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HyperPac 25 MPa fills the gap between the Ménard pressuremeter and the flexible dilatometer

L'HyperPac 25 MPa comble le vide entre le pressiomètre Ménard et le dilatomètre flexible

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ABSTRACT

The bore hole expansion test can be applied to any ground material, from the softer to the harder one, so as to obtain its stress-strain behavior in situ. The authors submit their research on equipment which permits to extend the use of the Ménard pressuremeter up to 25 MPa test pressure. They also give the first test diagrams towards this pressure in slightly fractured rocks.

RÉSUMÉ

L'essai d'expansion in situ d'une cavité cylindrique peut s'appliquer à tous les types de matériaux, des plus mous aux plus résistants, pour déterminer leurs propriétés mécaniques. Les auteurs présentent un appareil permettant d'étendre le domaine du pressiomètre Ménard jusqu'à des pressions d'essai de 25 MPa, ainsi que ses premières utilisations dans des roches peu fracturées.

Keywords: Pressuremeter, flexible dilatometer, rock moduli, rock limit pressure, hard soils.

Mots-clés: Pressiomètre, dilatomètre, modules des roches, pression limite des roches, sols raides.

1 INTRODUCTION.

In situ geotechnical borehole expansion tests on loose soils and soft rock were initially developed by Louis Ménard from 1955 onwards. Thus, various techniques were created to drill the hole and carry out the test and subsequent methods were proposed to obtain the best from the results in order to design all types of foundations and earth works. [1] [2]

Similarly in situ measurements of deformation in hard, slightly weathered rocks have been developed, such as the flexible dilatometer, also known as a rock dilatometer. However this equipment did not have the same influence on the history of rock mechanics as the pressuremeter had on geotechnical engineering.

Both the pressuremeter and the dilatometer have the same goal, namely the measurement of E-moduli in soil and rock by radial deformations

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but for very different mean strain and stress levels, since with a pressuremeter one tries to obtain a limit pressure of soils p_{LM} whereas with a dilatometer one wants to produce precise readings of very small deformations of rocks [3]. Finally the pressuremeter is easier to handle than the dilatometer.

2 SPECIFIC REQUIREMENTS FOR SOFT AND WEATHERED ROCK TESTS.

There has always been a gap between the readings obtained in soils by the pressuremeter and those taken in rocks by the dilatometer.

Although type A dilatometers are very precise, the extension of their displacement sensors is limited which considerably hampers their use in rocks that are too fractured or weathered, so that the calibration of the borehole cannot always be performed at the place where the test should have been carried out.

Although a progressive increase of the Ménard pressuremeter maximum testing pressure was reached throughout its history, it was not possible to match the range of pressures used in rocks by the dilatometer. With reference to the French Standard, and later the European and ISO Standards, its use is limited to 5 MPa [4] [5] and maximum allowable testing pressure, in ever greater demand, hardly exceeds 10MPa.

However, the increasing need to apply stresses both to the hardest soils and to the ground material ranging at the subjective borderline separating soils and rocks entails the application of pressuremeter probes and pressure-volume control units that can be used beyond 10 MPa. There is as yet little knowledge of the E_M moduli and limit pressures p_{LM} of weathered rocks or more generally of the behavior of these ground materials under radial expansion. Yet knowledge of these parameters are more and more needed in civil engineering as shown by the topic chosen at the 2011 Athens Conference.

3 BEYOND THE CONVENTIONAL LIMITS OF THE PRESSUREMETER.

Despite its name, the Ménard "pressuremeter", since its origins, has systematically used the energy of a gas under pressure to apply equal stress increments to the borehole wall through a water column permitting both the expansion of the probe and the record of the volumetric displacements. The present limitations are, on one hand, the maximum pressure of the industrial gas cylinders, that is 20 MPa, on the other hand the resistance of the probes designed to fit the standard fulfilment of 5 MPa. Design of the probe allows a safety margin well beyond 5 MPa, generally up to 10 MPa, which is twice as much, but probe use is restricted to exceptional cases, since the probe cover bursting risk will systematically increases when the probe expansion increases.

