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New portable pressiocone system for carrying out CPT+FDP tests.

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ABSTRACT

Geotechnical investigations in the subsoil of existing buildings have always been challenging due to limited space and difficult access. URETEK has developed a portable integrated system for simultaneously carrying out a CPT and a pressumeter test with Full Displacement Pressuremeter (FDP). The 30 kN thrust penetrometer to be used is very small. The reaction is given by two “microanchors”. The cone is a standard 10 cm^2 digital memory cone (no cable), capable of measuring q_c, f_s, u every centimetre. Above the cone there is the FDP equipment with a rubber sheath covered by steel plates and connected, by a tube filled with water, to a device for creating pressure to inflate the sheath and measure pressure-volume curves as in a standard pressumeter test. The pressure-volume device and the depth transducer are connected to a microcomputer that is programmed to carry out CPT+FDP tests in an easy-to-use/user-friendly way.

Keywords: CPTU, Pressuremeter, static penetrometer, Full Displacement Pressuremeter, Portable Equipment, Resin Injection

1. Introduction

The recovery of existing buildings is the key to building development in Western Europe. Among the various sectors, geotechnics has seen the birth and development of new technologies capable of restoring the mechanical characteristics of the soil of existing foundations with a minimum impact. Injections of expanding resins represent an example of this. It is a technology that can be done in structures in operation by applying a simple and non-invasive process (Dei Svaldi et Al. 2005)

The subsequent phase of verification and control of the effectiveness of the injection intervention is carried out by in situ geotechnical tests performed with small portable lightweight equipment, capable of operating in narrow and confined spaces.

For the verification of the improvement of the ground following the injection of resins, has been used mostly a small portable penetrometer, called 30-20 (Cestari, 2013) consisting of a falling weight of 0.3 kN which is dropped from a height of 20 cm onto the axis of a battery of rods with a conical tip screwed to the bottom. The vertical fall of the mass makes the cone penetrate the ground for a certain depth. The specific energy per driving stroke is equal to 60 kJ/ m^2 and the number of strokes required for the penetration of 10 cm represents the “resistance” of the ground. Dynamic tests 30-20 are mainly used for a comparison between the cone resistance of the natural soil and the treated soil. According to the current literature only in particular cases (clean sands), the measured values (number of strokes) can be correlated to the geotechnical parameters of resistance and deformability.

The success of the consolidation technique with expanding resins, the publication of the design guide and the dissemination of dedicated software have created the increasing need for more precise information on the geotechnical parameters of the treated soils (Manassero et Al.2014). For this reason, the R&D sector of Uretek, a multinational company operating in the consolidation sector with injections of expanding resins, is involved in the construction of a light and easy-to-use instrument capable of detecting directly with the due accuracy the resistance and deformability of the treated soil.

2. General outline of the equipment

Dynamic tests (especially the ones with low energy, like the above mentioned 30-20) are considered reliable only in certain contexts (clean sands or granular soils); therefore, it was decided to design equipment for static tests instead than dynamic, with piezocone CPTU or electrical cone CPTE.

In fact, for the CPTU/CPTE are available many correlations that allow to reliably calculate the geotechnical parameters of the subsoil (Cestari F. 2013).

However, the CPTU / CPTE are not deformative tests, but the resistance is measured breaking and displacing the soil, meaning that geotechnical parameters are obtained in an empirical/semi-empirical way and therefore do not give (if not indirectly) parameters related to the deformation and/or the stress history of the subsoil (Robertson 2009, Robertson, Cabal 2012).

For this reason, it was chosen from the beginning to couple an FDP (Full Displacement Pressuremeter) to the CPTU, so that the penetrometric and pressuremeter data could complement each other and provide a more complete picture of the geotechnical characteristics of the subsoil (Yu et Al., 1996, Briaud, 1992, Briaud et Al. 1979, Cosentino 2018, Amar et. Al. 1991, Robertson et Al.1983).

The pressuremeter is an instrument that, in the standard version with large diameter (60 mm), would require the careful execution of a pre-hole, but at this stage it was decided not to design a rotary drilling machine (albeit of small dimensions) as it would not adhere to the initial targets: portability, low or no impact, speed and ease of use even for operators who are not experienced in drilling and pressuremeter testing. There are few small diameter (36 or 44 mm) FDP systems available on the market, none of which are integrated with a CPTU / CPTE system. All the equipment used so far has been customized (P.E. Failmezger et 2005, A. Drevininkas 2017).

