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Validation of Medusa DMT test procedures in Fucino clay

Validation des procédures d'essai par Medusa DMT dans l'argile du Fucino

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ABSTRACT: The Medusa DMT is a self-contained, fully automated cableless probe able to autonomously perform dilatometer tests using a blade of standard dimensions. The pressurization is applied using a hydraulic motorized syringe which actuates a volume controlled expansion of the membrane. This procedure is highly repeatable, operator-independent and capable to impose a programmable pressurization rate for achieving the DMT pressure readings. The motorized syringe, controlled by the electronic board, is also able to maintain the membrane in equilibrium with negligible displacement, allowing to implement alternative test procedures. This paper illustrates the results of a field-testing campaign specifically planned to validate/compare different Medusa DMT test procedures at Fucino-Telespazio (Italy), a well-documented benchmark test site constituted by a geologically NC, cemented, quite homogeneous soft lacustrine clay of high plasticity. The comparison of results obtained by Medusa DMT adopting three different test procedures (Standard, Repeated *A*-readings, *A*-reading while penetrating) and by traditional pneumatic DMT indicates substantial accuracy and consistency of measurements provided by all test procedures.

RÉSUMÉ: Le Medusa DMT est une sonde entièrement automatisée, sans câble, capable d'effectuer de façon autonome des tests de dilatomètre à l'aide d'une lame de dimensions standard. La pressurisation est appliquée à l'aide d'une seringue hydraulique motorisée qui actionne une expansion contrôlée en volume de la membrane. Cette procédure est hautement reproductible, indépendante de l'opérateur et capable d'imposer un taux de pressurisation programmable pour atteindre les lectures de pression DMT. La seringue motorisée, contrôlée par la carte électronique, est également capable de maintenir la membrane en équilibre avec un déplacement négligeable, ce qui permet de mettre en œuvre d'autres procédures d'essai. Cet article illustre les résultats d'une campagne d'essais in situ spécifiquement prévue pour valider/comparer différentes procédures d'essai par Medusa DMT à Fucino-Telespazio (Italie), un site de référence bien documenté constitué par une argile lacustrine molle géologiquement NC, cimentée, assez homogène de haute plasticité. La comparaison des résultats obtenus par Medusa DMT en adoptant trois procédures d'essai différentes (Standard, Repeated *A*-readings, *A*-reading while penetrating) et par DMT pneumatique traditionnel indique une précision et une cohérence substantielles des mesures fournies par toutes les procédures d'essai.

KEYWORDS: Medusa dilatometer test, flat dilatometer test, in situ testing, benchmark test sites, soft clay

1 INTRODUCTION

The Medusa dilatometer (Medusa DMT) is a new generation, fully automated version of the Marchetti flat dilatometer (DMT). It is a self-contained cableless steel probe composed of a dilatometer blade of standard dimensions and a set of components connected behind it, protected with a watertight steel tube. Such components enable to generate and measure within the probe the pressure for performing autonomously dilatometer tests, without the need of a gas pressure source nor of a pneumatic cable. An optional electric cable may be used for obtaining real time results during test execution.

Originally conceived for offshore testing (Marchetti 2018), the Medusa DMT is increasingly used in routine onshore investigations, also due to its capability to perform additional measurements not feasible with the traditional pneumatic equipment.

The Medusa DMT has several advantages over the traditional DMT equipment, in terms of test automation, field productivity and increased accuracy (Marchetti et al. 2019). It has been tested in previous investigation campaigns in different soil types, including very soft soils (Marchetti et al. 2021) and intermediate soils (Monaco et al. 2021). However the available experience has pointed out the need for further experimentation, aiming towards (i) consolidation of the acquired knowledge, and (ii) standardization of the equipment and test procedures. In fact, while the traditional flat dilatometer test is standardized (ASTM

D6635-15, EN 1997-2:2007, ISO 22476-11:2017(E)), no official standards have been established yet for the Medusa DMT.

In this perspective, an optimal solution for validating innovative testing procedures implemented with the Medusa DMT was deemed to be planning a specific experimental program at a benchmark test site, selected to ensure both simplicity of geotechnical conditions (i.e. relatively homogenous soil deposit) and ease of interpretation (i.e. available pre-existing laboratory and field data).

