Laboratory Parameters of a Soft Soil Deposit in Macaé, Brazil

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Abstract. This article presents the geotechnical parameters from a laboratory investigation of a Quaternary sedimentary deposit located in a low-lying area of Macaé, Rio de Janeiro (RJ), Brazil, and, when possible, compares these parameters with those from field tests and other Brazilian studies on soft soils. The deposit is described in terms of its geological origin, physical, chemical and mineralogical characterization, compressibility, consolidation and strength. To that end, a series of laboratory tests were performed, including physical, chemical and mineralogical characterization, conventional and special consolidation, and triaxial tests. The results obtained made it possible to determine the geotechnical properties considered essential for improving knowledge on the behavior of this layer. Differences between laboratory and field parameters were observed, and the geotechnical characteristics of the Macaé deposits were found to be similar to those of other Brazilian soft soils.

Keywords: laboratory tests, Macaé, soft soil.

1. Introduction

Soft soil sedimentary deposits formed in the Quaternary period are common along the Brazilian coast. These soils normally exhibit high compressibility, elevated organic matter content, low bearing capacity and low penetration resistance.

In Brazil, a number of studies on Quaternary soft soils have been conducted over the last 50 years in cities such as Santos, Rio de Janeiro, Porto Alegre, Recife and Belém. These studies resulted in a data bank on geotechnical characterization of soft deposits that has been systematically used by engineers in these regions.

In the Norte Fluminense mesoregion, particularly in the low-lying part of the city of Macaé, there is an extensive Quaternary sedimentary deposit, which has been used to expand the urban area, due mainly to the development of the oil and gas industry.

In contrast to the rest of the Brazilian coast, studies on the geotechnical parameters for these soils are scarce in the Norte Fluminense region, especially in Macaé, and constructive problems are observed in this region due to the lack of knowledge concerning the properties of the soft soils from Macaé.

In this respect, the present study shows the results (geotechnical parameters) from laboratory tests performed on the Quaternary sedimentary deposit located in a low-lying area of Macaé, Rio de Janeiro. When possible, the results are compared to parameters from field tests and other studies on soft soils.

2. Brazilian Sedimentary Deposits

The literature contains a number of studies on soft soil deposits aimed primarily at increasing knowledge on the behavior of geotechnical structures, including investigations in Rio de Janeiro state, such as Almeida & Marques (2002), Santos (2004), Crespo Neto (2004), Sandroni & Deotti (2008), Baroni (2010), Queiroz (2013), Marques (2008), Lima & Campos (2014), Lima (2007), Baldez (2013) and Carneiro (2014).

Some of these studies enabled Futai *et al.* (2001) to develop simple stratigraphic profiles to facilitate profile comparisons (Fig. 1). Additionally, Fig. 1 shows the profiles created in the present study, which complement those developed by Futai *et al.* (2001). It is important to underscore that the Sarapuí deposit is the main Brazilian reference in terms of soft soils. Several studies have been carried out in Sarapuí, including Ortigão (1975), Antunes (1978), Sayão (1980), Gerscovich (1983) and Sandroni (1993).

The profiles in Rio de Janeiro state demonstrate that layers of sand and sandy clay are usually just below the soft soil, and that the soft soil has a thickness ranging from 5 to 15 m. Costa Filho *et al.* (1985) found that the water table in clays in the low-lying regions of Guanabara and Sepetiba bays coincides with the level of the terrain in most profiles, with slight variations throughout the year.

In addition to the Quaternary sedimentary deposits of Rio de Janeiro state, other deposits along the Brazilian coast have been investigated, including Santos (SP), Porto Alegre (RS), Florianópolis (SC), Itajaí (SC), and Porto de

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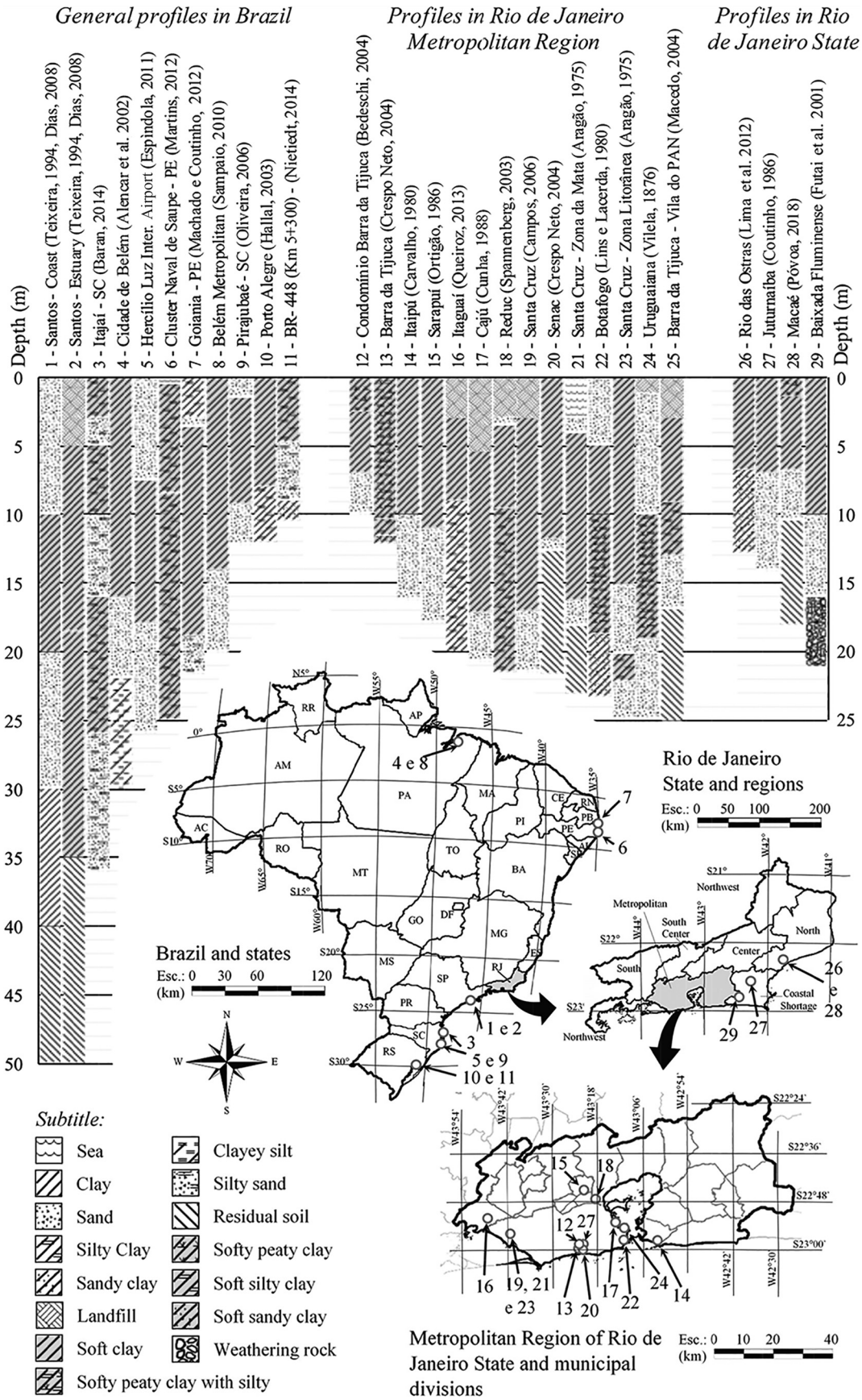

