Geotechnical parameters of very soft clays from CPTu

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ABSTRACT: Results of piezocone (CPTU) tests carried out on very soft soil deposits of Barra da Tijuca and Recreio in the city of Rio de Janeiro are presented together with a data of geotechnical properties. Data of vane shear strength are compared with piezocone data, and values of cone factor N_{kt} are obtained. Values of the coefficient of consolidation from piezocone dissipation tests are also compared with values from laboratory oedometer tests.

1 INTRODUCTION

Piezocone (CPTU) tests have been carried out in Brazil in various marine deposits along the Brazilian coast (Danziger and Schnaid, 2000; Coutinho, 2008; Schnaid, 2009) and also in the state of Rio de Janeiro (Almeida & Marques, 2003; Almeida et al. 2008a).

This paper presents data of in situ (mainly piezocone) and laboratory tests carried out on very soft clays deposits of Rio de Janeiro city at eight sites located in the Barra da Tijuca and Recreio dos Bandeirantes districts, west of the city of Rio de Janeiro. These results allowed the creation of a geotechnical data bank for these areas and also made it possible to compare the geotechnical properties of the sites.

2 DESCRIPTION OF THE SITES

The eight sites presented here are distributed along a 7.4 km^2 area, where the thickness of soft clay deposits varies from 2 to 30 m (Almeida et al. 2008a). The stratigraphy of these eight sites obtained from 443 boreholes is shown in Figure 1. The water table in general is quite shallow, at about 0.5 m depth. At the majority of the sites the soil beneath the soft deposit is sand with gravel. As these sites are surrounded by rivers or lagoons, the upper layer in many cases is either peat, dredged material, or uncontrolled fills.

Figure 2 shows an example of geotechnical characteristics of the Panela deposit. This site presents very high water content, void index, and compression ratio CR = $C_c/(1+e_o)$.

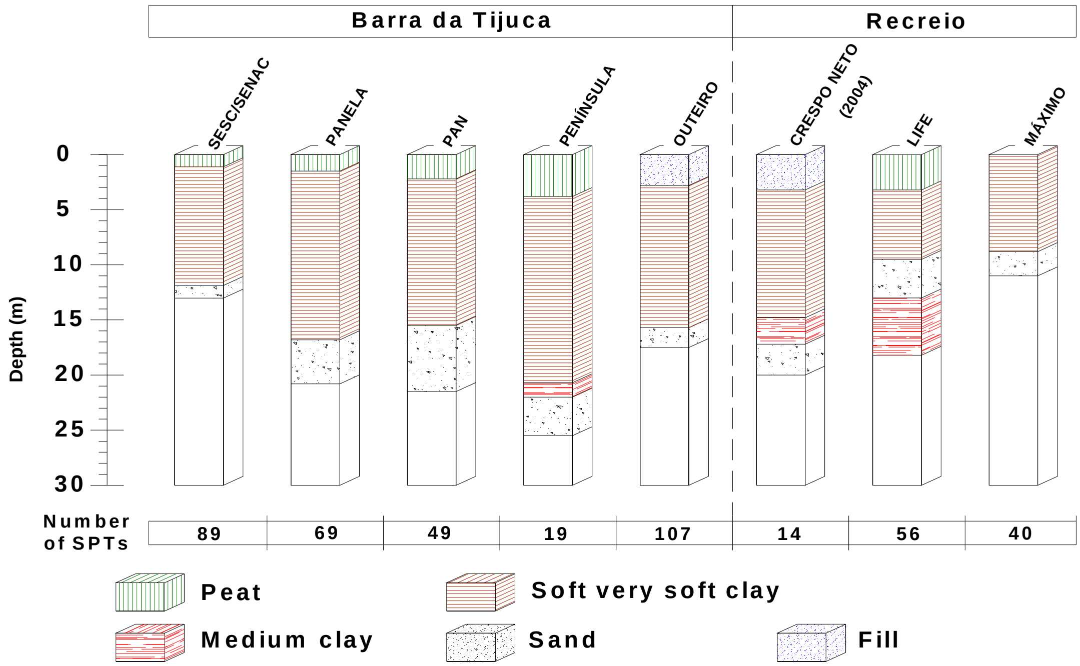

Figure 1. Stratigraphy of the sites.

