Medusa DMT for automated Dilatometer testing – a major advance in geotechnical in situ testing

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ABSTRACT: The Medusa DMT is a fully automated flat dilatometer of recent development (2018). A DMT blade of standard dimensions is combined with a motorized hydraulic syringe for generating the required source pressure within the probe. An electronic board, powered by rechargeable batteries, activates the motorized syringe and records the DMT field readings using a pressure transducer. The generation and measurement of the pressure at depth significantly improves the accuracy and repeatability of the test results compared to the standard DMT equipment employing a pneumatic cable. Although the probe could operate as cableless, an electric cable is generally employed for control on all the available parameters and for accessing real time test results. The paper describes in detail the new instrumentation and the corresponding test procedures. Comparisons of results are shown with measurements obtained from the traditional flat dilatometer and also with the CPT results in Australian territory.

KEYWORDS: Medusa DMT, automated dilatometer, flat dilatometer, in situ testing.

1 INTRODUCTION TO DILATOMETER TESTING

The flat dilatometer (DMT) is an in situ testing technology developed by Prof. Silvano Marchetti in the late '70s (Marchetti 1980). The instrument is currently employed in over 80 countries for site investigations to estimate soil parameters required in engineering design and applications. The test is coded in the ASTM (ASTM D6635-15), Eurocode (EN 1997-2:2007) and ISO (ISO 22476-11:2017(E)) standards.

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 total horizontal pressure of the soil. In the standard pneumatic configuration, the blade is connected to an electropneumatic cable running through the penetration rods, up to the DMT 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.

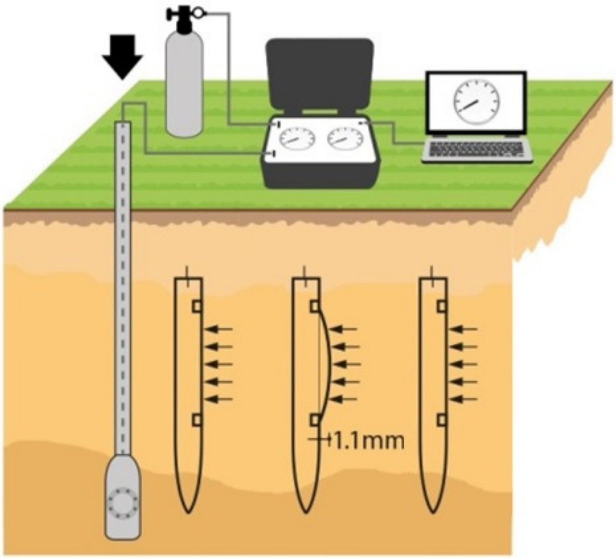

Figure 1. DM T test layout.

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 advancing the dilatometer blade 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 in 15 s ± 5 s after reaching the test depth and the B-pressure reading in additional 15 s ± 5 s after the A-reading.

2 MEDUSA DMT TESTING EQUIPMENT

The Medusa DMT is the combination of a flat dilatometer blade of standard dimensions with a hydraulic motorized syringe to autonomously carrying out DMT tests (Marchetti 2018). Figure 2 shows the main components of the instrument. An electronic board, powered by a rechargeable battery pack, drives a custom designed motorized syringe. The DMT membrane contact status is acquired by the electronic board and the pressure is measured using a pressure transducer. The built in algorithm coded in the electronics activates the motorized syringe for generating the pressure required to obtain the standard DMT A, B and C readings. Currently, the maximum pressure operated by the instrument is 25 MPa.

The Medusa DMT may also operate as cableless storing the DMT test results in a non-volatile memory. The data may then be downloaded at the end of the test, when the probe is retrieved (Marchetti 2019). More often the instrument is employed using an electric cable, running from a computer laptop at ground surface down to the probe at depth. In this configuration, the operator has full control on when to start the DMT measurements and may access all the system parameters, such as the battery status, the voltage and current provided to the engine, the position of the piston of the motorized syringe, the probe inclination and other additional information available real time. The standard DMT parameters, in particular the current pressure and membrane contact status, are displayed real time during the measurement as for the traditional DMT pneumatic technology.

