

# Comparison of DMT results using traditional pneumatic equipment and the Medusa DMT in the Sarapuí II soft clay deposit in Brazil

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**ABSTRACT:** The Sarapuí II research test site is a soft clay deposit located in a swampy area on the left bank of the Sarapuí river, near the city of Rio de Janeiro in Brazil. The test site is very well documented with both in situ and laboratory test data. DMT measurements were performed with traditional pneumatic equipment, providing acceptable single pressure readings  $p_0$  and  $p_1$ , but unacceptable scatter for  $\Delta p = p_1 - p_0$  and for all the geotechnical parameters deriving from this difference. In September 2018 the tests were repeated using the Medusa DMT equipment, a new device able to hydraulically operate the standard dilatometer blade at depth. The pressure is generated and measured in the probe at depth, eliminating any pressure equalization problem at the opposite ends of the pneumatic cable. The automated membrane inflation and the incompressibility of the pressurizing fluid enables the Medusa to enforce the standard rate of membrane inflation with high precision and repeatability. The results obtained using the Medusa DMT showed improved consistency for  $p_0$  and  $p_1$ , and very low scatter for the difference  $\Delta p$ .

**Keywords:** dilatometer, automated dilatometer, Medusa, soft clay deposit

## 1. Introduction

Dilatometer tests (DMT) using the traditional pneumatic equipment (Marchetti, 1980) and the seismic SDMT (Marchetti, et al., 2008) have been performed in Sarapuí very soft clay test site in Brazil since 1985 (e.g., Soares et al., 1986, Danziger et al., 2015). It was 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).

A new DMT equipment (Medusa) which uses oil instead of gas was recently developed (Marchetti et al., 2019).

A comparison of DMT results using the traditional equipment and the Medusa DMT in the Sarapuí clay is shown in this paper.

## 2. The Medusa DMT and the traditional pneumatic equipment

The Medusa DMT is the combination of a flat dilatometer blade with an instrumented rod connected behind it (Marchetti et al., 2019). 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  $p_2$ ). Preliminary comparisons have shown good agreement between measurements taken with the

standard DMT and with this new integrated system (Marchetti, 2018).

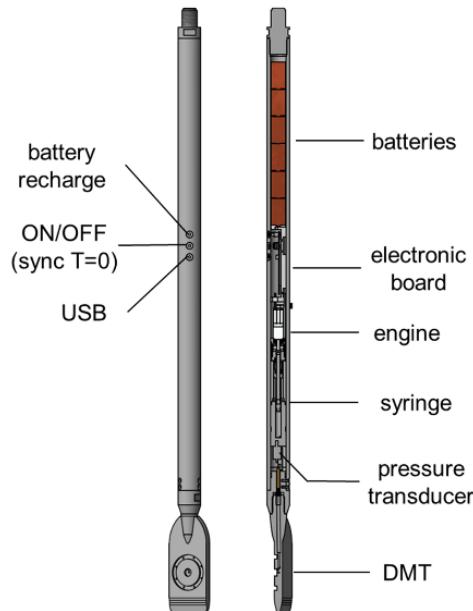


Figure 1. The Medusa DMT.

Compared to the traditional pneumatic DMT equipment, 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; iv) a technician for operating the DMT control unit.

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.

Correct DMT testing requires to take the field pressure readings with a specific timing, documented in detail in each of the DMT international standards (Eurocode, 2007, ASTM, 2007, TC16, 2001, ISO, 2017). It is not always simple to regulate the gas flow for obtaining the readings within such acceptable time ranges, especially when long cables are used. Trained and attentive operators are able to do so, however average users may have difficulty or forget to follow this important indication. The motorized syringe of the Medusa DMT applies pressure with a liquid (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.

