Governolo (Italy) Experimental Site: In Situ Test Comparisons and Mutual Conversions

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ABSTRACT: The Authors had the opportunity to perform a wide range of in situ test at an experimental site in Governolo (Italy). The survey included: a continuous core sample drilling with SPT (using a conical point) and DMT and a series of continuous in situ tests such as cased and uncased DPSH, mechanical CPT, CPTu, SCPTu, SDMT well as V_p and V_s, seismic tomography and HVSR. This rare concentration of in situ tests, made it possible to evaluate their convergences trying to transform them first into CPTu and then into DMT, considered as reference, proposing a series of empirical relations whose validity will need to be confirmed in other places with different lithostratigraphic and mineralogical characteristics.

1 INTRODUCTION

The Governolo workshop (2013) was planned to offer participants the full range of most practiced in situ tests in Switzerland and Italy, accompanying them with a continuous core sample drilling to provide lithostratigraphic profile, samples for laboratory analyses and a series of geophysical surveys to complete the operational framework necessary to define the behavior of the soils with an acceptable accuracy.

The unusual abundance of information, at least for the authors, has led them to look for links among the different in situ tests with the goal of their mutual conversion.

This practice is not an end in itself but rather an useful instrument of knowledge because, often, the familiarity with the conversion to various test types is the only way to make a reasoned geotechnical evaluation when faced with incomplete site investigations, not to mention the prospects of being able to take advantage of the larger database of the more common in situ tests (e.g. CPTu, CPT, SPT).

The Governolo site, characterized by alluvial Holocene-Age lentoid deposits, consisting of clay layers sometimes weakly organic, which alternate with silt and sand mixtures of different thickness, lend itself well for the purpose despite the significant carbonate content makes them special.

At the time of the investigations, the water table was at depth of between 4 to 5m (i.e. elevation 17m).

The Governolo geographic position and the investigations layout are both depicted in Fig. 1.

Fig.1 Site Map and Investigation Layout.

2 SITE INVESTIGATION DATA

The basic CPTu, DMT, SPT, DPSH and (mechanical) CPT plots together with the borehole stratigraphy (S.1) appear respectively in Fig. 2, Fig. 3 and Fig.4.

Fig. 4 confirms previous observations that the sleeve friction (f_s) from the mechanical CPT is very different than that measured from the (electric) CPTu.

The results from the seismic surveys referred to

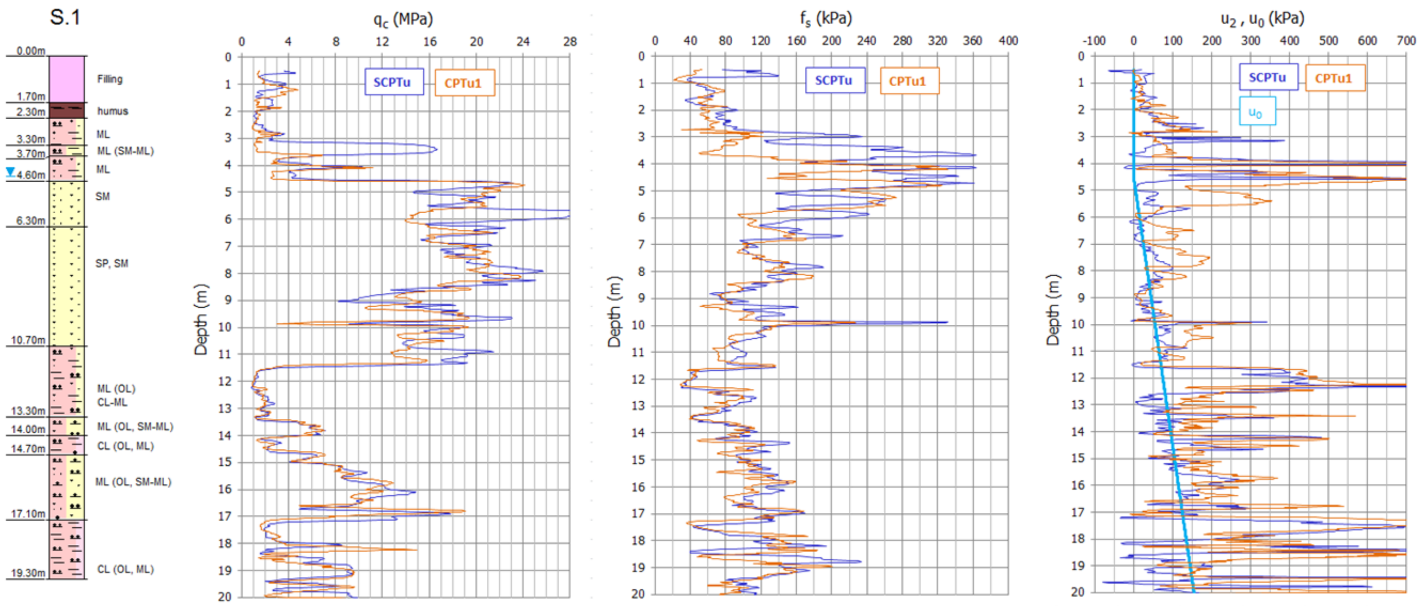

Fig. 2. CPTu1and SCPTu Plots.

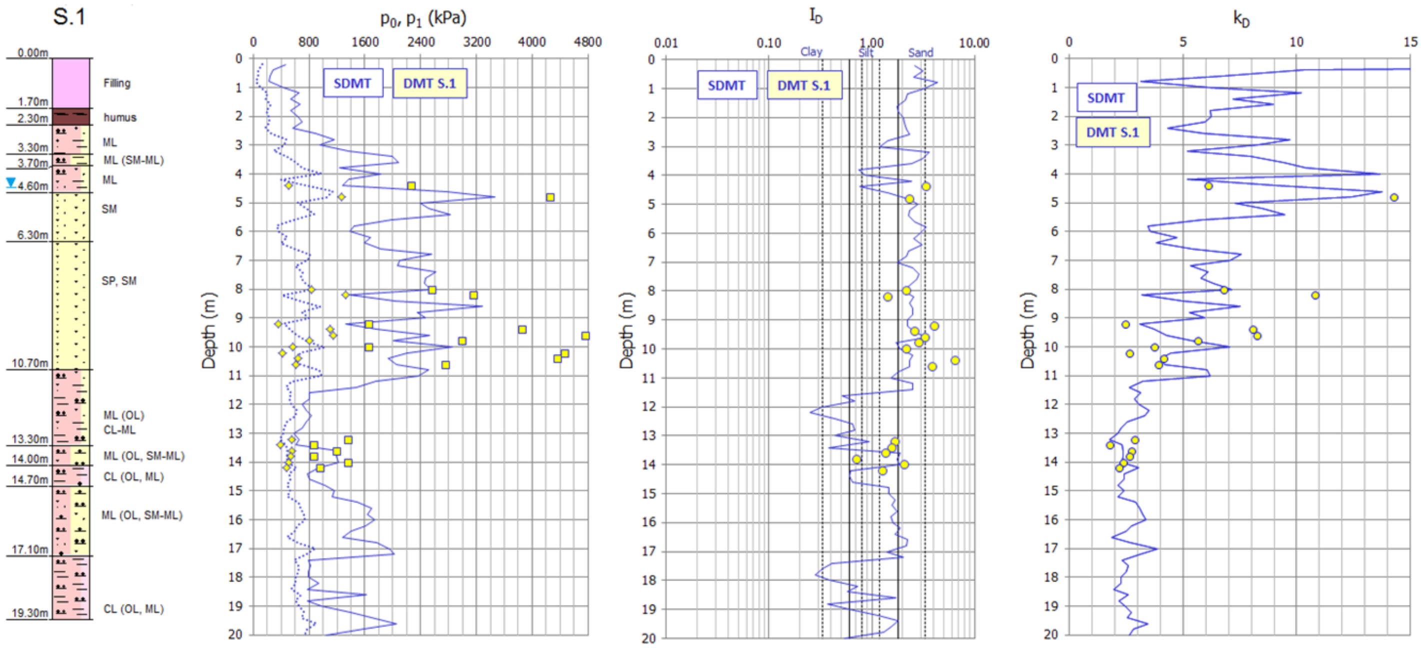

Fig. 3. DMT S.1, SDMT Plots.

mean (tomographies) and high resolution (SCPTu, SDMT) methods, are shown in the Fig.5 which includes estimated V_s values derived from q_c modifying the equation of Baldi et al. (1989) as following:

