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In situ tests by Medusa DMT

Essais in situ par Medusa DMT

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ABSTRACT: The Medusa DMT is a self-contained cableless probe able to autonomously perform dilatometer tests using a blade with standard dimensions. The pressurization is applied using a hydraulic motorized syringe, which enables volumetric control during membrane expansion. An electric cable may optionally be used for obtaining real-time test data and for monitoring automation parameters during the execution of the measurements. For deeper investigations, the cable may be omitted and the instrument may work independently, performing measurements at preset time intervals and storing the results in the embedded memory. Initially conceived only for offshore testing, the Medusa DMT provides higher quality dilatometer data also onshore, with the possibility of additional measurements not feasible with the traditional pneumatic equipment. This paper illustrates a validation of Medusa DMT data compared with adjacent measurements carried out using the traditional pneumatic equipment. Other preliminary measurements obtained with this new instrumentation in the field, in particular short dissipation tests prior to membrane expansion, are presented.

RÉSUMÉ: Le Medusa DMT est une sonde capable d'exécuter de manière autonome essais au dilatomètre à l'aide d'une lame aux dimensions standard. La pressurisation est appliquée à l'aide d'une seringue hydraulique motorisée, qui permet un contrôle volumétrique au cours de l'expansion de la membrane. Un câble électrique peut être utilisé pour obtenir des données de test en temps réel, ainsi que le contrôle des paramètres d'automatisation lors de l'exécution des mesures. En cas d'investigations plus profondes, le câble peut être omis et l'instrument peut travailler de façon autonome, effectuant des mesures à des périodes de correction programmable et enregistrant les résultats dans la mémoire intégrée. Initialement conçu uniquement pour les essais offshore, le Medusa DMT fournit des données dilatométrique de qualité supérieure également sur terre, avec la possibilité de mesures additionnelles non réalisables avec l'équipement pneumatique traditionnel. Cet article illustre une validation des données de Medusa DMT comparées aux mesures faites à l'aide de l'équipement pneumatique traditionnel. Autres mesures préliminaires obtenues avec cette nouvelle instrumentation in situ sont présentées, en particulier les essais de dissipation brève avant l'expansion de la membrane.

Keywords: Medusa; DMT; Flat Dilatometer; Automated Dilatometer; Cableless Dilatometer

1 INTRODUCTION TO DILATOMETER TESTING

The flat dilatometer is an in situ testing equipment developed about 40 years ago by Prof. Silvano Marchetti (Marchetti 1980). The device is currently used in all the most industrialized areas for a total of over 70 countries. The flat dilatometer test (DMT) equipment and procedure are coded in the ASTM (ASTM D6635-15), Eurocode (EN 1997-2:2007) and ISO (ISO 22476-11:2017(E)) standards. The DMT has been the object of a detailed monograph by the ISSMGE Technical Committee TC16 (Marchetti et al. 2001).

Two distinctive features of the DMT are:

- the DMT is an in-situ deformation test rather than a penetration test, as it is based on pressure-displacement measurements. Therefore DMT results are more closely related to soil stiffness than penetration tests, which essentially test the soil near failure and are more strictly related to soil strength. The operative stiffness moduli estimated from DMT generally provide accurate predictions of settlements and displacements, that often govern geotechnical design.
- The DMT provides information on stress history, which has a dominant influence on soil behaviour. Knowledge of stress history is fundamental for obtaining realistic predictions, e.g. of settlements and liquefaction resistance.

The flat dilatometer consists of a steel blade having a thin, expandable, circular steel membrane mounted on one side (Figure 1). When the blade is pushed into the soil, the membrane is flattened against the surrounding plane behind it due to the horizontal pressure of the soil. The blade is connected to an electropneumatic cable running through the penetration rods, up to a control unit at surface. The control unit is equipped with pressure gauges, an audio-visual signal, a flow valve for regulating gas pressure supplied by a gas tank and vent valves for deflation.

