Continuous Medusa DMT tests in a very soft clay

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ABSTRACT

The dilatometer test (DMT) has been shown very useful in providing a number of geotechnical parameters, in different types of soils. The test is regularly carried out every 0.20 m, i.e., it is a discontinuous test. Therefore, its capability of detecting variations in the geotechnical profile is conditioned by the tests interval. The Medusa DMT, however, is able to obtain continuous measurements of the A-pressure reading, thus providing a much better picture of the soil stratigraphy. Medusa DMT tests have been carried out at Sarapuí II very soft clay deposit around Guanabara Bay, in Rio de Janeiro, and a detailed soil profile was obtained. A comparison was made with piezocone tests. The stratigraphy of the deposit obtained by both tests was almost the same.

Keywords: SDMT, Medusa DMT, CPTU, repeatability, soft clay

1. Introduction

The dilatometer test (DMT) is carried out by initially jacking the dilatometer blade into the soil, stopping the penetration at the desired depth and, without delay, inflating the membrane by means of pressurized gas (Marchetti, 1980). Two readings are taken: A and B, in which A is the pressure applied from the inside of the membrane to expand it against the soil starting from the contact with the sensing disc up to the A-position (position of the membrane when its center is 0.05 mm distant from the sensing disc) and B is the pressure applied from the inside of the membrane to expand it against the soil up to the B-position (position of the membrane when its center is 1.10 mm distant from the sensing disc) (Marchetti et al., 2019, Monaco, 2021). A third reading C ("closing pressure") can also optionally be taken by slowly deflating the membrane soon after B is reached (Marchetti et al., 2001). The blade is then advanced to the next test depth, with a depth increment of typically 0.20 m. The rate of gas flow to pressurize the membrane shall be regulated to obtain the A-pressure reading within ≈ 15 s after reaching the test depth and the B-pressure reading within ≈ 15 s after the A-reading (Marchetti et al., 2019). The pressure readings A, B (and C) are then corrected by the values ΔA, ΔB determined by calibration to take into account the membrane stiffness and converted into p_0, p_1 (and p_2) (Marchetti et al., 2001).

The first DMT was performed in Brazil in 1985, by Tom Lunne (NGI) and the late Marcio Miranda Soares (COPPE/UFRJ) at Sarapuí I deposit. The tests were performed in a joint research project on in situ tests in very soft clays between the Norwegian Geotechnical Institute (NGI) and Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia from Federal University of Rio de Janeiro (COPPE/UFRJ) (Soares et al., 1986, 1987, Danziger et al., 2015). A second series of tests was carried out in the same deposit in 1992 (Vieira, 1994, Vieira et al., 1997).

For security reasons, the research area moved to Sarapuí II, some 1.5 km from the previous Sarapuí I. The seismic DMT (SDMT, Marchetti, et al., 2008) was firstly tested in the area in two series of tests in 2012, and the tests have been reported by Jannuzzi (2013) and Jannuzzi et al. (2014).

An analysis of the scatter of the data in previous series of tests has shown that although the DMT readings p_0 and p_1 provided reasonable repeatability, unacceptable scatter was obtained for $\Delta p = p_1 - p_0$ and for all the geotechnical parameters deriving from this difference (Danziger et al., 2015). This was attributed to difficulties to maintain the rate of pressure increase during the tests, even with experienced operators. In order to try to reduce the scatter, tests have been carried out with a membrane with a reduced thickness (0.15 mm) with respect to the original membrane (0.2 mm in thickness). In fact, the scatter has been reduced, and the corresponding results will still be published.

Another alternative to improve repeatability was to carry out tests with the Medusa DMT equipment, which uses oil instead of gas and is able to control the pressure increase during the tests (Marchetti et al., 2019). Tests with the Medusa DMT at Sarapuí II, carried out in 2018, did present a much better repeatability, in fact showing the role of pressure increase during the tests (Marchetti et al., 2021).

More recently, a new Medusa equipment – with slight modifications with respect to the previous one, tested in 2018, also with the seismic module –, was used to perform two serious of tests at Sarapuí II, the first one in December 2023 and the second one in January 2024. This last test series aimed at conducting continuous DMT tests. A summary of all tests performed at Sarapuí I and II, including the recent tests carried out, are presented in Table 1.

The present paper aims at analyzing the accuracy and repeatability of the Medusa DMT in the tests carried out in 2018 and 2023-2024, with different equipment, as well as to discuss the continuous Medusa DMT test.