If $\sigma'_v \leq 100$ $\quad V_s=277q_c^{0.13}\sigma'^{\,0.22}_v$ (1)

otherwise $\quad V_s=277q_c^{0.13}\sigma'^{\,0.17}_v$ (2)

as well as those determined by SDMT and DMT using the well-known equation:

$$V_s=(G_0/\rho)^{0.5} \quad (3)$$

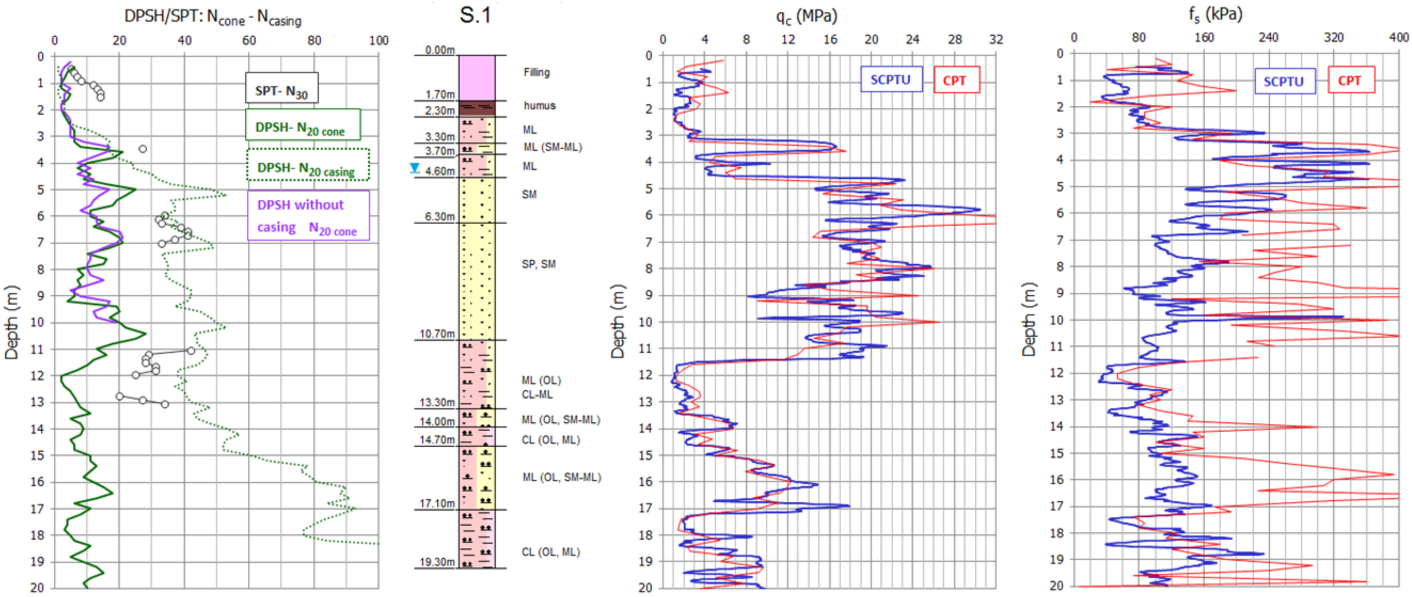

Fig. 4. SPT, DPSH, (mechanical) CPT Plots.

In Fig.5 the best measured passive HVSR curve was also included, which lacks credibility compared to the other V_s derived curves and the stratigraphic profile. Since seismic tomography includes measured V_p, it was possible to estimate the depth of saturation based on either the calculated Poisson ratio and directly from V_p. The Fig. 6 shows that the GWT is around a depth of 4m beyond which the Poisson ratio values are constantly > 0.45. Fig. 6 also shows that the V_p curve has the change in slope that usually marks the presence of the water table at 6m depth with values lower than usual (1.5-1.6 km/sec), that may reflect the predominant carbonate soils character.

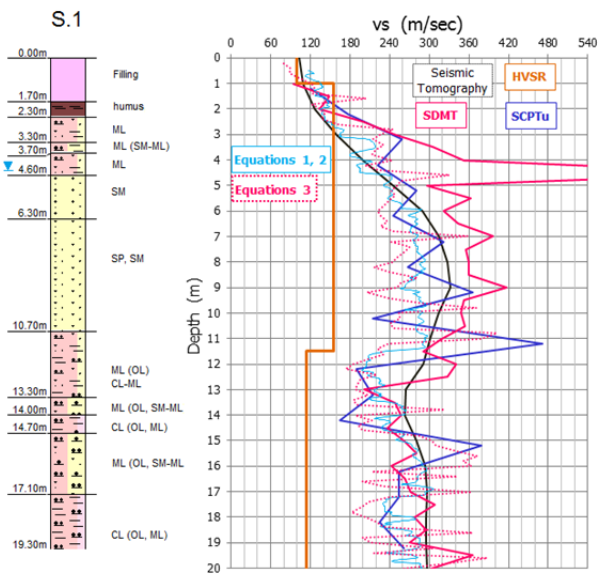

Fig. 5. Borehole stratigraphy and v_s plots.

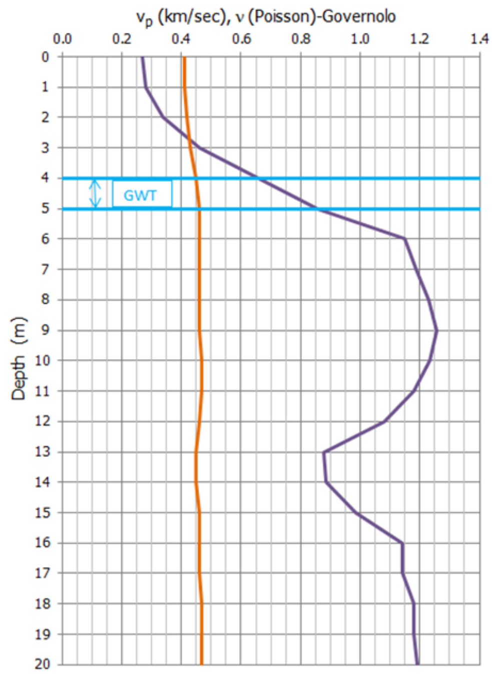

Fig. 6. GWT vs V_p and Poisson ratio.

The laboratory analyses results summarized in the Table 1, complete the general information about the site.

Such analyses reveal that the carbonates content reaches and exceeds 50% that may influence the measured plasticity.

Plasticity index (IP) values between 2 and 6, for most samples, are an evident indication of a significant presence of "calcareous mud" in the clay fraction with consequent alteration of its usual behaviour.

It is notheworty that the natural water content (W_n) is often close to plastic limits (W_p) that is an indication of the overconsolidation in the soils.

Table 1. Lab. Analyses Governolo

Depth (m)	W_n	W_l (%)	W_p	I_P	γ (kN/m3)	Clay	Silt	Sand (%)	Gravel	CaCO3
3.0	19.4	21	19	2		24.3	59.8	13.1	2.8	
3.5	19.5	21	18	3		26.9	56.8	15.1	1.2	48.4
4.0	18.1	25	19	6	21.4	33.4	61.8	4.6	0.2	
5.3	17.8					2.8	31.4	63.1	2.7	53.7
7.3	15.6					5.8	20.5	73.3	0.4	51.9
12.0	28.1	33	27	6	19.7	29.4	67.9	2.7		
12.6	29.9	39	27	12	19.3	30.4	67.1	2.5		
17.7	33.4	42	28	14	18.9	42.2	54.6	3.1	0.1	

Fig. 7 (based on combined Vs and CPT) suggest that the clean sand (I_c < 1.8) may have some residual/cemented.

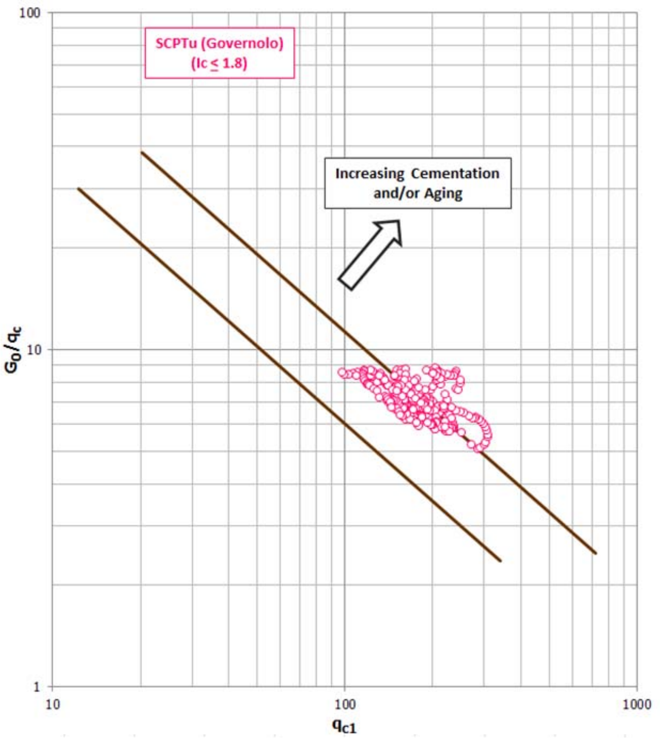

Fig. 7. Sands Behaviour (Robertson et al, 1997).

