Piezocone tests in the Rio de Janeiro soft clay deposit

Essais de Piézocone dans les couches argileuses molles de Rio de Janeiro

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SYNOPSIS Piezocone tests in a very soft clay deposit have indicated results that could be classified as good, reasonable and very poor, applied, respectively to pore pressure, point and friction sleeve measurements. Correction factors applied to measured point resistance, to take into account the partial contribution of the hydraulic pressure, may well reduce the wide variation of the undrained bearing capacity factor, N_k, reported in the technical literature.

INTRODUCTION

Electrical cone penetration tests, with point and friction sleeve resistances and pore pressure measurements, were carried out, aiming to investigate the undrained and drained properties of a clay deposit. The testing site, located, approximately, 7,0 km north of Rio de Janeiro City, consists of 11 m of a very soft clay underlied by sand and gravel layers. Previous research work, carried out at this site, including a vast programme of field and laboratory investigations and an instrumented trial embankment, have been described by Costa Filho et alii (1977); Lacerda et alii (1977), Werneck et alii (1977); Collet (1978); Ramalho-Ortigão et alii (1983), among others. It has been found that this clay deposit has a liquid limit varying from 150% to 90%, corresponding, respectively, to the top and botton of the layer; the in-situ water content slightly higher than these values; the plasticity index about 90% and sensitivity between 2 and 4. The first results indicated that the quality of the friction sleeve measurements were very poor, due mainly to temperature effect and electrical magnetic intererence, which imposed a zero shift to the load cell of the same magnitude as the sleeve resistance. Hence, it was decided to abandon the friction sleeve measurements.

PIEZOCONE TESTS AND ANALYSIS OF RESULTS

Figure 1 presents results of three piezocone tests carried out near the trial embankment edge, with a height of 1,8 m and the unit weight of 2,01 T/m^3. As it can be observed the results show repeatable U compared to qc values. Test 3 has indicated values of qc lower than tests 1 and 2. Two tests have indicated localized sand pockets with a thickness of approximately 0,15 m.

Rocha Filho (1979) showed that measured qc values should be corrected to take into account the partial transference of the hydraulic pressure from the point to the friction sleeve load cell. The correction factor is a function of the geometrical configuration of the penetrometer (cylindrical sleeve wall thickness, δ and the penetrometer radius, R) and also of the total pore pressure value at the lower edge of the friction sleeve (U_L). Hence, the corrected value can be expressed as :

$$qcc = qc + U_L \left[1 - (R-\delta)^2/R^2\right]$$

For the used penetrometer (δ=3 mm and R=17,8 mm) it comes to: qcc=qc + 0,31 U_L. The ratio between U_L and the measured pore pressure value depends upon the position of the porous filter. Sugawara and Chikaraishi (1982) showed that values of U_L can be 86% or 73% of the measured value if the porous filter is located, respectively, at the point or middle of the conical penetrometer tip. For the presented tests it was used a conical filter corresponding, approximately, to one third of the total penetrometer tip, hence, as a first approximation, U_L can be taken as 0,8 of the measured value (U), leading to qcc=qc + 0,25U.

In order to investigate the influence of this correction on the determination of the undrained bearing capacity cone factor, N_k, computations were made considering :

$$N_k = \frac{qcc - \sigma vo}{Su} \text{ or } = \frac{\alpha qc - \sigma vo}{Su}$$

where: α is the correction factor, depending on the cylindrical sleeve wall thickness and filter position, σvo is the total vertical stress and Su is the undrained strength of the clay. Outside the trial embankment influenced zone, it has been found that: qc $\simeq$ 2,55Z + 2,83 (tf/m^2) (Guimarães, 1983, using the same penetrometer) ; Su $\simeq$ 0,09Z + 0,40 (tf/m^2) (Collet, 1978, using vane tests); Su = 0,12Z + 0,3 (tf/m^2) (Costa Filho et alii, 1977, using unconsolidated undrained triaxial test) and σvo = 1,32Z (tf/m^2). The clay deposit also presents an upper clay crust , extenting to a depth of 2,5 m, below which the OCR varies from 2,3 to 1,5, according to Lacerda et alii (1977). Table 1 presents the results of this analysis, indicating that the introduction of the correction factor in the analysis could increase the N_k values about 30% or 50% as it is assumed, respectively, a diferential or an all around pore pressure surrounding the penetrometer. As mentioned by Campanella et alii (1982), this correction can not be eliminated except with a unitized, jointless design where the sleeve is strain gauged to measure the tip load. However, such design requirements are uneasy to be fulfilled.

