Experimental In Situ Test Sites

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ABSTRACT: The IST-SUPSI has promoted the construction of two experimental test sites in the southern part of Switzerland in order to compare the results of the most commonly used in situ tests. The Gordola site is characterized by alluvial and deltaic deposits while the Stabio site presents alternating fluvial and lacustrine deposits, both recent and of glacial origin. Even though the program is still in its initial phases and the results obtained remain to be confirmed and eventually adapted to the various regional situations, the developments of the DPSH with casing seem promising, especially for lithological and geotechnical interpretation of the soils encountered. Hopefully this will encourage greater use. Similar considerations can be made for a proposed non-conventional SPT.

1 TEST SITES: CONCEPT DESIGN

The experimental sites established in the Canton of Ticino were settled out to attain the following objectives, listed in order of priority:

- compare results obtained from different in situ tests,
- have sites available for the certification of local operators in this sector,
- organize training courses for technical personnel and continuing education courses for engineers and geologists,
- verify the reliability of assessed geotechnical parameters with full scale test on surficial and deep foundations.

The execution of in situ tests was arranged in a 12 m diameter circle with a control borehole in the center (see stratigraphies in Fig.1). Until today only the first objective has been partly accomplished; despite this limitation, the obtained results provide some new insights.

2 TEST SITES: GEOLOGICAL OVERWIEW

2.1 *Gordola*

This field test site located near the Maggiore Lake, is characterized by alluvial sediments formed after the retreat of the Würmian glaciers (10'000 years B.P).

The surficial deposits of humus and man made fill, are underlain by sand and then by gravel deposited by the meandering Ticino River nearby flowing.

Lateral sedimentation basin zones deposits with clayey organic silt are then found, followed by sand and silty sand deltaic deposits with coarse stratification down to depths exceeding 30 m. (as confirmed by previously drilled boreholes).

The parent rocks are ortho and paragneiss with high content of micaceous minerals, thus giving to the deposits an high degree of anisotropy.

2.2 *Stabio*

This test site, located between the Lugano Lake and the Würmian frontal moraine, is characterized by a succession of fluvial and lacustrine deposits of both recent (between 3000 and 11000 years BP, organic silts) and glacial age.

Also at this site, surface deposits made up of humus and man made fill overly recent alluvium constituted primarily of sandy gravel.

Lacustrine deposits formed of clayey organic silts and silty sands and/or sandy silts with marked stratification, are then found, followed by fluvio-lacustrine deposits with alternating strata of silty sand and sandy gravels (Würmian).

Finally we found lacustro-glacial silty sands (Würmian Interstadial - Allogruppo di Besnate).

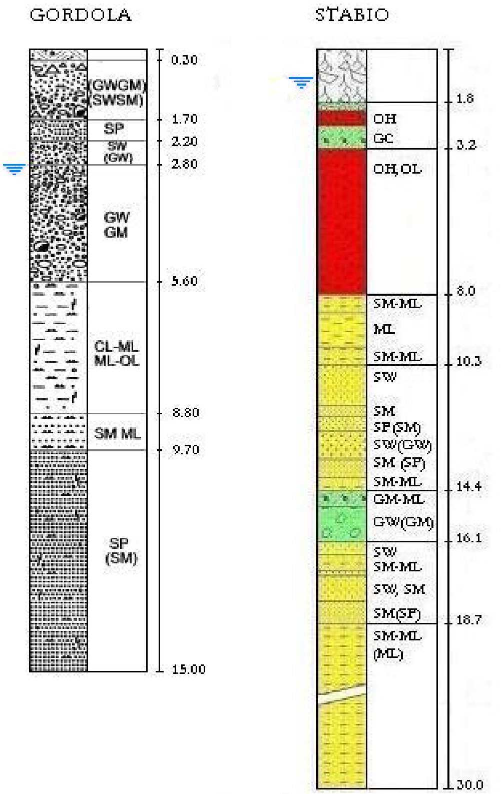

Figure 1. Boreholes stratigraphy

3 IN SITU TESTS CARRIED OUT

3.1 *Statically pushed tests (rate 20 mm/sec) with manual (CPT and DMT) or automatic (CPTU) recording: basic features (Fig. 2)*

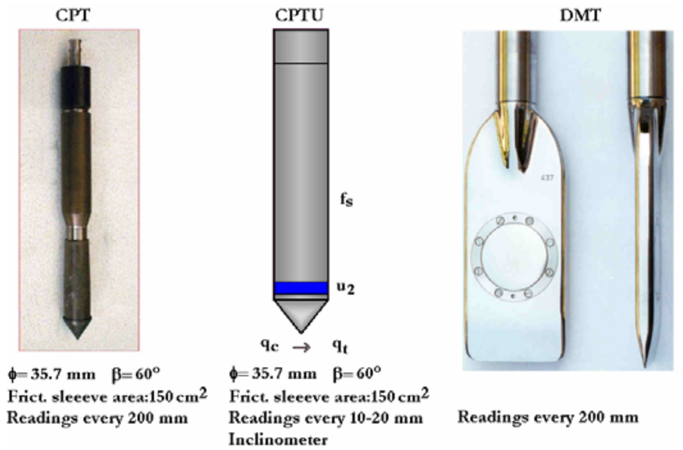

Figure 2. CPT, CPTU and DMT

3.2 *Dynamic penetrometers*

The distinctive characteristics of these equipment, shown in the following table, correspond to the light to medium penetrometer used in Switzerland (SNV 670417) and to the heavy penetrometer included in the European draft standard currently under way (pREN22476-2). Unique to the equipment used is the casing applied to eliminate skin friction on the rods (Fig.3).