3 SPT, DPSH, CPT INTO CPTU CONVERSION

In both Italy and Switzerland it is common that the SPT is executed in cased borings with continuous sampling, almost always using a conical point instead of the sampler, therefore allowing the test to extend beyond the standard 0.45m in order to bypass the drilling remolded zone.

The absence of any energy measurement and the randomness of the correction factors, justify the choice to transform the obtained reliable N_{15} values at first into dynamic resistance using the Dutch formula and then in equivalent static resistance via a coefficient which depends on soils lithology and compactness (both known through the boring).

The DPSH (one, cased 20m length and the other, uncased 10 m length), whose dynamic resistance is calculated using the simplified formula, are similarly converted.

The main characteristics of the equipment are summarized in Table 2.

Table 2. SPT- DPSH Equipment

DP Type			SPT	DPSH
Hammer	(M)	(kg)	63.5	63.5
Fall Height	(H)	(cm)	76	75
Cone: diameter		(mm)	50.8	50.8
β	(°)		60	60
Area	(A)	(cm^2)	20.3	20.3
Rod: diameter		(mm)	50	32
length		(mm)	1500	1000
weight		(kg)	7	6.5
Bows aver. penetr.	(e)	(cm)	30 (N_{30})	20 (N_{20})
Casing: diameter		(mm)	-	48
Length		(mm)	-	1000
Weight	(m)	(kg)	-	5.5
Bows aver. penetr.		(cm)	-	20 (N_{20})

Below the reference equations:

3.1.1 *SPT*

$$q_d\,(\text{bar})=\{(M^2H)/[Ae(m+M_1)]\} \quad (4)$$
$$q_c\,(\text{bar})=\alpha q_d \quad (5)$$

3.1.2 *DPSH*

$$r_d\,(\text{bar})=MH/Ae \quad (6)$$
$$q_c\,(\text{bar})=\alpha r_d \quad (7)$$

where: M_1= hammer +anvil weight;
α= conversion coefficient (Table 3)

Table 3. α and I_c Guide

α	USCS	I_c
1.2	GW, GP, GM, GC	$\leq$ 1.25
1.1	GM-ML, GC-CL	$\leq$1.25
1.0	SW-GW	$\leq$1.80
0.9	SW,SP,SM	$\leq$1.80
0.8	SC, SM-ML	$\leq$2.40
0.7	SC-CL	$\leq$2.40
0.6	ML, CL-ML	$\leq$2.67
0.5	CL	>2.67
0.4	CH, MH, OL	$\geq$3.22
0.3	Pt, OH	$\geq$3.22

Equation 4 which sometimes tends to penalize the q_c values when the depth exceeds 12m and Table 3 that specifies the conversion coefficient values both already proposed (Togliani et al., 2004 and Togliani, 2012), are now integrated by a check equation based on the equality N_{cone}-$N_{sampler}$ (strictly speaking justified only for gravelly soils).

The Jefferies & Davies (1993) equation, first used to convert q_c into N_{30} to verify the validity of above

equality, seeing its fair success, it was then employed to the contrary choosing I_c from Table 3 (in the specific case the mean value for each USCS subdivision).
Therefore, the Jefferies & Davies (1993) equation becomes:

$$q_c \text{ (bar)} = 8.5 N_{cone} [1-(I_c/4.6)] \quad (8)$$

Below, some equations are suggested for f_s evaluation of both SPT and DPSH: the first two for clay like and the other for sand like soils.

$$f_s = 0.4\sigma'_v OCR^{0.8} \quad (9)$$

$$\text{where } OCR = 0.106(V_s^{1.47})/\sigma'_v \quad (10)$$

$$f_s = q_c^{0.5} \quad (11)$$

Equation (9) repeats in practice that used by Ladd et al. (1991) to calculate the undrained cohesion (the first term is incremented from 0.23 to 0.4) having noted that generally f_s is considered the s_u disturbed value while OCR is derived by Mayne et al. (1998) formula.

To obtain f_s by mechanical CPT the lateral limit resistance R_l, is used as follow (R_l and q_c in kPa):

$$\text{if } OCR \geq 3 \quad f_s = (R_l - q_c)^{0.59} \quad (12)$$

$$\text{otherwise} \quad f_s = (R_l - q_c)^{0.56} \quad (13)$$

Finally, for all tests, u_2 is calculated by the following Robertson (2009) equation, imposing some restriction:

$$\text{If } R_f > 2 \quad u_2 = (K_D \sigma'_v) + u_0 \quad (14)$$

$$u_2 = u_0 \quad (15)$$

$$\text{where if } R_f > 2 \quad K_D = 0.4 Q_{t1}^{0.6} + 0.8 \quad (16)$$

$$\text{otherwise} \quad K_D = 0.2 Q_{t1}^{0.6} + 0.8 \quad (17)$$

The conversion results graphically displayed in the Fig. 8, lend themselves to the following considerations:

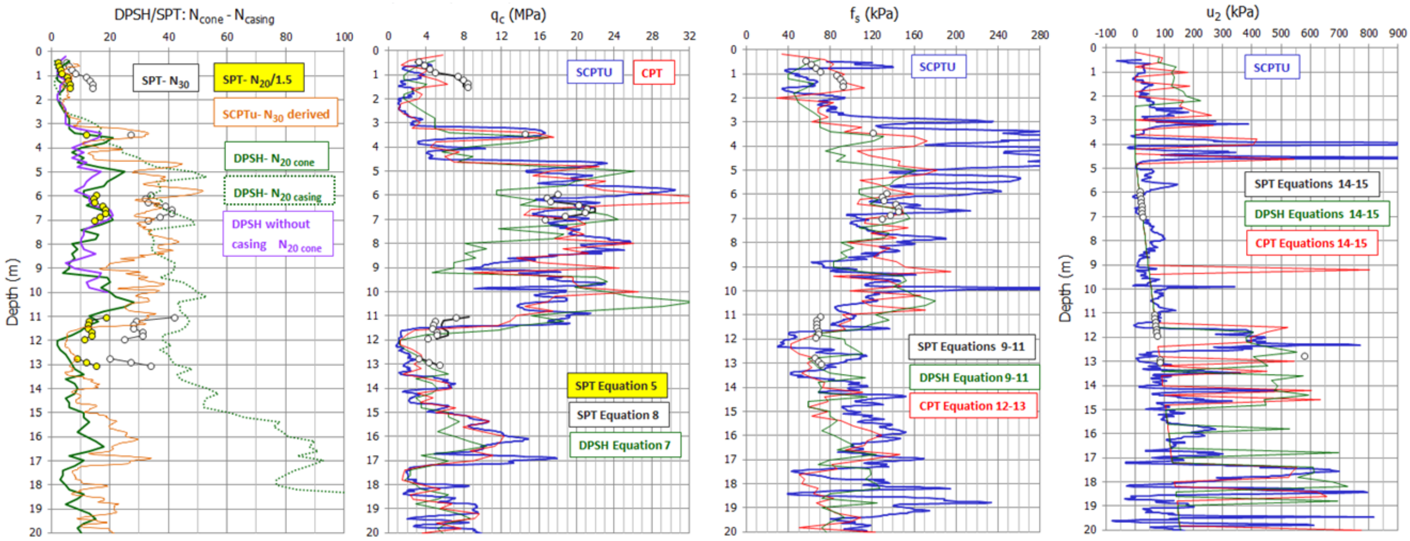

Fig.8. N_{cone} - q_c to f_s and u_2.

- As expected, the predominant cohesionless soils presence to 10m depth, has not braked the penetration of the uncased DPSH (then abandoned for the supervening darkness) and so the cased and uncased N_{20} coincide, proving that even performing a SPT of the same length would have been possible besides advantageous.
- N_{30} by SPT when normalized to N_{20} and then divided by 1.5 [$(2N_{30}/3)/1.5$], generates values that overlap the N_{20} DPSH curves, proving that everywhere the soil friction on the rods is negligible SPT and DPSH can be perfectly correlated.
- In the specific case the equality N_{cone}-$N_{sampler}$ seems evidently valid also for not gravelly soils seeing the q_c equivalent results overlap.
- N_{30} values derived by SCPTu seem in good agreement with those measured up to 12m depth and then are placed close to the DPSH N_{20} values demonstrating that this dynamic sounding, when necessary and if cased, can be a valid alternative to CPT/CPTu.
- In every case all of the conversion equations proposed, seem to give reasonably accurate results.