3.1 Beyond 10 MPa using a Ménard type pressuremeter with compressed gas.

There are examples that illustrate the use of the standard pressuremeter, at the end of the 60s, often at great depths, still with the current volumeter on which readings were copied manually. Ménard had then already worked out recommendations to use the pressuremeter in rock [6] [7]. Later, in the 90s, a new control unit was developed, called Geopress, which digitally registered readings:

- Bologna, Italy, 1986, granite, from 80 m to 190m, 7MPa test pressure
- Alise-Sainte-Reine, France, 1991, marl, less than 40m, 10 MPa test pressure
- Limoges, France, 2004, gneiss, less than 20m, 11 MPa test pressure

The tests mentioned above are represented in the following graphs.[2] (figures 1, 2 and 3).

[2] The graphs represent, on arithmetical scales:
- the pressuremeter curve, the volume being given on the vertical axis versus the pressure on the horizontal one,
- the creep curve, closer to the horizontal axis on the same graph, in terms of volume, , the volume scale being increased by a factor of 10 on the vertical axis,
- the various secant modulus value for a pressure range starting from the point [P1] to any pressure up to the creep pressure; its value is read on a secondary vertical axis on the right; its form, bell-shaped or regularly sloping, being a function of the hyperbolic law followed by the pressuremeter curve [8].

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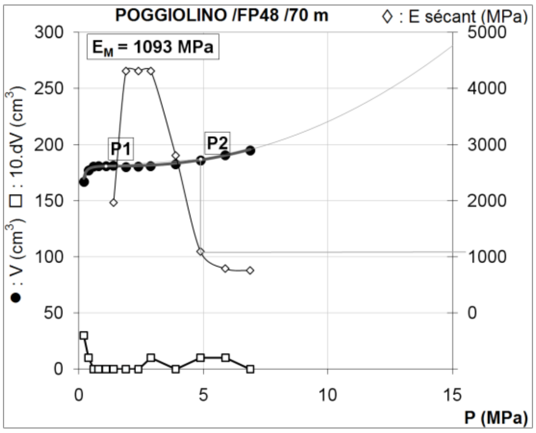

Figure 1. A high pressure test, Poggiolino, province of Bologna, 1986, Ménard pressuremeter type GA. PMT curve, creep curve and the bell-shape E_M curve are shown.

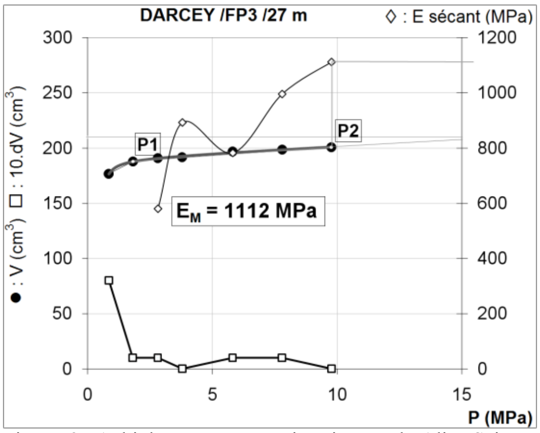

Figure 2. A high pressure test in Lias marl, Alise-Sainte-Reine, 1991, Geopress pressuremeter. E_M curve is rather irregular.