The blade is advanced into the ground using common field equipment, mostly penetrometers as used for the cone penetration test (CPT), or also drill rigs. The test starts by inserting the dilatometer into the ground and, when the blade has reached the desired test depth, the penetration is stopped. Without delay the operator inflates the membrane and takes two pressure readings: the *A*-pressure, required to just start the membrane expansion (lift-off pressure), and the *B*-pressure, required to expand the membrane center 1.1 mm against the soil. A third reading *C* (closing pressure) can optionally be taken by slowly deflating the membrane just after the *B*-reading. 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 is specified in the existing standards. According to ISO 22476-11:2017(E), such rate 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.

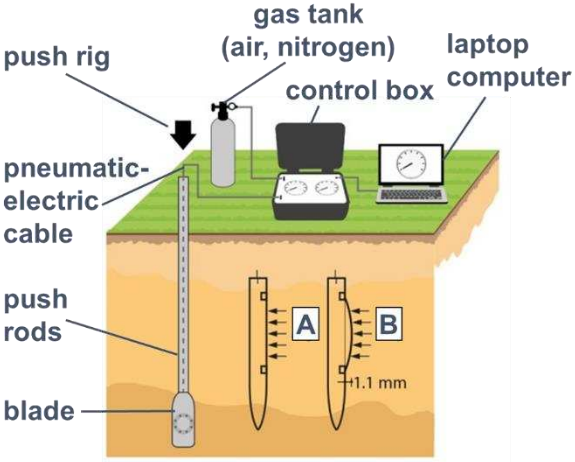

Figure 1. Main components of the traditional pneumatic DMT equipment and test layout

2 MEDUSA DMT TECHNOLOGY

The Medusa DMT is the combination of the flat dilatometer with a hydraulic automation and measuring system for autonomously performing DMT tests (Marchetti 2018). Figure 2 shows the main components of the instrument. A rechargeable battery pack powers an electronic board, connected to a pressure transducer and to a custom designed motorized syringe. The firmware coded in the electronics activates the motorized syringe for generating the pressure required to obtain the DMT readings. The maximum operating pressure is 25 MPa. A high accuracy pressure transducer is used to measure the pressure generated by the syringe and operating on the membrane. An electric wire provides the contact status of the membrane to the electronic board. The A, B, C pressure readings are taken by the electronic's firmware with the same criteria used for the traditional pneumatic DMT equipment.

When the Medusa DMT is operated cableless, a programmable period (T_{MCP}) determines when to start each measurement cycle. In the first part of the period, the A, B, C readings are taken and stored in the EPROM memory. The system will then stay in an idle state, waiting for the penetration to the next test depth. A typical period for T_{MCP} is of 1 minute, where the measurements are taken in the first 30 seconds and the device is idle in the remaining seconds for completing the period. During these additional 30 seconds the instrumentation is advanced to the next test depth. The time origin for the synchronization ($T = 0$) is set with the ON/OFF switch. The USB connection enables to program test parameters, such as T_{MCP}, and to download the data at the end of the test, when the probe is retrieved.

The Medusa DMT may also operate with an electric cable running from a computer laptop at ground surface down to the probe at depth. In this configuration, the operator may activate the measurement cycle from the computer as soon as the test depth is reached. During the cycle all automation parameters, such as the battery status, the voltage and current provided to the engine, the position of the piston of the morized syringe, the probe inclination and other additional information, are available in real time. The DMT parameters, in particular the current pressure and membrane contact status, are displayed in real time during the measurement, as for the traditional DMT pneumatic technology.

As previously recalled, current DMT standards (ASTM D6635-15, ISO 22476-11:2017(E)) contain detailed specifications and acceptable tolerances concerning the pressurization rate for obtaining the A and B pressure readings. Such prescriptions are related to the gas compressibility, inherent in the traditional pneumatic DMT equipment. For the Medusa DMT the firmware embedded in the electronic board implements the procedure for inflating and deflating the DMT membrane.