Figure 1 - Geotechnical Profiles of Soft Soils in different states in Brazil.

Saupe (PE), among others. General profiles in Brazil reveal that the clay layers may be thicker than those in Rio de Janeiro state and, once again, that the layers containing sand and silty sand are just below the soft layer. The soft soils in the stratigraphic profiles have been extensively investigated, and the geotechnical parameters are summarized in the Annex (Futai *et al.*, 2001).

3. Macaé Sedimentary Deposit

The study area is located in the sedimentary deposit on the low-lying region of Norte Fluminense, in the city of Macaé (Fig. 2). The study area is near the Macaé River, coming from the environmental protection area of Nova Friburgo, flowing for approximately 136 km and discharging in the Atlantic Ocean.

According to Martin *et al.* (1997), the study area is denominated by a coastal Quaternary cover that is related to the last cycles of marine transgression and regression, which occurred along the coast of Brazil.

Dantas *et al.* (1998) reported that the continental Quaternary sediments in this area may be the result of intense erosion, which dissected the Serra do Mar escarpment and elevated areas of the coastal lowland.

According to Dantas *et al.* (1998), the study region is part of the coastal plains domain of the coastal lowland, which contains marine and fluvial-lagoon plains of sedimentary origin, namely alluvial and colluvial soils.

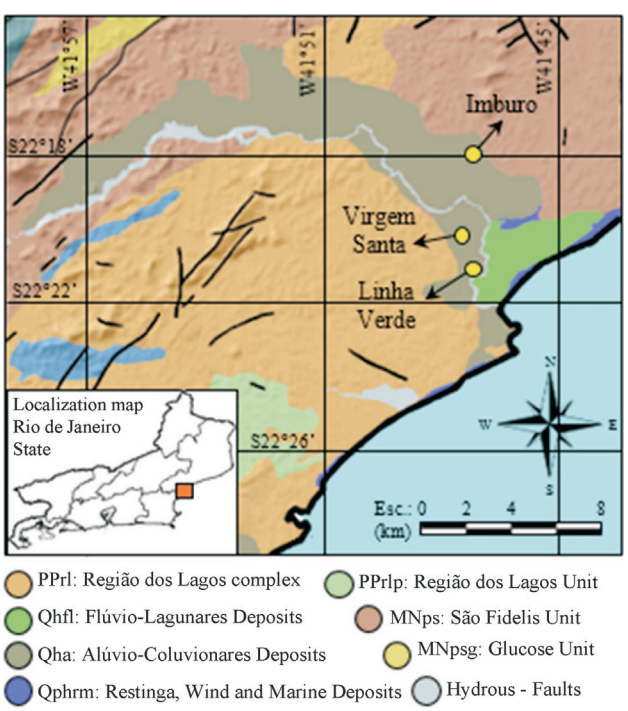

Figure 2 - Geographic location and Geological Map of the Norte Fluminense mesoregion, INEA, 2010.

Marine plains are formed by a succession of sub-horizontal sandy ridges, with a wavy microrelief of less than 5 m caused by marine sedimentation.

Fluvial-lagoon plains consist of organic clayey soil from paleolagoons, with flat, difficult-to-drain surfaces and a sub-outcrop phreatic zone.

4. Experimental Program

A battery of simple recognition probes was conducted to determine local stratigraphy. The investigation points are located in the Imburo, Linha Verde and Virgem Santa deposits (Fig. 2). The experimental program for each area is described in Table 1 and the typical stratigraphies obtained from the probes are shown in Fig. 3.

Table 1 - Experimental program.

Tests	Imburo	Linha Verde	Virgem Santa
SPT	6	12	4
Physical characterization	Complete		
Minerological characterization chemistry characterization	Complete		
Consolidation	7	-	-
Triaxial	2	-	-
CPTU	-	2	2
Experimental embankment	2	-	-

Obs: Field investigations are presented for discussion purposes and are not the objective of the study.

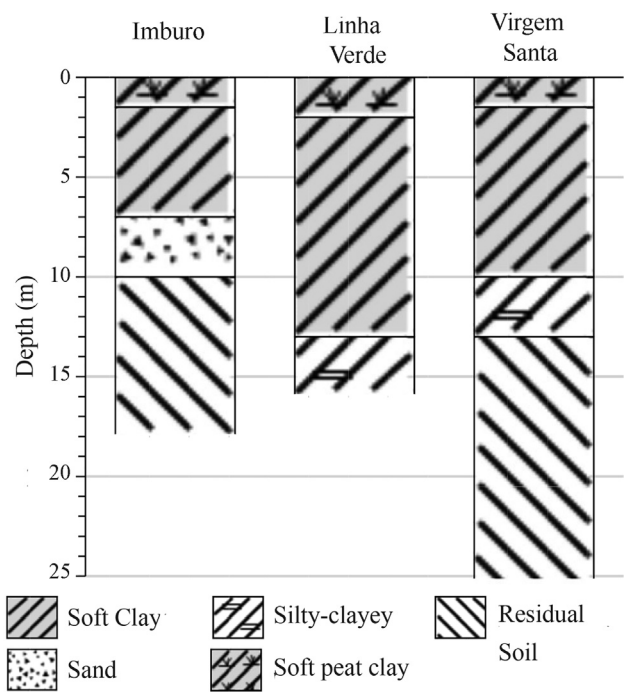

Figure 3 - Stratigraphic profile of the points investigated.