One suitable benchmark test site meeting the above requirements, located in central Italy, is the site of Fucino-Telespazio, which was selected for the field-testing campaign with Medusa DMT described in this paper. Fucino-Telespazio is a well-documented research test site, constituted by a thick deposit of geologically normally consolidated (NC), cemented, quite homogeneous soft lacustrine clay of high plasticity. The site was extensively investigated at the end of the 1980s by means of several in situ and laboratory tests carried out by various international research groups (Burghignoli et al. 1991). Earlier experimentation with the flat dilatometer at this site was reported by Marchetti (1980). Subsequently in 2004-2005 the same site was selected for validation of the seismic dilatometer (SDMT), combination of the flat dilatometer with an add-on seismic module for measuring the shear wave velocity V_S (Foti et al. 2006, Marchetti et al. 2008). Along these lines, Medusa DMT testing at Fucino-Telespazio ideally links past experience and recent technological developments.

This paper illustrates the main results of the field-testing campaign carried out at Fucino-Telespazio in September 2020, specifically aimed to validate, compare and correct, if needed, different Medusa DMT testing procedures. Details on the Medusa DMT equipment and test procedures are provided in the first part of the paper. The focus in this paper is on the comparison of results obtained from Medusa DMT adopting three different test procedures (Standard, Repeated *A*-readings, *A*-reading while penetrating), also in comparison with traditional DMT results. Details on the site characterization are outside the scope of this paper and may be found in the above referenced papers, or in the available literature.

2 MEDUSA DILATOMETER TEST

2.1 *Equipment*

The Medusa DMT is a self-contained, fully automated version of the flat dilatometer, able to autonomously perform dilatometer tests without the pneumatic cable (Marchetti 2014). A motorized syringe, driven by an electronic board powered with rechargeable batteries, hydraulically expands the membrane to obtain the DMT pressure readings, which are acquired and stored automatically at each test depth.

As for the traditional pneumatic DMT, the basic Medusa dilatometer test consists of inserting the probe vertically into the soil and measuring, at selected depth intervals, two pressures: the *A*-pressure, required to just start the membrane expansion, and the *B*-pressure, required to expand the membrane centre 1.10 mm against the soil. A third pressure, the *C*-pressure, can optionally be measured by slowly deflating the membrane just after the *B*-pressure reading.

The device may operate without any cable. However an optional electric cable is generally used to obtain 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.

The Medusa DMT is advanced into the ground using the same field machines, commonly penetrometers or drill rigs, used for the traditional pneumatic DMT. Also the field of soil type application of the Medusa DMT is the same as for the traditional DMT (clays, silts, sands).

Figure 1 illustrates the main components of the instrument. In detail, the Medusa DMT probe is composed of a dilatometer blade of standard dimensions combined with a rod behind it containing all the necessary components for performing DMT measurements, without necessarily requiring a cable to the surface. An electronic board, powered by a rechargeable battery pack, is connected to a pressure transducer and to a motorized syringe. The firmware coded in the electronic board activates the motorized syringe for generating the pressure required for expanding hydraulically the membrane to obtain the DMT pressure readings. A high accuracy pressure transducer measures 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 board with the same criteria used for the traditional pneumatic DMT equipment.

When the Medusa DMT is operated in cableless mode, a programmable time (Medusa Cycle Period, T_{MCP}) determines when to start each measurement cycle starting from a time origin. A waterproof connector on the rod provides a rapid connection for battery recharge, for time synchronization of the time origin, for defining the Medusa Cycle Period and for downloading the data after the test. The T_{MCP} period is the sum of the times necessary to perform the following two operations:

1. Perform DMT measurements: the electronic board activates the motorized syringe to acquire the *A*, *B*, and (optionally) *C* pressure readings, which are stored in the EPROM memory (T_M = maximum time allocated for measurements).
2. Wait for penetration to the next test depth, with the system set in an idle state ($T_W = T_{MCP} - T_M$ = time allocated for penetration to the next test depth).