Pagani Equipment			TG 30-20	TG 73-200
DP type			DPL/M	DPSH
Hammer	(***M***)	kg	30	63.5
Fall Height	(***H***)	cm	20	75
Cone: diameter		mm	35.7	50.8
β		°	60	60
Area	(***A***)	cm^2	10	20
Rod: diameter		mm	20	32
length		mm	1000	1000
weight	(***m***)	kg	2.4	6.5
Blow aver. penetr.	(***e***)	cm	$10/N_{10}$	$10/N_{10}$
Casing : diameter		mm	33	48
length		mm	1000	1000
weight		kg	3.5	5.5
Blow aver. penetr.		cm	$20/N_{20}$	$20/N_{20}$
Efficiency		%	-	73

Table 1. Dynamic penetrometers features

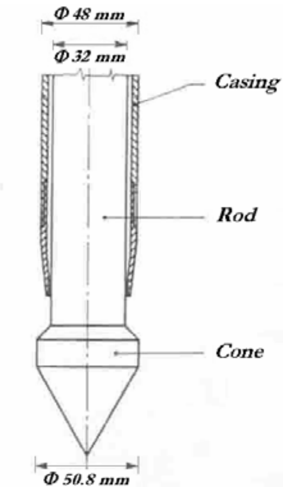

Figure 3. DPSH cased rod

The DP tests results were processed as follows:

$$r_d = \boldsymbol{MH}/(\boldsymbol{e}\ \boldsymbol{A}_{cone}) \quad (1)$$
$$q_d = \boldsymbol{M}^2\boldsymbol{H}/\{\boldsymbol{e}\ \boldsymbol{A}_{cone}\ [\boldsymbol{M}+(\boldsymbol{m}\ Depth)]\} \quad (2)$$

$$q_{c\ equiv.} = \alpha\, r_d \qquad [0.3\ (\text{clay}) \leq \alpha \leq 1.2\ (\text{gravel})] \quad (3)$$

$$f_d = \boldsymbol{MH}/[(Depth/\Sigma N_{20})\ A_{shaft})] \quad (4)$$
$$f_d \leq f_{s\ equiv.} = f_d\ 0.6\ ln\ (N_{20}) \quad (\text{all soils}) \quad (5)$$

Explanatory notes:
1) it was decided to measure, as well for DPSH, the value N_{10} (point resistance) in order to obtain a more detailed profile.
2) Equations 1 and 2, both well known (Dutch's formula), do not require explanation while the successive (3 to 5) are only tentatively, considering the limited number of available tests.
3) The aim of determining the quantities $q_{c\ equiv}$ and $f_{s\ equiv}$ is that of reconstructing a reliable soil profile in the same way of CPT and CPTU. In case of positive result the values so obtained can be considered sufficiently approximated and finally utilizable for a

corrected geotechnical interpretation also for DPSH, using the algorithms developed for CPT and CPTU.

4 IN SITU TESTS: RESULTS COMPARISON

4.1 *CPTU vs. CPT and CPTU Soil Profiles*

An analysis of Figures 4 and 5 confirm that the only reliable value obtained in CPT is the point resistance (q_c).

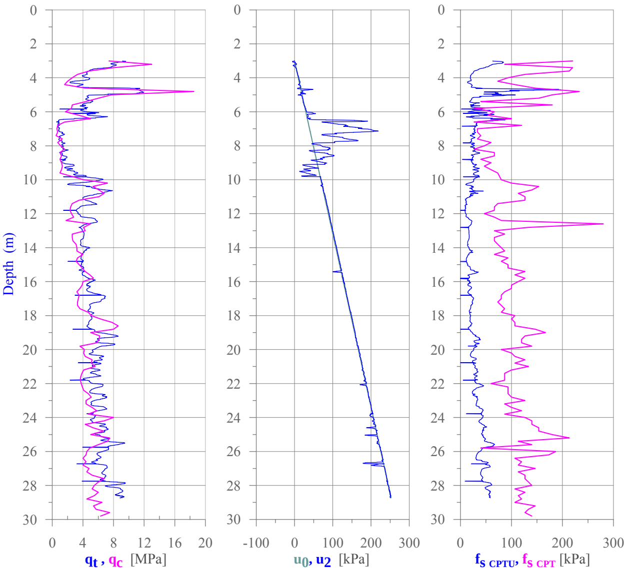

Figure 4. Gordola:CPTU1-CPT1

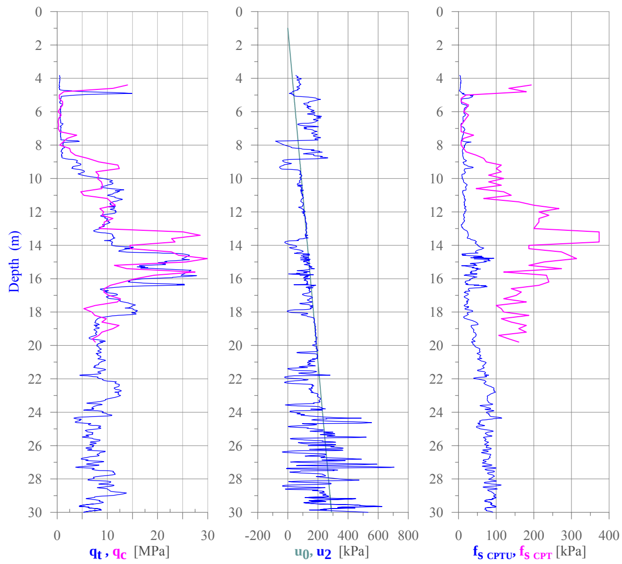

Figure 5. Stabio: CPTU1, CPT1 (stopped for excessive out of plumb of the rods)