The undisturbed soft soil samples were collected using Shelby samplers (diameter = 100 mm and length = 600 mm) at maximum depths of 4.5 m. Although sampling was not performed at great depths, preliminary SPT and CPTu indicated a homogeneous layer and the samples are therefore considered representative.

The water table in general is quite shallow (about 0.5 m). Since these sites are surrounded by rivers or lagoons, the upper layer is peat, dredged material, or uncontrolled fills.

4.1. Mineralogical chemistry

The light grey odorless soft soil of Macaé has an organic matter content of approximately 7%. X-ray diffraction analyses at different deposit sites identified the presence of quartz, kaolinite and smectite.

Chemical and mineralogical analyses were conducted on samples from different depths of the sedimentary deposit. X-ray fluorescence spectrometry revealed that the soil contained a higher proportion of silicates (45.3%) and aluminates (28.1%) than the other samples, which likely indicates the existence of quartz and clay minerals such as kaolinite, smectite and illite.

Sorption complex analysis found a mean cation exchange capacity (CEC) of 83, suggesting that the samples exhibited reactivity. Moreover, associating CEC values with the clay minerals contained in the clay structure indicates the presence of smectite and vermiculite.

The mean indices of K_i and K_r, obtained by the molar ratios SiO_4/Al_2O_3 and $SiO_4/(Al_2O_3 + Fe_2O_3)$ respectively, were 2.7 and 2.5, suggesting the presence of 2:1 clay minerals. The mean SiO_2 and Al_2O_3 contents were 26% and 16%, respectively, similar to the values reported by Campos (2006) for soft soil from the Industrial Zone of Santa Cruz, Rio de Janeiro.

Therefore, the mineralogical characterization of the soil is compatible with chemical analyses, since both indicated the presence of smectite.

The pH in water varies from 4.8 to 6, the range established by Coutinho (1986) for soft clays from Barragem de Juturnaíba, RJ. The mean value in electrical conductivity analyses was 4.5, corroborating the results of Lima *et al.* (2012) for soft clay in Rio das Ostras, RJ.

4.2. Physics

Soft soil from Macaé is composed, on average, of 65% clay, 34% silt and 1% sand. Figure 4 shows the profiles of liquidity limit (w_L), plasticity index (I_p), water content (w_n), initial void ratio (e_0) and natural specific weight (γ_{nat}). To determine the liquidity limit, the test was conducted using samples with their natural water content and no previous drying, in contrast to the standard. The decision not to dry the samples beforehand was based on the guidelines of Bjerrum (1973), who reported that liquidity limit and plasticity testing in silty clay with organic matter should be performed using samples in their natural state, since drying affects the plasticity of clay.

The water content of the surface layer (0.15 to 0.75 m deep) is 80.8%, with values ranging from 187.7% to 217.7% for the deeper layers.

The specific natural weight was approximately 12.6 kN/m^3; however, the specific weight of the surface

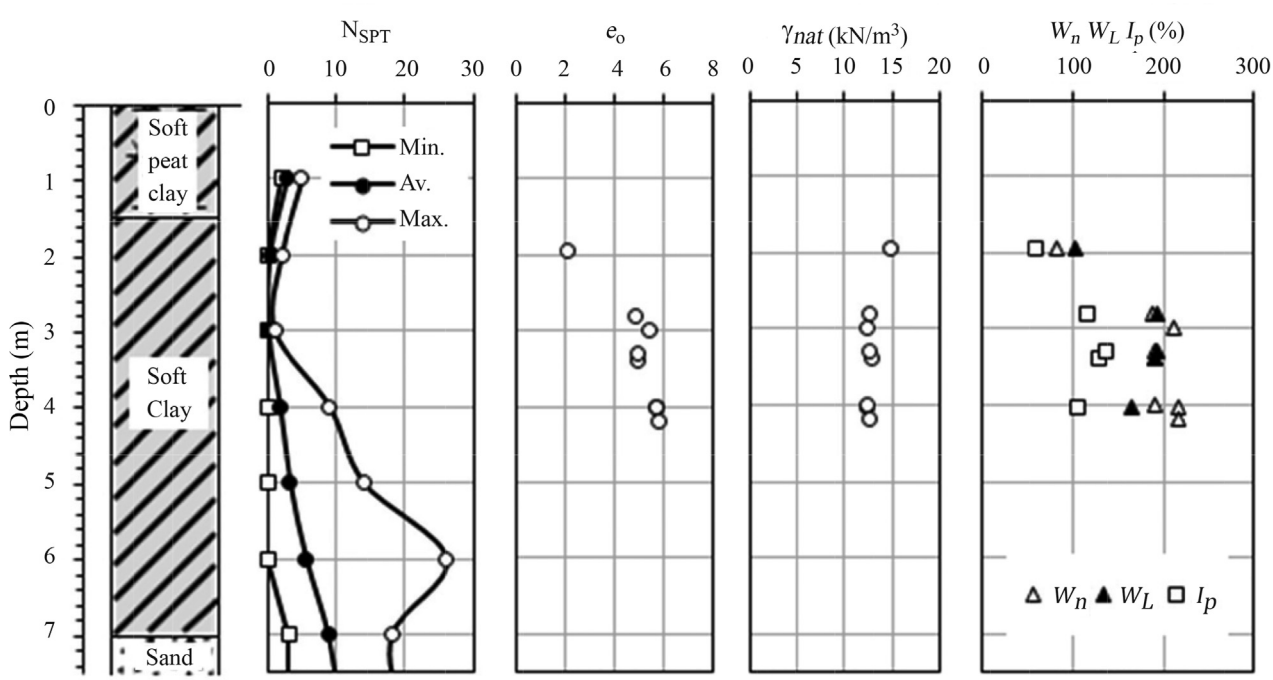

Figure 4 - Physical properties of soft clay.

layer was slightly higher than 14.9 kN/m^3. The differences in water content and specific weight in the surface layer can be explained by the seasonal water level variations in this layer.