The combination of CPT (Cone Penetration Test) and PRESSUREMETER (hence the name PRESSIOCONE) requires to be used with a static penetrometer. The penetrometers that are on the market, although some models are small, are not very suitable for working in contexts where we would like to operate.

Some commercial models are small and can be disassembled with an external power unit but require a considerable effort for setup before each test, being equipment that are not produced in large series they are also relatively expensive.

Furthermore, all the small penetrometers on the market are anchored with augers for the reaction to the thrust, which is almost never feasible in the contexts of confined spaces inside existing buildings.

For these reasons we have opted for the design of a "custom" penetrometer that meets the basic requirements of ease of use, portability, electrical operation, reduced height, anchoring without augers, with a thrust of at least 30 kN and standard driving speed. of 2 cm / s interval.

3. FEATURES OF THE DIGITAL PIEZOCONE

Although there are cones of reduced diameter (5 cm^2 with a diameter of 2.6 cm) we chose to develop a standard cone with an area of 10 cm^2 and a diameter of 3.6 cm, to have more space for digital electronics and especially for having no problems in interpreting the data (the 10 cm^2 cones are the most widely used and the correlations are robust). In order not to have problems related to the management of the cable, given that the passage through the rods would interfere with the FDP pressuremeter tube, creating many problems on site, it was decided to design a custom system with memory.

The cone responds to the most recent standards and allows the measurement of q_c, f_s, u; the design of the cone and electronics leaves the possibility of making a CPTE cone with only the q_c and f_s or a cone equipped with additional sensors (for instance inclinometers, seismic, resistivity, thermal, etc.).

The cone is designed for extremely easy maintenance, with the tip, filter and sleeve that can be removed and maintained on site.

The filter for the u can be either in sintered metal saturated with deaerated silicone oil or slotted (slot filter) saturated with silicone grease.

Figure 1. Digital piezocone with memory and rechargeable NiMh battery

The cone electronics are structured as follows:

-high resolution analogic to digital circuit (24 bits)

- programmable microprocessor

- large memory capacity and expandable

-high-capacity and small in length rechargeable NiMh battery (60 hours of power before recharge)

A great effort was directed to optimize the power consumption of electronics, for limiting the dimensions of the piezocone (in length), the total length of the piezocone being comparable to most cones without memory. It has been designed to be used (eventually) also with cable, transmitting digital signal.

The test procedures with the memory cone are:

a) preparation of the cone and connection with a computer, tablet or data logger, which is connected to the encoder depth transducer.
b) synchronization of the cone and datalogger and definition of the time T = 0; starting from T = 0 the cone starts storing all the values of Qc, Fs, U as a function of time (scanning every second or half second) and the data logger the values of depth as a function of time (data logger is connected to the depth transducer)
c) execution of the test
d) recovery of the cone
e) downloading data from the cone and from the datalogger, at this point there are two data matrices, one coming from the cone with all the data as a function of time only, one coming from the datalogger with depth as a function of time.
f) synchronization of the matrices: the matrices are automatically synchronized allowing to have the penetrometric data vs. depth (not only vs. time, with exception of the eventual dissipation tests).

4. FEATURES OF FULL DISPLACEMENT PRESSUREMETER (FDP)

The FDP (Full Displacement) Pressuremeter is made of a special rubber sheath coated with six shaped steel plates and mounted on a cylindrical body which has an attachment for the piezocone in the lower part and an attachment for the penetrometer rods in the upper part. The steel lamellae can slide up and down at both ends so to follow the expansion of the sheath.

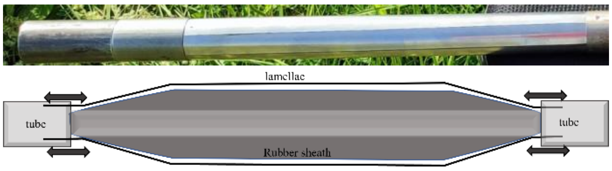


Figure 2. Lamellae covering the sheath of full displacement pressuremeter.