The previous two differences with the traditional pneumatic equipment enable the Medusa DMT to improve the accuracy and repeatability of the test results. In standard soils, particularly in medium to dense soils, such improvements are almost negligible when profiling the soil parameters. In very soft soils, however, the technical improvements of the Medusa DMT may enable to obtain high quality data even when it is not possible with traditional pneumatic equipment.

### 3. The Sarapuí II soft clay test site

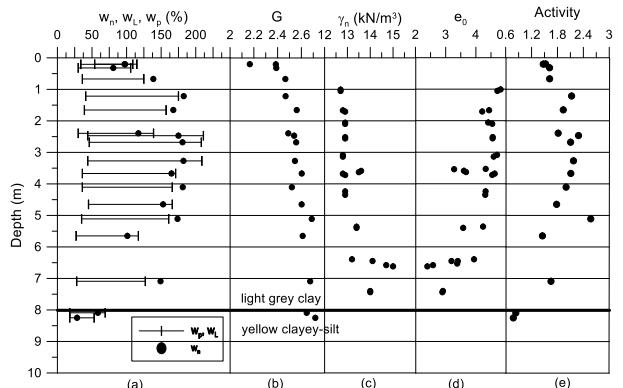
The early studies on the very soft clay of the region where the Sarapuí test site is located were conducted by Pacheco Silva (1953). The Sarapuí test site is situated in a flat swampy area, around Guanabara Bay, on the left bank of the Sarapuí river, some 7km from Rio de Janeiro City, with average coordinates  $22^{\circ}44'41''$  (S) and  $43^{\circ}17'23''$  (W). It was established in the mid-1970s as a research site by the Transportation Research Institute of the Brazilian Federal Highway Department (IPRDNER), with focus on the study of embankments on soft soils. A number of in situ and laboratory tests have been performed (e.g., Lacerda et al. 1977, Werneck et al., 1977). A comprehensive report about the deposit has been provided by Almeida and Marques (2002).

In the last twenty-five years, however, security reasons have prevented the use of the test site. 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) have been performed in this new area, which is being used by the Research Center of the Brazilian Oil Company (CENPES/PETROBRAS) and 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 is around 8 m deep, 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).

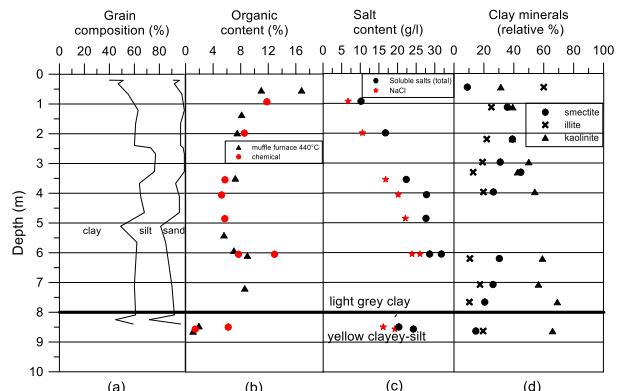
The liquid limit, plastic limit and natural water content, specific gravity, total unit weight, initial void ratio, activity versus depth are included in Fig. 2. The grain

size distribution, organic content, total salt content and NaCl content, relative percentage of clay minerals versus depth are shown in Fig. 3.

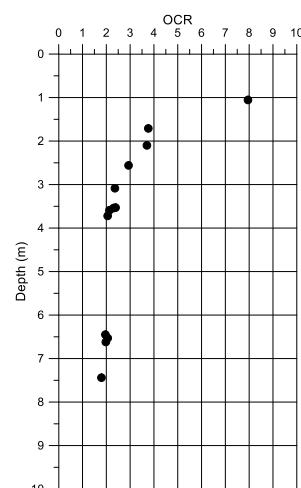
The overconsolidation ratio (OCR) versus depth, from 24h incremental loading tests performed on very good quality samples, based on the Lunne et al. (1997) criterion, is shown in Fig. 4. The specimens in the depth range 4.0 – 5.5 m presented a significant number of shells, providing meaningless results. It can be observed that the deposit is lightly overconsolidated due to secondary consolidation (Danziger et al., 2019) below 3 m depth, approximately, with OCR around 2.