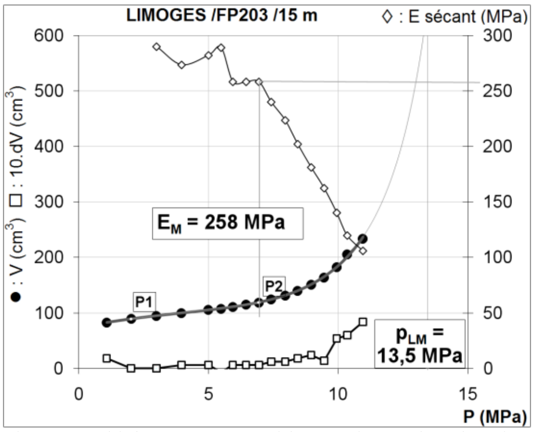

Figure 3. A high pressure test with creep in weathered gneiss, Limoges, 2004, Geopress pressuremeter.

As soon as 1976 an internal report by the French Research Centre for Coal Mines -- CERCHAR / Houillères du Bassin de Lorraine - described tests up to 90 MPa using the prototype of a Ménard pressuremeter control unit of 1000 bars, connected to a probe that had retractable end-pieces [9] [10]. This pressuremeter, recently put back in use by Eurasol Geotechnical Consulting Engineers in Luxembourg, achieved a pressure of 36 MPa at which the original probe bursted [11]. Its practical as well as its technical reliability has been recently studied at the French LCPC [12].

Finally, R. Massonet, a French Consulting Engineer, submitted test results pushed up to 12 MPa, performed with a conventional Ménard pressuremeter control unit which was fitted with 16 MPa Bourdon gauges at full scale and which had reinforced cover sleeves with additional steel strips and fixing rings. The tests shown were performed in London's sands of Thanetian age. The author drew attention to the fragility of the control unit burette which is prone to break beyond 10 MPa.

Conclusions from these examples of Ménard pressuremeter tests carried out at very high pressure are as follows:

- In hard rocks which are slightly fractured and in which the creep pressure has not been reached during testing, and with a pressuremeter equipment in perfect condition , it is possible to complete 12 MPa tests relatively safely and without leakage. The standard pressuremeter probes, when carefully fitted either with a rubber cover in direct contact with the soil or with a slotted tube, can stand the pressure without risk for the cover to slip off its fixing rings in a well calibrated borehole, the wall of which deforms only slightly.
- If the soft soil shows creep pressures between 5 MPa and 12 MPa, it is more difficult to perform this type of test and there are fewer opportunities to complete them during a geotechnical investigation.

The few examples given above show that an altered rock can have the same behaviour during borehole expansion as a soil, with a hyperbolic shaped curve that can be extrapolated towards pressure limits from 12 MPa to 20 MPa.

- Despite these successful yet sporadic attempts throughout the history of the Ménard pressuremeter, Engineers and Contractors have shown little interest,

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either because of a lack of knowledge on the E_M modulus obtained by volumetric displacement readings during borehole deformations, or because of the more difficult task to reach a reliable p_{LM} limit pressure.

- However more and more users of pressuremeter test results wish to extend the range of applications of the pressuremeter. This is due, in particular, to the difficulty of finding an equivalent to the Ménard limit pressure on core samples; for example, compressive strength values on intact rock samples are not significant to characterize a rock mass because of the fracturing of the rock which is readily taken into account during a pressuremeter test.
- Control units with automatic recording of readings without visible burette, such as Geospad2 at Apageo, are available to-day; they are limited to a pressure of 15 to 18 MPa, a pressure beyond which the rapid tearing of standard probe covers and the vast output of gas volumes leads to a certain limitation of use.

3.2 The contribution of the automated pressuremeter (GeoPac) and its evolution in the 25 MPa version (HyperPac).

In this new generation pressuremeter (a paper about it will be published[3]) is included the supply of an automatic Ménard pressuremeter loading programme through a volumetric system fitted with a motor-driven piston. The movement of this piston is self controlled by an electronic regulator which back-analyses the generation of the pressuremeter curve and stabilises the standard pressure holds without the action of the operator. The pressuremeter is remotely piloted from a distance by a ruggedly built site computer, the Geobox.

The necessary implementation of a micrometric piston advancement has at once permitted this device

- to yield very precise volume readings during standard pressuremeter tests at 2.10^{-3} cm^3
- to precisely stabilise the pressure holds in the circuit of the readings (depending on the precision of the sensors used).