It is therefore surprising that CPT is still so widely used. The lower cost respect to CPTU (ca. 40-50%) does not represent a valid justification especially in fine-grained soils in which CPTU provides other important parameters, such f_s and u_2. All data, available with a major detail (10-20 times), are besides automatically recorded and so much more easily managed. On the other hand, as we will see, even in mixed sandy and gravelly soils, CPT seems to perform less well than DPSH with casing moreover with a slightly higher cost.

At both sites, the variation in u_2 reflects the lithological variability with remarkable sensitivity, confirming the fundamental importance of this measurement for the preparation of a detailed stratigraphic profile.

Such considerations led us to choose among the available "Soil Charts" those of Robertson (q_t-B_q, 1986/1988) and Eslami & Fellenius (q_E-f_s, 2000) which are able to take u_2 into account even though in different ways.

These were used, as an example, at Stabio site, which presents more complicated stratigraphy.

The result obtained (Fig.6) shows the reliability of both methods, with a preference for Robertson classification that seems more precise about the evaluation of some details.

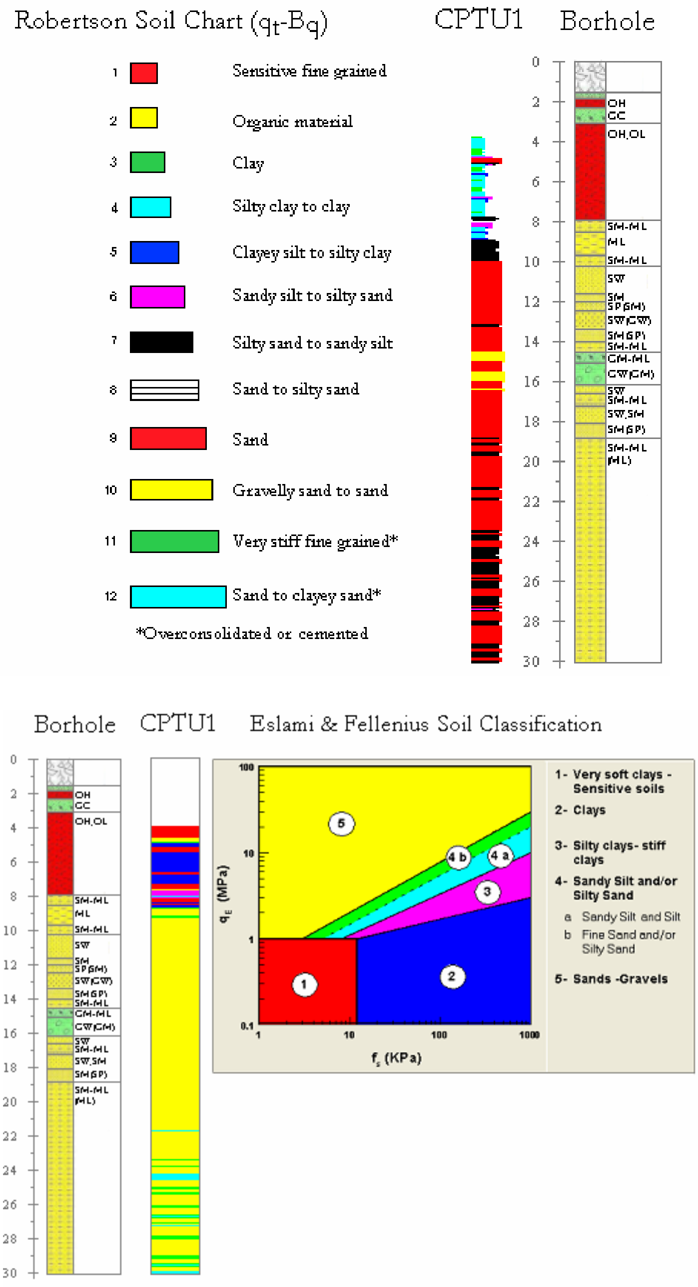

Figure 6. Stabio: Soil Profiles comparison

4.2 *DPSH with casing vs. DPSH without casing*

In both sites, good correlation is seen between the values of $q_{c\ equiv.}$, obtained by equation 3, and q_t even taking in account at Stabio the layer between 14 and 16 m in mostly gravelly soil, where the scale effect (*DPSH A* $_{cone}$*= 20 cm*^{2} *vs. CPTU A* $_{cone}$*= 10 cm*^{2}) probably induces the CPTU cone to enhance the impact with the bigger sized gravel. The value q_d usually proposed for the interpretation of dynamic tests shows, instead, a random character given that it matches q_t only in Gordola (Fig.7, Fig.8).