4 DMT INTO CPTU CONVERSION

Following Tsai et al. (2009) and Robertson (2012) indications it was first verified if, at least for the clean sands, it was possible to take advantage by the equation that links K_D to $Q_{tn,cs}$ and then to derive q_c but the attempt was unsuccessful for the excessive scattering of the values as shown in Fig. 9. It was then decided to use both Q_t and q_c, searching the relations with the best convergence, obtaining the results below detailed.

4.1.1 *q_c Evaluation*

if $OCR \geq 4$ $\quad q_c = 3.3(p_l - p_0)\, K_D^{0.2}$ (18)

otherwise $\quad q_c = 6.6(p_l - p_0)\, K_D^{0.35}$ (19)

4.1.2 *Q_t Evaluation*

if $I_D \leq 1.8$ $\quad Q_t = K_D^{1.7}$ (20)

otherwise $\quad Q_t = 9\, I_D\, K_D$ (21)

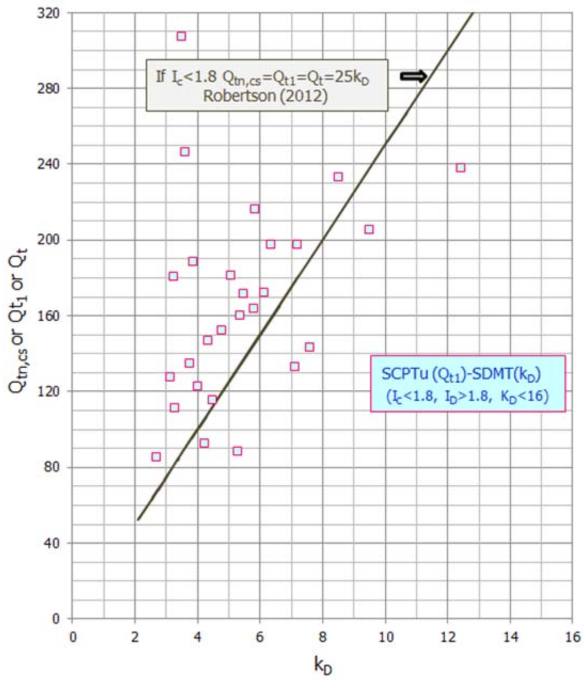

Fig. 9. Q_{t1}-K_D measured.

The 18 to 21 equations, recalling that OCR is obtained from the equation 10 and that:

$$q_c = Q_t \sigma'_v + \sigma_v, \tag{22}$$

gave the encouraging results shown in Fig.10.

Now, by entering the new Q_t- K_D pairs in Fig. 11, one notices, as is expected, that the clean sands gather around values closer to those proposed by Tsai et al. (2009) but also the other soils follow a precise trend line.

The following equation is instead proposed for the sleeve friction evaluation

$$f_s = (p_l - p_0)^{0.68} \tag{23}$$

For the pore pressure, on the basis of equation 14, being known the K_D formula and imposing a restriction for I_D and not for R_f as before, you get:

if $I_D \leq 1.5$ $\quad u_2 = p_0$ (24)

otherwise $\quad u_2 = u_0$ (25)

The f_s and u_2 equations outcome, once again promising, are summarized in Fig. 12 and 13.

About u_2 it should be highlighted that in Fig.13 are also shown the p_2 besides the $u_{initial}$ derived by the dissipation test interpretation (all with dilatory behaviour) and then, to judge the u_2 derived accuracy, this phenomenon must be considered

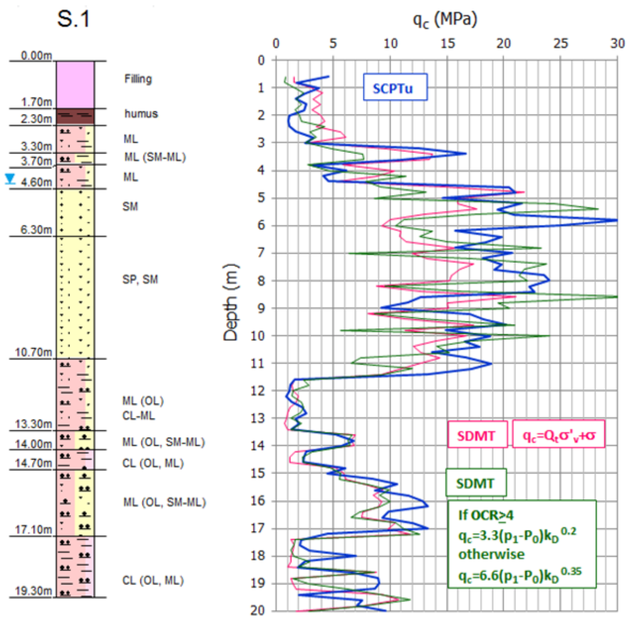

Fig. 10. q_c Comparisons.

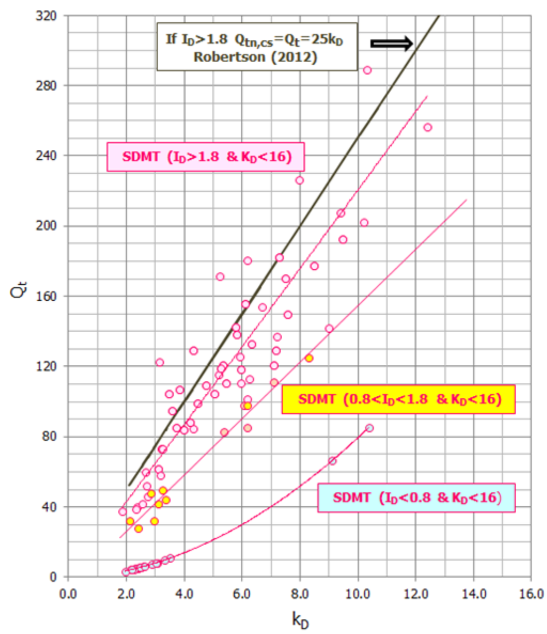

Fig. 11. Q_t derived-K_D measured.

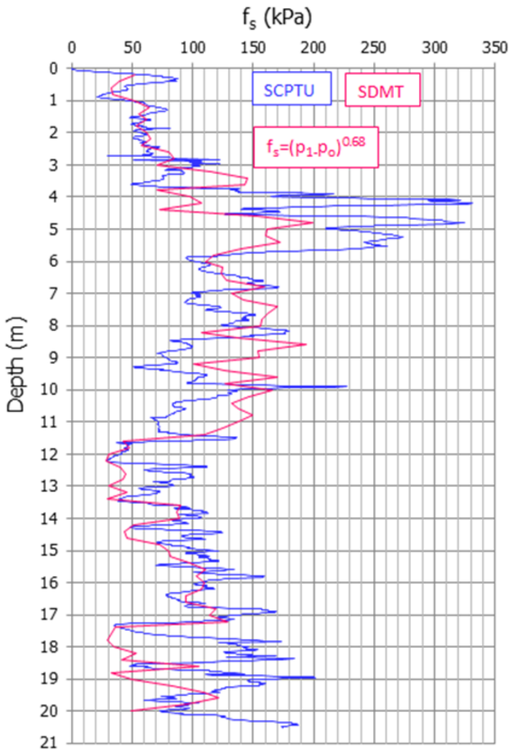

Fig. 12. f_s Comparisons.

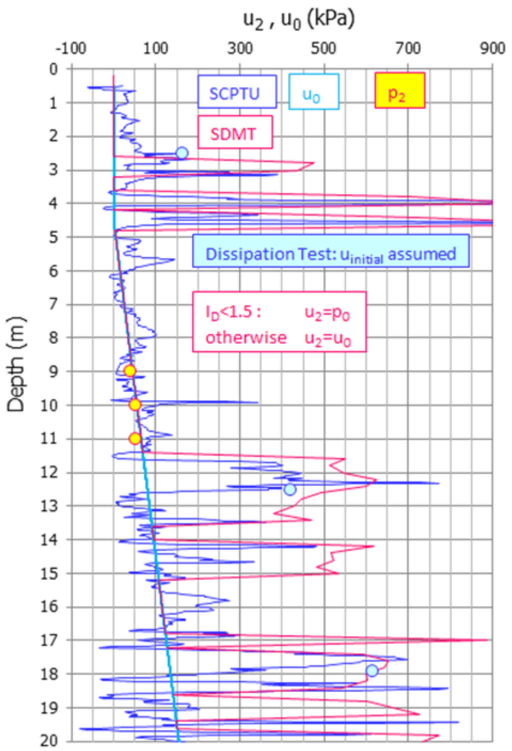

Fig.13. u_2 Comparisons.