The void index in the surface layer is 2, ranging from 4.8 to 5.7 in the rest of the soft soils, indicating that the deposit is composed of compressible soil (Póvoa *et al.*, 2016).

Relative grain density (G_s) was 2.6, showing a slight increase in depth. This behavior suggests there is no significant variation in minerology across the profile. The same observation was made by Lima & Campos (2014) for the region of Guaratiba, RJ.

The Skempton activity index classified all depths analyzed as active, except for the surface layer, which was classified as normal.

The geotechnical characterizations are compatible with chemical analyses, since cation exchange capacity (CEC) values were in line with Skempton activity indices.

4.3. Characterization of compressibility

Póvoa (2016) performed seven incremental oedometer consolidation tests (two types): conventional (AEI-1, AEI-2, AEI-3, AEI-4 and AEI-5), and with secondary compression (AEI -6 and AEI-7).

The conventional tests lasted 24 h for each loading stage and until readings stabilized at unloading. Consolidation with creep testing differed from conventional testing in that the loading stage lasted 72 h (AEI -6 and AEI-7).

Figure 5 shows that the consolidation curves of the 7 samples tested exhibit similar behavior. Two conventional tests (AEI-3, AEI-4) and one with creep measurement (AEI-7) for a depth between 2.1 and 2.7 m showed that the sample had a tendency to declining void indices if the loading stages were higher. This is also observed for depths between 1.3 and 1.9 m, where a test with a 24-h loading stage (AEI-5) and another lasting 72 h (AEI-6) were performed.

The behavior of the soft clays studied in laboratory may be affected by sample remolding. Coutinho (1976) was a pioneer in studying the quality of clay samples in Brazil. This was followed by other investigations, such as those by Ferreira (1982) and Martins & Lacerda (1994).

Technical studies conducted by Coutinho (1986), Mesri & Choi (1985), Ferreira and Coutinho (1988) and Martins & Lacerda (1994) reported that the virgin compression behaves curvilinearly rather than rectilinearly for good quality samples.

The findings of Martins & Lacerda (1994) agree with those of Coutinho (1986) for soft soil from Sarapuí I, in which the S-shaped curve is characteristic of a good quality sample. In order to validate the results of consolidation tests performed in the present study, the quality of test specimens was assessed based on the criteria of Lunne *et al.*

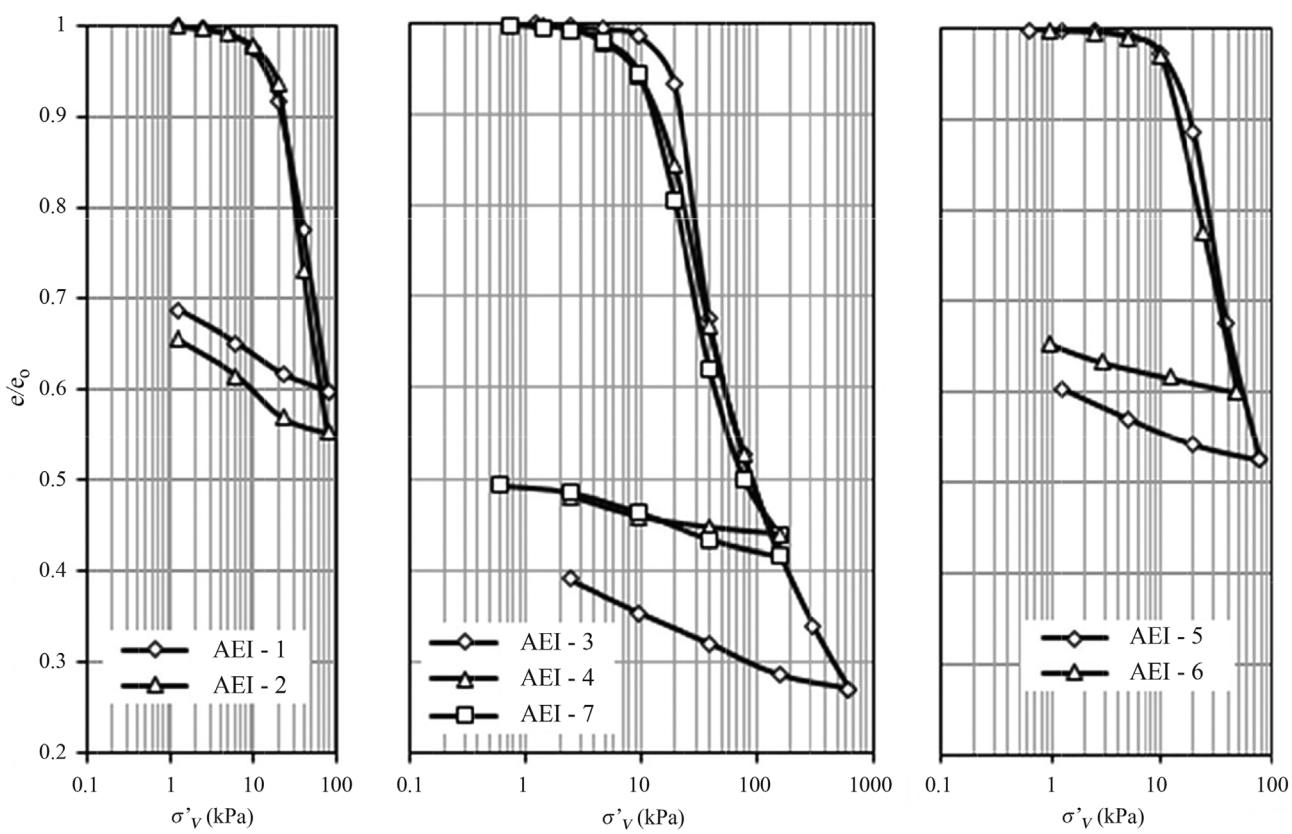

Figure 5 - Comparison between effective stress and void index curves.