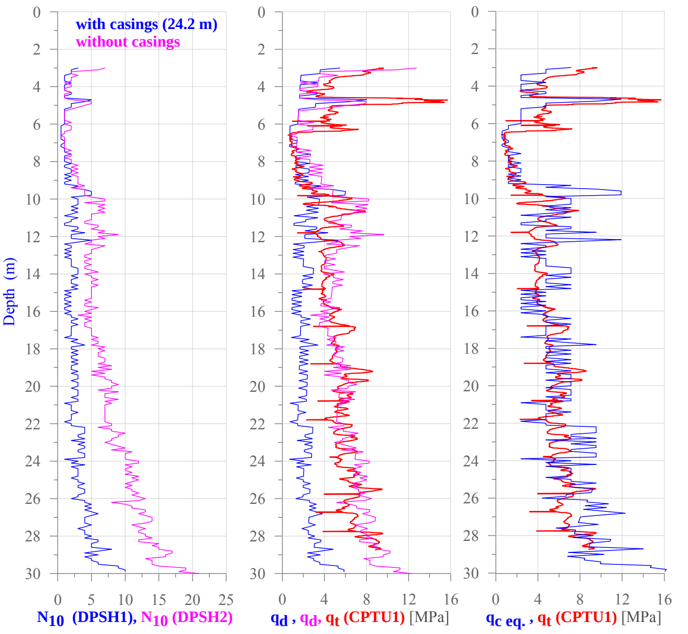

Figure 7. Gordola: DPSH1, DPSH2, CPTU1

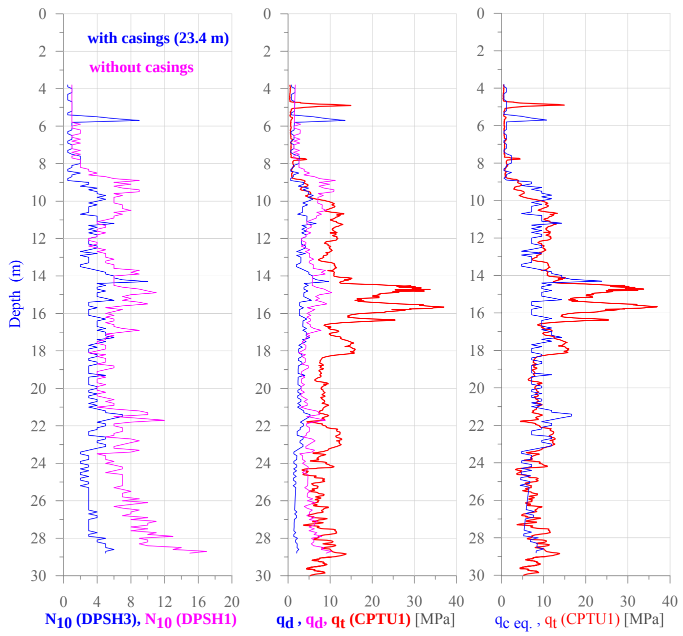

Figure 8. Stabio: DPSH1, DPSH3, CPTU1

4.3 *DPL/M with casing vs. DPL/M without casing*

In both sites these tests are characterized by curves which are not always comparable to the reference CPTU also using the casing, especially for depths greater than 10-12 m (Fig.9, Fig.10).