Table 1. DMT tests performed at Sarapuí test site.

Series	Date	Test Site	No. of soundings	Equipment	Owner
1	Oct. 1985	Sarapuí I	4	DMT	NGI
2	July 1992	Sarapuí I	5	DMT	Geomecânica
3	June 2012	Sarapuí II	2	SDMT	COPPE/ UFRJ
4	Dec. 2012	Sarapuí II	2	SDMT	COPPE/ UFRJ
5	July 2019	Sarapuí II	2	SDMT	COPPE/ UFRJ
6	Set. 2018	Sarapuí II	2	Medusa DMT	Marchetti inc.
7	Dec. 2023	Sarapuí II	1	Medusa DMT	COPPE/ UFRJ
8	Jan. 2024	Sarapuí II	3	Medusa DMT	COPPE/ UFRJ

2. The Medusa DMT

Despite the Medusa DMT had been described in previous publications (e.g., Marchetti, 2018, Marchetti et al., 2019, 2021), it was considered important, for the sake of clarity, to include it in the present paper. The Medusa DMT is the combination of a flat dilatometer blade with an instrumented rod connected behind it. The rod contains an electronic board, rechargeable batteries, a pressure transducer and a motorized syringe, composed of an engine, a piston and a cylinder (Fig. 1). The motorized syringe injects oil under pressure directly inside the blade, to hydraulically expand the dilatometer membrane. The device is able to autonomously perform DMT tests to obtain the standard dilatometer readings (p_0, p_1 and p_2, Marchetti, 1980, 2015).

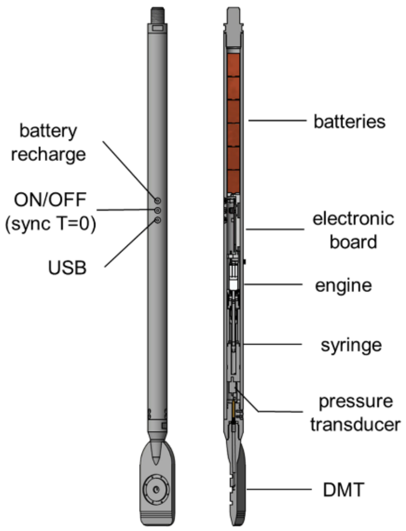

Figure 1. The Medusa DMT (Marchetti, 2018).

Compared to the traditional pneumatic DMT equipment (Marchetti, 1980), the Medusa DMT does not require: i) a gas tank; ii) a control unit with pressure valves; iii) pneumatic cables for transmitting the pressure from the control unit to the blade at depth (Marchetti et al., 2021).

With the traditional equipment, the pressure is generated and measured at surface, although it operates on the membrane of the blade at depth. Any pressure equalization difference at the opposite ends of the cable introduces an error on the test readings. The Medusa DMT generates and measures the pressure directly at depth, eliminating any possible pressure equalization problem (Marchetti et al., 2021).

The motorized syringe of the Medusa DMT applies pressure with oil, which is incompressible. For this reason it is possible to calculate and impose the speed of the motorized syringe for obtaining high accuracy in the timing of the dilatometer pressure readings.

3. The Sarapuí II soft clay test site

In the last twenty-five years, security reasons have prevented the use of the Sarapui I test site, whose characteristics have been reported in a number of papers (e.g., Lacerda et al. 1977, Werneck et al., 1977, Almeida and Marques, 2003). A new area (named Sarapuí II) in the same deposit, 1.5 km from the previous area and inside a Navy Facility, has been used since then. A number of studies (e.g., Alves, 2004, Francisco, 2004, Alves et al., 2009, Porto et al., 2010, Jannuzzi et al., 2012, 2021, Fernandes et al., 2022) have been performed in this new area, which is being used by the Research Center of the Brazilian Oil Company (CENPES/PETROBRAS) and the Federal University of Rio de Janeiro as a state-of-the-art test site on very soft organic clay. The very soft clay in the test area has an average thickness of 8 m, and a clayey-silt layer underlies the very soft clay. A comprehensive study about the Sarapuí II deposit was undertaken by Jannuzzi (2009, 2013), Jannuzzi et al. (2015) and Danziger et al. (2019).