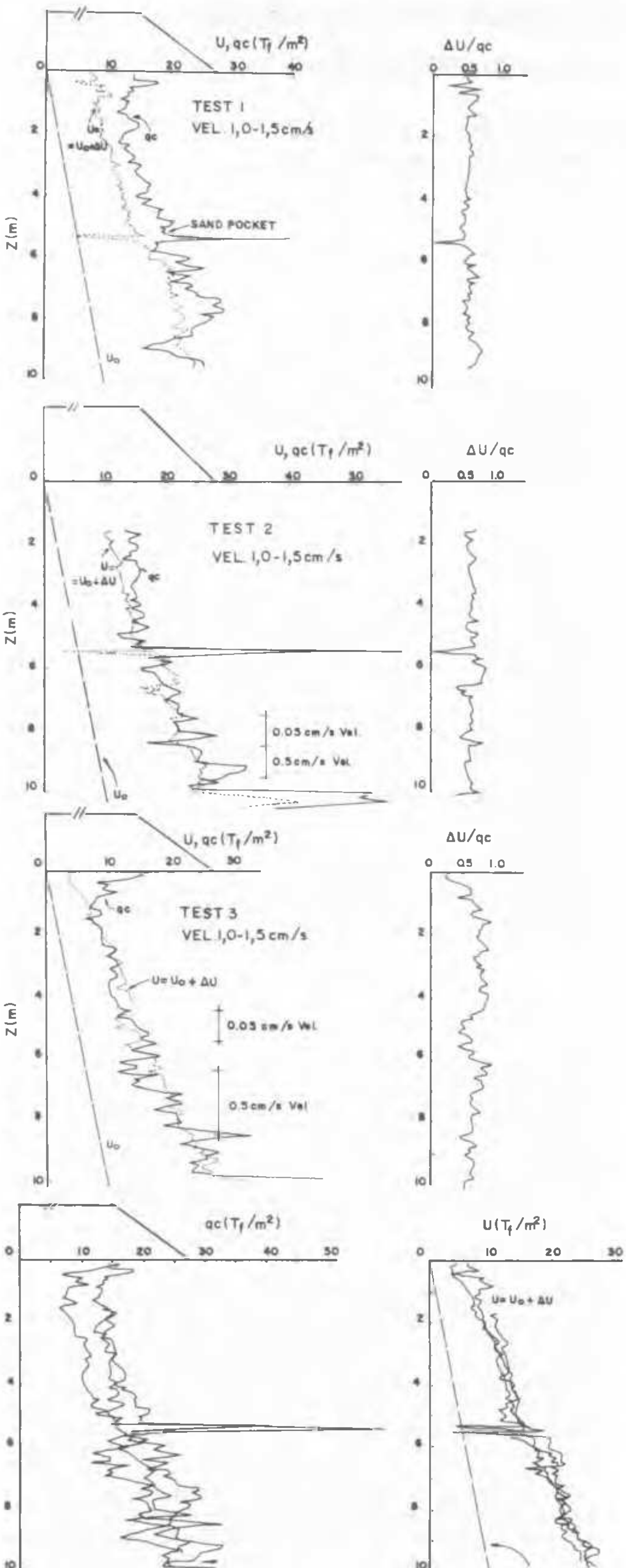


FIGURE 1 - PIEZOCONE TESTS RESULTS

TABLE 1 - N_k as function of correction factor.