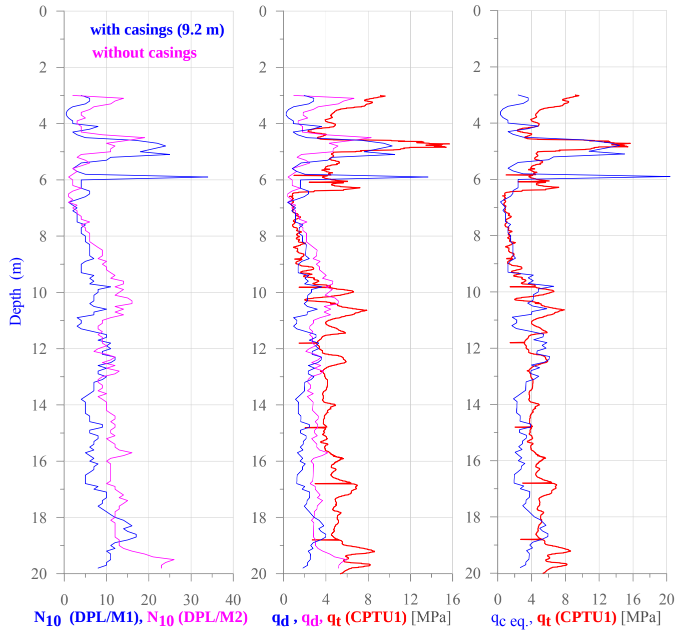

Figure 9. Gordola: DPL/M1, DPL/M2, CPTU1

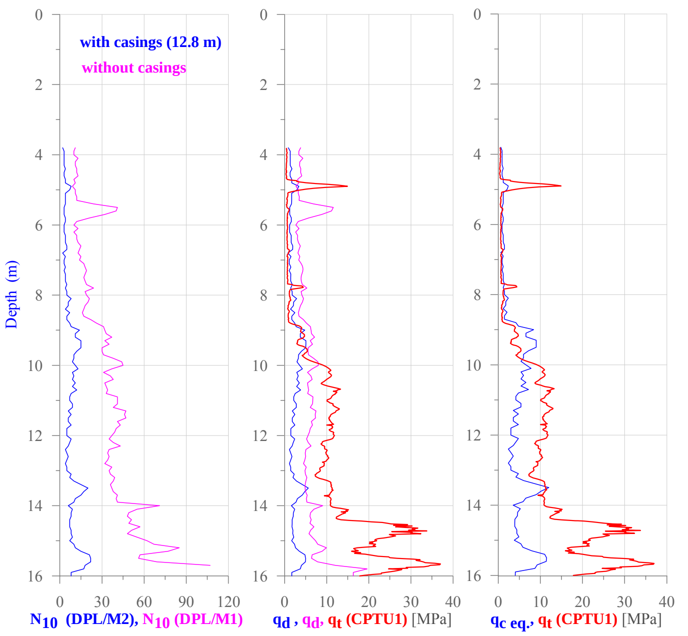

Figure 10. Stabio: DPL/M1, DPL/M2, CPTU1

Neither the trend of N_{10} values is comparable to the corresponding N_{10} of DPSH, also considering the lens-like nature of the strata, which renders dubious to find a correlation coefficient that binds these DP tests, contrary to opinion of many practitioners (Fig.11, Fig.12).