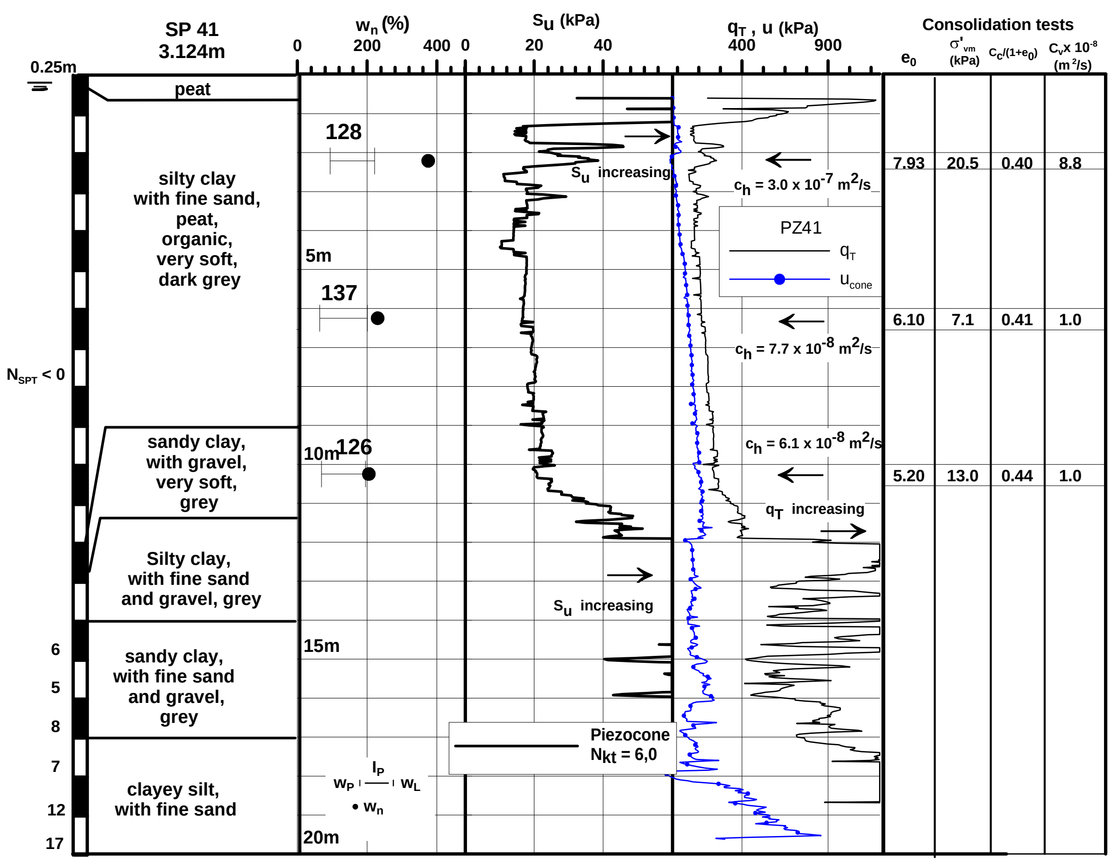

Figure 2. Geotechnical characteristics of the Panela deposit.

Some geotechnical properties and characteristics of the eight soft clay deposits are presented in Table 1. The high values of the compression ratio CR observed for SESC/SENAC, for example, led to an extensive study of secondary compression at that site (Garcia, 1996), which showed that important secondary settlements could occur at the sites. The results presented in Table 1 show that geotechnical parameters have a wide range despite the relative proximity of some deposits.

Table 1. Geotechnical parameters and characteristics of Barra da Tijuca and Recreio soft clay deposits.

