the tip resistance. In fact, the tip resistance increase is less evident. This is because while the tip resistance increases approaching the drained conditions it decreases with the pore pressure.

At the moment the proposed method represents just a working hypothesis that need further research activity and assessment in order to be validated.

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