**Figure 2.** Natural water content, liquid limit and plastic limit; specific gravity; total unit weight; initial void ratio; 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).



**Figure 4.** OCR versus depth, Sarapuí II test site.

## 4. Tests performed

### 4.1. Previous DMT and SDMT tests

The first dilatometer test (DMT) was performed in Brazil in 1985, by Tom Lunne (NGI) and the late Mário 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).

Four tests have been performed in this first series, and the same blade was used in all tests. The COPPE/UFRJ rig, designed and manufactured at COPPE/UFRJ machine shop specifically for these tests (Fig. 5), was used for all tests, which have been performed with the standard penetration rate of 20 mm/s. The water table was 0.30 m above ground level during this first series of tests (Danziger et al., 2015).



**Figure 5.** Readings taken by Tom Lunne in the first series of dilatometer tests at Sarapuí I deposit (Danziger et al., 2015).

The second series of tests at Sarapuí I deposit, in 1994, was performed with Geomecânica equipment, a Brazilian geotechnical company, in a partnership established between this company and COPPE/UFRJ.

The same rig used in the first series of tests was also used in the second one. The water table varied between 0.32 m and 0.36 m above ground level at the time of the tests.

Since insufficient cycling of the membrane was a possible cause of inaccuracy of one test from the first series, a study was undertaken by Vieira (1994) on this subject. 11 membranes (type H, nominal thickness of 0.2 mm) were cycled with different number of cycles and the variations of  $\Delta A$  and  $\Delta B$  (membrane stiffness) values due to the cycling process were evaluated. The tests performed provided the information required to be sure that in the second series of tests any scatter in the

data could not be attributed to inadequate or insufficient cycling of the membranes. Test results were reported by Vieira (1994) and Vieira et al. (1997).

The addition of the seismic device in the DMT equipment (Marchetti et al., 2008) lead COPPE/UFRJ to purchase in 2011 its own equipment. Thus the third and fourth series of tests were carried out in 2012, with the same rig used in the previous series of tests, but now at Sarapuí II test site. The water table was 0.28 m above ground level at that time. The SDMT poses an additional difficulty with respect to the regular DMT, because the seismic device requires a larger distance between the rig and the soil, as illustrated in Fig. 6. The procedure of performing SDMT in Sarapuí II deposit is very cumbersome, which was described in detail, together with the test results, by Jannuzzi et al. (2014).



**Figure 6.** Seismic SDMT at Sarapuí II test site (Jannuzzi et al., 2014).

An error was made in the first test related to the fact that in the case of very shallow depth the soil pressure is not sufficient for getting the membrane to the “zero” position. Since the audio signal could not be heard, it was thought that some mistake had happened, and then the membrane was pressurized. This process caused the membrane to be damaged, which was verified after the test, where a bulging was observed in the membrane.

Irrespectively the damage with the membrane, the seismic test could be carried out.

It must be pointed out that when using the SDMT no more manual readings are required, and the values of A and B are automatically recorded in the acquisition data system. A comparison was undertaken between the recorded values and readings taken in the conventional way, and good results were obtained. The only difference is that the recorded values consider the zero shift in the manometer automatically.

The main purpose of the third series of tests was to obtain shear wave velocity measurements. The corresponding data were presented by Jannuzzi et al. (2014).

Table 1 summarizes the previous tests performed.

**Table 1.** Previous tests performed at Sarapuí test site

Series	Date	Test Site	Number of tests	Equipment owner
1	Oct. 1985	Sarapuí I	4	NGI
2	July 1992	Sarapuí I	5	Geomecânica
3	June 2012	Sarapuí II	2	COPPE/UFRJ
4	Dec. 2012	Sarapuí II	2	COPPE/UFRJ

## 4.2. Medusa DMT tests

In September 2018 two tests were performed using the Medusa DMT equipment, developed by Studio Prof. Marchetti. As in all previous tests, the penetration rate of 20 mm/s was used. The water table was 0.09 m above ground level at the time of the tests.