5 CPTu INTO DMT CONVERSION

The benchmark is, in this case, given by the q_c and f_s values obtained in the course of seismic piezocone test, displayed in Fig. 1.

The paper published on the matter by Robertson (2009) was then used for this aim, choosing the following equations:

$$I_D=10^{(1.67-0.67Ic)} \quad (26)$$

$$K_D=0.144Q_{t1}/I_D \quad (27)$$

modifying them, after, as defined below:

If $I_c \geq 2.67$ $\quad I_D=10^{(1.67-0.67Ic)}$ OCR $^{0.3}$ (28)

If $1.8 \leq I_c < 2.67$ $\quad I_D=10^{(1.67-0.67Ic)}$ OCR $^{0.2}$ (29)

otherwise $\quad I_D=(0.7)10^{(1.16-0.67Ic)}$ (30)

If $I_c \geq 2.67$ $\quad K_D=(0.9)0.144Q_{tn}/I_D$ (31)

otherwise $\quad K_D=(0.6)0.144Q_{tn}/I_D$ (32)

The reasons for these changes are:

- The soils with greater fines content (FC) benefit in this way of the stress history, precondition to obtain credible conversion results, being DMT is influenced more by this factor.
- Q_{tn} values are related to I_c.

The conversion result is displayed in Fig.15 (SDMT and DMT S.1 are 6m away and then the differences between the measured I_D and K_D values justify the derived one).

Known I_D and K_D it is then possible to find p_0 and p_1 whose curves, shown in Figures 14 and faced with those measured, appear reasonably accurate.

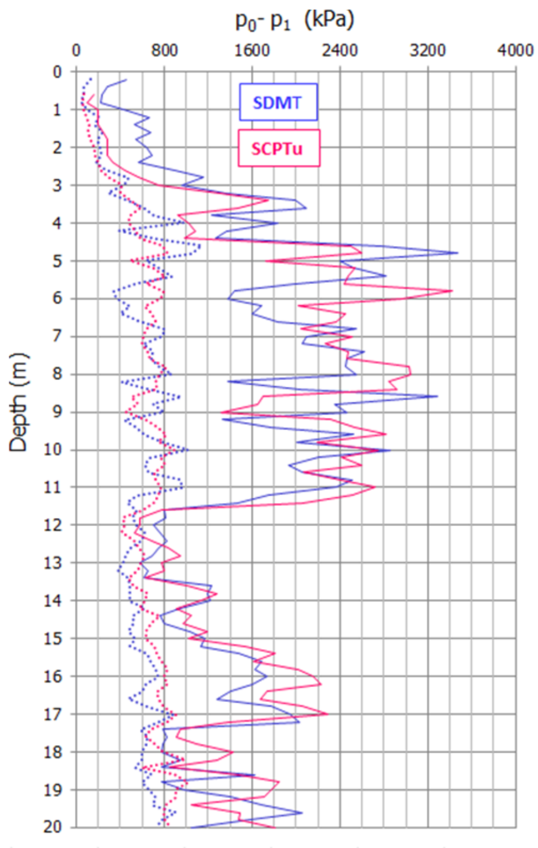

Fig.14. $p_0 - p_1$ Comparisons.

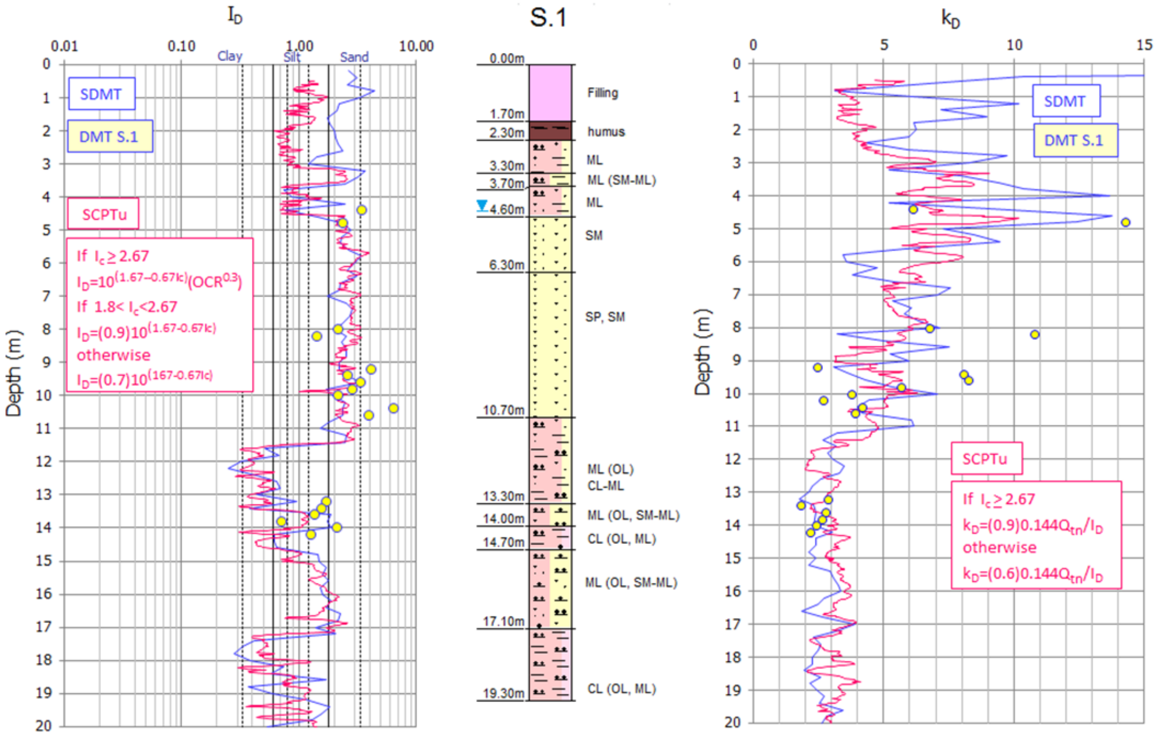

Fig.15. I_c to I_D & Q_t to K_D Curves.

6 GEOTECHNICAL CHARACTERIZATION

The market offers a large number of softwares, some of excellent quality, which can facilitate this task, but only if their results are critically analysed on the basis of personal experiences and prior knowledge on the investigated places.

For example the authors routine for the CPTu, is to verify the soils main features using CPeT-IT which are then introduced into an Excel Spreadsheet and compared with the results obtained using different correlations both well-known or unpublished but which have already proved suitable to characterize the soils of the area of interest and, as consequence, the final choices are made on the basis of personal convictions often in conflict with that proposed by the software, as indeed logic, being its validity inevitably more general than local.

In the specific case the first step was to define the soils behaviour (clay or sand like) via Ku et al. (2010) criterion attempting also their classification according to the USCS via the Yi (2010) method.

This procedure yielded the results illustrated in Fig. 16 and 17.

The FC-I_c comparison was particularly useful to identify the layers in which calculate the undrained cohesion that, according to Authors, must meet both of the following restrictions: Ic $\geq$ 2.67 and $FC_{mean} \geq$ 60%.

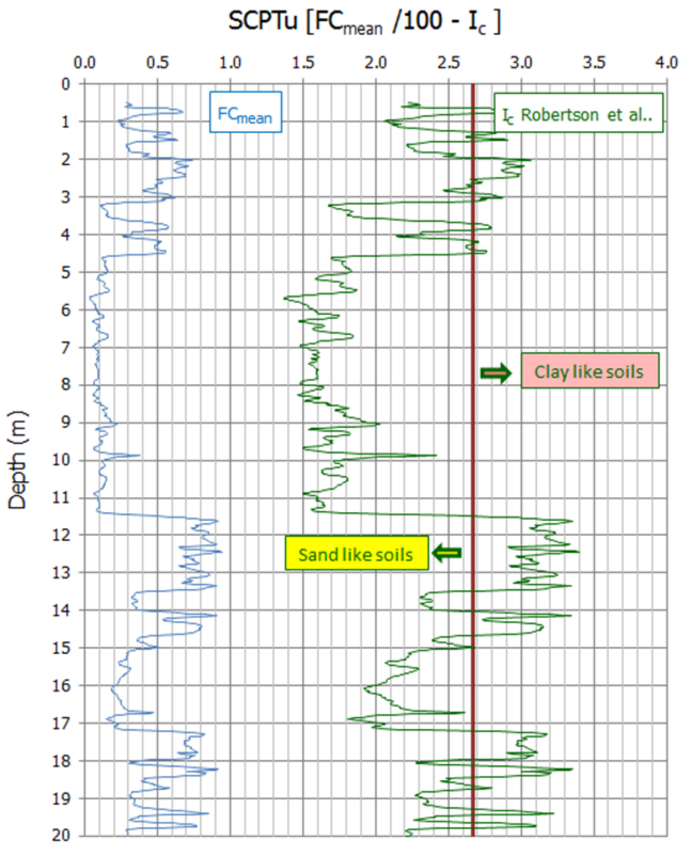

Fig. 16. FC and I_c Reference Curves.