The liquid limit, plastic limit and natural water content, specific gravity, total unit weight, initial void ratio, activity versus depth are included in Fig. 2. The grain size distribution, organic content, total salt content and NaCl content, relative percentage of clay minerals versus depth are shown in Fig. 3. The deposit is lightly overconsolidated due to secondary consolidation (Danziger et al., 2019) below 3 m depth, approximately, with OCR around 2. In situ permeability decreases with depth, from $7x10^{-9}$ to $6x10^{-10}$ m/s (Vargas et al., 2023).

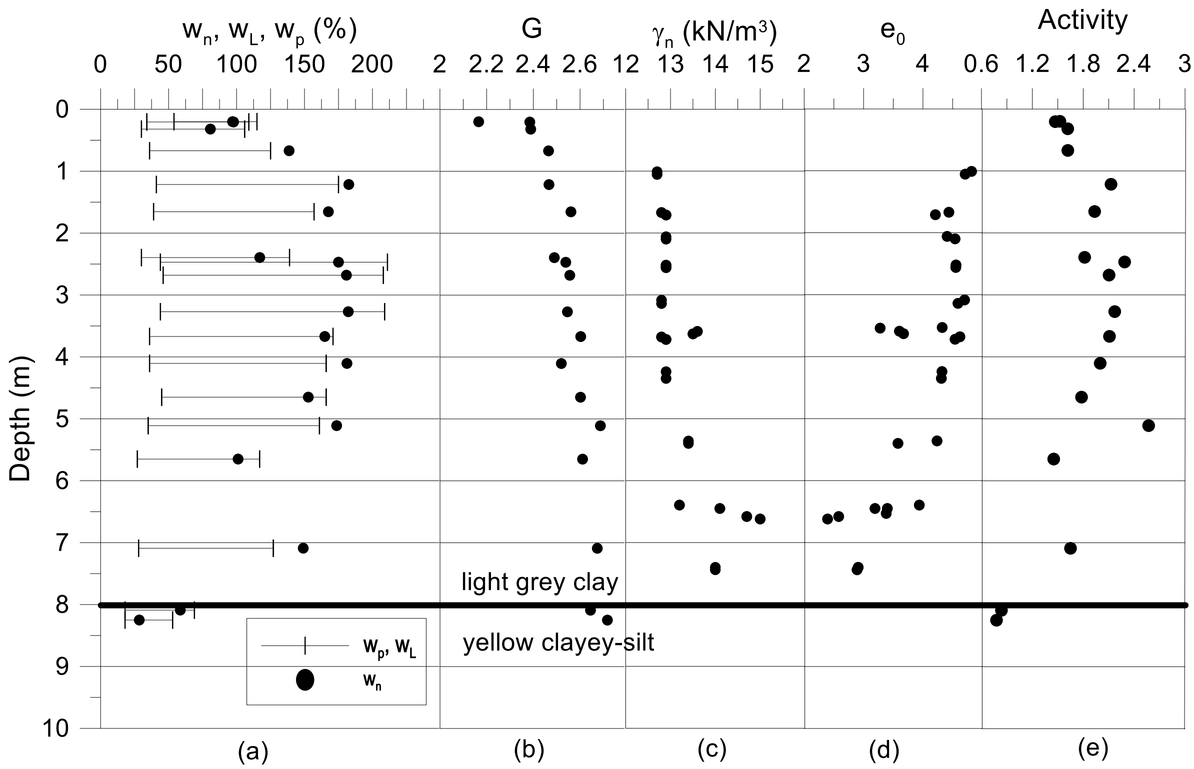

Figure 2. (a) Liquid limit, plastic limit and natural water content; (b) specific gravity; (c) total unit weight; (d) initial void ratio; (e) activity versus depth (adapted from Jannuzzi 2013, Jannuzzi et al. 2015).