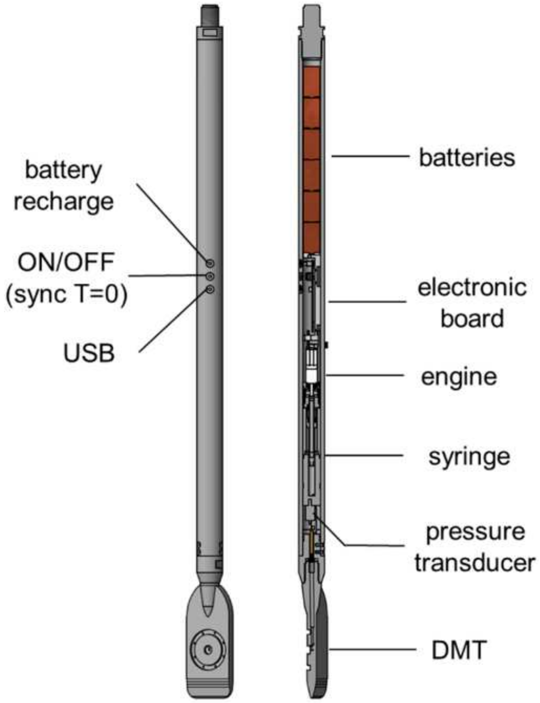

Figure 2. Main components of the Medusa DMT

The hydraulic pressurization of the motorized syringe actuates a volume controlled expansion of the membrane, which enables to impose a programmable timing for achieving the readings. Therefore the Medusa DMT is capable to perform dilatometer tests with the best recommended timing suggested in the international standards.

The motorized syringe, controlled by the electronic board, is also able to maintain the membrane in equilibrium with negligible displacements of the membrane. This capability enables to obtain continuous measurements of the total horizontal pressure of the soil against the membrane. Applications of this functionality are discussed further on in the paper.

As in the standard pneumatic DMT, the *A*, *B*, *C* readings must be corrected with the calibration offsets ΔA and ΔB to obtain p_0, p_1, p_2, respectively (Marchetti et al. 2001). All subsequent steps of data processing and interpretation of soil parameters are the same as for the traditional pneumatic DMT equipment.

3 MAIN IMPROVEMENTS USING THE MEDUSA DMT TECHNOLOGY

The Medusa DMT has several advantages over the traditional pneumatic equipment, both in terms of simplification of the probe and test procedure, and in terms of increased accuracy of the measurements. The major advantages are listed here below.

1. The overall equipment occupancy is reduced to the size of the standard blade with a rod connected on its top, for a total height of about 1 m. The gas tank, the control unit and the pneumatic cables are no longer required.
2. The probe may operate in cableless mode, which is a significant practical advantage, especially in the offshore industry. An optional electric cable may be used for obtaining real-time results during test execution.
3. The pressure is generated and measured locally at depth, not at ground surface. This eliminates any possible problem of pressure equalization along the pneumatic cable of the traditional equipment.
4. The pressurization rate of the membrane is independent of the operator. The automatic (volume controlled) procedure of membrane pressurization operated by the motorized syringe is highly repeatable and capable to impose the correct timing to obtain the *A* and *B* pressure readings, strictly according to the specifications of the international standards.

In addition, the capability of the Medusa DMT of measuring (virtually continuously) the total horizontal pressure against the membrane with time enables new research possibilities.

a. DMT-A dissipation tests for estimating the in situ coefficients of consolidation and permeability (Marchetti & Totani 1989, Totani et al. 1998) may be conducted also in intermediate permeability soils (silts and silty sands), thanks to the high reactivity of the motorized syringe in following the horizontal pressure decay. Differently, using the traditional pneumatic equipment DMT-A dissipation tests are feasible only in low permeability soils (clays and silty clays).

b. Short *A*-dissipations, consisting in repeated *A*-readings (without expansion of the membrane from *A* to *B*) for a couple of minutes, may be executed to detect intermediate or partially draining soil layers (Marchetti 2015, Marchetti & Monaco 2018). The duration of such short *A*-dissipations (much shorter than conventional DMT-A dissipation tests that provide the entire *A*-decay curve) is sufficient to discover whether an appreciable reduction of the total contact pressure *A*, reflecting pore pressure dissipation, occurs during the test. This may occur in a relatively narrow subset of "niche silts" (Marchetti et al. 2001), for which the interpretation of soil parameters from DMT data would require specific corrections (Schnaid et al. 2018).