α	N_k(3 to 10m)	N_k (average)	N_{kc}/N_k	Remarks
1,0	a) 9 - 13	11	1	No correction
	b) 9 - 11	10	1	
1,2	a) 13 - 16	14,5	1,32	U_L=0,8=0,64qc
	b) 13 - 14	13,5	1,35	
1,25	a) 13,5 - 17,0	15,5	1,41	U_L=0,8U≃0,8qc
	b) 14,0 - 15,0	14,5	1,45	
1,31	a) 14,5 - 18,5	16,5	1,5	U_L = U = qc
	b) 15,0 - 16,0	15,5	1,55	

a) Su from Collet (1978), b)Su from Costa Fº (1979)

Schmertmann (1975) has recomended N_k values of 10 and 16, corresponding, respectively, to electrical and mechanical penetrometer. Applying the proposed correction factor on the first value may well approach these two values, as it should not be expected the same correction to be applied to mechanical penetrometers. Lacasse and Lunne (1982) has obtained $15 \leq N_k \leq 17,5$, for clays with I_p≃36%, sensitivity of 5 and OCR of 1,3, using electrical penetrometers.

Table 2 presents values of the ratio between pore pressure (total and excess) and point resistance (measured and corrected). These values are in agreement with values presented in the technical literature for soft clay deposits, see for example, Rust and Jones (1983).

TABLE 2-Measured and corrected porepressure ratios

	TEST 1	TEST 2	TEST 3
U/qc	0,75 - 0,85	0,9 - 1,0	0,9 - 1,05
Δu/qc	0,50 - 0,60	0,60 - 0,70	0,60 - 0,90
Δu/qcc	0,4 - 0,5	0,5 - 0,55	0,5 - 0,7

For the determination of the stress history of the clay deposit it was used the proposal of Hajibakar (1981) and was obtained OCR of 1,8 and 1,5, corresponding , respectively, to ΔU/qc and ΔU/qcc ratios.

To investigate the penetration rate influence on the measured values, penetration velocity was decreased as indicated in Figure1. Figure 2 shows the variation of the excess pore pressure with the effective vertical stress. It can be observed that the measured values do not differ as the velocity decreased to 0,5 cm/sec, as compared to the values corresponding to 1,5cm/sec penetration velocity. However, the 0,05 cm/sec penetration rate has indicated a noticeable reduction in the excess pore pressure value. As suggested by Campanella et alii (1982), values of the corrected effective point resistance (qcc-U) were calculated to quantify this influence. Values of q'cc/qcc ratio were found to vary from 0,24 to 0,2 and from 0,36 to 0,33 corresponding, respectively, to 1,5 cm/sec and 0,05 cm/sec penetration rates, indicating an increase in the q'cc/qcc ratio of 50% - 65%. Campanella et alii (1982) have found values for the q'cc/qcc ratio of 0,28 and 0,33, corresponding, respectively, to 1,0 cm/sec and 0,05 cm/sec penetration rates.

The shear strength effective parameters (c' and ϕ') were also obtained using the proposal by Senreset et alii (1982), see Figures 2 and 3.

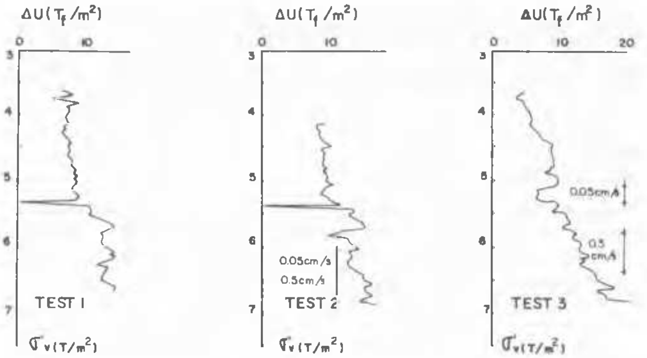


FIGURE 2 - ΔU VARIATION WITH VERTICAL EFFECTIVE STRESS

Table 3 presents the results of this analysis. Taking average values it has been found c'=0,26 tf/m^2 and ϕ'=23º, corresponding to a depth between 2,5 m - 5,5 m and c'=0,0 tf/m^2 and ϕ=28º for 6,0 m to 10 m depth. These values are in good agreement with values obtained by Costa Filho et alii (1977) obtained from triaxial tests.