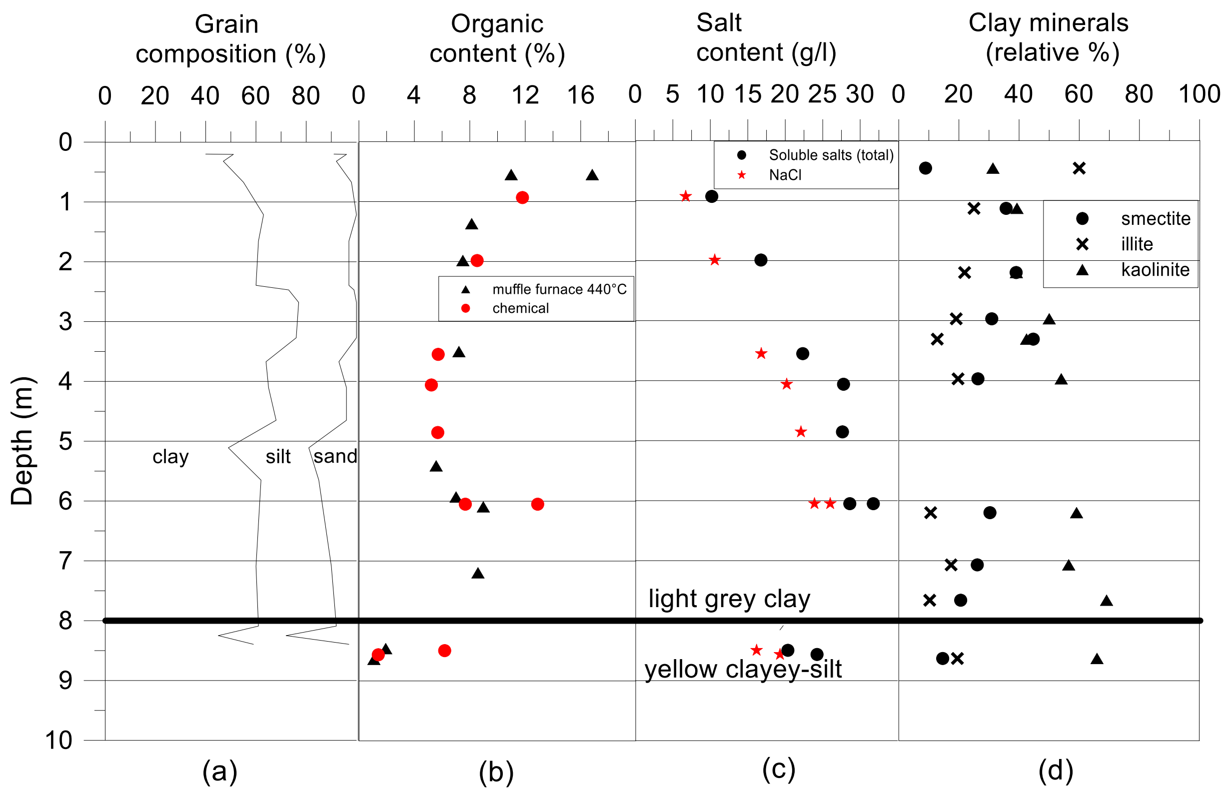

Figure 3. (a) Grain size distribution; (b) organic content; (c) total salt content and NaCl content; (d) relative percentage of clay minerals versus depth (Jannuzzi et al. 2015).

4. Medusa DMT tests performed at Sarapuí II very soft clay deposit

As mentioned before, three series of Medusa DMT tests (series 6, 7, 8 in Table 1) have been carried out at Sarapuí II test site, with two different versions of the equipment. Fig. 4 illustrates the onset of a test during series 8. The COPPE/UFRJ rig was used in test series 1-6 and a Pagani rig in test series 7 and 8. In all tests, a rate of 20 mm/s was used, either for advancement for one DMT test to another or during the continuous test.

The continuous test is not carried out with the regular procedure, but performed in the so-called dissipation mode, i.e. a dissipation test is simulated during penetration. The rate of penetration is calculated from the test results. The A-reading is measured during penetration every 0.15 - 0.20 s approximately, therefore readings are obtained every 3-4 mm. A chart A versus depth is obtained from the test. In the tests herein reported, all readings A, B and C have been measured after every meter penetrated, before changing rods.

Figure 4. Onset of a Medusa DMT test at Sarapuí II test site, series 8.

5. Presentation and analysis of the results

The results of test series 6 have been reported by Marchetti et al. (2021). Test series 7 was carried out with an updated version of the equipment, therefore it was considered important to verify the differences between the results obtained in these two series. Recorded values of A and p_0 are presented in Fig. 5. The charts have been limited to 8 m depth, in order to focus the results in the soft clay layer. It can be observed that despite the differences in A values, due to differences in the membrane thicknesses and stiffnesses, p_0 values present excellent repeatability.