c. The Medusa DMT permits to execute routinely short *A*-dissipations before recording each standard *A*-reading, which is taken 15 s after reaching the test depth. In clays no appreciable pore pressure dissipation occurs in 15 s and the *A*-readings remain nearly constant, indicating fully undrained conditions. A substantial reduction of *A* in 15 s prompts for partial drainage.

d. Research in progress investigates the potential use of the Medusa DMT for performing dilatometer tests adopting variable pressurization rates in intermediate soils. This potential descends from the highly accurate and repeatable time-for-reading facility provided by the instrument.

e. The Medusa DMT may be used to obtain continuous measurements of the total horizontal pressure during penetration (equivalent *A*-reading at $T = 0$ seconds instead of $T = 15$ seconds). These measurements could provide useful indications for the assessment of the in-situ stress state and the at-rest lateral earth pressure coefficient (K_0).

4 TESTING AND VALIDATION OF THE MEDUSA DMT

A specific calibration chamber was designed and constructed for testing the Medusa DMT up to 25 MPa (Figure 3). Details can be found in Marchetti (2018). Preliminary experimental results in the calibration chamber have shown high accuracy and repeatability of the pressure measurements in the order of ± 1 kPa.

The first validation of the Medusa DMT in the field was carried out in 2016 at the test site of Cesano, Rome (Italy). The results obtained using the traditional pneumatic DMT equipment were compared with the results obtained using the Medusa DMT in an adjacent sounding. Figure 4 shows a fairly good agreement between the parameters obtained from the interpretation of the parallel test data provided by the two instruments, using for both common DMT data reduction formulae and correlations (Marchetti 1980, Marchetti et al. 2001). In particular, Figure 4 shows the profiles with depth of: the material index I_D (indicating soil type), the constrained modulus *M*, the undrained shear strength c_u (in clay), the friction angle φ' (in sand), and the horizontal stress index K_D (related to stress history).

Additional measurements with the Medusa DMT were carried out at the same test site of Cesano in August 2018, aimed at assessing the applicability of short *A*-dissipations carried out before expanding the membrane to the *B*-reading. Figure 5 shows the results of an *A*-dissipation of duration about 120 seconds performed before the expansion of the membrane. In particular, Figure 5a shows the pressure readings as a function of time.