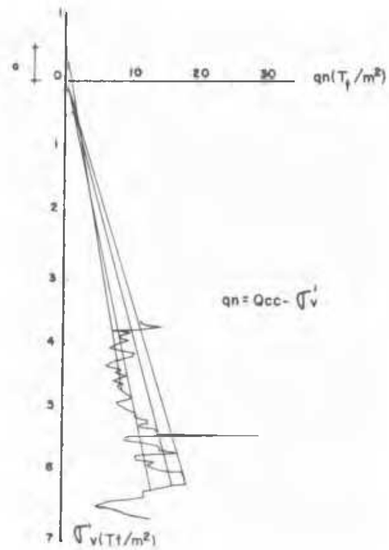


FIGURE 3 - NET POINT RESISTANCE VARIATION WITH VERTICAL EFFECTIVE STRESS

TABLE 3 - Effective Shear Strength Parameters

DEPTH	TEST 1	TEST 2	TEST 3
2,5-5,5m	0.2-0.21(tf/m^2)	0.38 (tf/m^2)	0.18-0.2tf/m^2
	23º - 24º	23º	21º - 23º
6.0 - 10m	0.0(tf/m^2)	0.0 (tf/m^2)	0.0(tf/m^2)
	27º - 30º	28º - 29º	28º - 29º

The excess pore pressure accompanying changes in total stress may be expressed as function of the average changes in normal and shear stresses as: $\Delta U = \alpha\Delta\sigma + \beta\Delta\tau$, the well known Henkel's equation. For field conditions, difficulties in using this approach arise with the definition of the final state of stress. Using the cavity expansion theory to represent the penetration process, it can be shown that:

$$\Delta U = \sigma_{3f} + A\,(\sigma_{1f} - \sigma_{3f}) + (\sigma_{3i} - \sigma_{1i}) - \sigma_{3i}$$

where A is the Skempton's pore pressure parameter. At the penetrometer-soil interface, it can be assumed σ_{1f} = Pu = qc, where Pu represents the ultimate pressure (Vesic, 1972). For the undrained condition and assuming an initial isotropic state of stress (σ_i), it comes :

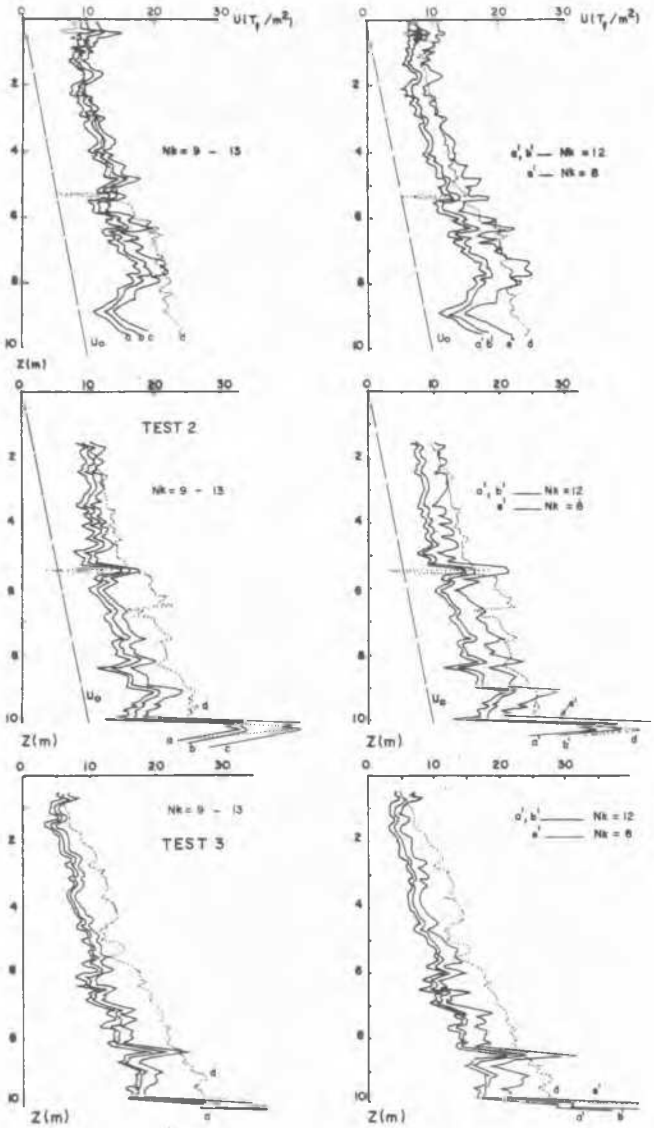
$$\Delta U = \sigma_{if} - 2Su + 2SuA - \sigma_i$$