A conclusion that rises from the observation of Fig. 5 is the role of the rate of pressurizing the membrane. Provided it is properly controlled, the p_0 values can be accurately obtained. It must be reminded that in the case of the Medusa equipment this procedure is independent of the operator.

It must be emphasized an advantage of the Medusa DMT with respect to DMT pressurized with gas in the case of extremely soft clay. In that case, when the blade is pushed into the ground, the stress induced by the soil is so low that it is not able to take the membrane to the "zero" position. As a consequence, no audio signal is heard during penetration, and there is always a doubt if the equipment has some problem, like ineffective earthing, for example. If testing conditions are satisfactory, the solution for performing the test is to use the syringe and apply a negative pressure (i.e., suction), to take the membrane to the "zero" position. In the case of the Medusa, this procedure is not necessary, and the equipment applies automatically the suction. This is illustrated in few tests carried out in depths less than 1 m, shown in Fig. 5. The same occurs in the continuous test, as will be presented below.

If now the p_0 values from pneumatic equipment are included in the comparison, the corresponding results are shown in Fig. 6. Although the scatter of p_0 may be considered satisfactory in the case of pneumatic DMT, the repeatability in the case of the Medusa DMT is better, especially considering the number of tests carried out. The values designated as corresponding to continuous tests in the figure are in fact regular tests carried out every meter, as mentioned before. Also, the p_0 values for the pneumatic DMT are slightly greater than those from the Medusa DMT.

Regarding the continuous tests, the A-values of the 3 soundings performed are presented in Fig. 7. A remarkable repeatability can be observed in the very soft clay, it is even difficult to distinguish between the three soundings, except in the upper 0.7 m of the profile, influenced by the presence of roots. The differences in the lower layer are due to local heterogeneities.

To verify if the A-values measured by the continuous tests are consistent with the A-values obtained in tests carried out in a regular procedure, i.e., taken after halting the rod penetration every 0.20 m, Fig. 8 presents a comparison between these two procedures. The obtained values are again in a remarkable repeatability, demonstrating the effectiveness in the A-readinds taken during continuous tests.

Data from Fig. 8 is presented in a magnified scale in Fig. 9. It can be observed that the continuous test is able to provide a better detailing of the stratigraphy than the regular tests.

Fig. 10 compares the continuous Medusa DMT tests with piezocone tests, in which the traces of changing rods have not been removed. The stratigraphy provided by both types of tests is almost the same, with 3 sub-layers of the soft clay, indicated in the figure. Differences in the upper 1 m depth were attributed to the presence of thick roots in the area where the piezocone tests have been carried out.