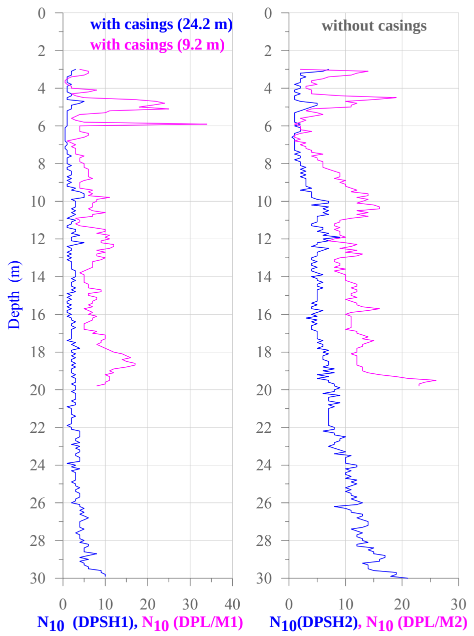

Figure 11. Gordola: DPSH1, DPL/M1, CPTU1

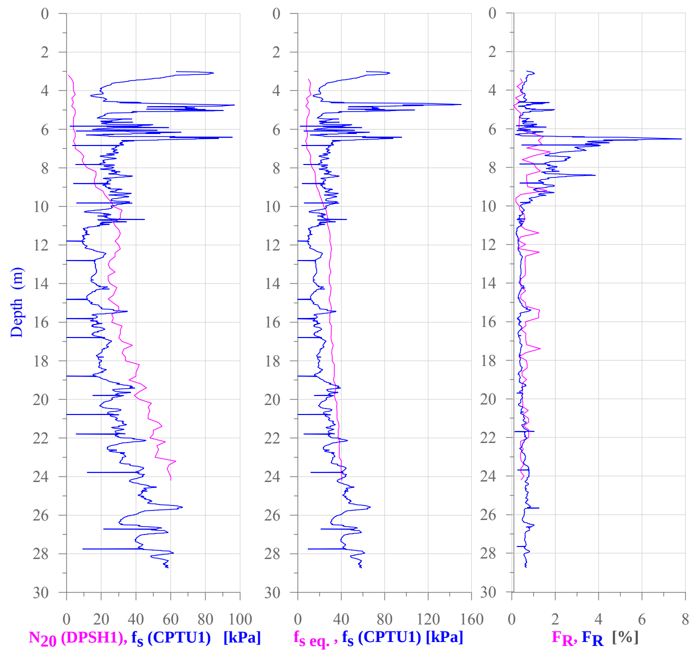

Figure 13. Gordola:DPSH1, CPTU1

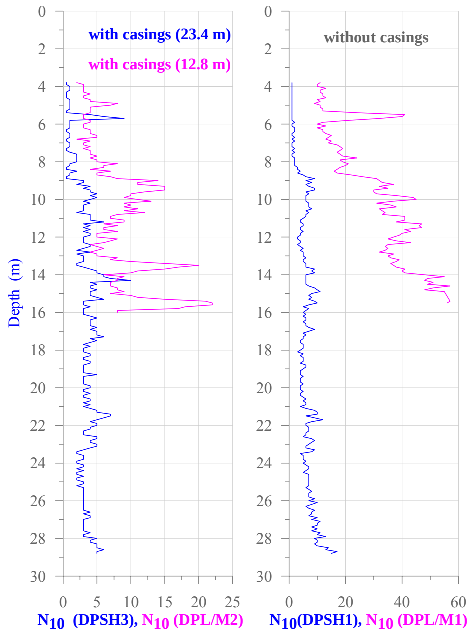

Figure 12. Stabio :DPSH3, DPL/M2, CPTU1

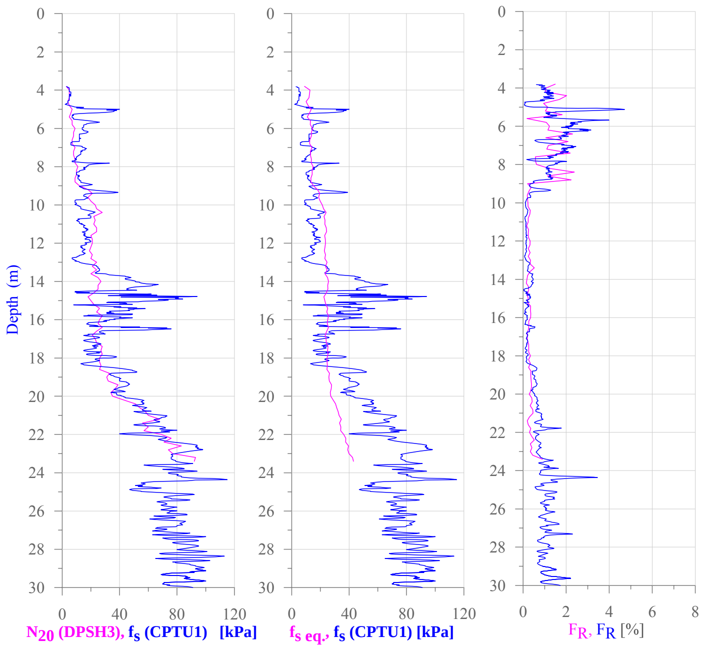

Figure 14. Stabio: DPSH3, CPTU1

4.4 *DPSH vs. CPTU:* f_s , $f_{s\ equiv.}$,F_R

A value of f_s which approximates that obtained by CPTU, was determined using Equations 4 and 5, elaborating the N_{20} values of DPSH casings penetration (Fig.13, Fig.14).
Also the friction ratio ($F_R = f_{s\ equiv.}/q_{c\ equiv.}$) show good correspondence, which permits, as well with DPSH, the preparation of soil profiles to be considered almost at the same qualitative level of those derived by CPTU, at least for the sites studied.
N.B.: the singular correspondence (especially at Stabio) between N_{20} and f_s by CPTU, expressed in kPa especially after 10 m depth, is probably casual but worthy of further checks.

A verification of this statement may be made by analysing the figures below (Fig.15, Fig.16), which result applying the soil classification of Zhang & Tumay, based on a statistically fuzzy approach of q_c and f_s values, not only for CPTU but also for DPSH. It may be seen how the comparison with the CPTU of reference, is surprisingly good for both sites.
Finally, DPSH tests, if interpreted correctly, show themselves to be superior to CPT tests and deserve to substitute them where there is primarily granular soil as may frequently be found in Switzerland and northern Italy.
It should be remembered that the use of casing with the DPSH enables the measurement without great difficulty of the increase in adhesion of cohesive soil on the casing itself as a function of time (set up).

This is not of negligible importance for the design of driven piles.

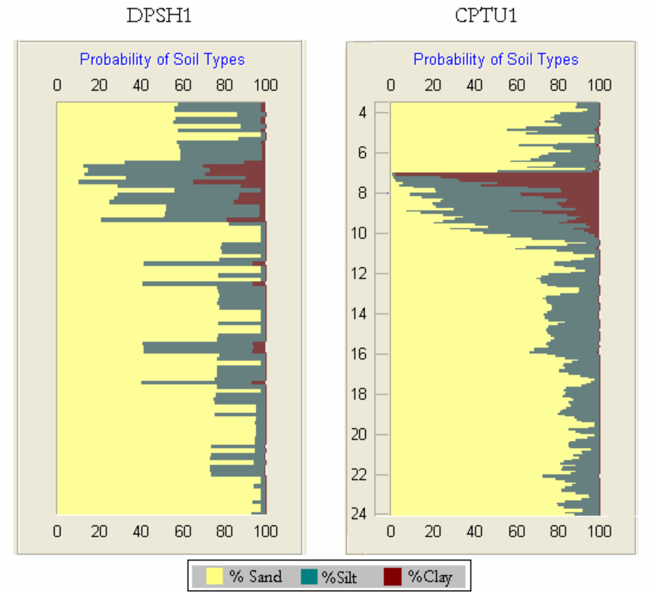

Figure 15. Gordola: Stratigraphy by PClass-CPT (LSU)

N.B.: the probability of a silty region in the deposits deeper than 10 m, revealed by the above profile but not justified both by the grain size distribution of these soils (see stratigraphy in Fig.1) and the overlap of u_2 and u_0 lines (Fig.4), is perhaps caused by the already mentioned anisotropy imputable to the presence of mica horizons.

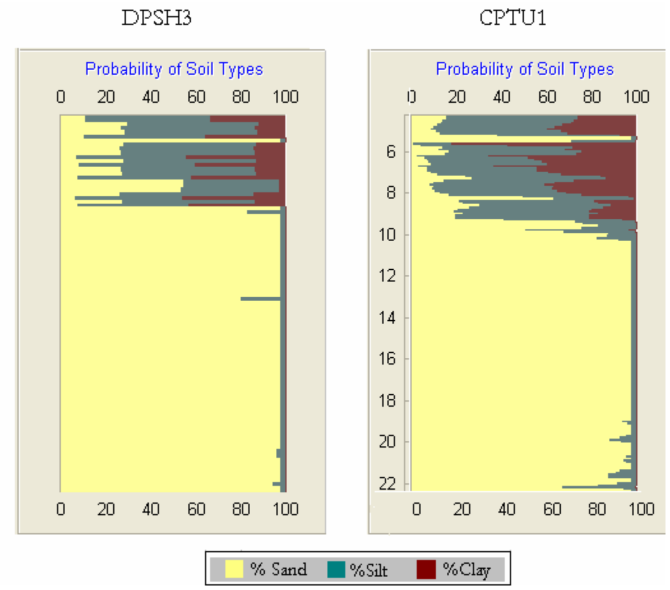

Figure 16. Stabio:Stratigraphy by PClass-CPT (LSU)

4.5 *DMT vs. CPTU*

We consider DMT, which we use with excellent results since 1978, to be of comparable geotechnical importance as CPTU, the two tests complementing each other.