(1997), Oliveira (2002), Coutinho (2007) and Andrade (2009). However, quality was only evaluated for consolidation tests with 24-h loading stages because the classification criteria considered the over consolidation ratio (*OCR*). This parameter depends on pre-consolidation stress which, in turn, is influenced by loading time. Five samples were classified as very good to excellent and one as good to fair, based on the criteria of Lunne *et al.* (1997) Oliveira (2002) and Coutinho (2007), and very good to good according to Andrade (2009).

4.3.1. C_s, C_c and C_a indices

Figure 6 shows a summary of some of the parameters obtained in oedometer tests, where C_s and C_c are the recompression and compression indices, respectively. Figure 6 also depicts C_s and C_c corrected using the method proposed by Schmertmann (1955), which takes remolding into account. In general, the corrected C_c parameters increased by an average of 19% and C_s parameters declined by an average of 12%, values similar to those reported by Oliveira (2002).

Soft soil compressibility is normally assessed using $C_c/1 + e_0$ values, given their much smaller dispersion and, according to Martins *et al.* (2006), should be considered representative of natural soft clay compressibility, rather than C_c.

Furthermore, the coefficient of secondary compression was obtained via the time *vs.* void index curve for each loading stage, based on the slope of the straight line at the end of primary consolidation, for samples AEI-6 and AEI-7. Their effective stress behavior is presented in Fig. 7. This graph shows that C_α increases with a rise in stress, reaching a peak and then declining. This behavior was also observed by authors such as Ladd (1973), Coutinho & Lacerda (1994) and Campos (2006). The variation in coefficient C_α was similar to that reported by Feijó (1991) for the coefficient of secondary compression of clay from Sarapuí. For the first loading stages, C_α values were very low, similar to those obtained by Campos (2006), who established a coefficient of secondary compression of 0.02% for the first stages. Andrade (2009) found a very small C_α value for effective vertical stress, which was half the pre-consolidation stress.

Mesri & Godlewski (1977) proposed that C_α/C_c is constant, whereas Mesri (1973) suggests that the coefficient of secondary consolidation declines with effective vertical stress.

Martins & Lacerda (1989) hypothesized that C_α should decrease over time and tend towards zero.

Secondary consolidation has been widely studied, but there is still no consensus concerning this phenomenon (Futai, 2010).

4.4. The c_v coefficient

According to Yu (2004), the coefficient of consolidation is one of the most difficult soil properties to measure in geotechnical engineering. It can be obtained from laboratory tests, *in situ* tests and retro analyses. In the present study, the coefficients of consolidation were measured in

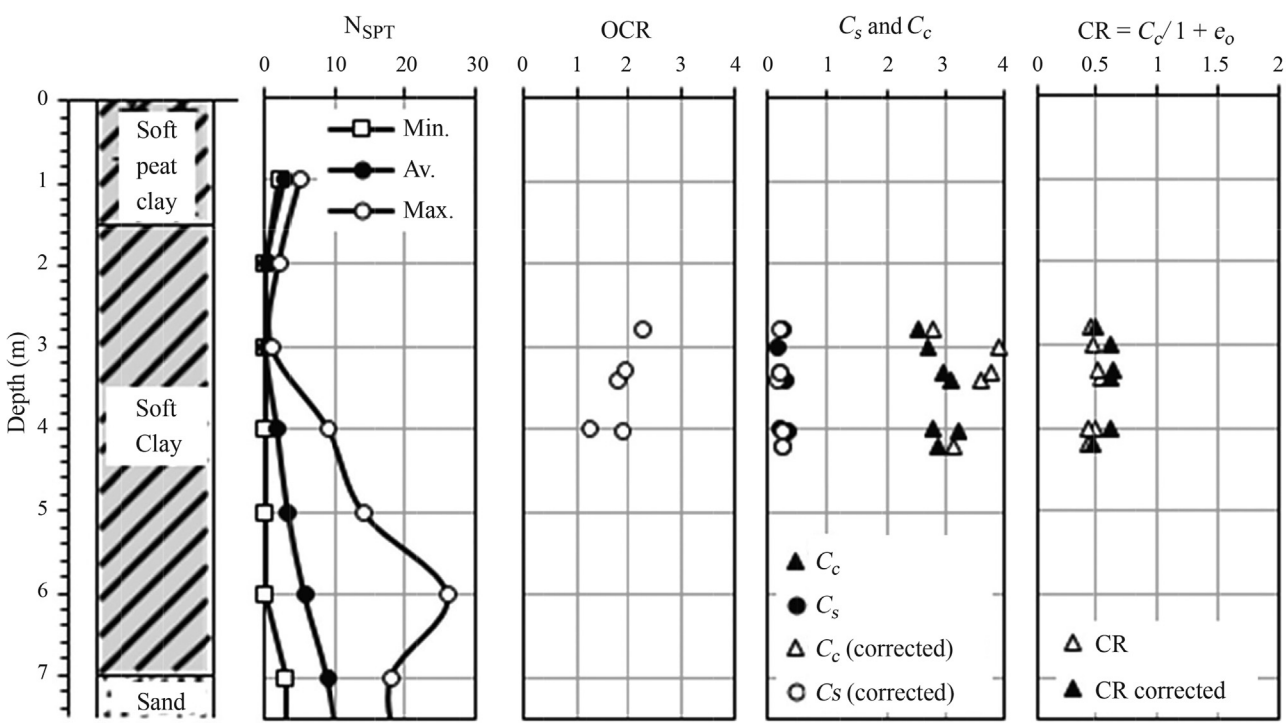

Figure 6 - Compressibility parameters of one-dimensional consolidation tests.

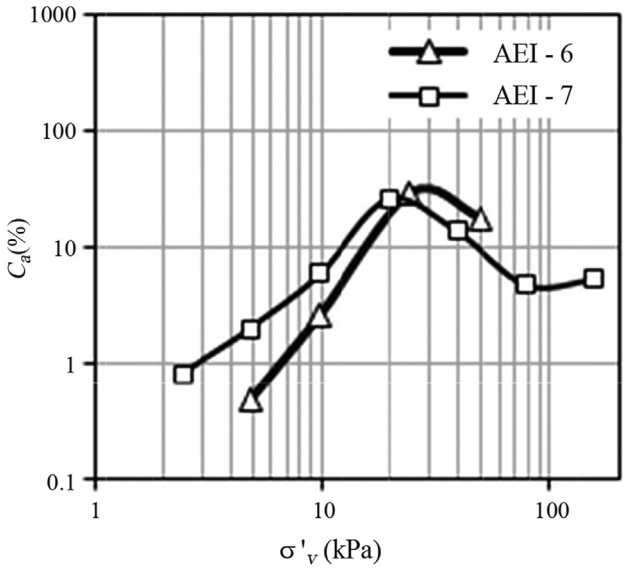

Figure 7 - log σ' *vs.* C_α curves of consolidation tests with creep measurement.