Instead Fig 17 makes explicit how, in the same sample (0.2-0.3m height), the FC values can be close or extremely scattered, providing an important judgment criterion how to treat the analysis results. The Yi (2010) method, that provided sufficiently adequate results therefore can become very useful in those cases, unfortunately numerous, where is missing a borehole to use as guide for USCS.

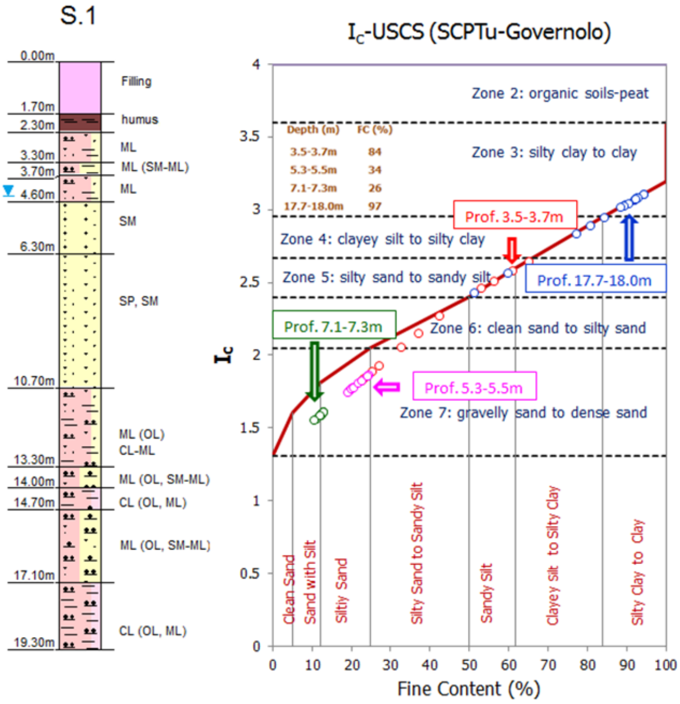

Fig. 17. Ic-USCS.

6.1 *OCR and s_u*

The overconsolidation ratio and the undrained cohesion are coupled being closely linked and moreover needy of restrictions to avoid mutually incompatible values enclosed in a space of few centimeters as happens relying uncritically on commercial software (the reason of this is well explained in Fig. 17).

For DMT the general OCR estimate is derived from the following equations::

$$\text{if } R_M \leq 1.5 \qquad OCR = K_D^{0.5} \qquad (33)$$
$$\text{if } I_D \leq 0.8 \qquad OCR = R_M^{2.8} \qquad (34)$$
$$\text{otherwise} \qquad OCR = R_M^{1.6} \qquad (35)$$

For both DMT and CPTu, OCR can be evaluated also using the equation 10 (with V_s derived), in good agreement with the one above and also with the few values, due to the imposed restriction ($I_D \leq 0.8$), directly derived from DMT using the Marchetti's, 1980 formula (Fig. 19).

The determination of s_u by CPTu occurs by the well-known Ladd (1991) equation (also the basis of the specific Marchetti's, 1980 formula):

$$s_u = 0.23\ \sigma'_v\ OCR^{0.8} \qquad (36)$$

The s_u values both for DMT and CPTu (the restrictions are respectively $I_D \leq 0.8$ and $I_c \geq 2.67$ & $FC_{mean} \geq 60$), fit congruently between them and in the OCR separation lines of the s_u graph Fig. 19).

Note that the FC_{mean} is obtained combining the Robertson et al (1998), Idriss et al (2008) and Yi (2010) specific formulas.

6.2 *M (confined modulus)*

For CPTu, the equations were arranged considering also the soil stress history calculated via OCR according to equation 10 and for this the obtained M curves (Fig. 18) are close to those derived from DMT taken as reference, as indeed those derived from CPTu into DMT conversion demonstrating its proper approach.

Hereinafter the equations:

$$\text{if } Ic > 2.67 \qquad M = Ic^{1.4} qc\ OCR^{0.4} \qquad (37)$$
$$\text{if } Ic > 1.8 \qquad M = Ic^{1.55} qc\ OCR^{0.4} \qquad (38)$$
$$\text{otherwise} \qquad M = Ic^{2} qc\ OCR^{0.4} \qquad (39)$$

6.3 *Relative Density (Dr) and ϕ_{peak}*

The proposed relations give results close to those of the reference equations developed respectively by Jamiolkowski et al., 2001 and Kulhawy & Mayne, 1990 (Fig. 20).

$$\text{if } I_D \geq 1.8\ \&\ 4 \leq K_D \leq 7 \quad Dr = 43LN(K_D) \qquad (40)$$
$$\text{if } I_D \geq 1.8\ \&\ K_D < 4 \quad Dr = 48LN(K_D) + 9 \qquad (41)$$
$$\text{if } I_D \geq 1.2\ \&\ K_D \leq 7 \quad \phi_{peak} = 17 + 11 I_D^{0.32} K_D^{0.32} \qquad (42)$$

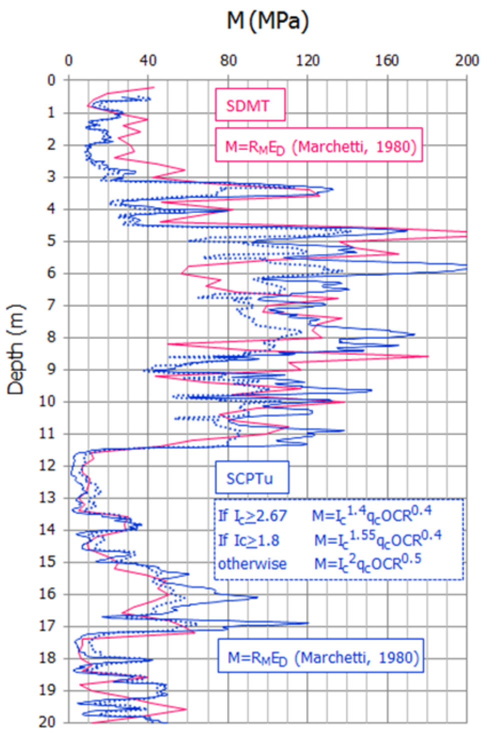

Fig. 18. M comparisons.