For example, the total period T_{MCP} may be set to 1 minute, with $T_M = T_W$ = 30 seconds. In the first 30 seconds (T_M) the DMT pressure readings will be completed, then the probe will stay in the idle state for the remaining 30 seconds (T_W), until the total programmed period (T_{MCP}) of 1 minute has elapsed. During these last 30 seconds (T_W), the instrumentation is advanced to the next test depth.

The Medusa DMT test cycles are repeated sequentially until the probe is retrieved and connected to the computer at surface. During test execution, the computer will display if the Medusa DMT is performing measurements or is in the idle state, so that the operator may correspondingly wait for the test cycle to complete or penetrate the probe to the next test depth.

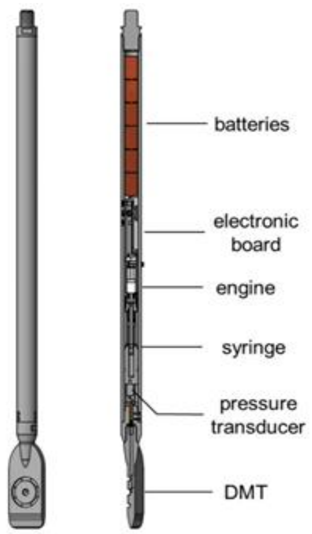

Figure 1. Main components of the Medusa DMT.

The operator must indicate in the software the test depth for each sequentially numbered test cycle. When the data will be downloaded, the software will associate the correct depth to the DMT readings of the corresponding test cycle.

In the cabled version of the Medusa DMT, an electric cable connects the control unit and computer to the probe at depth. The operator activates each measurement cycle from the computer as soon as the test depth is reached. During the cycle all automation parameters, such as the battery status, voltage and current provided to the engine, position of the piston of the motorized syringe, probe inclination and other additional information and the DMT parameters, such as pressure and membrane contact status, are displayed real time. The DMT pressure readings are also collected and stored in real time, with the possibility of plotting preliminary profiles of the results. The cabled configuration should be used whenever possible. In this case the overall test productivity is higher.

2.2 *Test procedures*

The Medusa DMT may perform dilatometer measurements using distinct test procedures. The 'standard' DMT procedure is the same procedure of the traditional pneumatic flat plate dilatometer test. All the alternative procedures differ from the standard procedure mainly in the technique used for taking the *A*-pressure reading(s).

2.2.1 *Standard DMT procedure (STD)*

The Medusa DMT shall be inserted vertically into the soil, from the ground surface or from the bottom of a borehole, and then advanced to the selected test depths, typically adopting depth intervals of 0.20 m as for the traditional pneumatic DMT.

The standard DMT procedure (STD) consists of the following sequence of operations.

1. Advancement of the probe, stop of penetration and start of pressurization

During the insertion of the probe, the membrane is not pressurized. As the blade penetrates, the electrical signal shall be activated, because the soil flattens the membrane against the sensing disc. If the soil pressure is not sufficient for this purpose, the Medusa DMT will apply the minimum suction necessary for activating the membrane contact. As soon as the next test depth is reached, the penetration is stopped and the DMT test cycle shall start. In the cabled Medusa DMT configuration, the operator will activate the DMT test cycle through a command button of the software. In the cableless version, where the start time of the test cycles is periodic and pre-programmed, the probe penetration will be tuned to ensure that the probe will arrive at the test depth when the start time of the cycle will start.

2. A-pressure reading

The activated motorized syringe gradually increases the hydraulic pressure to the membrane. When the internal oil pressure equals the external soil pressure, the membrane lifts-off from its seat and starts to expand laterally. When the membrane has expanded of 0.05 mm at its centre, the electric contact between the membrane and the sensing disc is deactivated and the pressure is recorded and assigned to the *A*-pressure reading. The pressurization rate is regulated so that the *A*-pressure reading is obtained in approximately 15 s after reaching the test depth (i.e. start of pressurization), with generally ± 1 s tolerance, in accordance with ± 5 s specified in the standards of the traditional pneumatic DMT (ASTM D6635-15, ISO 22476-11:2017(E)). Different timings may also be set, although not compliant with the current standards of DMT test.