Deposit	SESC/SENAC [1]	Panela	PAN [2]	Península II	Outeiro
w_0 (%)	72–500	126–488	116–600	61–294	75–119
w_L (%)	70–450	121–312	100–370	52–93	118–133
I_P (%)	47–250	80–192	120–250	100–300	97–105
% clay	28–80	26–54	32	23–71	32–65
γ_{nat} (kN/m^3)	12.5	9.8–13.4	11.6–12.5	10–12.7	13.5–15.7
CR=$C_c/(1+e_0)$	0.29–0.52	0.40–0.84	0.36–0.50	0.35–0.79	0.25–0.68
c_v (10^{-8} m^2/s) (3)	0.17–80	0.6–8.8	0.4–1.2	0.9–15	2.1–49
e_0	2.0–11.1	3.3–8.2	4.8–7.6	4.03–12.37	1.8–3.01
S_u (kPa)	2.0–11.2	3.0–38	5.0–23	4.0–29	7–41 (4)
N_{kt}	7.5–14.5	4.0–16	4.0–9	6.5–15	-

Deposit	Crespo Neto	Life	Máximo
w_0 (%)	72–496	114–895	72–1200
w_L (%)	89–172	86–636	88–218
I_P (%)	42–160	59–405	47–133
% clay	14–49	15–60	19–60
γ_{nat} (kN/m^3)	11–12.4	9.2–14.0	10.9–14.2
CR=$C_c/(1+e_0)$	0.27–0.46	0.22–0.49	0.27–0.38
c_v (10^{-8} m^2/s) (3)	0.07–0.6	0.3–3.3	1.3–6.3
e_0	3.8–15.0	3.0–15.1	2.0–11.6
S_u (kPa)	3.0–19	4.0–18	2.0–19
N_{kt}	5.0–13	4.0–16	5.0–14.5

(1) - Almeida et al. (2002) and Crespo Neto (2004).
(2) - Macedo (2006) and Sandroni & Deotti (2008)
(3) - c_v values from oedometer and piezocone tests.
(4) - S_u values from piezocone tests (N_{kt} = 13).

3 UNDRAINED STRENGTH

In Brazilian geotechnical practice, piezocone data are used in combination with vane data to obtain the undrained strength S_u profiles. The cone factor N_{kt} is obtained using corrected tip resistance (q_t) of the piezocone tests and S_u values of vane tests at each depth of vane results, as follows:

$$N_{kt} = \frac{(q_t - \sigma_{vo})}{S_{u(vane)}} \tag{1}$$

where σ_{vo} is the total vertical stress.

In order to obtain S_u profiles, for all depths of the piezocone tests, an average cone factor N_{kt} is then used. Values of N_{kt} of the eight deposits are presented in Figure 3(a), which shows a wide range of N_{kt} values of these sites, which are not too far from each other. Values of N_{kt} obtained for other coastal Brazilian clay deposits are shown in Figure 3(b) for comparison. It seems that even compared with Brazilian coastal clays, the range of N_{kt} values at these eight sites are wider and this may be due to the large soil variability in the region.