Figure 3. Calibration chamber used for preliminary tests on the Medusa DMT

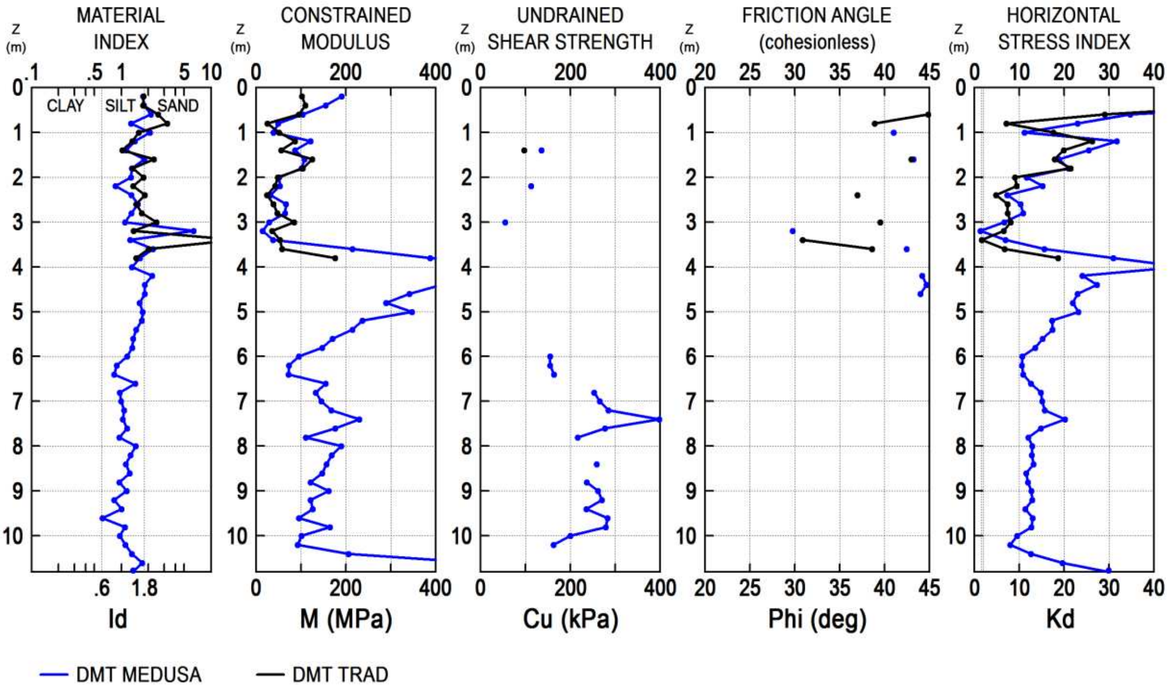

Figure 4. Comparison of dilatometer test results obtained with the traditional pneumatic DMT equipment and with the Medusa DMT at the site of Cesano, Rome, Italy (2016)

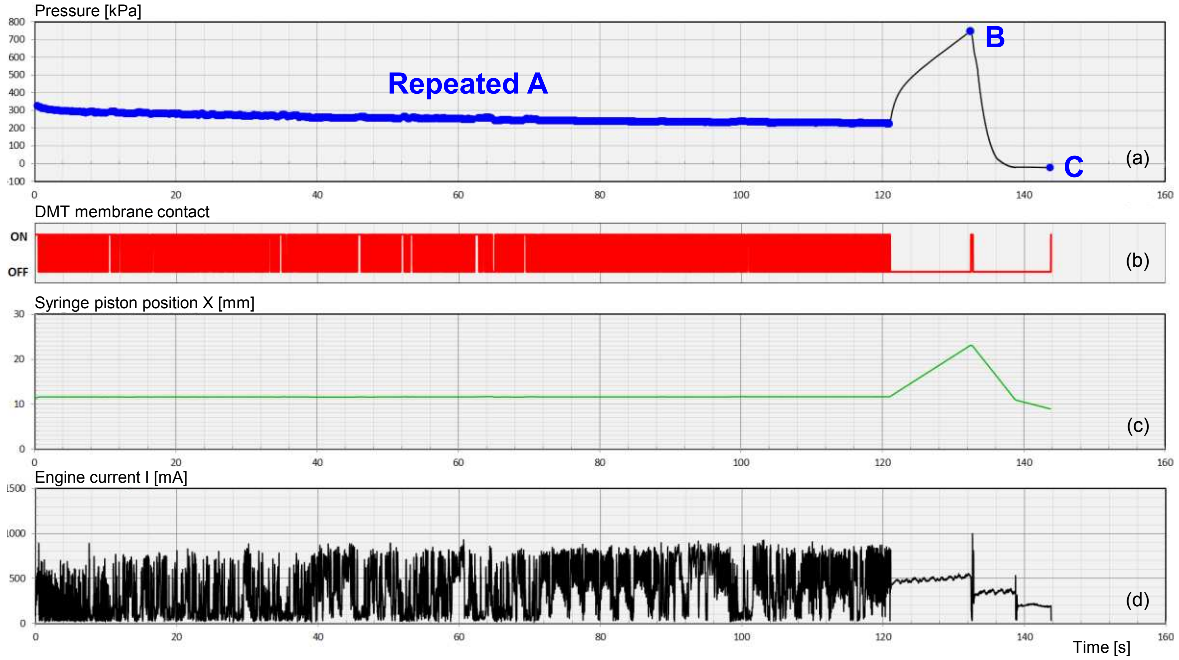

Figure 5. Results of a short A-dissipation test prior to membrane expansion obtained by Medusa DMT at the site of Cesano, Rome, Italy (2018)