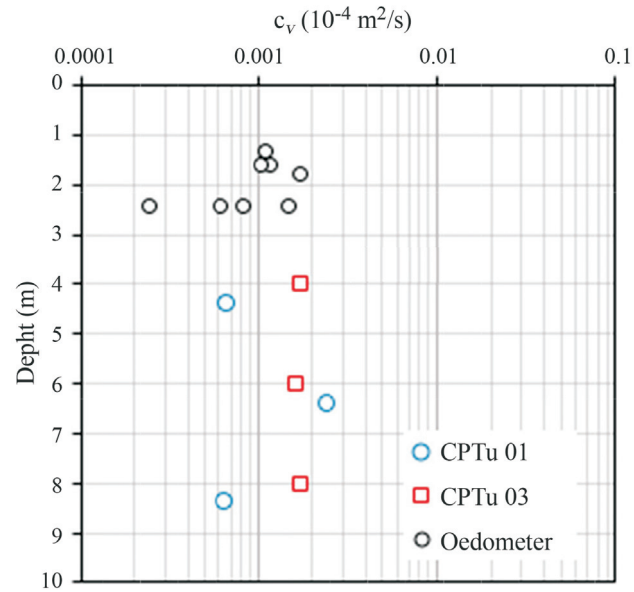

Figure 8 - Convergence of the vertical coefficients of consolidation, CPT 01 and CPT 03.

conventional oedometer consolidation tests and compared to values obtained in piezocone dissipation tests.

The horizontal coefficients of consolidation were estimated from the dispersion of excess pore-pressures in the piezocone tests and defined according to Houlsby and Teh's method (1988) and the standard procedures proposed in the literature (Lunne *et al.*, 1997; Schnaid, 2009).

These horizontal coefficients of consolidation (c_h) correspond to the soil properties in the preconsolidated range, since the material surrounding the cone is submitted to high strain levels during penetration, and then behaves like soil in recompression (Baligh & Levadoux, 1986). Coefficient of consolidation values in the overconsolidated range were calculated for 50% pore-pressure dissipation at the cone shoulder, and the t_{50} values were obtained from Δu *vs* log *t* curves using the time factor $T * 50 = 0.245$. Next, the method proposed by Jamiolkowski *et al.* (1985) was used to estimate c_h values in the normally consolidated range and transform them into the vertical coefficients of consolidation.

Figure 8 shows the vertical coefficient values estimated through consolidation and piezocone tests. The c_v values estimated using piezocone tests varied from 6.7 x 10^{-8} to 2.4 x 10^{-7} m^2/s. The average c_v values estimated by consolidation tests in Imburo were similar to those estimated by piezocone tests. In addition, the overall average of the consolidation coefficients was 1.2 x 10^{-7} m^2/s, which is in line with those found by Lima & Campos (2014) for the region of Guaratiba - RJ.

Figure 8 shows a difference between the c_v results obtained in the field using the CPTU test and those found in the laboratory applying the oedometer test. The ratio between coefficients c_v *in situ* and c_v in laboratory ranges from 6 to 15, corroborating the bibliography for similar soils. According to Lacerda & Almeida (1995) and Spotti (2000), this ratio for soft soil from Sesc/Senac-RJ varies between 20 and 30, the same as that observed by Gerscovich (1983) and Ortigão (1980) for clay from Sarapuí. Baroni (2010) recently obtained a relation of 6 for the Barra da Tijuca region.

One of the reasons suggested by Almeida *et al.* (2005) for the difference between c_v *in situ* and laboratory values is the influence of secondary consolidation. The authors subsequently agreed with Teixeira (2012), who reported that the fact test specimen deformability is not consistent with the real condition makes it difficult to assess the coefficient of consolidation in the laboratory and comparatively analyze the values.

4.5. The *K* coefficient

Figure 9 shows the permeability coefficient values obtained in consolidation and dissipation tests in the CPTU. It is important to underscore that Robertson's (2012), Eq. 1, was used to estimate the permeability coefficient via dissipation and piezocone tests:

$$k = \frac{c_v \gamma_n}{M} \tag{1}$$

where *M* is the oedometer modulus. As expected, the *k* coefficient declines with a rise in vertical stress (σ'_v) due to the decline in void index with an increase in σ'_v.

4.6. Characterization of undrained shear strength

The undrained shear strength of soil can be determined in laboratory tests, *in situ* tests and analyses in the same way as the vertical coefficient of consolidation. In the present study, undrained strength was measured in uncon-

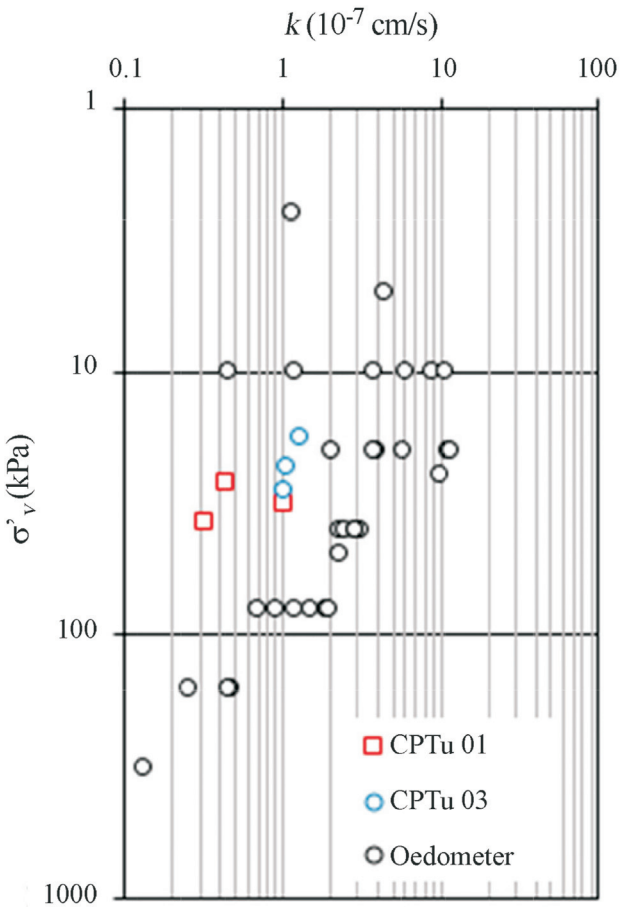

Figure 9 - Variation of the permeability coefficient *vs.* effective stress.

solidated undrained (UU) triaxial tests using a retroanalysis of an instrumented embankment in the same deposit induced to rupture, as described by Nascimento *et al.* (2016). This procedure was used to validate the estimated undrained shear strength calculated by a limited number of triaxial tests.