In 2020 the Medusa DMT was enhanced with seismic receivers to enable shear wave velocity measurements. The new probe was named Medusa SDMT.

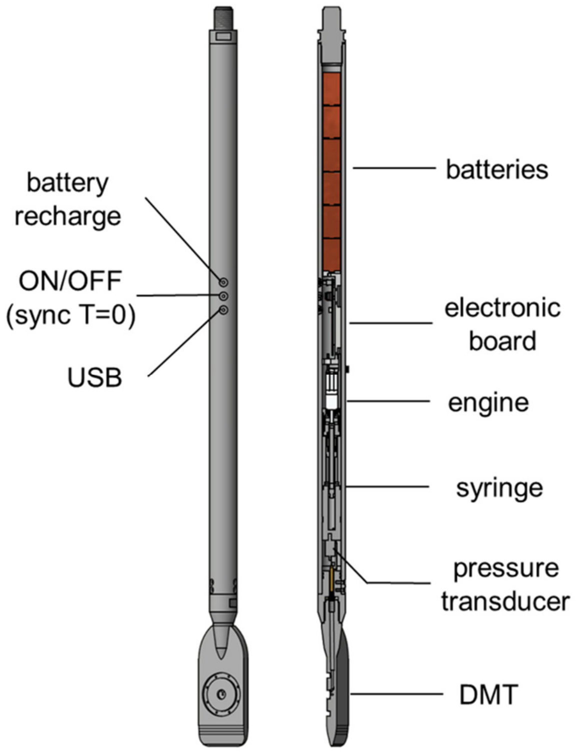

Figure 2. Medusa DMT components

3 MEDUSA DMT TEST PROCEDURES

The current DMT international 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 with the traditional DMT equipment. The reason of such indications are related to the gas compressibility, inherent in the traditional pneumatic DMT equipment.

The hydraulic pressurization of the motorized syringe inside the Medusa DMT performs a volume controlled expansion of the membrane, which enables to accurately program the time rate for executing the DMT test cycle. This feature allows to perform dilatometer tests with the exact recommended timing suggested in the international standards.

The Medusa DMT is able to monitor the total horizontal pressure of the soil with time after blade insertion. The motorized syringe, driven by the electronic board, applies small fine pressure adjustments to maintain the membrane in equilibrium with the total horizontal pressure of the soil against the membrane. This feature is employed to implement standard DMT-A dissipation tests which, as with the standard pneumatic equipment, provides an estimation of the consolidation and permeability coefficients (Totani et al). Compared to the traditional pneumatic equipment, a continuous high resolution dissipation curve is obtained, autonomously performed by the motorized syringe without requiring a human operator inflating and deflating gas.

The Medusa DMT is basically an automation operating on a blade of standard dimensions. Several publications have documented excellent agreement between results from standard pneumatic equipment and from the new automated device [Monaco et al 2020]. Thus, the standard Marchetti 1980 DMT formulae apply on Medusa DMT results and no additional correlations nor corrections of correlations are required for interpretation.

In addition to the standard test procedure for the traditional DMT, the Medusa DMT enables additional test procedures that are not possible employing the pneumatic equipment and that are totally new.

Let us define $A_{t=x}$ an A reading taken with the DMT at x seconds after the blade has penetrated to the corresponding test depth. The standard DMT test procedure provides $A_{t=15\pm5}$, where the A reading is taken 15 seconds after penetration stopped and the blade is at the test depth, with a tolerance of ± 5 s. Using the Medusa DMT, the tolerance may be negligible an the ideal $A_{t=15}$ indicated in the standard is obtained.