Figs. 7a and b show the equipment assembly for one test, and Fig. 8 a Medusa DMT test under execution.



Figure 7. (a) Preparation for Medusa DMT test; (b) blade.



Figure 8. Execution of a Medusa DMT test at Sarapuí II test site.

## 5. Presentation and analysis of results

Fig. 9 presents the intermediate parameters  $I_D$ ,  $K_D$  and  $E_D$  for all tests in the four series of tests for which no errors or nonconformities could be attributed, all performed with the pneumatic DMT. It must be pointed out that the thickness of the very soft material is around 11 m in the case of Sarapuí I test site, whereas is around 8 m in the case of Sarapuí II test site. Therefore, values measured at depths below the very soft material must be disregarded in each deposit.

A significant scatter is found for  $I_D$  and  $E_D$ , and less for  $K_D$ . In fact, when Sarapuí I and Sarapuí II are considered separately, a trend of higher values is observed for Sarapuí II.

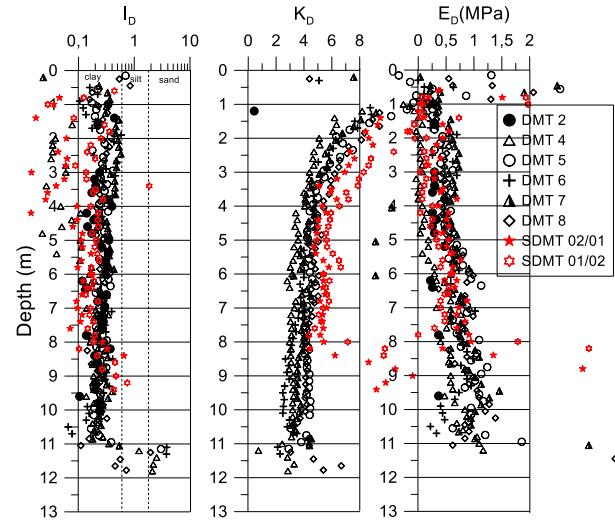


Figure 9.  $I_D$ ,  $K_D$  and  $E_D$  from all tests (from Sarapuí I and Sarapuí II sites) with no errors or nonconformities. Tests performed with the pneumatic DMT from 1985 to 2012 (Danziger et al., 2015).

If only the values of  $p_0$  and  $p_1$  for all tests are now compared, the scatter is not very significant. In fact, both  $p_0$  and  $p_1$  have been able to capture the trend of higher values in Sarapuí II with respect to Sarapuí I. However, when the difference  $\Delta p = p_1 - p_0$  is plotted (Fig. 10), a significant scatter is found, which explains the scatter in the intermediate parameters and also in the associated geotechnical parameters, as in the case of the constrained modulus  $M$ , presented in Fig. 11 for both Sarapuí I and II sites.