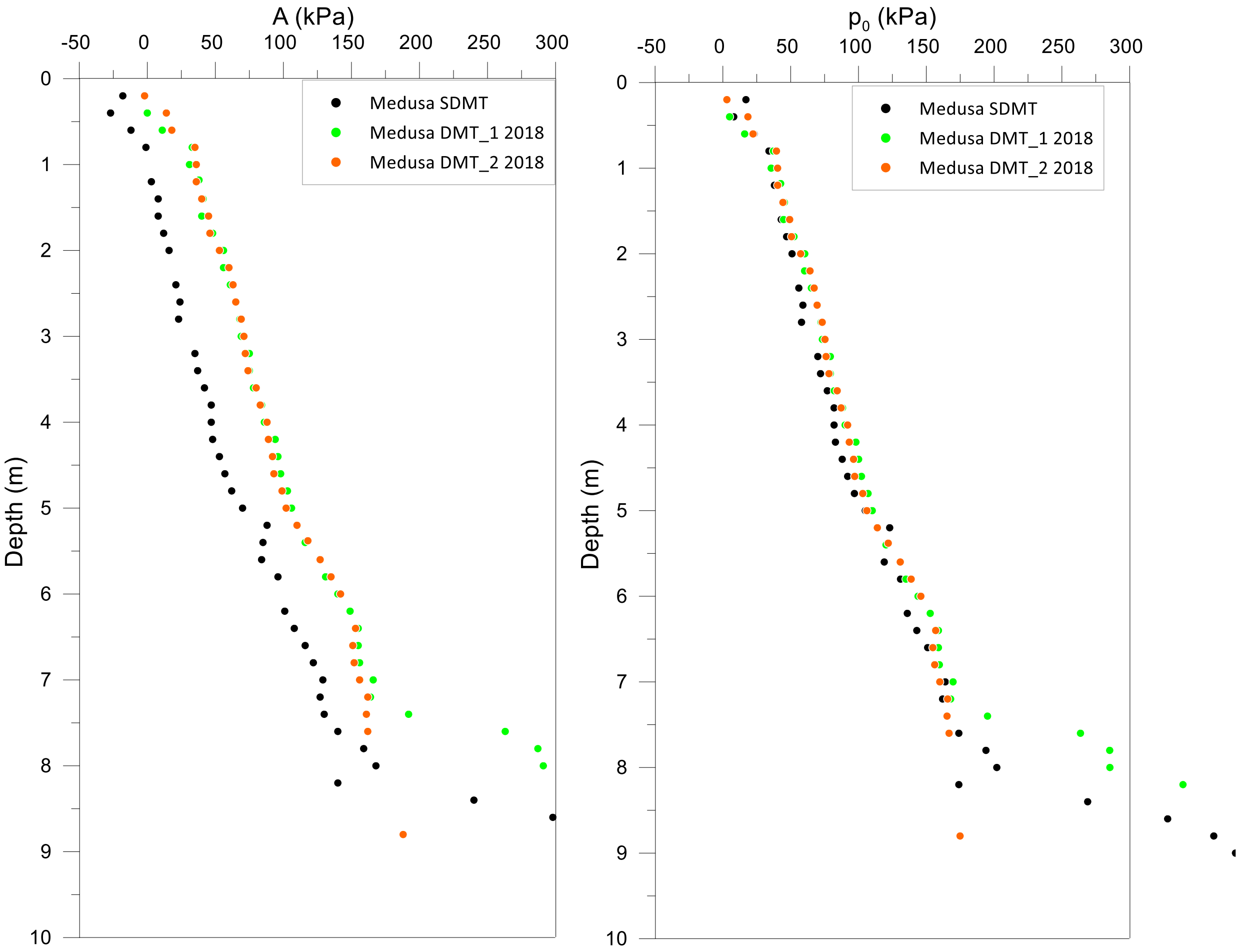

Figure 5. A and p_0 versus depth, series of tests 6 and 7, two Medusa DMT equipment.

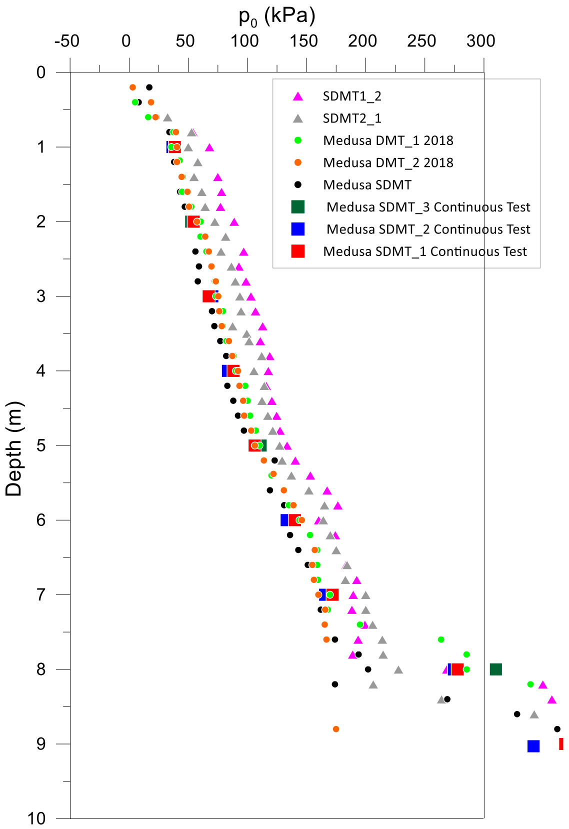

Figure 6. p_0 versus depth, series of tests 3, 4, 6, 7, 8.