3. B-pressure reading

After the *A*-reading, the motorized syringe continues to increase the pressure. During the consequent membrane expansion the electric contact between the membrane and the blade body remains deactivated, until the membrane displacement at the centre equals 1.10 mm. At this instant the electric contact reactivates and the second pressure reading *B* is recorded. The pressurization rate is tuned by the motorized syringe to obtain the *B*-pressure reading in approximately 15 s after the *A*-pressure reading, with generally ± 1 s tolerance. Different timings may be set, although not compliant with the current standards of DMT tests.

4. Depressurization and optional C-pressure reading

As soon as the *B*-reading is obtained, the motorized syringe will start decreasing the oil pressure until the membrane will return to its initial position. If only the *A* and *B* pressure readings are of interest, the basic dilatometer test procedure is completed. In this case the depressurization will be fast, to minimize the time to be ready to start the next test cycle. If the *C*-pressure reading is requested, the motorized syringe will apply a gradual and controlled depressurization after the *B*-reading. The membrane will slowly return to its initial position against the sensing disc. At the instant in which the contact reactivates, the corresponding pressure is assigned to the *C*-pressure reading. The *C*-reading is typically obtained in approximately 30-40 s after start of depressurization following the *B*-reading. The probe is then ready to advance to the next test depth or to be retrieved if the target depth has been tested.

The test sequence (steps 1 to 4) is repeated at each test depth, down to the maximum depth of the sounding.

Figure 2 shows a set of graphs of a sample full Medusa DMT test cycle carried out according to the standard DMT procedure. Time starts ($t = 0$) when the operator activates the cycle from the software when using the cabled version of the Medusa DMT, or at every multiple of T_{MCP} in the cableless version. The graphs in Figure 2 show the registration during the test cycle of the following parameters: (a) pressure to the membrane generated by the motorized syringe; (b) membrane contact status; (c) position of the piston in the motorized syringe; (d) current provided to the engine of the motorized syringe.

Initially, the membrane contact status will be activated (ON) and the pressure will be at an initial (irrelevant) value, lower than the *A*-pressure. The electronic board starts to supply current to the engine which advances the piston in the motorized syringe, gradually increasing the pressure to the membrane. When such generated pressure is equal to the total horizontal pressure of the soil against the membrane, it will start to expand and, after the 0.05 mm displacement imposed by the feeler, the contact status will deactivate (OFF) and the *A*-pressure reading will be recorded and stored. The motorized syringe will continue to increase the inner pressure and the membrane will expand further. When the membrane will have expanded 1.10 mm at its centre, the *B*-pressure reading will be stored. The motorized syringe will

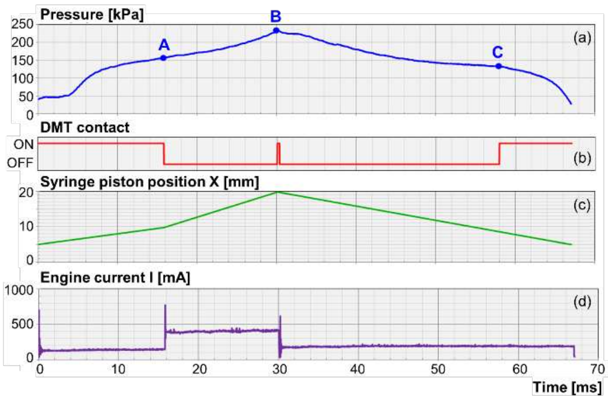

Figure 2. Example of data recorded in a full Medusa DMT test cycle adopting the Standard DMT procedure (STD): (a) pressure and *A*, *B*, *C* readings, (b) membrane contact status, (c) syringe piston position, (d) engine current. All data are plotted versus time, where $t = 0$ corresponds to the instant when penetration stops and the test cycle begins.

continue to increase the inner pressure and the membrane will expand further. When the membrane will have expanded 1.10 mm at its centre, the *B*-pressure reading will be stored. The motorized syringe will immediately invert the direction of the piston movement and the pressure will start to decrease. If the *C*-pressure reading is requested, the depressurization of the membrane will be gradual and the reading will be recorded when the signal will reactivate. If the *C*-pressure reading is not requested, the motorized syringe will depressurize as fast as possible, returning the membrane in its initial position ready for the next test cycle.