The length of the sheath and the lamellae is 34 cm, the diameter of the sheath (including the lamellae) is 34 mm, with an internal volume of around 200 cm^3 (not inflated), see figure 2. The pressure gauge, unlike the others on the market, has been designed to be inflated with water instead of nitrogen.

The water, in this prototype, emulsified with oil, is pressurized through a "Rilsan" plastic tube that is placed through the rods; however, we plan to use special sealed rods to avoid using the internal tubing and pressurize directly through the rods.

The sheath is pressurized by a system essentially consisting of a cylinder and a piston which will be driven (in the final version) by a worm screw connected to an electric stepping motor, digitally controlled by the programmed data logger.

Each revolution of the motor corresponds to a movement of the piston and therefore a certain volume, measured with great accuracy.

In the cylinder there is a digital pressure cell connected to the data logger (same device that manages the cone). However, the preliminary trial tests (carried out for designing the pressuremeter) have been carried out with a manometer using a preliminary version of the system, not yet automatized and with a manually driven piston and a manometer for measuring the pressure.

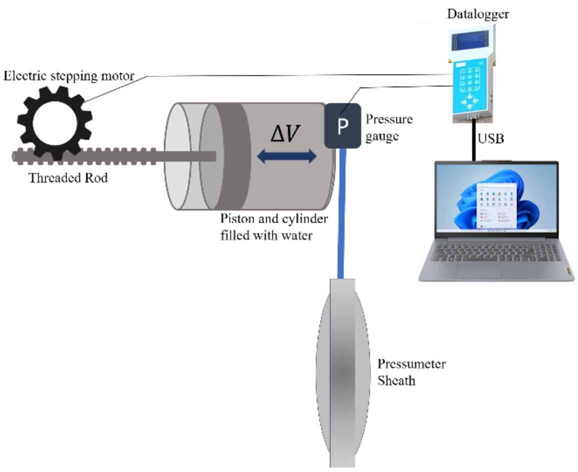


Figure 3. Diagram of the pressuremeter system

Figure 4. manual pressurization System and manometer (first prototype)

Figure 5. Second prototype of pressurization system

The datalogger is programmed not only to manage the test manually, but also to automatically perform some pressuremeter test “sequences”. Each sequence contains a certain number of steps which define time, volume, pressure. In this way it is possible (for instance) to set a preset for a certain automatic sequence for a certain type of soil or to memorize a manual sequence of a test in progress.

This procedure ensures maximum operational flexibility, ease of use even for Users with little or no experience in pressuremeter testing and the possibility to manage tests remotely.

5. FEATURES OF THE PENETROMETER

The most important feature of the new type of penetrometer, which distinguishes it from all models on the market, will be the anchoring, in relation to the operational context in which the tests will be performed. In fact, the pressiocone tests will be carried out mainly under the existing foundations, mostly inside buildings, in the not treated soils first and after in treated soils with resins; therefore, it would be impossible to anchor with augers or use ballasted penetrometers.

For this reason, the penetrometer is anchored with two Microanchors (URETEK, 2017), being small tie rods placed in the foundations after execution of a small hole (26 mm diameter) and fixed with expanding resins; numerous tests have confirmed that two anchors are more than sufficient for a thrust of 30 ÷ 50 kN (which is the maximum thrust obtainable with the penetrometer).

The smallest penetrometer, used for trial tests, is a custom one, with double action pistons and a double clamping system for the rods. The automatic clamping system allows to leave the upper hole of the rods free, to be able to manage the tube without problems.

The penetrometer is powered by a hydraulic control unit that runs on electricity, eliminating pollution due to the use of internal combustion engines.