Its flexibility (the DMT can be point or continuous), its robustness, ease of maintenance and simplicity of use, the limited soil disturbance during penetration, its repeatability and reliability, render the DMT indispensable for the characterization of fine grained soils .

This test was used in Stabio where the stratigraphic profile is more complex and also in this evaluation, not sure the best one of the interpretative DMT qualities, we see a good correspondence with the CPTU test carried out near by, as highlighted in the Figure 17 .

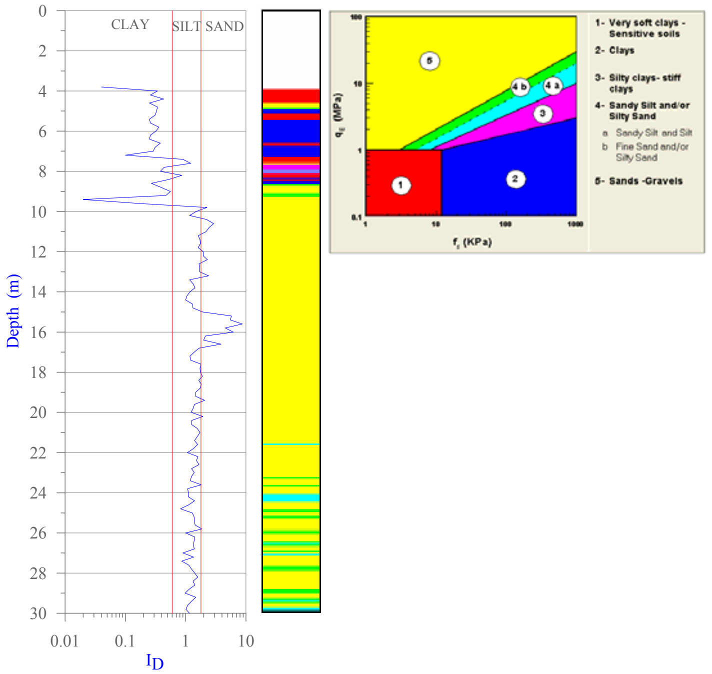

Figure17 Stabio: DMT1 and CPTU1

The versatility of the DMT has been demonstrated as well as the possibility to obtain a reliable value of q_t in more or less silty sands in the absence of a CPTU test (Fig.18), while the execution of both tests provides a useful reciprocal check on the derived geotechnical parameters (in this study $\phi°$ and M have been chosen as examples) .

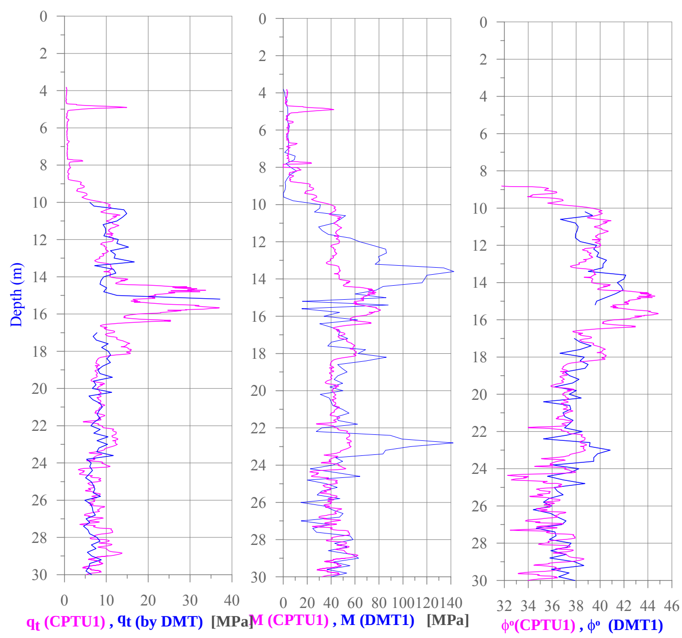

Figure18 Stabio: DMT1 and CPTU1

The following equations were used:

- DMT

$q_t=33\ p_a\ I_D\ K_D^{0.4}$ (cohesionless soil) (7)

$M= R_M\ E_D$ (all soils)* (8)

$\phi'=20+1/0.04+0.06/K_D$ (cohesionless soil)** (9)

- CPTU

$M= q_c 10^{(QC-0.0075*Id)}$ (cohesionless soil)*** (10)

$M= q_t OCR^{0.4} SBT$ (2<SBT<6:qt-Bq, Figure 6) (11)

$\phi'=17+11\log(q_{c1})$ (cohesionless soil)*** (12)

* *Marchetti(1980)*
** *Mayne (modified after Marchetti 1997)*
*** *Kulhawy & Mayne (1990)*

N.B.: in cohesive soils the value of c_u obtained with the DMT may serve very well to aid in the choice of the coefficient N_{kt} [$c_u= (q_t - \sigma_{vo})/ N_{kt}$] which have usually a wide field of variation (from 10 to 20).