2.2.2 *DMT Repeated A-readings procedure (DMT-RA)*

The DMT Repeated *A*-readings procedure (DMT-RA) differs from the standard DMT procedure only in the first part of the measurement sequence, before membrane expansion, while the *B*-pressure and the optional *C*-pressure readings are taken exactly in the same way.

As previously described, in the standard DMT procedure the *A*-reading is taken when the membrane centre has expanded horizontally 0.05 mm against the soil, replicating exactly the same procedure implemented in the traditional pneumatic DMT test.

The motorized syringe of the Medusa DMT, driven by the electronic board, is also able to maintain the membrane in equilibrium with negligible horizontal displacement of the membrane. This new test procedure makes use of this capability.

The initial stage of the DMT test cycle with the DMT-RA procedure, before penetrating to the next test depth, consists in maintaining the membrane in equilibrium with the soil pressure. This state is obtained with very rapid pressure corrections operated by the motorized syringe in equilibrium on the contact transitions (ON-OFF-ON-OFF etc.), with negligible membrane displacement. In this situation the membrane is in equilibrium at 0.05 mm distance from the sensing disc. When the new test depth is reached, the test cycle starts ($t = 0$) and repeated sequential *A*-readings are taken with time during the rapid pressure corrections of the motorized syringe, monitoring the total horizontal soil pressure against the membrane with time. All the sequential *A*-readings are obtained without any displacement of the soil, because the blade is advanced to the test depth with the membrane already at 0.05 mm displacement from the sensing disc.

Such DMT Repeated *A*-readings test procedure is characterized by the duration (T_{diss}) of the sequential *A*-readings taken with time (dissipation), before concluding the DMT test cycle with the standard *B* and optional *C* readings. The parameter T_{diss} may be selected and pre-programmed before starting the test cycle, so that the membrane expansion will be activated after time T_{diss} has elapsed. Alternatively, the sequence of dissipation readings may be interrupted by the operator through a command-button of the software, which starts membrane expansion to *B*. Typically T_{diss} is set between 10-20 seconds, commonly equal to 15 seconds to comply with the timing suggested by the pneumatic DMT standards (ASTM D6635-15, ISO 22476-11:2017(E)). The procedure and timing for taking the *B* and *C* pressure readings are the same as in the standard test procedure.

2.2.3 *DMT A-reading while penetrating procedure (DMTA-WP)*

The capability of the Medusa DMT to maintain the membrane in equilibrium with negligible horizontal displacement enables to obtain continuous measurements of the total horizontal pressure of the soil against the membrane during penetration of the probe.

The DMT *A*-reading while penetrating procedure (DMTA-WP) consists in performing repeated *A*-pressure measurements (equivalent to *A*-pressure reading at $t = 0$ instead of the standard DMT time of $t = 15$ s) recorded during penetration of the Medusa DMT at a constant rate. The sequence of *A*-readings is generally taken over depth intervals of 1 m, corresponding to the typical length of push rods. Almost all penetrometers require to stop penetration every meter to add a push rod, during which *B* and *C* pressure readings may be taken without employing additional time. A constant penetration rate of 20 mm/s (± 10.0 mm/s), as in the standard test procedure, is generally adopted.

The current Medusa DMT equipment does not include instrumentation to measure the penetration depth during the readings. Most penetrometers include an encoder (for CPT measurements) and may output a time versus depth file, helpful for accurately associating the *A*-readings to the corresponding depth at which they were taken. When such information is missing, the time-depth relation may be estimated assuming an average speed of penetration, estimated by measuring the time for penetrating a 1-meter rod. The average speed and the time from the start of penetration enables to estimate the depth of each *A*-reading. Although not as accurate as with an encoder, the error is reasonably limited in terms of % error, since each measuring interval is maximum 1 m long.