A first alternative procedure is named DMT-RA (DMT Repeated A-readings), which consists in a dissipation test before expanding the membrane to B and eventually a C-reading. If the dissipation test is of only 15 seconds, the test procedure is very similar to the standard DMT procedure. However, instead of only a single A reading taken at 15 seconds after the blade arrived at the test depth ($A_{t=15}$), this new procedure, possible only using the motorized syringe of the Medusa DMT, records several subsequent A-readings ($A_{t=1}$, $A_{t=2}$.. $A_{t=15}$) before expanding the membrane for the B reading and then eventually recording the C-reading. The rapidity of the motorized syringe provides many A-readings that define a trend through a dissipation curve. The total duration of the dissipation may be fixed and pre-programmed or activated manually by the user during the repeated acquired A-readings. Published comparisons have shown that $A_{t=15}$ reading obtained from the standard test procedure compares well with the $A_{t=15}$ reading using a DMT-RA procedure. However, the DMT-RA procedure with dissipation time t=15 is equivalent to the standard DMT test procedure enhanced with a short dissipation curve in the first 15 seconds before membrane expansion.

Several research groups have employed this procedure in partially drained geomaterials, such as silts and mine tailings deposits, indicating that it is helpful to improve soil parameter interpretation (Monaco et al 2020).

A second test procedure, very recently proposed and not yet sufficiently experimented, is named DMT-WP (DMT While Penetrating). The test is performed similarly to a CPT, with a standard penetration rate of the blade, generally 2 cm/s, or also with higher or lower penetration velocity. As in a dissipation test, the membrane is maintained in equilibrium with the soil pressure, measuring the total horizontal stress during the penetration of the blade. The obtained A-readings are all $A_{t=0}$, since they are taken at the instant at which the blade is at the corresponding test depth. Such measurements are fully undrained, as they are taken instantly at each test depth, without allowing the water to dissipate. As expected, preliminary results have shown that the $A_{t=15}$ readings taken with the standard procedure and the $A_{t=0}$ taken with the DMT-RA procedure are very similar in fine-grained materials such as clays, because the test is fully undrained for both procedures. Presumably, the readings of the two procedures should be in good agreement also in coarse-grained sediments, such as sands, where the test is fully drained. However, in partially drained geomaterials, such as silts, the A-reading may differ significantly employing the two different test procedures. The reason is that $A_{t=15}$ of the standard DMT procedure will be lower than $A_{t=0}$, due to the decrease of pressure caused by water dissipation. Current research projects are looking into the time dependency of A-readings to examine if it may improve the interpretation of soil parameters in partially drained geomaterials, which both DMT and CPT standard procedures tend to underestimate.

4 RESULTS IN AUSTRALIA

Standard pneumatic DMT has been in use in Australia for almost 20 years and has become a well-accepted tool in geotechnical site investigation. Some testing companies have had training direct from Studio Marchetti.

The supporting author's company Insitu Geotech Services (IGS) has been one of the leaders in this. They own and operate several standard DMT kits on a daily routine basis.

They have for the past year also been operating a Medusa system and more recently a Seismic Medusa and have now had experience that distinguishes this evolved automated Dilatometer in a very positive way compared to the standard DMT.

The differences in design and operation are described well in the foregoing, so are not re-described here. What is described here is the enhanced sensitivity and capability of the equipment, making it a very capable tool for use in testing soft and very soft soils (as well as the firmer and denser soils that have traditionally proved so testable using standard DMT).

Repeatability and sensitivity in soft and very soft materials is greatly enhanced by the Medusa as the test is no longer dependent on "operator dexterity", being now fully automated.

Until the Medusa evolved, IGS did not prefer DMT as a tool of choice in soft and very soft soils, due to data scatter associated with the operators (even though well trained). The Medusa is now a tool of choice in such materials, including mine tailings, and has proven to be as meaningful and reliable in such soils as CPTu and Vane Shear, and of course providing significantly additional and different data to those named other tests.

The best way to demonstrate is to compare a single parameter, estimated shear strength, one test to another, as is shown in the Figures 3 and 4 that follow.