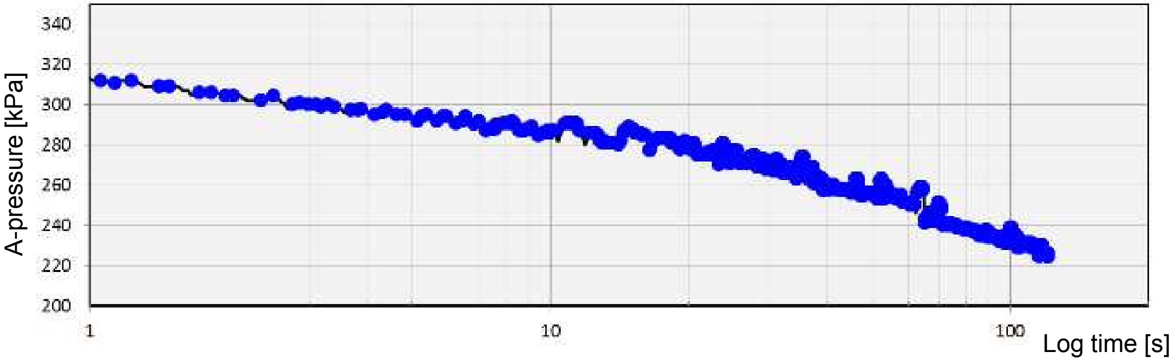

Figure 6. Detail of the A-pressure vs. log time measurements during a short A-dissipation test prior to membrane expansion at the site of Cesano, Rome, Italy (same data as in Figure 5a)

The black line is the pressure applied by the motorized syringe to the membrane. Each blue dot superimposed on the black line in the first ≈ 120 s represents one *A*-pressure reading, which is taken with an average frequency of 15 Hz. After the initial *A*-dissipation the membrane is expanded to the *B*-pressure and then the system is deflated. The *C*-pressure reading is the last blue dot on the right of the graph.

The other graphs in Figure 5 show some of the automation parameters recorded during the same test cycle, namely the DMT membrane contact status (ON/OFF, Figure 5b), the position of the piston of the motorized syringe (Figure 5c), and the voltage/current provided to the engine (Figure 5d). In the first 120 seconds the electronic board drives the syringe to take rapid consecutive *A*-readings. Figure 5b shows the corresponding oscillation of the membrane contact between ON and OFF. Each *A*-reading is taken in the transition from ON to OFF. Figure 5d shows the high reactivity of the engine driving the motorized syringe for the *A* repetitions. The constant value of the position of the syringe piston shown in Figure 5c clearly indicates that the membrane does not apply displacement to the soil during the short dissipation test of 120 seconds. Thus the recorded A-readings represent the decay of the total horizontal soil pressure against the membrane. Such decay curve is more clearly visible in Figure 6, where only the *A*-dissipation readings in the first ≈ 120 s are plotted versus time (same data as in Figure 5a, but plotted on an expanded vertical scale and a semilogarithmic horizontal scale). This plot format highlights the typical initial trend of an *A*-decay curve. The graph clearly shows that the dissipation was interrupted, although still in progress, indicating that the behaviour of the soil is partially drained.

5 CONCLUSIONS

The new Medusa DMT is able to autonomously perform standard dilatometer tests using a hydraulic motorized syringe. Such automation implies several distinctive advantages of the Medusa DMT over the traditional pneumatic equipment, both in terms of simplification of the probe and test procedure, and in terms of increased accuracy of the test results.

Preliminary validations are shown for a test site in Italy, where the results provided by the Medusa DMT were compared to the results obtained using the traditional pneumatic DMT equipment.

The capability of the Medusa DMT of measuring (virtually continuously) the total horizontal pressure against the membrane with time enables new research possibilities and additional test procedures, which are not feasible with the traditional pneumatic equipment. In particular, this paper shows and comments on the results of a short *A*-dissipation test carried out prior to the membrane expansion.

Research in progress investigates the potential use of the Medusa DMT for performing dilatometer tests with variable pressurization rates in intermediate soils and for obtaining continuous measurements of the total horizontal pressure during penetration.

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