2.3 *Data processing and interpretation*

As for the traditional pneumatic DMT test, the Medusa DMT pressure readings *A*, *B*, *C* must be corrected with the calibration offsets ΔA and ΔB to obtain p_0, p_1, p_2, respectively, in order to account for membrane stiffness. The calibration correction eliminates also any zero offset error of the pressure transducer, since all the measurements are performed with the same pressure sensor. All subsequent steps of data processing and interpretation of soil parameters are the same as for the traditional pneumatic DMT (see ISSMGE TC16 Report, Marchetti et al. 2001 for details):

1. correct the field pressure readings *A*, *B*, *C* to obtain the corrected pressures p_0, p_1, p_2;
2. calculate the intermediate parameters: material index I_D, horizontal stress index K_D, dilatometer modulus E_D and pore pressure index U_D;
3. obtain interpreted soil parameters of common use in geotechnical engineering by means of well-established correlations.

The interpretation of Medusa DMT test results in terms of soil parameters takes advantage of the wide experience available for the traditional pneumatic DMT test, and essentially shares the same set of established soil property correlations available in literature. An exhaustive collection of most widely used DMT correlations can be found in the ISSMGE TC16 Report (Marchetti et al. 2001) and subsequent updates (Marchetti 2015, Marchetti and Monaco 2018).

3 MEDUSA DMT TESTING AT THE FUCINO-TELESPAZIO BENCHMARK TEST SITE

The experimental program at the Fucino-Telespazio test site, completed in the week 22-25 September 2020, included one traditional pneumatic DMT sounding, carried out using the SDMT equipment (SDMT 1), and three Medusa DMT soundings (Medusa 1, Medusa 2, Medusa 3). All soundings were performed at close mutual distance and to a depth of 30 m.

The three Medusa DMT soundings were carried out using the three different test procedures described in § 2.2, which differ essentially for the technique adopted for measuring the *A*-pressure:

- Medusa 1: Standard DMT procedure (STD), with *A*-pressure measured 15 s after start of pressurization;
- Medusa 2: DMT Repeated *A*-readings procedure (DMT-RA), with initial series of *A*-readings for $T_{diss} = 15$ s;
- Medusa 3: DMT *A*-reading while penetrating procedure (DMTA-WP), with continuous *A*-pressure measurements

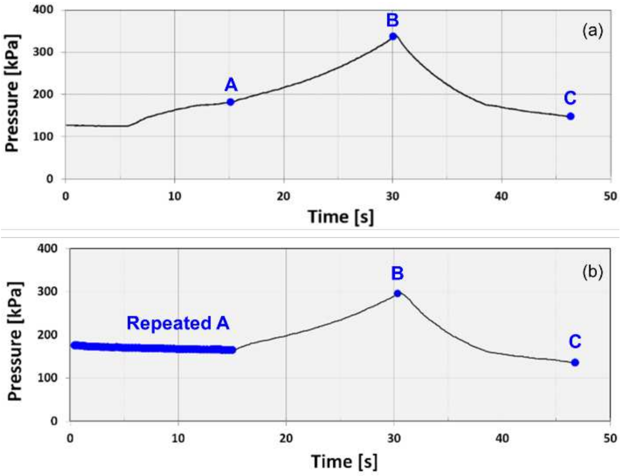

Figure 3. Medusa DMT test cycles (pressure vs. time and A, B, C readings) obtained at Fucino-Telespazio by: (a) Standard DMT procedure (STD), sounding Medusa 1, depth 8 m, (b) DMT Repeated A-readings procedure (DMT-RA), sounding Medusa 2, depth 8 m.

during penetration over 1 m depth intervals and B and C pressure readings taken every 1 m.

Figure 3a illustrates an example of results obtained by the Standard DMT procedure (Medusa 1, depth 8 m). Figure 3b illustrates the results obtained by the DMT Repeated A-readings procedure (Medusa 2) at the same depth. The decrease of the horizontal soil pressure observed during the A-pressure readings in 15 seconds is ≈ 6 %, as expectable in clay.

