LOUIS MÉNARD AND THE PRESSUREMETER TEST

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This report presents a brief biography of Louis Ménard and a short description of his remarkable invention, the pressuremeter test, which was an innovative ground investigation technique to assess deformation and failure ground parameters for foundation design.

The engineer and inventor

Louis Ménard was a French engineer who lived from May 1931 to January 1978. He is internationally known for the invention and the development of the pressuremeter as it is still employed nowadays.

Ménard patented the testing equipment in 1955 at the age of 23 and carried out the first theoretical developments aiming at the determination of soil properties (strength and stiffness) during his graduation project in France at the *Ecole Nationale des Ponts et Chaussées* and further during his master thesis at the University of Illinois in the USA.

Besides an engineer and inventor, Ménard was a businessman: he created the company "*Les pressiomètres Louis Ménard S.A.*" in 1957. He provided licenses to other companies interested in using the testing equipment in this same year. He is also the author of several other patents related to the improvement of bearing capacity of piles, ground improvement by dynamic compaction and other things.

The development of the ground investigation techniques using the pressuremeter evolved significantly during the 60's. In 1962, Ménard created the bilingual journal "Sols-Soils", where many papers were published about the new tests and other innovations in geotechnics. In this same year, he started carrying out full-scale loading tests on shallow foundations. The goal was to investigate the relationship between the parameters determined using the pressuremeter and the performance and bearing capacity of the foundations, enabling the direct use of the pressuremeter test for their design. The first semi-empirical design formulas were established based on these studies, finding a huge success amongst French practitioners due to their reliability and ease of use. They have only slightly evolved and are still used in today's practice, which is a proof of their robustness.

In the early 70's Ménard devoted his time to the study and implementation of ground improvement techniques by dynamic compaction. As a contractor, he developed and patented the first dynamic compaction machines which were able to lift a mass of up to 40 tons to approximately 40 m above ground level. The technique consisted in dropping down the mass in order to compact the ground. It was employed in several work sites in different countries (Saint Domingo, U.S.A., Bangladesh, Singapore, South Africa, Germany). The Airport of Nice in France is one of these notorious works.

Louis Ménard passed away at the age of 46, only 23 years after issuing his first patent on the pressuremeter. During his life, he promoted a notorious evolution in the domains of ground investigation, foundation design and ground improvement. Today, more than 90 years after his birth, his genius still inspires the younger generations of passionate geotechnical engineers willing to innovate and to develop new techniques. Indeed, a huge source of inspiration, because "in less than ten years, starting from scratch, Louis Ménard developed not only an *in situ* soil test and various drilling and measuring devices, but concepts, a method, a truly original school of thought that is now part of our heritage". (Gonin, 2005)

The technique

The general principle of the pressuremeter test is to insert a cylindrical probe equipped with an expandable flexible membrane into a borehole into the ground (sometimes it is driven inside a slotted tube). The probe is expanded following a predefined loading program, and the ground responds to the applied load yielding a cavity pressure versus cavity volumetric strain curve. This curve is called a **cavity expansion curve** and it can be interpreted to derive **deformability** and **strength** parameters of the ground. The resulting parameters can be used in many ways, such as to estimate foundation design parameters. The test interpretation relies either on a theoretical analytical background, or on semi-empirical correlations.

The test is performed according to the simplified scheme shown in Figure 1(a). A simplified cross-section and a photo of a Ménard type pressuremeter probe are presented in Figure 1(b) and (c). The following successive steps are performed:

- Drill a borehole into the ground
- Insert the probe into the cavity
- Control the probe expansion using a control unit (C.U.)
- Keep records of pressure and volume during the test

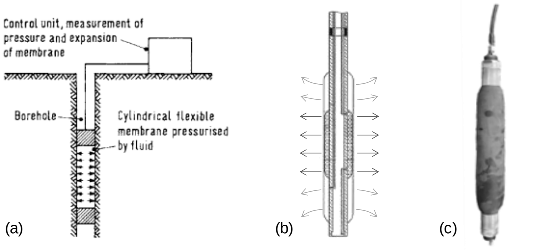

Figure 1 – Principle of a pressuremeter test, Ménard probe scheme and photo.