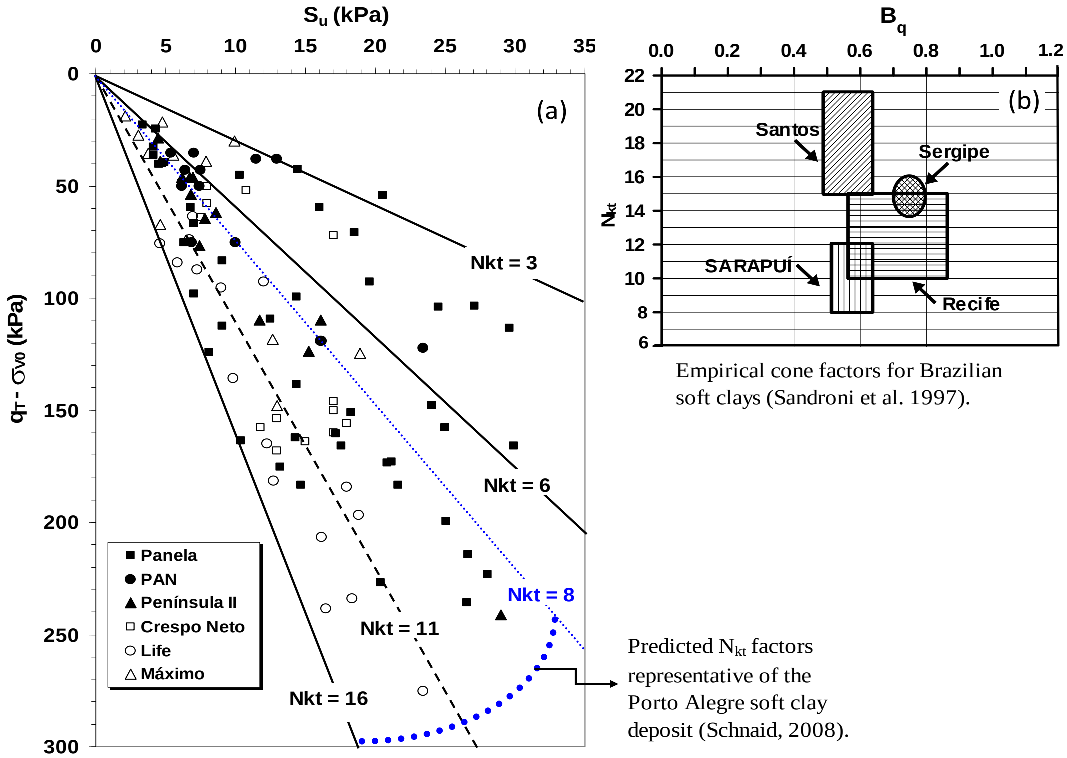

Figure 3. Values of the cone factor N_{kt} obtained at all sites.

Profiles of N_{kt} of two sites shown in Figure 4 indicate the large variation in N_{kt} with depth. Therefore, difficulties are encountered in obtaining an average value of N_{kt} even for a single site.

The experience of 20 years of piezocone tests carried out in Brazilian coastal clays (Danziger & Schnaid, 2000), as well as the wide range of values shown in Figures 3 and 4, indicates that N_{kt} values should be obtained for each deposit. This could be attributed to a number of factors such as soil variability and strength anisotropy. Some studies indicate that the cone factor N_{kt} is also dependent on the equipment used at each site (e.g., Ladd & De Groot, 2003). Two types of piezocone equipment were used in the studies reported here: a COPPE piezocone and a commercial piezocone.

Figure 5 presents uncorrected S_u from piezocone and vane tests data of the Península II deposit. Tests data show slightly higher S_u values at the top of compressible peat layers and then an increase with depth. This trend has been found in most deposits studied in the region (Borba, 2007; Crespo Neto, 2004; Almeida et al. 2008a; Nascimento, 2009). However, the higher S_u values of the top peat layers are due to the presence of fibres and organic matter that are not yet decomposed.

Field evidences indicate that this strength is not mobilized in situ, and thus a strength profile increasing with depth without a crust is usually considered in design.