The test results obtained from all soundings (SDMT 1, Medusa 1, Medusa 2, Medusa 3) were processed using the same data reduction formulae used for the traditional DMT test (ISSMGE TC16 Report, Marchetti et al. 2001). For the sounding Medusa 2 (DMT-RA), the A-pressure reading used in data processing is the last value obtained from the A-dissipation series, i.e. the A-pressure recorded 15 s after start of pressurization (Figure 3b). In the processing of data from all soundings the groundwater table was assumed at a depth z_w = 0.60 m below the ground surface, as indicated by the C-pressure readings performed in the very few thin sand layers.

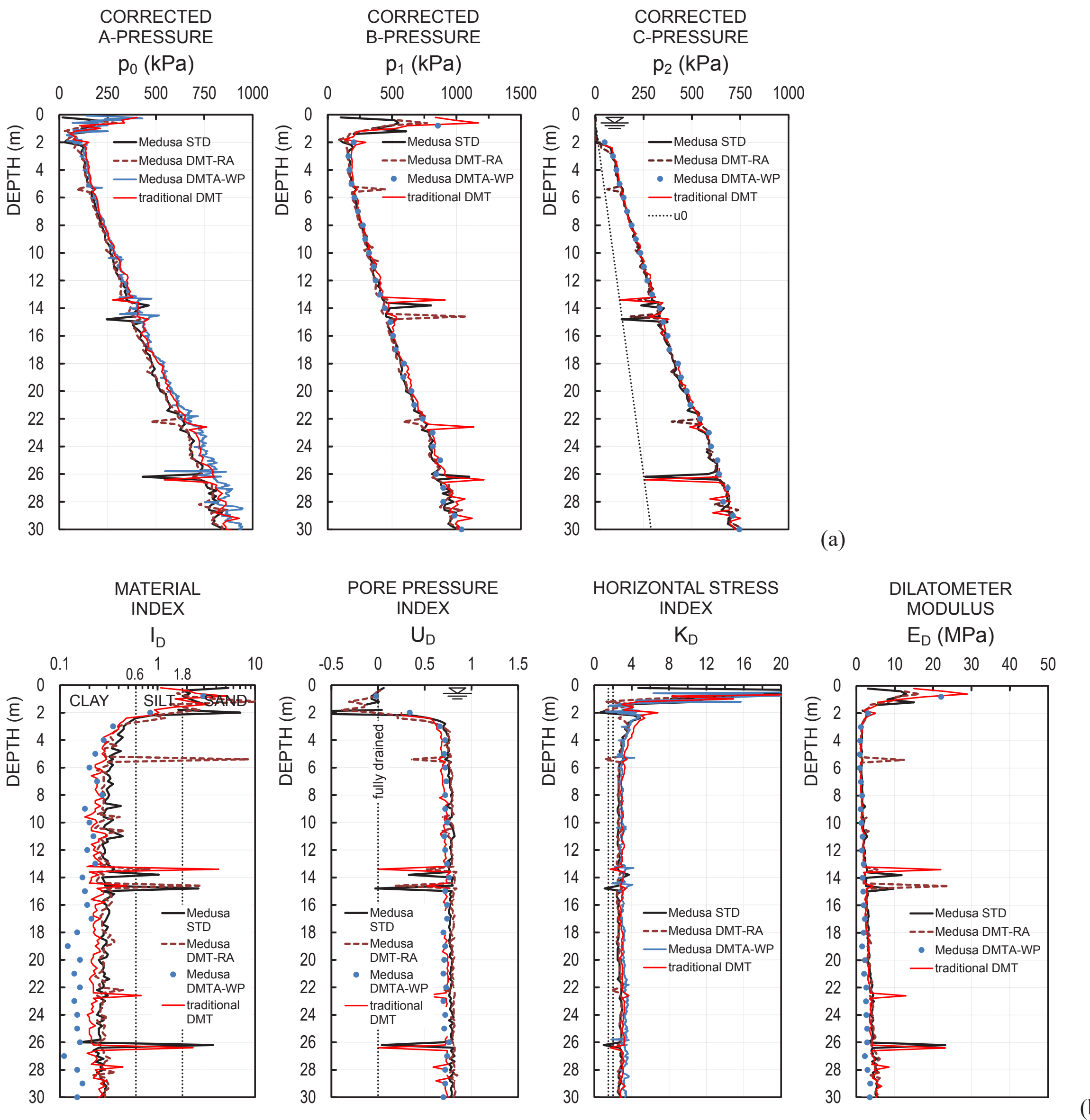

Figure 4. Comparison of results obtained by Medusa DMT using different test procedures and by traditional DMT at the benchmark test site of Fucino-Telespazio: (a) corrected pressures p_0, p_1, p_2, (b) intermediate parameters I_D, U_D, K_D, E_D.

Figure 4 shows the comparison of the results obtained by Medusa DMT using the three different test procedures (STD, DMT-RA, DMTA-WP) and the results obtained by traditional DMT, in terms of depth profiles of the corrected *A*, *B*, *C* pressure readings p_0, p_1, p_2 (Figure 4a) and of the intermediate parameters I_D, U_D, K_D, E_D (Figure 4b).

The profiles of p_0 obtained by Medusa DMT using the three different test procedures are very similar, despite the different techniques adopted for measuring the *A*-pressure, and in good agreement with the profile of p_0 obtained by traditional DMT.

The profiles of p_1 and p_2 obtained by Medusa DMT (all test procedures) and traditional DMT are nearly coincident. The values of p_1 and p_2 obtained by the DMTA-WP procedure are discontinuous, because in this case the *B* and *C* pressure readings are performed at depth intervals of 1 m, instead of 0.20 m as in the STD and DMT-RA procedures.

Among the intermediate parameters, only the profiles of the material index I_D and, to a lesser extent, the dilatometer modulus E_D, i.e. the parameters depending on the difference ($p_1 - p_0$), show some inconsistency between the values obtained by different test procedures. In particular, the values of I_D calculated from p_0 and p_1 data acquired by the DMTA-WP procedure appear significantly lower than the I_D values provided by the STD and the DMT-RA procedures. This discrepancy could be due to the fact that in the DMTA-WP procedure the *A*-pressure is measured at $t = 0$ instead of $t = 15$ s, resulting in lower values of the difference ($p_1 - p_0$), and for low I_D values such incongruity is amplified by the logarithmic scale. The above issue requires additional insight.