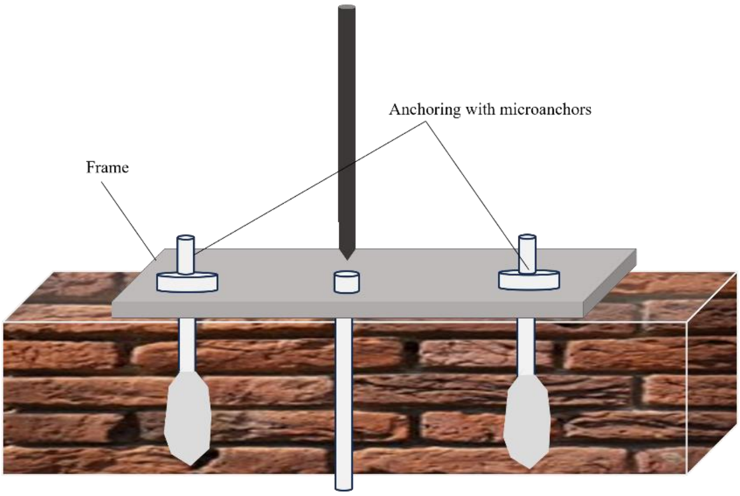


Figure 6. Setup of the penetrometer

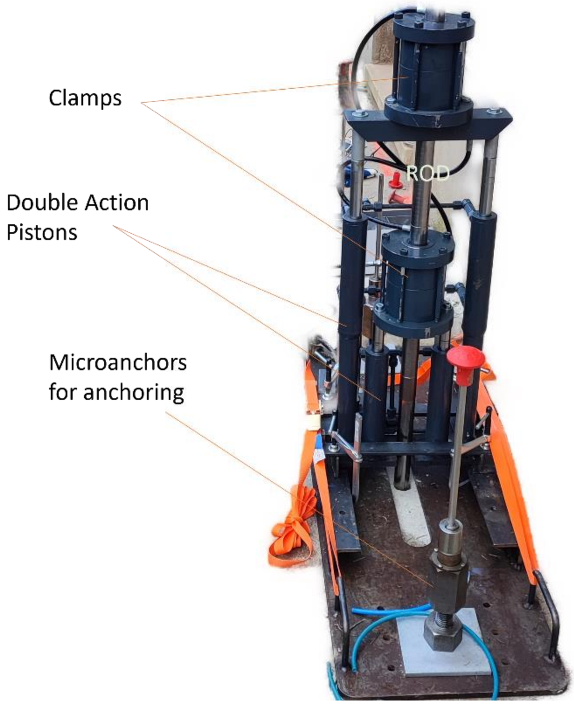


Figure 7. Prototype of the penetrometer

6. TRIAL TESTS

At present we have carried out some preliminary trial tests, for testing separately the piezocone, the FDP pressuremeter with different types of sheaths and lamellae and the penetrometer; finally, we tested all equipment together.

The first field tests have been carried out during summer 2021 in a site (San Felice Extra, north of Verona, North Italy) where the stratigraphy is gravel and small cobbles embedded in stiff silty clay, as shown in the following graph.4).

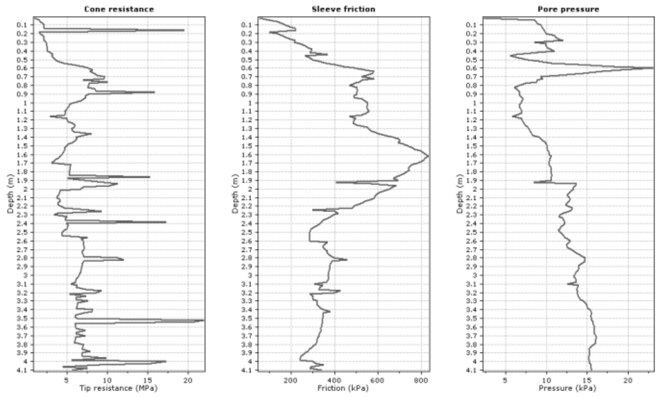


Figure 8. qc, fs, U graph (first test)

The groundwater table in that area is deeper than the maximum depth reached with the tests, (around -4 m) so the U seems not to be significant.

Before starting the test, a very careful saturation of the system (pressuremeter, Rilsan tube, manual pump) has been made with water (emulsified with oil), not to leave any air bubble in the circuit.

The pressiometric tests have been carried out every meter starting from -1.0 ÷ -1.5 stopping the pushing of the rods and making the sheath expand up to the double of the initial volume, sometimes with loops, measuring pressure vs. volume at times T=0 (immediately after expansion) and T=180 s (180 seconds after).