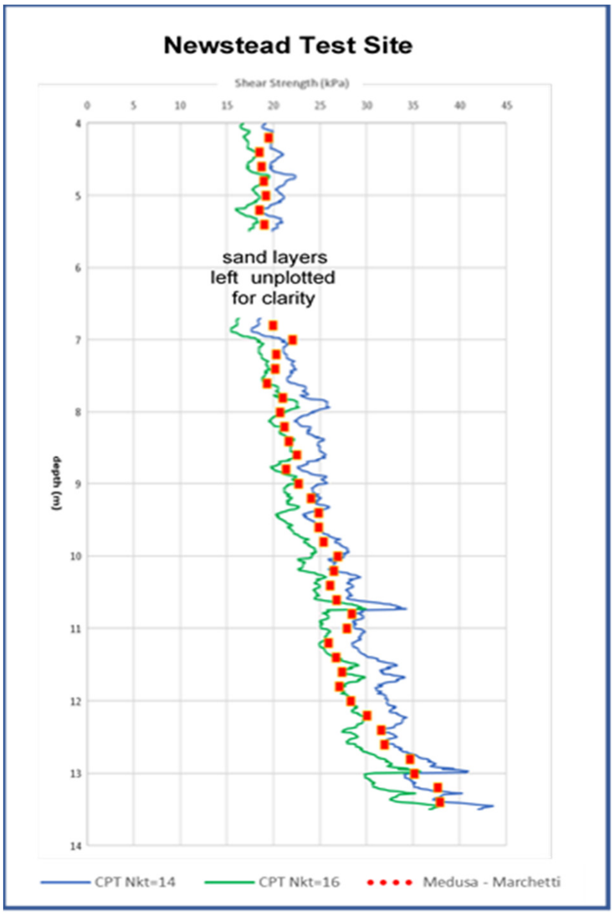

Figure 3. Comparative test data from Newstead on-land site

Figure 3 compares Medusa derived undrained shear strength to CPTu derived undrained shear strength in soft to firm clays on a test site in the suburb of Newstead in Brisbane.

These tests were made in soft to firm alluvial clays that from experience on many site investigations would be expected to exhibit N_{kt} in the range 14-16, the range used to prepare the plot in Figure 3.

This plot in Figure 3 clearly shows that the Medusa DMT in those conditions has provided an estimate of undrained shear strength equally well as estimates made from CPTu.

The second example, shown in Figure 4 is from testing in a marine environment, approximately 17m water depth, in clay soils that are all in the very soft to soft strength range. This example has two additional characteristics making it worthwhile as a comparison: (i) the CPTu testing was made using an extremely well calibrated super-sensitive 3MPa Geomil cone (McConnell 2022), ensuring that the CPT data was the best achievable in these very weak soils; (ii) Vane Shear Testing was also done, using a carefully calibrated A.P. van den Berg vane shear system with motor drive and torque sensing "at the bottom", ensuring again, the best data reasonably possible.