Undrained shear strength measured by UU triaxial tests varied between 6 and 7.5 kPa. When these results were related with the S_u of 8.8 kPa obtained by Nascimento *et al.* (2016) in a retroanalysis, a ratio between 1.2 and 1.5 was found between S_u *in situ* and S_u in laboratory. This field and laboratory ratio for undrained shear strength agrees with that obtained by different authors and deposits, as shown in Table 2.

Laboratory test results are generally lower than their field counterparts, corroborating the reports of Almeida *et al.* (2005) and Coutinho (2007). The latter associates this difference with sample disturbance, equipment conditions and the test procedures used.

The undrained shear strength values obtained for Macaé corroborate those reported by Spannenberg (2003) for Baixada Fluminense, Oliveira (2006) for Florianópolis and Sayão (1980) and Almeida *et al.* (2005) for Sarapuí.

Table 2 - Field and laboratory ratio of a number of embankments in Brazil.

Site	References	S_u *in situ*/S_u *lab*
Itaguaí - RJ	Queiroz (2013)	1.40
Sesc/Senac - RJ	Lacerda and Almeida (1995), Spotti (2000)	1.2-1.5
Sarapuí - RJ	Gerscovich (1983), Ortigão (1980)	0.77-2.30
Recife - PE	Bello (2004)	1.5
Juturnaíba - RJ	Coutinho (1986)	1.23
Macaé - RJ	Póvoa (2016), Nascimento (2016)	1.17

5. Summary of the Geotechnical and Mineralogical Properties of Macaé - RJ

The deposit is described in terms of its geological origin, physical characterization, compressibility, consolidation and strength. Table 3 presents a summary of the main geotechnical and mineralogical properties obtained for the compressible layer of Macaé - RJ. It is important to underscore that the surface layer parameters were not included in the average.

6. Conclusions

This study presented and discussed the geotechnical parameters from laboratory tests of a Quaternary sedimentary deposit located in a low-lying area of Macaé, Rio de Janeiro (RJ). The results led to the following conclusions:

- The sedimentary deposit, formed during the Quaternary period, is related to the last transgression and marine regression cycles. The thickness of the compressible layer varies between 5 and 12 m and the surface layer is signif-

Table 3 - Summary of the geotechnical and mineralogical properties of Macaé - RJ.

Minerals	Kaolini, smectite and quartz
w_n (%)	201 ± 13.7
w_L (%)	186 ± 14
Ip (%)	186 ± 14
% clay	121 ± 14
γ_{nat} (kN/m^3)	12.5 ± 0.1
% OM	7 ± 0.2
e_0	5.3 ± 0.4
$*CR = C_c/(1 + e_0)$	0.47 ± 0.04
c_v (m^2/s) x 10^{-7}	1.29 ± 0.6
Su (kPa)	7.5 ± 1.5

*Values not corrected by the Schmertmann (1955) method.

icantly affected by the natural variation in the water table in the area.

- The geotechnical and mineralogical characterizations of the soil are compatible with the chemical analyses, indicating the presence of smectite clay minerals.
- According to consolidation tests, the soft soils are slightly preconsolidated, with mean OCR of 1.8, the compression ratio (*CR*) varied from 0.42 to 0.52, considering Schmertmann's (1955) correction, and mean *CR* was 0.47, suggesting highly compressible soil.
- The behavior of log σ'_v x C_α curves of consolidation tests with creep measurement was also observed by authors such as Ladd (1973), Coutinho & Lacerda (1994) and Campos (2006).
- A comparison of the vertical coefficients of consolidation obtained from oedometer consolidation tests and CPTu tests indicates that the methods were adequate. The magnitude of c_v aaried from 2.45 x 10^{-8} to 2.4 x 10^{-7} m^2/s.
- The results of undrained shear strength, determined in UU triaxial tests, were satisfactory, since they were similar to those obtained in embankment retroanalyses. In this respect, the mean undrained shear strength estimated for the deposit was 8 kPa.
- The ratio between field and laboratory vertical coefficients of consolidation for undrained shear strength showed that the values obtained in field tests are higher than their laboratory counterparts, and that those for Macaé are compatible with the bibliography for similar soils.
- The main geotechnical and geological parameters found for soft soil from Macaé - RJ are summarized in Table 3 and suggest a close approximation with the experimental data reported in the literature for soft quaternary soils on the Brazilian coast.
- The present article is the first to characterize the Macaé deposit. As such, it does not eliminate the need for further laboratory and field investigations to better characterize the properties of the layer.

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List of Symbols

CEC: cation exchange capacity
CPTU: piezocone test
CR: compression ratio
M: oedometer modulus
N_{SPT}: blow count
OM: organic matter
SPT: Standard Penetration Test
C_c: compression index
c_h: horizontal coefficient of consolidation
C_s: recompression index
c_v: vertical coefficient of consolidation
C_α: Coefficient of secondary consolidation
e_0: initial void ratio
G_s: relative grain density
I_p: plasticity index (%)
k: permeability coefficient
K_i: molar ratios SiO_4/Al_2O_3
K_r: molar ratios $SiO_4/ (Al_2O_3 + Fe_2O_3)$
S_u: undrained clay strength (kPa)
w_L: liquidity limit
w_n: water content
σ'_v: vertical effective stress

Appendix

Table A - Geotechnical properties of soft soils in Brazil, modified from Futai *et al.*, 2001. (Part 1).