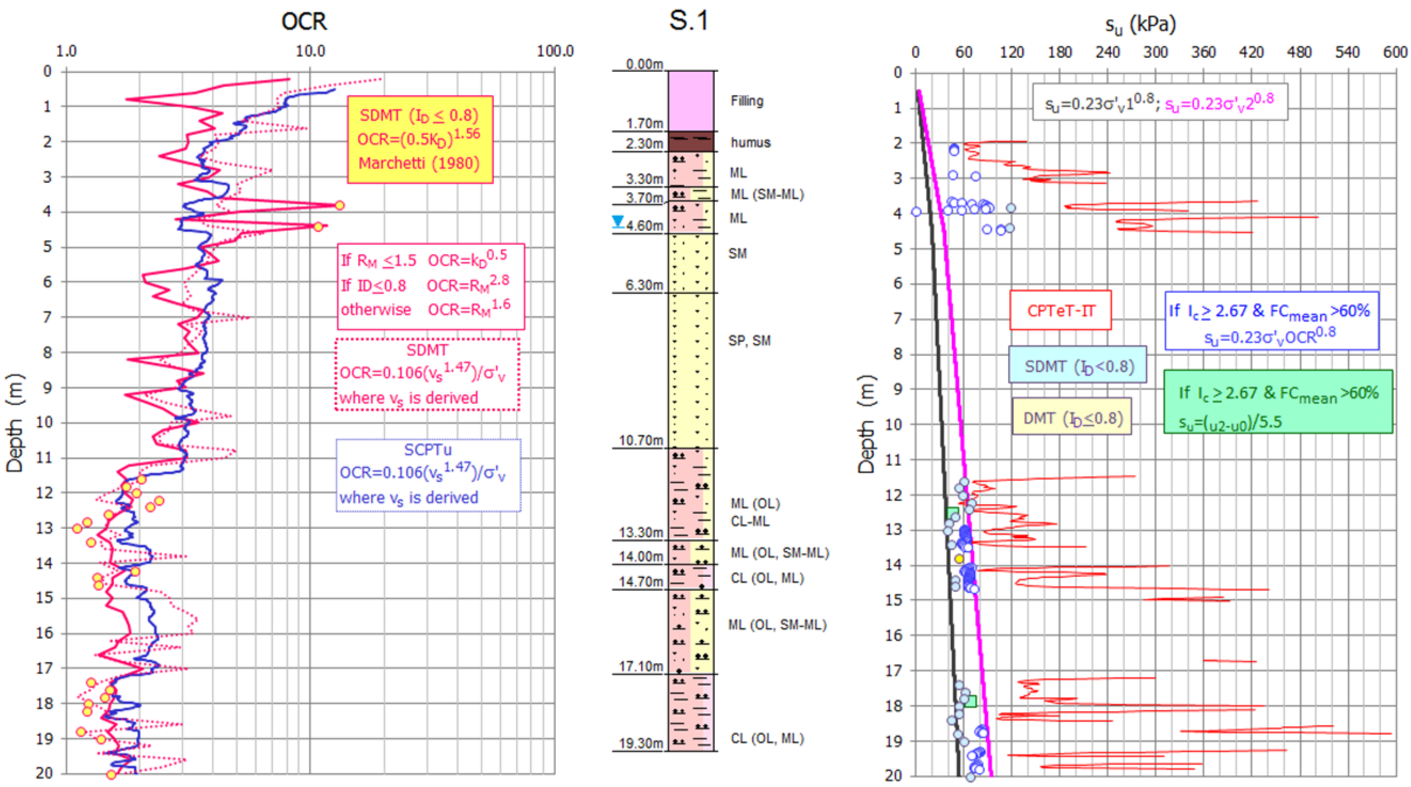

Fig. 19. OCR – s_u comparisons.

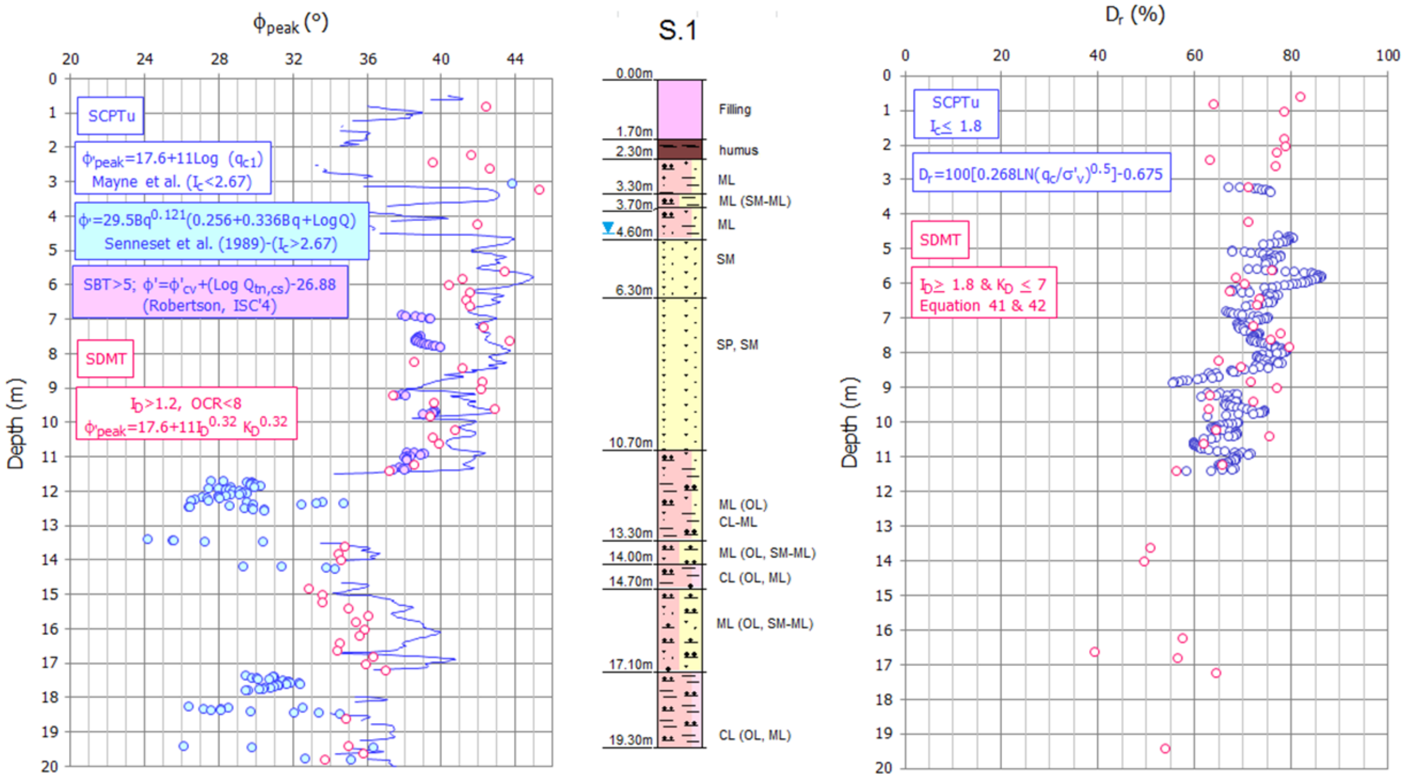

Fig 20. D_r - ϕ'_{peak} comparisons.

About Jamiolkowski equation, it is necessary to add that for calcareous soil the last term (-0.675) should be changed (-0.525). However this suggestion was ignored considering that the sands are OC or slightly cemented (Fig.7).

6.4 *Permeability (Fig.21)*

To note about that the dissipation tests results are generally in agreement between them (the formulas are specified in the plots as well as the values derived by the Robertson equation implemented in CPeT-IT).

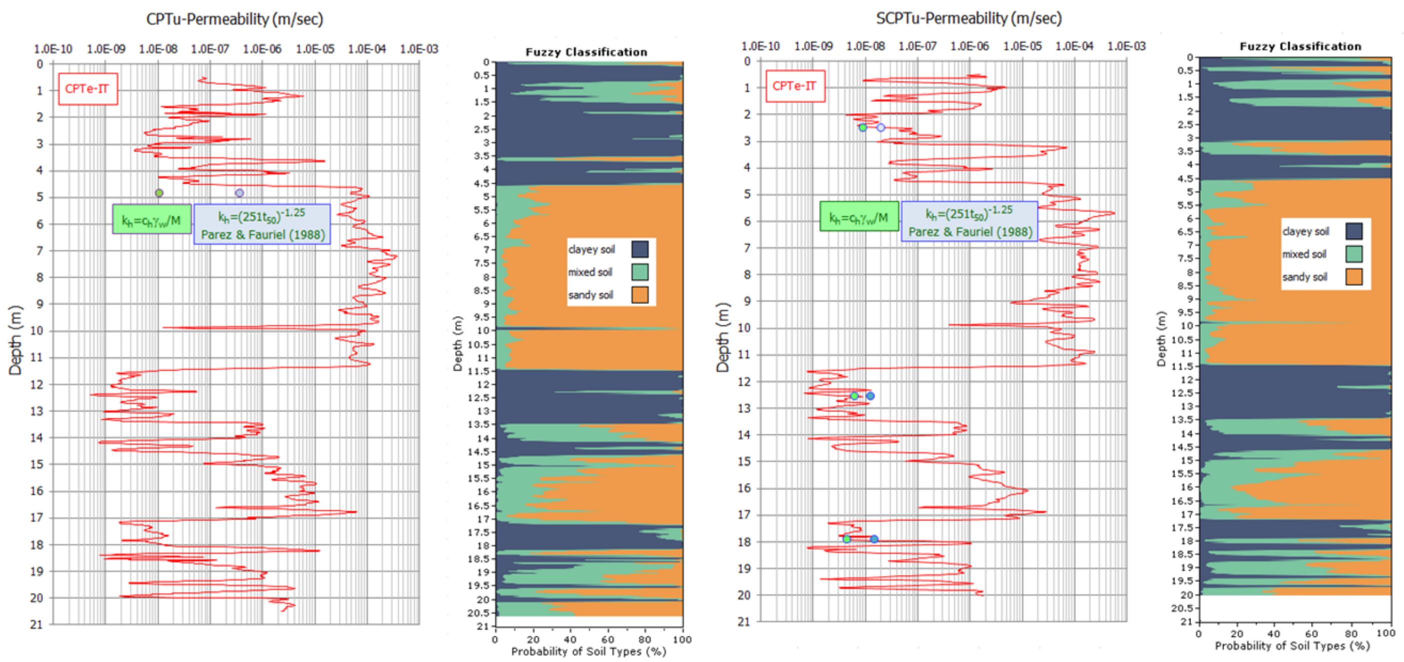

Fig. 21. Permeabilty Curves (based on CPTu SBTn and dissipation tests).