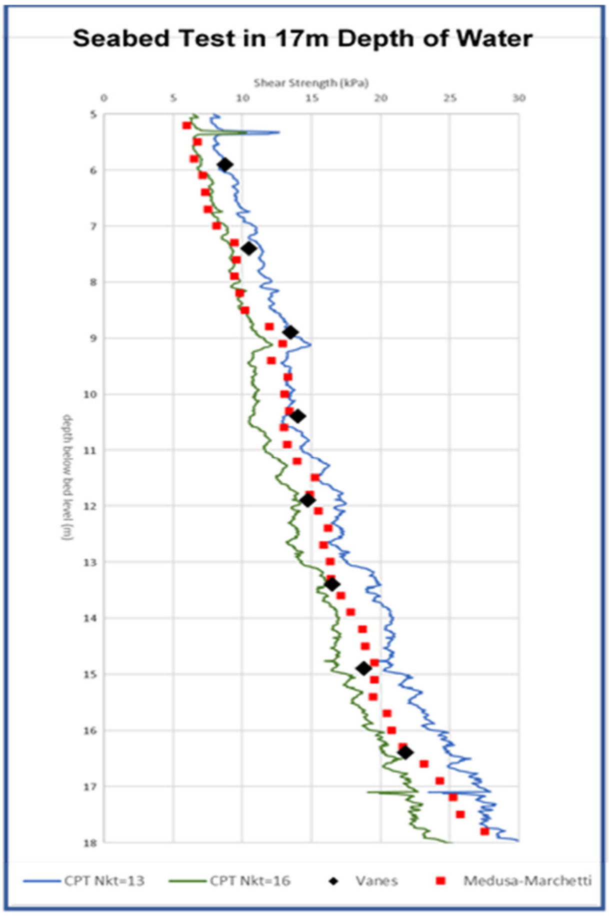

Figure 4. Comparative test data from over-water site

On this occasion a site-specific N_{kt} range of 13-16 was defined by the comparison of CPTu and Vane Shear data.

It is clear that the Medusa DMT provided data of the same level of sensitivity as the Vane Shear, and arguably it may have been more reliable than CPTu profiling using N_{kt}. The Vane Shear data is almost identical to the estimates made by Medusa.

In Section 3 of this paper (and reiterated for expedience here), it is described how the Medusa DMT is able to monitor the total horizontal pressure of the soil with time after blade insertion. The motorized syringe, driven by the electronic board, applies small fine pressure adjustments to maintain the membrane in equilibrium with the total horizontal pressure of the soil against the membrane. This feature is employed to implement standard DMT-A dissipation tests which, as with the traditional pneumatic equipment, will provide an estimation of consolidation and permeability coefficients (Totani et al).

Using the traditional pneumatic DMT equipment for this purpose however, requires a human operator to inflate and deflate the diaphragm over and again manually, making meaningful long-term dissipation tests more-or-less impractical in a commercial environment. Using the now-automated Medusa DMT this is simply a matter of choice. IGS has recently commenced using the Medusa for tests in ground that is "difficult" by CPTu and also to check dissipation tests made by the traditional CPTu method. The result of one IGS test is shown below, a test run over a period of approximately 18 hours.

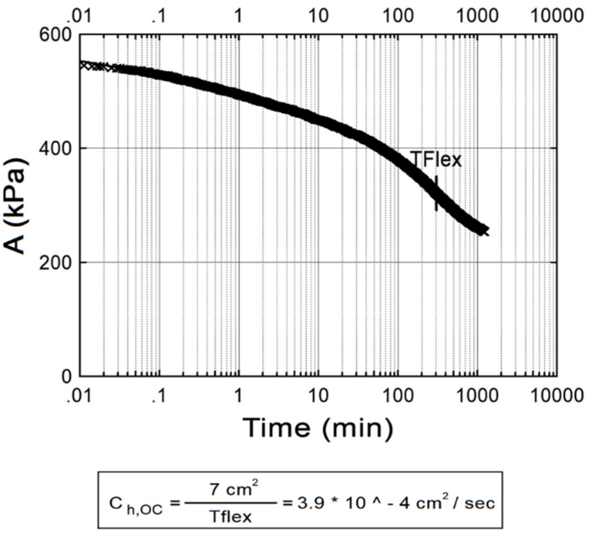

Figure 5. DMT dissipation test run over approximately 18 hours

This particular test is compared to adjacent CPTu dissipations using both U_1 and U2 filter positions, in a paper by Kelly et al in Sydney 2022.

5 CONCLUSIONS

A recently developed fully automated version of the Flat Dilatometer was described in detail. The new device may operate with the same standard test procedure of the traditional pneumatic DMT, using an automated motorized syringe for pressurizing the membrane. Additional test procedures have been described, in particular for implementing higher resolution dissipation tests and for attempting a fully undrained test during blade penetration.

Australian experience confirms benefits of the Medusa DMT compared to the traditional pneumatic device, and also confirms this new tool's efficacy in very soft to soft soils (as well as in stiffer soils as per the traditional DMT).

6 ACKNOWLEDGEMENTS

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