[3] G. Arsonnet, J.P. Baud, M. Gambin, W. Youssef, The self-controlled pressuremeter Géopac.

Industrial compressed gas (nitrogen) is no longer needed for the measuring cell inflation. Still, compressed gas is used for the guard cells.

As soon as this equipment was put into practice in a standard control unit with electro-mechanic components and in particular with pressure sensors a little above the standard limit of 5MPa, it appeared that the same design could be used at much higher pressures.

When constructing the HyperPac prototype, the aim was to achieve a pressure of 25 MPa, which is five times the limit of standard PMT's. This pressure has the advantage of corresponding to both the range of measurements that fill the gap between pressuremeter tests and dilatometer tests and to the capacity of the mechanic and electro-mechanic industrial components that were tested and were proved reliable during the trials.

The use of a large-sized cylinder (fig. 4), within which the piston moves, eliminates every risk of a blow-up in the event of a leak or the failure of one of the components of the hydraulic system including the connecting lines and the probe.

The resolution of the measure of displacement of the motor-driven piston is inferior to 1 μm, which corresponds to a theoretical measure of volume change of 1.10^{-3} cm^3, that is to say, for the probe (fig. 5) described, a mean displacement of the borehole wall of 3.10^{-2} μm.

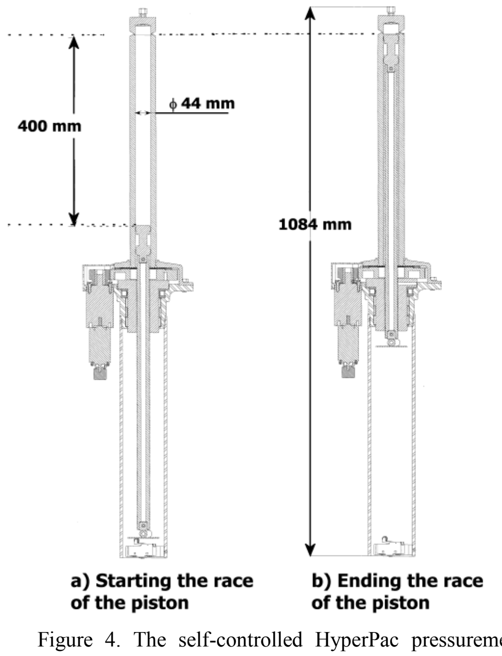

Figure 4. The self-controlled HyperPac pressuremeter. Diagram of the volumetric measurement using a motor-driven self-controlled piston.

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Particular attention has to be given to the measuring probe which is in close contact with the borehole wall and the calibration of the latter. We used a mono-cell probe, 46 mm in diameter, with different types of covers in accordance with a range of Shore hardness of 40 to 90, similar to that of the probes designed by Ménard for his ‘1,000 bars pressuremeter’ [9].

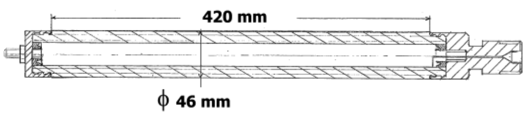

Figure 5. Diagram of the THP probe 46 mm by Géomatech

3.3 Examples of tests done using the automatic HyperPac 25 MPa pressuremeter.

The readings and tests presented here seem like a ‘simple’ transposition of the usual operations carried out when performing a standard pressuremeter test, but following the appropriate steps for a type B dilatometer probes [14].

- The calibration of a very high-pressure probe is done through increments of 2 to 3 MPa in a thick high elastic resistance steel tube, the correction of its own deformation being either obtained by calculation or by the use of an equally pressurized double tube [15].
- The expansion of a 46 mm O.D. very high pressure probe demonstrates that its rubber cover own resistance reaches between 0.6 and 1.2 MPa, depending on the Shore hardness and the thickness of the cover used.
- The capacity of volume deformation of these probes is presently limited to 350 cm^3, that is, for this measuring cell (fig. 5), a relative deformation dV/V = 50% or dr/r = 23%.