as: $\sigma_{1f} = \frac{4}{3}Su\left[\ell n\left(\frac{E}{3Su}\right) + 1\right] + \sigma_i$, it results:

$$\frac{\Delta U}{Su} = \frac{4}{3}\left[\ell n\left(\frac{Eu}{3Su}\right) + 1\right] + 2A - 0{,}7$$

Figure 4 presents the results of predicted pore pressure values using the formulation showed above and adopting various values for Su and Eu/Su. Costa Filho et alii (1977) have found values for A of 1,3 and Eu/Su varying between 100 and 200. Values of Su have been obtained by applying the measured point resistance in the undrained bearing capacity formulation and adopting various N_k values, as indicated in Figure 4. For the test 1 and depth from 2,0 to 5,5 m, there is a good agreement between the measured and predicted values, adopting Eu/Su = 200 and N_k varying with depth. For Eu/Su of 100 and 500 the predicted values, were, respectively, 10% lower and higher than the measured values. For the depth below 5,5 m, reasonable agreement between the measured and predicted values came only if adopted Eu/Su of 800 or if taken N_k equal to 8 and Eu/Su of 200. For test 2 and depth 2,0 to 5,0 m, the predicted values were 80% and 90% of the measured pore pressure, corresponding, respectively, to Eu/Su 200 and 500 and adopting N_k varying with depth. For test 3, for all cases, the predicted values were considerable lower than the measured ones, this, possibly, due to the low qc values obtained.

The dissipation rate of induced excess pore pressure with time obtained after the penetration process has stopped, may be used to estimate the coeficient of consolidation of the soil. For this purpose it was used the solution proposed by Torstensson (presented by Gillespie and Campanella, 1981), based on the spherical cavity expansion theory and adopting values corresponding to 20% and 50% level of dissipation. The results of the analysis have indicated a wide range of C_v values. For Eu/Su of 200 it has been found average values of $10{,}2\times10^{-3}$ cm^2/sec and $2{,}6\times10^{-3}$ cm^2/sec corresponding, respectively, to 20% and 50% dissipation. Lacerda et alii (1976) based on radial consolidation tests have found values of the consolidation coeficient of $4{,}0 \times 10^{-3}$ cm^2/sec, for highly over consolidated state. Results by Campanella et alii (1982) have, also, indicated that consolidation takes place in the recompression mode after cone penetration testing in cohesive soils. Analysis were, also, carried out adopting Eu/Su of 100, however, the results did not show any significative difference.



Su from Nk varying with depth
a,a' - Eu/Su = 100
b,b',e' - Eu/Su = 200

Su from Nk constant
c - Eu/Su = 500 (0 to 5,5m) and 800 (5,5 to 10m)
d - measured values.

FIGURE 4 - MEASURED AND PREDICTED PORE PRESSURE VALUES

CONCLUDING REMARKS

In this series of penetrometer tests with pore pressure measurements, carried out in a very soft clay deposit, it has been found that temperature effects and electrical-magnetic interference may impose a zero shift to the friction sleeve load cell of the same magnitude as the sleeve resistance. The results also indicated repeatable pore pressure measurements compared to point resistance values. Correction factor, depending upon the geometrical configuration of the penetrometer and the pore pressure values at the sleeve lower end, should be applied to the measured point resistance values, to take into account the partial contribution of the hydrostatic pressure. The use of the correction factor on qc measurements may well narrow the wide variation in N_k values reported in the technical literature. Interpretation of the penetrometer results has indicated soil parameters in agreement with values obtained by previous work, using laboratory tests carried out on undisturbed samples.

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