An example of a pressuremeter test graph carried out at -2.5 m is shown below, the two curves show the V-P values at time T = 0 and T = 180 s

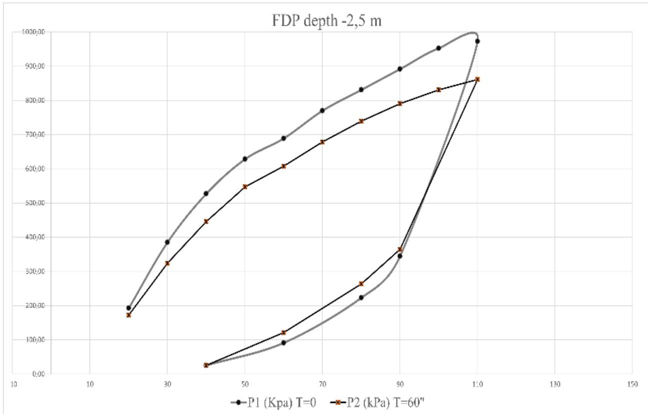


Figure 9. V-P (volume-pressure) graphs at time T = 0 and T = 180 s (first trial)

The last field tests have been carried out in December 2023 in Vicenza on a site where resin injections were carried out in the foundation soil of a condominium (whose original structure dates to the fourteenth century), with the aim of consolidating the layers immediately under the foundation, washed away and softened by a large loss of water and at the same time improve the seismic behaviour of the structure.

On this site, located on a slope, the soil is predominantly silty and clayey, but with different characteristics depending on the location; groundwater was found at -5.6 m, near the top of bedrock; below is represented a geotechnical section.

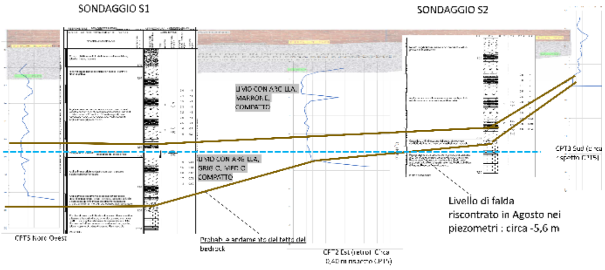


Figure 10. Geotechnical section of the site

Before the injection of resins, an exhaustive campaign of site and laboratory investigations was carried out to determine the causes of the noticeable failures and cracks observed in the building and to design the resin improvement intervention. To evaluate whether the slope on which the building is located had horizontal movements, inclinometers and piezometers were installed, along with crackmeters in some points of the building and monitoring of relative movements.

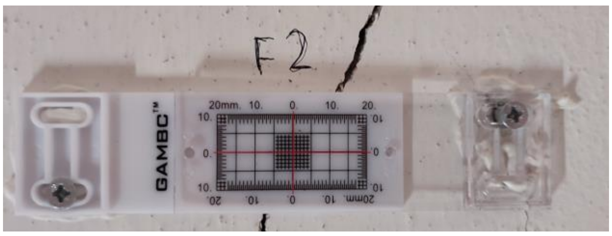


Figure 11. Crack-meter.

After that, after the completion of the work of resin injection, some locations close to the building have been equipped with a triplet of microanchors, exploiting the central anchor for having a couple of holes in which carry out the pressiocone testing.

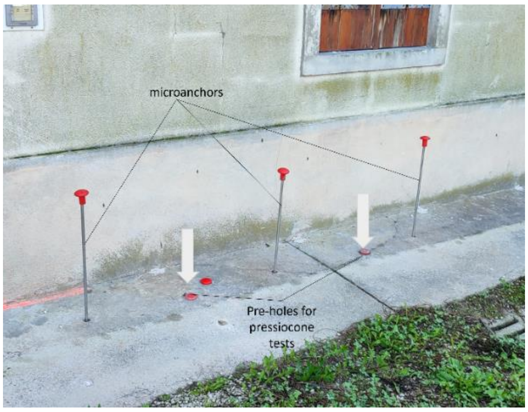


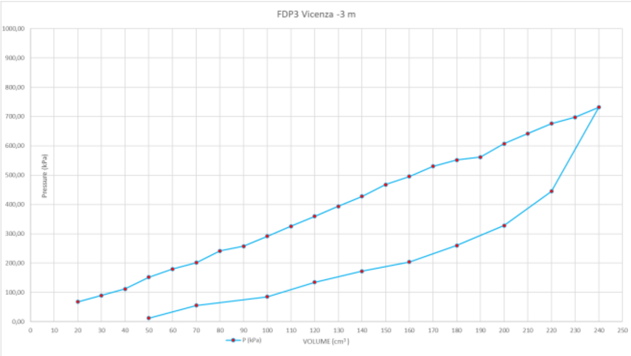
Figure 12. Preparation of anchors and pre-holes for the penetrometer

Additionally, have been carried out dynamic penetration tests before and after the resin injection as per URETEK' protocol.