  The two standard corrections on pressure and volume readings are given on the following graphs (Figures 6 and 7). They also show tests performed with a core barrel of 46 mm O.D. fitted with a diamond cutting tool in the following rocks:

- Fontainebleau sandstone, an old quarry of paving stones at Saulx-les-Chartreux in Ile de France (91) and
- Beauce limestone, the Roncevaux quarry (45).

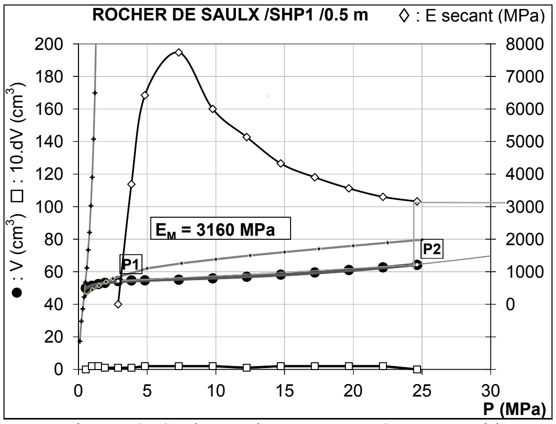

Figure 6. Saulx sandstone up to 25 MPa without creep; probe standard calibration curves are in grey. The bell-shape curve is the variation of E_M along the PMT curve.

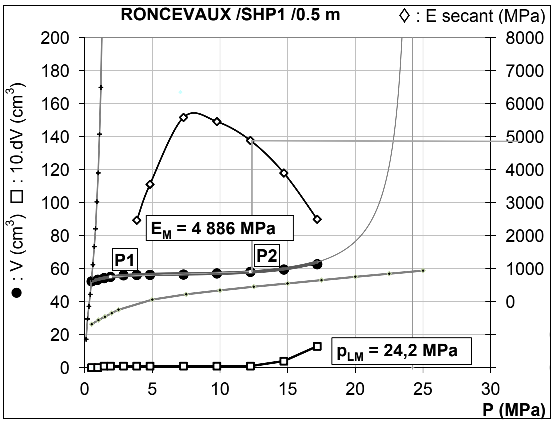

Figure 7. Beauce limestone, creep beginning at 18 MPa; probe standard calibration curves are in grey. The bell-shape curve is the variation of E_M along the PMT curve.

Note the slope of the calibration curves, quasi-rectilinear between the contact pressure at the tube and 25 MPa, the slope being here in the order of 1 cm3/MPa, using water as the transfer and measuring fluid. The quality of adjustment by either linear regression or by a hyperbole, gives an indirect degree of the precision obtained by the equipment when measuring volumes. For instance if water is replaced by an incompressible oil, calibration indicates an excellent reliability of the measurements and a drastic decline in the slope of the curve.

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3.4 Measurements of moduli in the range of 0-25 MPa and creep of very hard soils and soft rocks.

The interpretation of the tests at very high pressure may result in estimates of E-moduli that vary according to the intervals of pressure selected.

Among the examples submitted and considering the widest possible pressure interval, the E_M moduli obtained are respectively 3,200 MPa in sandstone and 4,900 MPa in limestone (Figures 6 and 7). For this last test, the shape of the PMT curve after creep allows to extrapolate a limit pressure of 24.2 MPa, that is an E_M/p_{LM} relation of 200.

4 CONCLUSION. FUTURE DEVELOPMENTS

The equipment submitted here, the HyperPac 25 MPa, consists of a totally new control unit including a volumetric system made of a servo-controlled piston so that the standard pressure holds are rendered stable without the help of an operator. This device with a capacity of 600 cm^3 permitting to obtain 25 MPa is designed to test soft rocks through borehole expansion that may present initial failure before reaching 25 MPa and in cemented rocks.