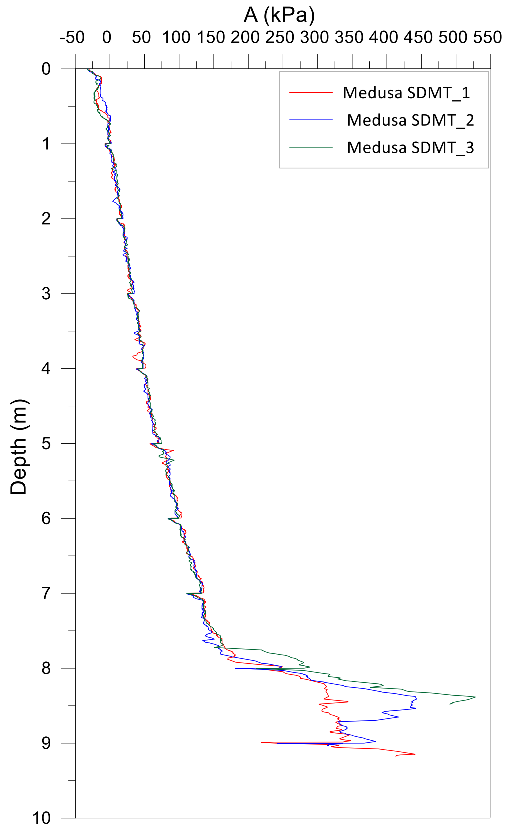

Figure 7. A versus depth, 3 Medusa continuous tests.

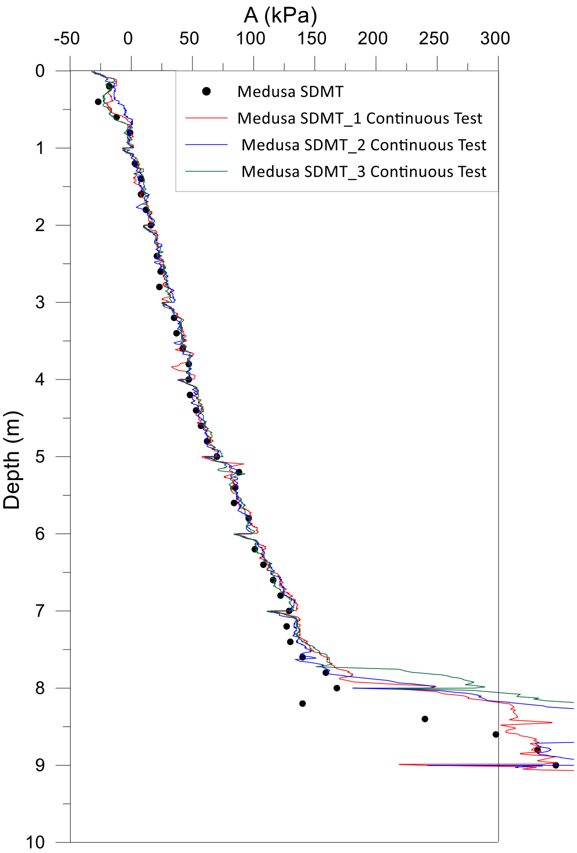

Figure 8. A versus depth, comparison between continuous tests and regular procedure, same Medusa equipment.

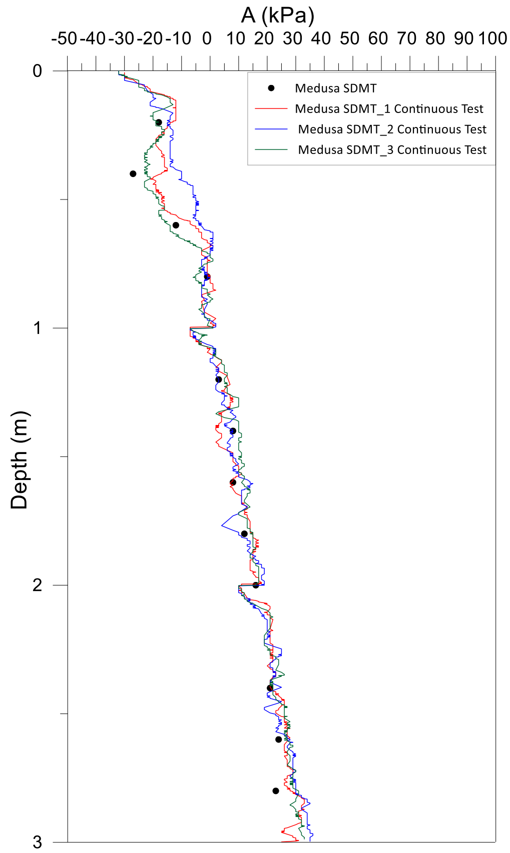

Figure 9. A versus depth, 3 Medusa continuous tests, magnified scale.