5 NOTES ABOUT THE SPT

In Gordola and Stabio, no particular space has been reserved for this test which is habitually carried out both in Switzerland and in Italy, replacing the standard sampler with a cone of equivalent section (Fig.19) considering that boreholes with continuous core recovery are usually executed.

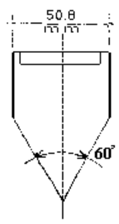

Figure 19. SPT Cone

Practical limits (disturbance of the bottom of the borehole due to perforation sometimes exceeds the 45 cm over which the test is carried out) and interpretative limits (see Fig.20) that make the traditional SPT often inadequate, are well known.
The fine grained soils studied are much better characterized with other types of in situ tests (DMT in the specific case).

Figure 20. Prof. P.W. Mayne's question (Istanbul, 2001)

We are convinced, however, that in an unorthodox form, the SPT cone can be used in a useful way where it is necessary to cross soils with a variable gravel content.
In similar situations, the measurement of the SPT cone penetration should be made for at least 15 consecutive intervals of 15 cm each, thus yielding enough "undisturbed" values that can be elaborated to obtain corrected values of $q_{c\ equiv}$.
The following graph (Fig.21), taken from a recent investigation in sandy, gravelly alluvium (Lugano, near Ceresio Lake), demonstrate the above well, highlighting the negative influence on N_{15} of the borehole bottom disturbance or rupture (piping), resolved by carrying out tests > 2 m in length which do not have contraindications in those deposit (the friction on the rods was negligible).
In the specific case $q_d \cong q_{c\ equiv} \cong q_t$ by CPTU.

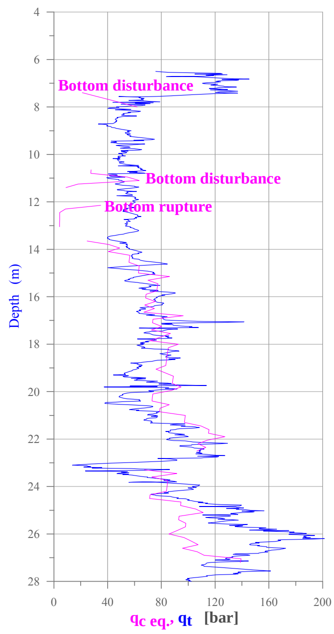

Figure 21 Lugano: SPT (cone) and CPTU

This simple precaution permit the rapid obtaining, at low cost, of corrected q_c values which are able to provide, once again using the interpretative algorithms for CPT and CPTU, a reliable basic geotechnical characterisation (i.e. $\phi°$, M) for soils which are often "lithologically" incompatible with other in situ tests.

6 CONCLUSIONS

The results obtained at Gordola and Stabio sites confirm the necessity to execute in situ test as CPTU and DMT, if one wants to obtain a reliable stratigraphic and geotechnical characterization of the fine grained soils.
The most important lesson learned however, is the capacity of DPSH with cased rods to provide, elaborating the dynamic penetration resistance of both, q_c

and f_s equivalent values comparable with that measured by CPTU.

This means that everywhere we have coarse soils with variable amount of gravel, able to obstruct or prevent the execution of CPTU and DMT, DPSH with casings become the recommended equipment (compared to CPT also has a much more extensive application field).

Assuming that each investigation requires at least a borehole with continuous core recovery not only to obtain undisturbed samples or to place a piezometer, but especially to have an interpretation key for all in situ tests, the use in coarse soils of the non-traditional proposed SPT, once more allow to obtain in a simple, rapid and inexpensive manner, elaborated reliable values of q_c, exploitable for a corrected geotechnical characterization.

Concerning the DPL/M we suggest using them (better with casings), only in cases of impossible access for others equipment and when the investigation does not exceed depths of 10-12 m.

Finally, the common habit of passing from DPL/M to DPSH by the application of a simple correlation coefficient is unadvisable even modifying it with the soil characteristics encountered.

ACKNOWLEDGEMENTS

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Definitions

CPTU

q_c= cone penetration resistance

a= net area ratio

u_2= pore pressure measured on shoulder of cone

q_t= corrected cone penetration resistance= q_c+u_2 (1-a)

p_a= atmospheric pressure, usually=0.1 MPa

σ'_{vo} = overburden effective stress

σ_{vo} =overburden total stress

q_{c1}=normalized cone penetration resistance=$(q_c/p_a)/(\sigma'_{vo}/p_a)^{0.5}$

I_d= density index =$[q_{c1}/(305*Q_C*Q_{OCR}*Q_A)]^{0.5}$

Q_C= compressibility factor $0.91 < Q_C < 1.09$

Q_{OCR}= overconsolidation factor= $OCR^{0.18}$

Q_A=ageing factor=1.2+0.05log (t/100)

SBT= soil behaviour type number (q_t-B_q, Figure 6)

DMT

A & B= "normal" readings

ΔA & ΔB= calibration of membrane

p_o= lift-off pressure = corrected A reading ≅A+ΔA

p_1=expansion pressure=corrected B reading ≅B-ΔB

I_D=material index = $(p_1-p_o)/(p_o-u_o)$

K_D=horizontal stress index=$(p_o-u_o)/\sigma'_{vo}$

E_D=dilatometer modulus = $34.7(p_1-p_o)$

GEOTECHNICAL PROPERTIES

φ'=drained strength

c_u=undrained shear strength

M= constrained modulus