Site	Rio das Ostras	Juturnaiba	Itaipú	Cajú	Rua Uruguaiana	Botafogo
References	Lima *et al.* (2012)	Coutinho (1986)	Carvalho (1980) Pinheiro (1980)	Cunha (1988)	Vilela (1876)	Lins & Lacerda (1980)
Thicknesses (m)	1-6.8	7	10	12	9	6
w_n (%)	100-200	15495.6	240 ± 110	88	54.8 ± 1 9.5	35
w_l (%)	99-150	132 ± 44	175 ± 83	107	71 ± 30	38
Ip (%)	53-106	64 ± 22	74 ± 30	67	40 ± 22	11
% clay	47-66	60.7 ± 12.74			39.4 ± 10.11	28
γ_n (kN/m^3)	12-15	12.5 ± 1.87	12 ± 1.85	14.81	16.1 ± 1.39	17.04
% OM	7-11	19 ± 10.63	32.63 ± 20.46		2.56 ± 1.04	
e_0	2.6 -5.2	3.74 ± 1.98	6.72 ± 3.1	2.38	1.42 ± 0.36	1.1
$CR = C_c/(1 + e_0)$	0.4-0.46	0.31 ± 0.12	0.41 ± 0.12	0.267	0.31 ± 0.15	0.16
C_s/C_c	0.09 - 0.14	0.07 ± 0.06		0.21		0.19
c_v (cm^2/s) x 10^{-4}	1-9	1 - 10	5			30

Table A - Geotechnical properties of soft soils in Brazil, modified from Futai *et al.*, 2001. (Part 2).

Site	SESC/ SENAC	Baixada de Jacarepaguá	Duque de Caxias (REDUC)	Sarapuí	Sarapuí II	Itaguaí (RJ)
References	Crespo Neto (2004)	Cunha (1988)	Spannenberg (2003)	Almeida & Marques (2002)	Francisco (2004) and Alves (2004)	Queiroz (2013)
Thicknesses (m)	3- 12		11 - 13	12	6	2 - 7
w_n (%)	72 - 500	35.8 - 84.4	74.9 - 133.87	143 ± 21.7	183.5	84
w_l (%)	70 - 450	39 - 87	113.7	120 ± 18	158.2	70
Ip (%)	47- 250	12 - 49	85	73 ± 16	105.4	40
% clay	28 - 80	25 - 55	35	70	77	
γ_n (kN/m^3)	12.5		13 - 14.3	13.1 ± 0 49	12.1	14.7
% OM		5 - 13.9	6.6 ± 1			1.3 -15.8
e_0	1 - 11.1		1.94 - 3.55	3.71 ± 0.57		2
$CR = C_c/(1 + e_0)$	0.29 - 0.52		0.54	0.41 ± 0.07		0.25
C_s/C_c	0.17 - 80		0.1	0.15 ± 0.02		
c_v (cm^2/s) x 10^{-4}		1	2	9		1

Table A - Geotechnical properties of soft soils in Brazil, modified from Futai *et al.*, 2001. (Part 3).

Site	Santa Cruz (Coast)	Santa Cruz	Santa Cruz	PAN (Barra da Tijuca)	Western Region (RJ)	Eastern Region (RJ)
References	Aragão (1975)	Santos (2004)	Campos (2006)	Macedo (2004) Sandroni e Deotti (2008)	Bedeschi (2004)	Crespo Neto (2004)
Thicknesses (m)	15	5 - 15	5 - 15	5 - 16	7.5	2 - 11.5
w_n (%)	112	31 - 161.4	114 - 119	116 - 600	102 - 500	72 - 410
w_l (%)	60	18 - 161.4	56 - 121	100 - 370	97 - 368	23 - 472
Ip (%)	32	2.6 - 118	25 - 77	120 - 230	42 - 200	11 - 408
% clay		52 - 62	36.7 - 64.6			
γ_n (kN/m^3)	13.24		13.13	11.6 - 12.5	11.2 - 12.3	11 - 12.4
% OM		0.41- 10.4	1.2 - 4.13			
e_0	3.09	1.94 - 2.64	3.16 - 4.79	4.8 - 7.6	4.3 - 9	3.8 - 15
$CR = C_c/(1 + e_0)$	0.32	0.23 - 0.26	0.19 - 0.45	0.36 - 0.5	0.32 - 0.48	0.27 - 0.46
C_s/C_c	0.1		0.07 - 0.14			
c_v (cm^2/s) x 10^{-4}	0.2 - 18.2	62.5 - 80.3		0.4 -1.2		0.1 - 0.6

Table A - Geotechnical properties of soft soils in Brazil, modified from Futai *et al.*, 2001. (Part 4).

Site	Barra da Tijuca Recreio	Guaratiba	Hercílio Luz Airport, Florianópolis (SC)	Pirajubaé, Florianópolis (SC)	Municipality of Itajaí (SC)	Port of Santos SFL Clays
References	Baroni (2010)	Lima & Campos (2014)	Espíndola (2011)	Oliveira (2006)	Baran (2014)	Massad (1994)
Thicknesses (m)	2 - 21.8			10-20		< = 50
w_n (%)	191 - 670	34 - 184	75 - 93	120	93 -133	75 - 150
w_l (%)	147 -521	61.5 -148	38 - 87	105 - 165	37 - 54	40 - 150
Ip (%)	95 - 308	39 -100	20 - 54	60 -100	15 - 28	20 - 90
% clay	23 - 93		12 - 19	> 60		
γ_n (kN/m^3)	10.01 - 12.7	13.1-18.5	14 - 15	13.2 -14.2	13 - 16	13.5 - 16.3
% OM			2.8 - 6.2	5-6		
e_0	4 -12.4	0.85-4.69	2 - 2.4	3 - 4.5	1.9 - 3.6	2 - 4
$CR = C_c/(1 + e_0)$	0.31 - 0.54	0.11-0.46	0.03 - 0.04	0.26 -0.45	0.18 - 0.4	0.33 - 0.51
C_s/C_c		0.3	0.02 - 0.07	0.08 -0.14		8 - 12
c_v (cm^2/s) x 10^{-4}	0.018 - 19.8	1-10	0.14 - 0.89	1 - 5	0.28 - 39.10	