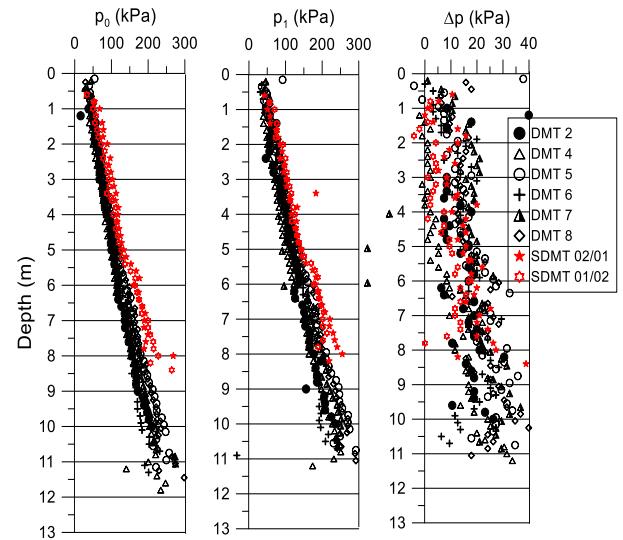
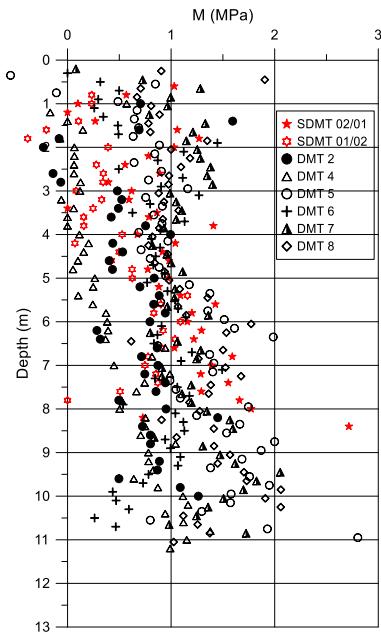
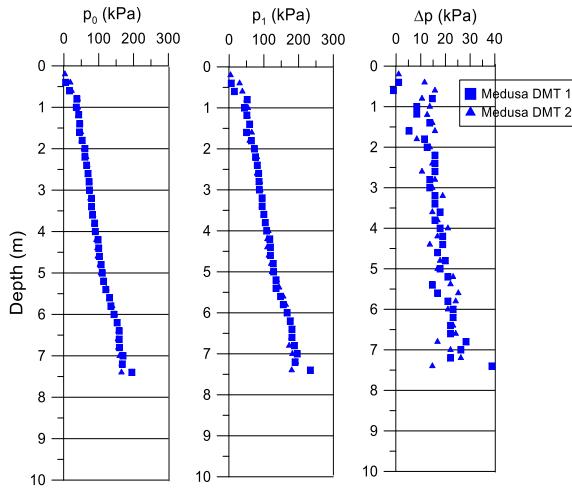


Figure 10.  $p_0$ ,  $p_1$  and  $\Delta p$  values for all tests with no errors or nonconformities. Tests performed with the pneumatic DMT from 1985 to 2012 (Danziger et al., 2015).



**Figure 11.** M values for Sarapuí I and Sarapuí II sites. Tests performed with the pneumatic DMT from 1985 to 2012 (Danziger et al., 2015).

Fig. 12 shows  $p_0$ ,  $p_1$  and  $\Delta p$  values from the Medusa DMT tests in Sarapuí II. A very small scatter was obtained in the case of  $p_0$  and  $p_1$  and even in  $\Delta p$ .