Figure 13. Pressiocone testing

This job is still in progress at the present date (8th February 8, 2024); in December 2023 during the first tests small inconveniences occurred which prevented the execution of all the planned tests (five in total). Over the next weeks the work will be completed, coupling the results of the pressiocone with those of the monitoring and preliminary investigations. Below is the result of a pressuremeter test performed at a depth of 3 meters.

Figure 14. Results of pressiometric test at depth -3 m



7. Conclusions

The first results were very encouraging, and all parts of the instrumentation worked properly. Thus, the guidelines for the future development of the instrumentation and for the definition of the test execution procedures were completely outlined: anchoring, preparation, calibration of the piezocone and of the FDP, programming of the FDP test sequences.

This first phase will be followed in a very short time by further comparative validation tests in which tests will be carried out (first in "natural" soils and then in soils treated with resins) with the pressiocone and, at a short distance, comparative tests with standard instrumentation (boreholes with sampling and laboratory tests, with execution of standard pressuremeter tests, SPT, Vane Test, execution of CPTU and DMT dilatometric tests).

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References

Manassero, Dominijanni, 2014 *Consolidamento dei terreni con resine espandenti – Guida alla progettazione* – McGraw-Hill Education.

Robertson, P.K., Cabal K.L., 2012 *Guide to Cone Penetration Testing for Geotechnical Engineering*, Gregg Drilling & Testing, Inc., 5th Edition,

Robertson, P.K., 2009 *Interpretation of Cone Penetration Tests - a unified approach*., Can. Geotech. J. 46(11): 1337–1355

A.Drevininkas, M. Manzari, 2017, *Evaluation of Full Displacement Pressuremeter for Geotechnical Investigation in Southern Ontario*, Proceedings GEO OTTAWA 2017

H.S.Yu, F.Schnaid, I.F.Collins. 1996 *Analysis of Cone Pressuremeter Tests in sands*. Journal Of geotechnical Engineering. Vol.122 Issue 8

Briaud, J.L.,Shields, D.H.,1979, *A Special Pressuremeter and Pressuremeter Test for Pavement Evaluation and Design*, Geotechnical Testing Journal, ASTM 2:3

Briaud, J. L. 1992. *The Pressuremeter*. Taylor & Francis Group plc, London, UK.

Failmezger, P.E. 2005. *Development of a Robust Push-In Pressuremeter*. Symposium International ISP5/PRESSIO 2005, Ponts & Chaussees, France

Dei Svaldi, A. Favaretti, M. Pasquetto, A. & Vinco, G.2005. *Analytical modelling of the soil improvement by injections of high expansion pressure resin. 6th International Conference on Ground Improvement Techniques*; Congress proceedings, Coimbra, 18-19 July 2005: 577-584

F. Cestari 2013 *Prove Geotecniche in Situ* Flaccovio Editore

P. Cosentino, A. Shaban, A.Boggs 2018. *Predicting Bearing Ratios of Granular Soils Using Dynamic Cone Penetrometer and Modified PENCEL Pressuremeter Tests* Proceedings IFCEE 2018

Amar S. et. Al., 1991. *Utilisation des résultats des essais pressiométriques pour le dimensionnement des fondations en Europe, 1ére partie: Pressiomètre Ménard/Pressiomètre auto-foreur.* Rapport du Comité Technique Régional Européen n° 4 Pressiomètres, comitat Français de la Mécanique des Sols et des Fondations , Rotterdam: Balkema,

Robertson, P.K., Hughes, J.M.O., Campanella, R.G., and Sy, A.,1983. *Design of Laterally Loaded Displacement Piles Using a Driven Pressuremeter*. ASTM STP 835, Kansas City

URETEK, 2017 *Microanchors*, patent IT201800002456