The evolution of Menard pressuremeter cavity preparation in France

Babak Hamidi[1], and *Serge* Varaksin[2]

[1]*Menard Oceania, Perth, Australia*
[2]*Apageo, Paris, France*
[#]*Corresponding author: bhamidi@menard.com.au*

ABSTRACT

Since Louis Ménard invented his first pressuremeter prototype in 1954, the pressuremeter and its placement techniques into the ground have gone through numerous advancements. In this paper, the authors review the cavity preparation developments in France from the early days of developing the pressuremeter to contemporary times. Pressuremeter probes were initially installed using hand augers, which was quite time consuming and cumbersome. Soon after, drilling was mechanized using drilling rigs with various abilities and capacities in the form of rotary and percussion drilling. Specific techniques such as STAF, RotoSTAF, and similar devices have now been developed to create holes with minimum disturbance in the ground.

Keywords: Pressuremeter; PMT; drilling; self-boring.

1. Introduction

1.1. Menard Pressuremeter

Louis Ménard attended the civil engineering school of École des Ponts et Chaussées in 1952. During the summer that he was employed to carry out compaction tests on a new runway in Paris, he realized that while strength-deformation properties were important, field tests and measurements were unable to measure them. Consequently, he developed the first prototype of the Ménard pressuremter as his dissertation and filed for a patent in 1954 at the age of 23.

Ménard later improved his invention and carried out the first tests with the new probe while studying for a master's degree (Menard, 1957) under the supervision of Professor Peck at the University of Illinois and filed for a second pressuremeter patent in 1959.

As shown in Fig. 1, the Menard pressuremeter (PMT) consists of three main components, i.e., a radially expandable cylindrical probe that is placed inside the borehole at the desired test level, a control or monitoring unit that remains on the ground surface, and the tubing that allows the probe to be pressurized.

Instead of a long chamber, the probe is made up of three independent cells stacked on top of each other. Each cell has a rubber membrane, top and bottom discs, and a rigid steel backbone. All cells are simultaneously inflated to the same pressure. The top and bottom guard cells protect the middle measuring cell from the end effects that are caused by the finite length of the probe and allow it to expand only in the radial direction, as if the probe had an infinite length. This results in plane strain deformation conditions (Baguelin et al., 1978).

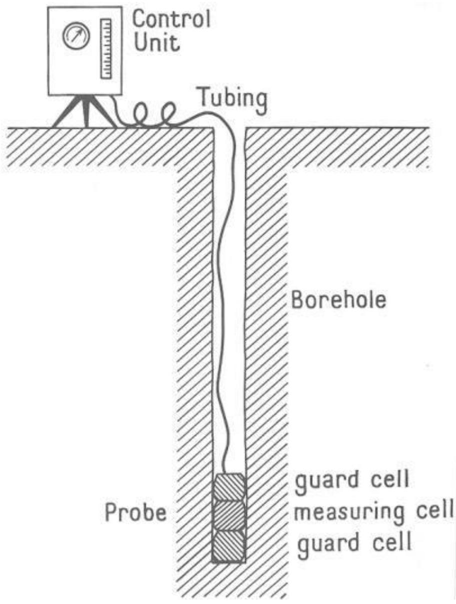

Figure 1. Menard Pressuremeter main components (Baguelin et al., 1978)

In subsequent developments, the probe-volumeter system underwent simplification. The deformation of the surrounding soil was induced by an external sheet pressurized with gas. Simultaneously, the cylindrical portion of this deformation was measured using the inner membrane fluid. The Lamé theory (1852), which pertains to the expansion of a cylindrical cavity within a semi-infinite medium, can be employed for determining moduli. Refer to Fig. 2 for a visual representation.

The schematic cross section of the Menard pressuremeter is shown in Fig. 3. The measuring cell fluid (water) is shown in blue, and the guard cell gas (nitrogen) is shown in green.

Figure 2. The new Menard pressuremeter probe's main components.