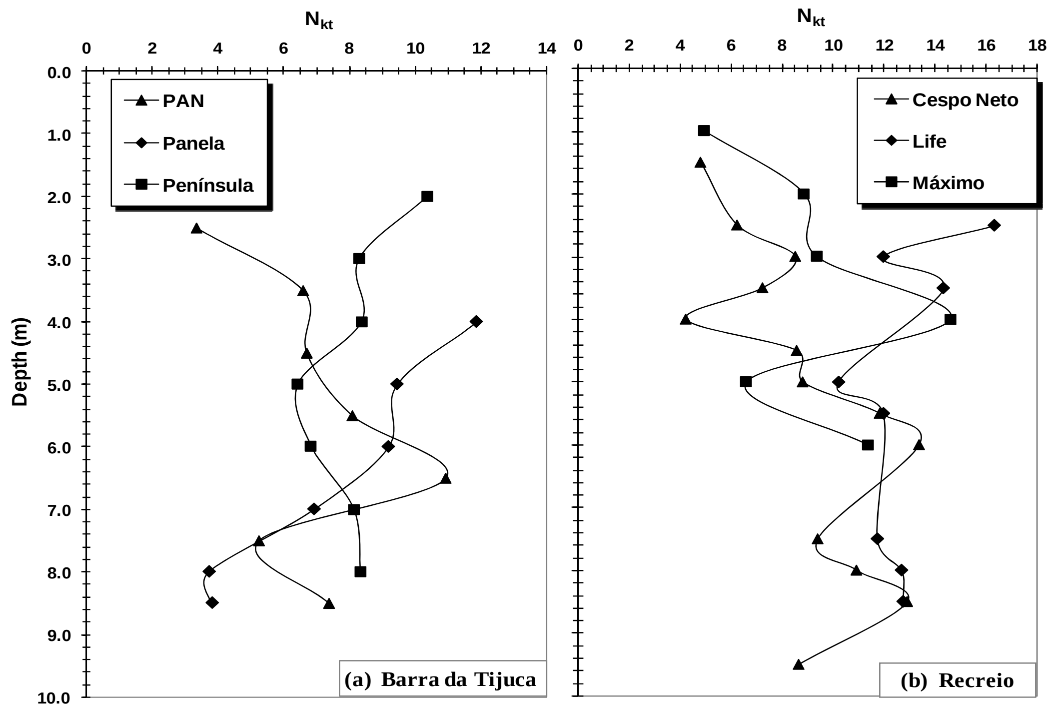

Figure 4. N_{kT} profiles obtained at two sites.

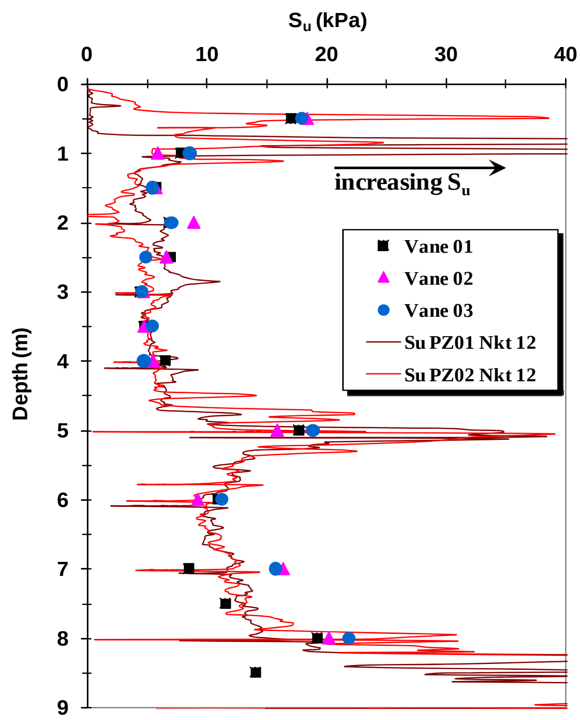

Figure 5. Vane and CPTu uncorrected undrained strength S_u profiles: Península II site.

As these clays present very high plasticity indexes, the Bjerrum correction that is usually adopted, also based on back analysis of failures, is around $\mu = 0.60$ (Almeida et al. 2008b). Thus, S_u design strengths are extremely low, making it impossible to build single stage embankments over these deposits. The construction techniques adopted in the region include, for instance, stage construction with berms, reinforcements, surcharge, and drains, all used concomitantly at the same site, but piled embankments have also been used at some sites (Almeida et al. 2008a,c).

4 COEFFICIENT OF CONSOLIDATION

The coefficient of consolidation obtained by laboratory oedometer tests and in situ piezocone dissipation tests were compared. Laboratory samples were collected with stationary piston Shelby tube following the recommendations of the Brazilian code NBR-9820/1994 as well as complementary specifications adopted at COPPE/UFRJ (Aguiar, 2008). The laboratary c_v values were obtained by Taylor's square root method.

The specimen preparation procedures proposed by Ladd and De Groot (2003) were adopted in order to reduce the remoulding effect during the extraction of the soil from the Shelby tube. However, due to the nature of these very soft clays, most were not good quality samples according to the criterion proposed by Lunne et al. (1997).

Coefficient of consolidation values were calculated from piezocone dissipation tests using Houlsby and Teh's method (1988) and the standard procedures proposed in the literature (Lunne et al. 1997; Schnaid, 2009). The coefficients of consolidation c_{hoc} values at the overconsolidated range were calculated for 50% pore-pressure dissipation at the cone shoulder, and the t_{50} values were obtained from Δu - (log)t curves using the time factor $T^*_{50} = 0.245$. The clay stiffness index $I_r = G/S_u$ adopted was equal to 50. In the majority of the deposits in the region the I_r range is between 50 and 100. For correction from the overconsolidated to the normally consolidated range, a ratio between RR (recompression ratio) and CR (compression ratio) equal to 0.10 was adopted. Values of the coefficient of consolidation c_v from piezocone tests presented in Table 1 were obtained using the ratio $k_v/k_h = 1.5$. The variation in the coefficient of consolidation with depth obtained for the eight sites is shown in Table 1.