7 SUSCEPTIBILITY TO LIQUEFACTION

The Governolo workshop was not intended to study liquefaction, but less than 100m from the investigation site, is located the Parish Church (1735) damaged by the May 2012 earthquake and, therefore, it was made a quick check even to this. Some damage is shown in Fig.22.

Fig. 22. Church Damages.

Using the following input data (a_{max}=0.17, M_w=6.14, GWT from 4.5m to 1.5m) and the CRR equation developed by Marchetti (2013) as discriminant for liquefaction and no liquefaction, it was detected some liquefiable interlayers.

It is interesting to note that, among them, are present also soils classified as clay like (yellow circles in Fig.23), something not surprising because most of these have an Ip≤6 thus falling into the intermediate soils range proposed by Boulanger et al. (2006).

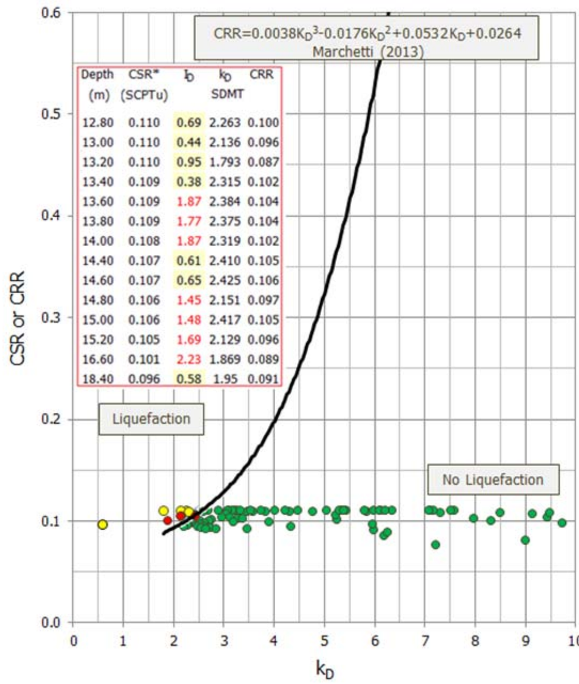

Fig. 23. K_D - CSR* Plot.

Considering only the soils with I_D>1.2 and using the ψ (state parameter)-K_D values pairs, also the plot in Fig.24 is proposed, to add a further judgment criterion towards the soils liquefiability. Probably the lentoid layering and the depth of the involved soils together with the characteristic of those overlying, have avoided mayor damages.

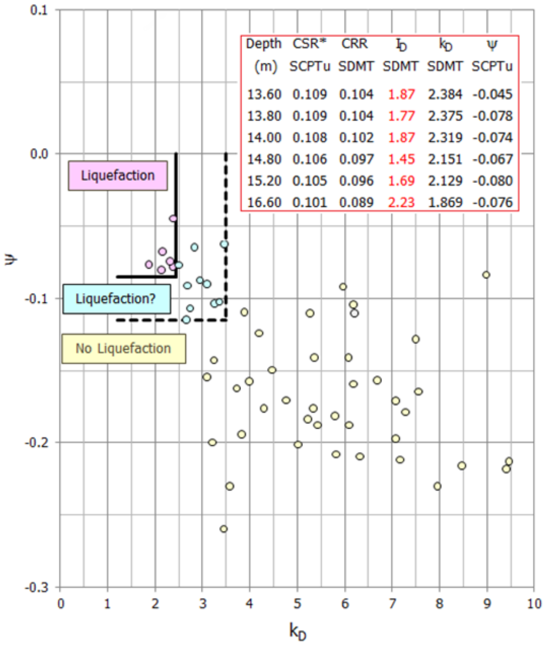

Fig. 24. ψ-K_D Plot.

8 CONCLUSIONS

According to the previous considerations a geotechnical investigation satisfy the best practice only if provides in its planning both DMT and CPTu, which complementing and checking each other, allow to obtain, with appropriate restrictions, a credible reconstruction of the soils geomechanical behaviour. However, this happens only when DMT and CPTu are associated with at least one continuous core sample drilling serving both as litostratigraphic interpretation key and for the execution of punctual in situ tests (DMT and SPT in the specific case). Also geophysical surveys are indispensable as well as identification laboratory analyses carried out on the extracted cores to have fundamental information on aspects scarcely covered or lacking from the in situ tests (exemplary, in this regard, the carbonate content). It was also observed that DMT, the only test sensible to soil stress history, should be considered, for this, as reference test and then its diffusion much better promoted by the academic community. Again, among the conversion equations proposed, stand out for their potentiality, those from CPTu to DMT and further studies in this direction are then recommended. In fact it may be taken advantage of the conspicuous CPTu database with great benefits, for example, for piles capacity prediction (p_0 and p_1 related respectively to small and large strain seem more suitable than q_c and f_s which are at failure values, instead routinely used), as well as for a more accurate analysis on soils liquefaction susceptibility and more. Finally worth noting are the solutions offered for the recovery of those in situ tests, next to be forgotten because giving a single parameter (e.g. SPT, DPSH, mechanical CPT), converting them into CPTu, an artifice that if improved, would keep alive and therefore usable, an inestimable treasure of background knowledge. Of course further research will be needed to verify the validity of the empirical relations developed in this study.

9 REFERENCES

Boulanger R.W. & Idriss I. M. 2006. “Liquefaction Susceptibility Criteria for Silts and Clays”. *Journal of Geotechnical and Geoenvironmental Engineering, Asce.*

Ku, C.S. & al. 2010. “Reliability of CPT Ic as an index for mechanical behaviour classification of soils”. *Geotecnique 60.*

Marchetti, 2013. "Using the DMT's parameter KD to estimate liquefaction resistance CRR and settlements in sand". Submitted to *ASCE J. Geotech. Geoenviron. Eng.*

Marchetti S. et al. 2008.” In Situ Tests by Seismic Dilatometer (SDMT)”. *GSP No. 270, 2008.*

Marchetti S. 1999. " The Flat Dilatometer and its applications to Geotechnical Design ", *Lecture notes Seminar on DMT held at the Japanese Geot. Society*, Tokyo, 12 Feb 1999.

Mayne, P.W. 2007. “NCHRP SYNTHESIS 368 Cone Penetration Testing A Synthesis of Highway”. *TRB Washington, D.C.*

Mayne, P:W, Christopher B.R. & DeJong J. 2001. “Manual on Subsurface Investigations”. *NHI Publication* NHI-01-031

Robertson, P.K. (2012). "Interpretation of in-situ tests – some insights". Mitchell Lecture, *ISC'4*, *Proceedings*, Porto de Galinhas, Brazil, September 18-21, 2012

Robertson, P.K. 2012 "Guide to Cone Penetration Testing," *Gregg.*

Robertson, P.K. 2009 "CPT-DMT Correlations". *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE.

Togliani G. 2012. “Some considerations about SOA-1. Summary (Alexandria, 2009)”. *ISC’4 Proceedings Porto de Galinhas*, Brazil, September 18-21, 2012.

Togliani G. 2012. “Some Considerations about SOA-1 Summary (Alexandria, 2009)”. *ISC'4*, *Proceedings*, *Porto de Galinhas*, Brazil, September 18-21, 2012.

Togliani, G. & Beatrizotti, G. 2004. “Experimental In Situ Test Sites”. *ISC-2 Proceedings*. Porto, September, 19-22, 2004.

Tsai, P.H., Lee, D.H., Kung, G.T.C. & Juang, C.H. (2009). "Simplified DMT-based methods for evaluating liquefaction resistance of soils". *Engineering Geology*, 103 (1-2), 13-22.

Yi, F. 2010. “Case study of CPT application to evaluate seismic settlement in dry sand”. *CPT’10 Proceedings*, Huntington Beach, CA.