For the common use of pressuremeter tests up to 25 MPa by consultancy firms, the development of the device actually rests on the following needs:

- expand the range of very high pressure probes whose diameter could be either 63 mm or 76 mm according to the pressuremeter standards.
- scale down to a minimum value the calibration correction term; the probes, however, will keep a high value of cover resistance (as measured during the calibration), not detrimental to the precision of the readings.
- provide a large range of calibrated drilling tools, core barrels and tools for open hole drilling suitable for working in the soils and rocks to be investigated [4].

[4] The authors consider that minimising the delay between drilling and testing is essential to achieve high-quality measurements of moduli; this applies to hard grounds and even rocks as well as to soils.

EXPRESSION OF THANKS

We would like to express our thanks to the technical team from Géomatech, Apagéo and Cedarnet, the companies which ensured that the HyperPac prototype became operational in 2010. The first public presentation of the functioning of the HyperPac 25 MPa was given during the 'Journées Techniques Apagéo' held from 23 to 24 September 2010.

REFERENCES

[1] M. Cassan, Les essais pressiométriques et leurs applications en France, rappels historiques et état des connaissances, *ISP5-PRESSIO 2005 Vol. 2. Gambin, Magnan and Mestat (ed.), LCPC, Paris* (2006), 125-200.
[2] M. Gambin, Le pressiomètre, in *I. Sharour and R. Gourvès, Reconnaissance des terrains in situ, Hermès Sciences - Lavoisier Ed.* (2005), Chapter 4, 104-146.
[3] M. Galera, M. Alvarez, Z.T. Bienawski, Evaluation of the deformation modulus of rock masses. Comparison by pressuremeter and dilatometer test, *ISP5-PRESSIO 2005 Vol. 2. Gambin, Magnan and Mestat (ed.), LCPC, Paris* (2006), 239-256.
[4] Norm NF P94-110-1, Afnor (2000).
[5] Norm EN-ISO 22476-4, CEN, UAP adopted project.
[6] L. Ménard, Essais pressiométriques dans le rocher, *Notice Etudes Pressiométriques Louis Ménard* **D21** (1967).
[7] L. Ménard, Application des essais pressiométriques aux études de tunnel en terrain rocheux, *Notice Etudes Pressiométriques Louis Ménard* **D36** (1966).
[8] J.-P. Baud and M. Gambin, Homogenising MPM test curves by using a hyperbolic model, *ISC3 Taïpeï, Geotechnical and Geophysical Site Characterization – Huang & Mayne (eds) London* (2008), 975-980.
[9] L. Ménard, Le pressiomètre éclateur de roches, *Notice Etudes Pressiométriques Louis Ménard* **D23** (1974).
[10] J. Arcamone, R.Poirot and R.Schwartzmann, Utilisation de la pressiométrie dans les études minières, C.*R. Symposium. Int. Essais en place*, Paris (1983), vol. 2, 187-193.
[11] R. Heintz, Rapport national du Grand-Duché du Luxembourg, *ISP5 – PRESSIO 2005 Vol. 2. Gambin, Magnan and Mestat (ed.), LCPC, Paris* (2006), 431-440.
[12] R. Heintz and P. Reiffsteck, Essais pressiométriques haute pression, Rapport de recherche n°11J021, *Laboratoire Central des Ponts et Chaussées, Paris* (2003).
[13] R. Massonnet, Le pressiomètre sous haute pression, *ISP5-PRESSIO 2005, Vol. 1. Gambin, Magnan and Mestat (ed.), Presses ENPC/LCPC, Paris* (2005), 81–90.
[14] Norm EN-ISO 22476-5, CEN, UAP adopted project.
[15] L. Ménard, Exécution des essais pressiométriques dans le rocher, *Notice Etudes Pressiométriques Louis Ménard* **D3** (1966).