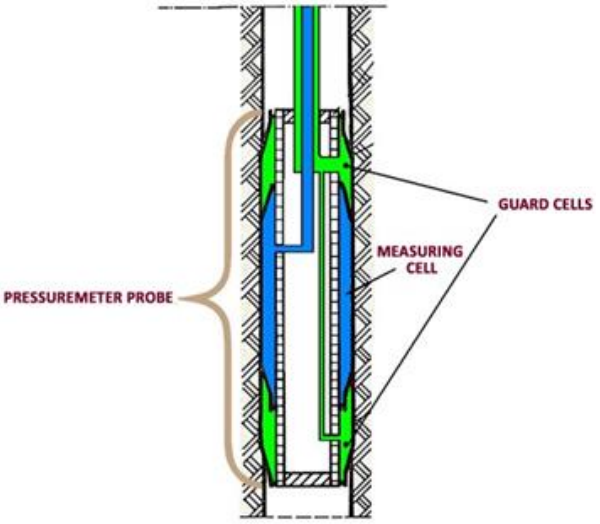

Figure 3. Schematic cross section of the Menard pressuremeter probe in the ground.

To protect the probe membranes against the sharp surface of a borehole, the probe can be initially placed inside a slotted casing, which is a thick steel tube with commonly six longitudinal slots that allow the tube to laterally expand. There are several standard sizes of slotted casings, but the most widely used has an outside diameter of 63 mm, an inside diameter of 49 mm, and protects a 44 mm diameter probe.

1.2. Preparation of the PMT hole

The PMT cavity can be prepared either by pre-boring a hole or by directly inserting the pressuremeter probe into the ground using a self-boring technique.

The cavity is typically prepared for the probe by pre-boring a hole with an appropriate diameter, which must be close to that of the probe to ensure adequate volume change capability. If the borehole diameter is too large, then its expansion limit may be reached before completion of the test. On the other hand, if the hole is too tight then the probe will have to be forced into the hole, and the pressure versus volume curve will not show a pseudo linear phase.

Amar et al. (1991) recommended that the hole diameter should not exceed the instrument diameter by more than 10%.

Ménard (Centre D'Etudes Menard, 1975) and later ASTM (2020) have specified probe diameters for typical borehole diameters as shown in Table 1. Derived from experience, ASTM further stipulates that the borehole diameter shall be from 1.03 times to 1.2 times the nominal probe diameter. If slotted casings are used, then the borehole diameters should also be adapted.

Table 1. Typical PMT probe and borehole diameters (ASTM, 2007, Centre D'Etudes Menard, 1975)

Hole diameter designation**	Diameter (mm)				
	Probe	Borehole			
		Menard		ASTM	
		Min*	Max*	Nom*	Max*
AX	44	46	52	45	53
BX	58	60	66	60	70
NX	74	76	80	76	89

* Min: minimum, Max: maximum, Nom: nominal

** Probe diameters are based on the standards of the Diamond Core Drill Manufacturer's Association (DCMA)

2. The evolution of PMT cavity preparation in France

2.1. Boring methods

To the knowledge of the authors, Hvorslev (1949) published the first book on ground exploration methods and the sampling of soils for civil engineering purposes, and for many years his book remained as the definitive guide for geotechnical practitioners.

Hvorslev notes that in accordance with the method used in displacing or removing material in advancing a borehole, the commonly used boring methods of the time were classified as:

a) Displacement boring
b) Wash boring
c) Percussion drilling
d) Rotary drilling
e) Auger boring
f) Continuous sampling

2.2. PMT hole preparation

For performing pressuremeter tests it is essential to create a stable hole without disturbing the ground, but there is no concern regarding the status of the bottom of the hole.

The PMT probe can be envisaged to be placed in the ground by three methods (Baguelin, 1978):

1. By inserting the probe into a predrilled hole, i.e., preboring.
2. By inserting the probe into the ground and causing the soil to displace around it.
3. By the pressuremeter drilling its own way, i.e., self-boring.

PMT boreholes were initially drilled out using hand-augers such as shown in Fig. 4, a tool that is still in use even though advancement is slow and somewhat dependent on the physical abilities of the driller.

The second author personally obtained his first experience of performing PMTs to the depth of 43 m using a hand auger almost 50 years ago. Louis Ménard was quite impressed with the efforts and hired him as his first overseas engineer in his construction company.

Hand augering can be done without using water or drilling mud. The auger is drilled into the ground in increments, then pulled out to the ground surface and emptied. The length of the drilling rod or auger is extended as needed. It is evident that the drilling and extraction cycle becomes longer as depth increases.