4 CONCLUSIONS

The Medusa DMT is a self-contained, fully automated cableless probe able to autonomously perform dilatometer tests using a blade of standard dimensions. The pressurization is applied using a hydraulic motorized syringe which actuates a volume controlled expansion of the membrane. This procedure is highly repeatable, operator-independent and capable to impose a programmable pressurization rate for achieving the DMT *A*, *B*, *C* pressure readings. The motorized syringe, controlled by the electronic board, is also able to maintain the membrane in equilibrium with negligible displacement, allowing to measure (virtually continuously) the total horizontal pressure of the soil against the membrane. This capability has permitted to implement alternative test procedures (Repeated *A*-readings, *A*-reading while penetrating), besides the 'standard' procedure, which differ essentially for the technique adopted for measuring the *A*-pressure.

The increased accuracy of pressure measurements and controlled pressurization rate provided by the Medusa DMT makes this instrument particularly useful for testing very soft soils, in which the measured pressures are typically very small.

The comparison of results obtained by Medusa DMT adopting different test procedures and by traditional pneumatic DMT at the benchmark soft clay test site of Fucino-Telespazio, presented in this paper, indicate a substantial consistency of measurements provided by all test procedures. In fact, the profiles of p_0 obtained by Medusa DMT using the three different test procedures (STD, DMT-RA, DMTA-WP) are very similar, despite the different techniques adopted for measuring the *A*-pressure, and in good agreement with the profile of p_0 obtained by traditional DMT. Also, the profiles of p_1 and p_2 obtained by Medusa DMT (all test procedures) and traditional DMT are nearly coincident. Further experimental validation in different soil types is needed to generalize the above findings, also in view of future standardization.

5 ACKNOWLEDGEMENTS

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