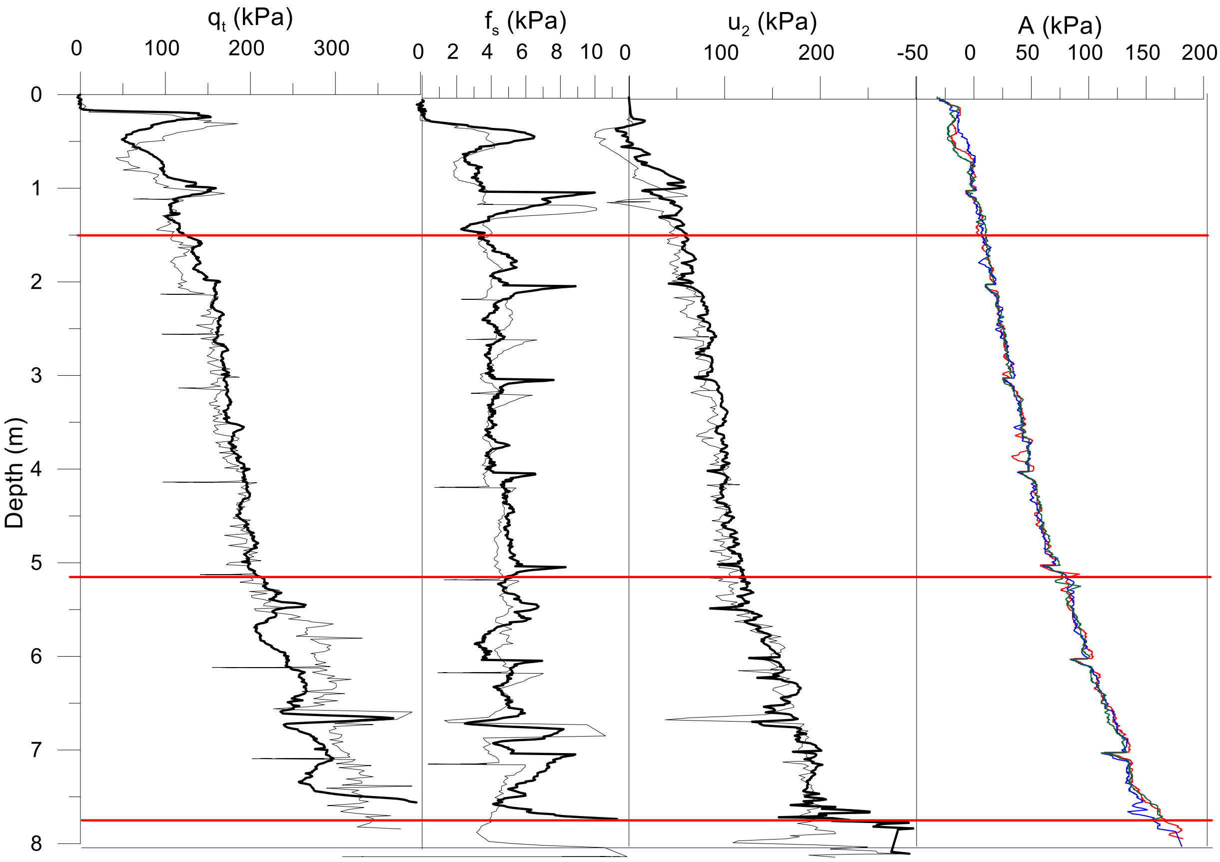

Figure 10. Cone resistance, q_t, sleeve friction, f_s, pore pressure, u_2, from piezocone tests, A from continuous Medusa DMT test.

6. Conclusions

Continuous Medusa DMT tests have been conducted at Sarapuí II very soft clay test site. Three series of tests carried out provided remarkable repeatability. The A-values measured during continuous tests have been compared with those obtained in tests carried out in a regular procedure, i.e., taken after halting the rod penetration every 0.20 m. The obtained values also presented a remarkable repeatability, demonstrating the effectiveness in the A-readinds taken during continuous tests. Regular tests (i.e. every 0.20 m) have been carried out with two Medusa equipment, having different membrane thicknesses and stiffnesses. Although different A-values have been obtained, p_0 values have provided excelent repeatability, better than pneumatic DMT. It was therefore demonstrated the role of the rate of pressurizing the membrane, i.e, provided it is properly controlled, the p_0 values can be accurately obtained.

The continuous Medusa DMT tests indicated a very good definition of the stratigraphy, almost the same as the one obtained by piezocone testing.

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