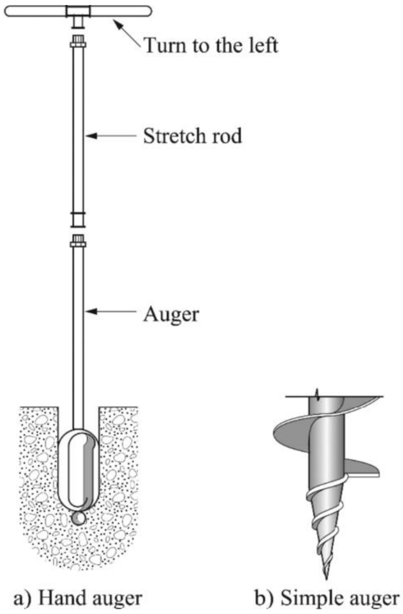

Figure 4. Hand auger (Monnet, 2015 (after ANFOR, 1995))

Alternatively, drilling can be advanced using drilling muds such as bentonite. The latter method is especially advantageous if the borehole wall is not stable and has the tendency to collapse. Furthermore, it is possible to extract the cuttings without pulling up the auger, which significantly increases drilling rate.

Ménard then designed a versatile little rig on wheels that was named D9000 (see Fig. 5). His idea was to manufacture a small rig that could implement multiple drilling methods with the ability to rapidly switch drilling method at the same location due to changes in the ground conditions.

The D9000 could take samples, and was able to drill as continuous flight auger (CFA) or core drill.

The rig was later equipped with a hammer and dropping mechanism similar to the Standard Penetration Test (SPT) to enhance boring granular soils. Typically, an AX-size probe was inserted in a BX-size slotted casing and blow counts were recorded to provide additional information about the driving resistance.

Later, the need to penetrate obstructions, glacial fills, etc. resulted in hydraulic percussion drilling as well as down-the-hole (DTH) or top-the-hole (TTH) hammers. This, combined with the replacement of the rig wheels with crawler tracks, resulted in the development of a new generation of rigs, such as the APAFOR (see Fig. 6).

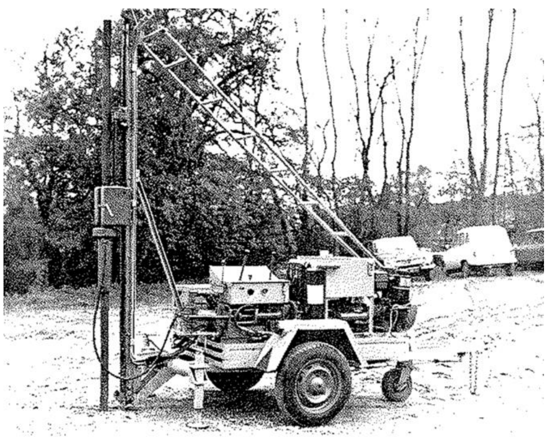

Figure 5. Pressuremeter drilling rig (Baguelin et al., 1978)

Figure 6. APAFOR 450 drilling rig.

The self-boring pressuremeter (SBP) has been mostly used for research purposes and has been less utilized in industry. The *pressiomètre autoforeur* (PAF) was larger than the pre-bored pressuremeter and required a substantially longer time to perform a test, sometimes only one test per day.

A British version of the self-boring pressuremeter has also been developed. Whilst more successful in the industry, this SBP was also expensive to operate. The SBP utilized electronic sensors and relied on electronic instruments for measuring borehole expansion.

In the early 1980s the second author was tasked with performing PMTs in a coal mine south of Louisville, Kentucky. The ground was composed of materials ranging in size from silt to very large blocks of rock. An idea was evolved to utilize an eccentric drilling bit to advance the casing. However, due to the large diameter of the casing, this idea remained as a research project and was never commercialized.

With the intent to minimize remolding of the cavity and the surrounding soil, the STAF (*Système de Tube Fendu Auto-Foreur)* which translates to Self-bored slotted tube system) was developed at the end of the 20th century. This system which is a technique for self-boring of the slotted casing must not be confused with the self-boring probe.

In STAF, an eccentric drilling bit is used to advance the casing string. The first casing at the toe of the string is slotted, but the following casings are non-slotted pipes with the same diameter.