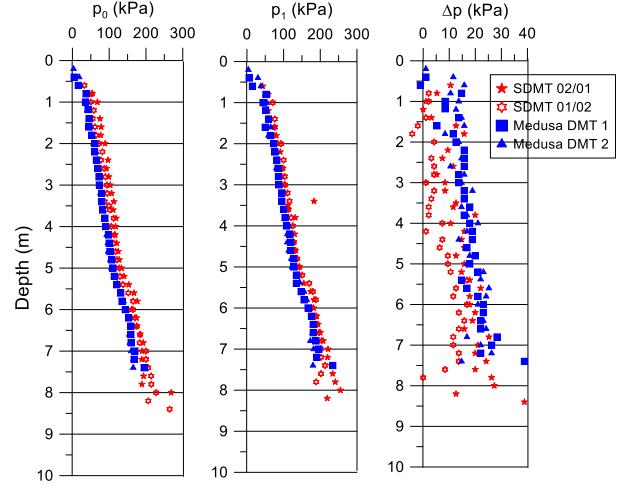


**Figure 12.**  $p_0$ ,  $p_1$  and  $\Delta p$  obtained from Medusa DMT tests at Sarapuí II test site.

Fig. 13 shows  $p_0$ ,  $p_1$  and  $\Delta p$  values for all DMT tests carried out in Sarapuí II test site, where it can be observed that even in the case of  $p_0$  and  $p_1$  there is a reduction in the data scatter when the Medusa equipment is compared with the pneumatic equipment. In order to quantify the scatter, a comparison is made for the tests performed with each equipment in the case of Sarapuí II test site. From visual observation, a linear trend was assumed for the tests performed between 1 m and 7 m, and the obtained results are presented in Table 2. The increase in the coefficient of correlation from the pneumatic SDMT to the Medusa equipment is significant. Also, the square root of the mean squared error of  $\Delta p$  reduces from 3.64 kPa in the case of SDMT to 2.60 kPa in the case of the Medusa equipment.

**Table 2.** Coefficient of correlation, SDMT and Medusa equipment

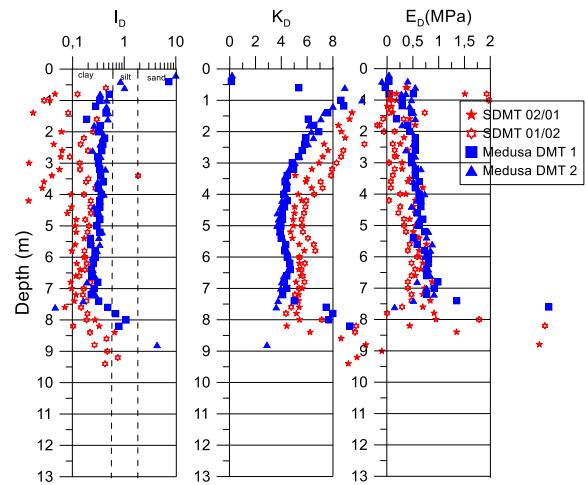
Value	SDMT	Medusa
$p_0$	0.88	0.99
$p_1$	0.86	0.99
$\Delta p$	0.75	0.83



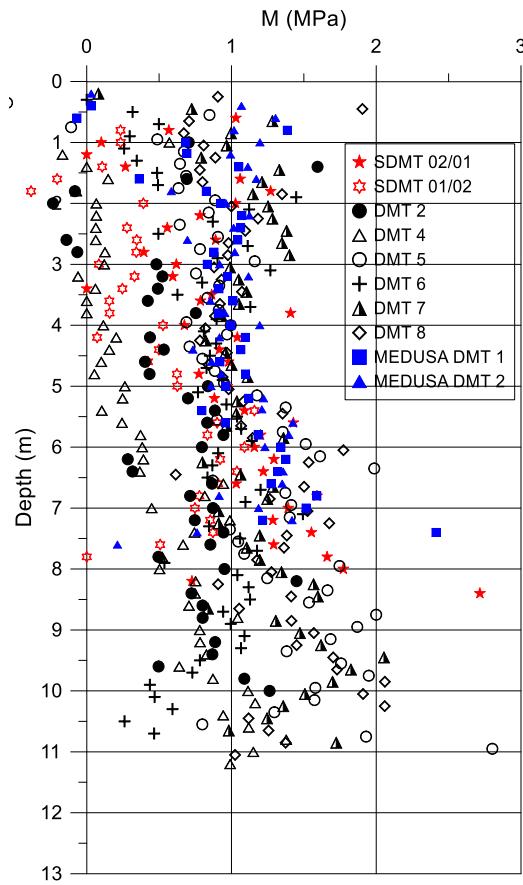
**Figure 13.**  $p_0$ ,  $p_1$  and  $\Delta p$  from all tests at Sarapuí II test site.