The variation in c_h values with depth from oedometer and piezometer results from the Outeiro deposit are shown in Figure 6. This wide range of c_h values was observed in the majority of the sites, and thus the monitoring of field behavior is very important in order to obtain more reliable data. The c_h obtained from data from the monitoring of an embankment constructed over vertical drains on SESC/SENAC deposit, of about 6×10^{-8} m^2/s (Almeida et al. 2005), was inside the range of tests results. For the Recreio deposit, c_h results from field monitoring, for example, were about 2.5×10^{-8} m^2/s (Almeida et al. 2008a).

5 CONCLUSIONS

The results from laboratory and field tests carried out of Rio de Janeiro clays in Barra da Tijuca and Recreio are part of extensive studies carried out on soft clay deposits in these neighborhoods, which are being used as reference for geotechcnical designs in these areas. However, it seems that due to the high variability of parameters, it is not possible to obtain characteristic properties of these deposits, even though they are very close.

The SPT boreholes profiles and stratigraphy are similar, but parameters as simple as Atterberg limits are quite different, as are compression parameters and strength parameters. Thus, for construction over these deposits in this area, high quality tests must be carried out.

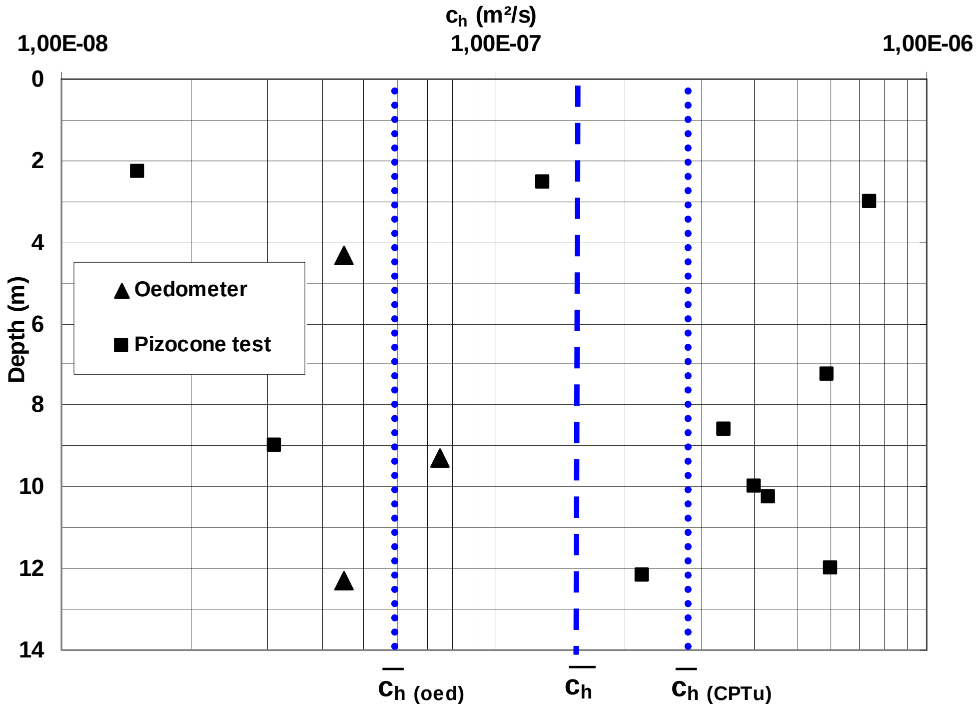

Figure 6. Coefficients c_h values of the Outeiro site from oedometer and piezocone results.

The scatter of coefficient of consolidation data is also very high, and it seems wise to be conservative when choosing design c_v values.

The very low strength of the upper layers of these deposits and the occurrence of layers of peat lead to difficulties in the building of the first stages of embankments. The variability of N_{kt} values, even for single sites, is also a problem when evaluating S_u values.

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