Two types of eccentric drill bits are shown in Fig. 7. The cutting section of the bit is pulled inwards to allow the bit to be inserted into the casing. The cutting section is then pushed outwards beneath the casing thickness in such a way that it can bore a hole with the same outside diameter as the casing.

Once drilling has been completed and the bottom of the hole has been reached, then the drill bit cutting section is pulled inwards and the drilling string is withdrawn, leaving a slotted casing (with follow up tubes) in the ground with minimal disturbance.

When using STAF, pressuremeter tests are conducted from the bottom to the top of the hole by raising the slotted casing to each test depth.

Figure 7. Blade and button eccentric drill bits (Arsonnet et al, 2005).

In STAF, the casing is driven into the soil without rotation. The friction between the soil and the casing's wall slows down the boring operation and may limit drilling depth stages to 10 m in granular soils and even less in cohesive soils (Arsonnet et al., 2013).

To resolve this problem, a mechanical system that can simultaneously rotate the casing during its advance and apply percussion to the drill bit was devised and resulted in the manufacturing of a new drill head called RotoSTAF

The main features of the RotoSTAF are:

- Simultaneous rotation and advancement: The RotoSTAF head allows both the rotation of the casing and the advancement of the internal drilling string.
- Rotary percussion: It combines rotary percussion of the internal drilling string with the simultaneous rotation of the casing.
- Directional control: When necessary, RotoSTAF can rotate the drilling string either to the right or left for deploying or retracting the tool.
- Expanded soil range: RotoSTAF extends its applicability from soft soils to rock.

An alternative drilling technique to RotoSTAF is TUBA, which uses a drilling tool common in the drilling industry (generally a roto-percussive cross bit or button bit) (Rispal, 2020).

Guidelines for pressuremeter probe installation techniques are shown in Fig. 8.

3. Conclusions

It is of utmost importance that holes that will be used for carrying out PMTs create the least disturbance in the ground to achieve the most reliable test results. The PMT probe can be inserted in pre-drilled holes, by displacing the soil around the probe or by the pressuremeter self-boring its own way.

Self-boring pressuremeters are infrequently used in industry.

Pre-drilled holes were initially created by hand-augering, which is slow and cumbersome. Ménard developed the D9000 rig specifically for pressuremeter testing and further developed it over time. These incremental developments were further progressed and eventually resulted in slotted casing self-boring techniques that created the least amount disturbance.

		SOIL TYPE										
		CLAYEY SOILS			SILTY SOILS		SANDY SOIL			COARSE SOILS	ROCKS	
BORING TECHNIQUES		SLUDGE AND SOFT	SOFT TO MEDIUM STIFF	STIFF	ABOVE WATER TABLE	BELOW WATER TABLE	LOOSE ABOVE WATER TABLE	LOOSE BELOW WATER TABLE	MEDIUM DENSE AND DENSE	GRAVELS, COBBLES	WEATHERED ROCK, SOFT ROCK	HARD
OPEN HOLE DRILLING	HA hand auger	***	***	*	***	**	**	*	***	-	-	-
	HAM hand auger and mud	***	***	**	***	***	***	***	***	-	-	-
	CFA Continuous flight auger	-	**	***	**	-	**	-	**	*	*	-
	STDTM Slotted tube with inside rotary tool and mud circulation	*	***	***	**	*	**	*	***	**	***	**
	CD Core drilling	-	**	***	**	*	*	-	*	-	**	***
	RP Rotary percussion	-	*	**	*	*	*	*	**	***	**	***
	PT Pushed tube	***	*	-	*	-	-	-	-	-	-	-
	VDT Vibro driven tube	-	-	-	*	-	-	-	*	*	*	-
FULL DISPLA-CEMENT	DST Driven slotted tube	-	*	*	*	*	**	**	**	**	-	-
SELF BORING	VIBRO-STAF®	-	**	**	***	***	***	***	***	***	*	-
	ROTO-STAF®	-	**	**	***	***	***	***	***	***	*	-
	SAF® self-bored probe	***	-	-	***	***	***	***	-	-	-	-

*** Recommended ** Suited * Acceptable - Not suited

Figure 8. Guidelines for pressuremeter probe installation techniques (Apageo, 2016).

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