The intermediate parameters  $I_D$ ,  $E_D$  and  $K_D$  for Sarapuí II test site are presented in Fig. 14. Again, a significant improvement on the data scatter can be observed when the Medusa DMT is compared with the pneumatic DMT, even on  $K_D$ , which depends only on  $p_0$ , and especially on  $I_D$  and  $E_D$ , which depend on  $\Delta p$ .

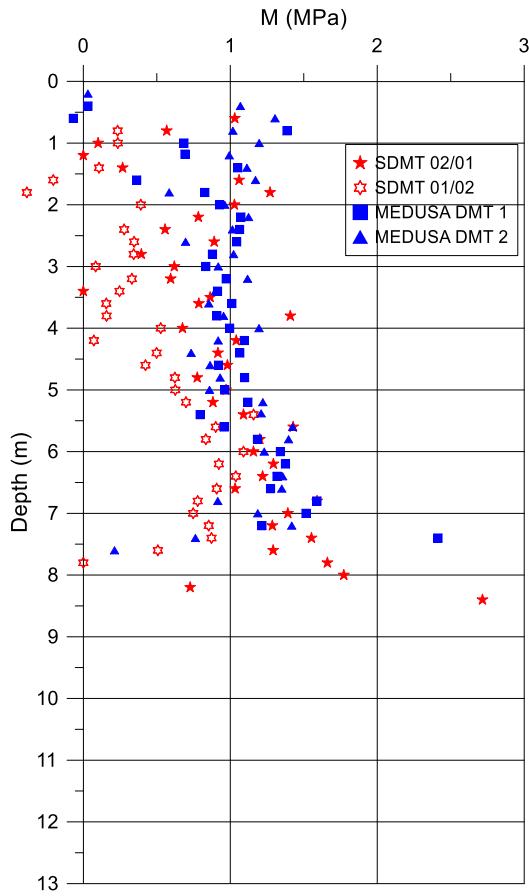
As in the previous section, the constrained modulus is used as an example to illustrate the data scatter from the two types of dilatometers, from tests performed in both test sites (Fig. 15) and only in Sarapuí II test site (Fig. 16). A significant scatter is obtained, not only when all tests are considered, but also when tests from Sarapuí II are analysed separately, when the data from the pneumatic equipment is considered. A significant improvement on the data reduction is obtained with the Medusa DMT.



**Figure 14.**  $I_D$ ,  $K_D$  and  $E_D$  from tests carried out in Sarapuí II.



**Figure 15.** M from all tests (from Sarapuí I and Sarapuí II sites) with no errors or nonconformities.



**Figure 16.** M from tests carried out in Sarapuí II test site.

## 6. Final remarks and conclusions

Dilatometer tests were performed in the very soft clay Sarapuí test site from 1985 to 2018. Different equipment was used, from the initial version to the most recent seismic DMT and also the Medusa DMT, in five series of tests. Careful procedures were always used. However, when the pneumatic version of DMT was used, significant scatter was obtained for the intermediate parameters  $I_D$  and  $E_D$ , which depend on  $\Delta p = p_1 - p_0$ , and less for  $K_D$ , which depends only on  $p_0$ . When  $p_0$  and  $p_1$  values are separately considered, the scatter is not very significant. However, when the difference  $\Delta p$  is considered, a significant scatter is obtained, explaining the higher scatter in the intermediate parameters  $I_D$  and  $E_D$ , which depend on  $\Delta p$  than  $K_D$ , which depends only on  $p_0$ . The same behaviour was not observed for Medusa DMT. In fact, a significant reduction in scatter of  $\Delta p$  was found, and even of the individual values of  $p_0$  and  $p_1$ . The improvement in the scatter on geotechnical parameters was illustrated for the constrained modulus M.

The improvement on the quality of the data obtained from the Medusa DMT with respect to the pneumatic equipment was attributed to the better control of the pressurizing system and on the rate the soil is loaded when the test is performed.

For very soft soils the use of Medusa DMT is therefore recommended.

## Acknowledgement

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