This general procedure can be applied either to soils or rocks, provided the testing equipment are adjusted accordingly.

After Ménard's invention, different testing equipment have been developed around the world, as well as different probe insertion techniques, loading protocols and interpretation methods. Different probe insertion methods can be chosen depending on the ground conditions, such as:

- Pre-boring method
- Self-boring method
- Pushing-in method

Probe technology also evolved. Probes can be:

- Tri-cellular (Ménard type)
- monocellular

Tri-cellular probes are generally controlled using pressurized gas (guard cells) and water (central measuring cell). Monocellular probes can be controlled using only water or only gas.

The assessment of cavity deformation can be done in two ways:

- By measuring the volume of water (or any other low compressibility fluid) injected into the probe's measuring cell
- By local displacement measurement sensors installed inside the probe

The assessment of stress and strain at the cavity wall is not direct and requires the probe to be preliminarily calibrated to take into account internal system losses. Ménard established calibration protocols that are still used in current practice.

The pressure-volume control unit (CPV) is the device that enables injecting the pressurized fluid into the probe and controlling it according to the desired testing protocol. These devices have significantly evolved since the invention of the pressuremeter test. While the first devices created by Ménard were manually controlled, fully automated devices are used today. The loading programme can be automatically controlled by the CPV, as well as the data acquisition.

Ménard type tests follow a specific standardized loading programme, as defined in Figure 2(a) (NF EN ISO 22476-4, AFNOR, 2015). The typical soil response obtained is presented in Figure 2(b). Three phases can be distinguished on the curve: a recompression phase on the beginning of the expansion curve (Phase 1), a quasi-linear phase usually called "pseudo-elastic" (Phase 2), and a plastic phase (Phase 3), characterized by significant volumetric changes during the constant-load steps (time dependent behaviour). The **pressuremeter creep pressure p_f** defines the frontier between "pseudo elastic" and plastic phases. The **Ménard pressuremeter modulus E_M** is calculated from the slope of the "pseudo-elastic" phase (Phase 2). The conventional **pressuremeter limit pressure p_l** is calculated as the pressure corresponding to doubling the initial cavity volume.

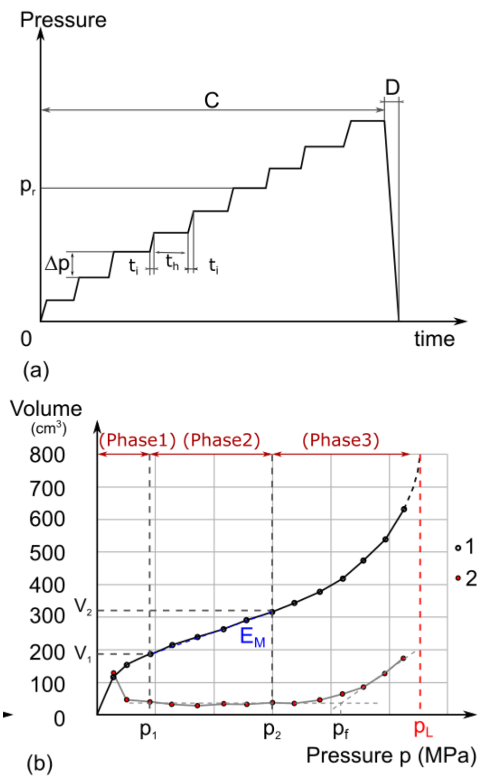

Figure 2 – (a) Ménard type loading programme. (b) Ground response to a Ménard pressuremeter test.

Other types of loading programmes can be performed, including one or more unload-reload loops, or using other techniques to control the probe pressure or expansion (AFNOR 2013a), enabling the determination of other ground parameters, which are out of the scope of the Ménard procedure.

Remarkable works

It would be difficult, if not impossible, to cite one specific remarkable work due to Louis Ménard. As mentioned before, he developed concepts and methods that contributed to a deep change in the way geotechnical investigation and design is carried out in France. In a broader context, the pressuremeter is known and reputed all around the world and has been since then the subject of dedicated international conferences, textbooks published in different countries, several patents, and international standards. Amongst the direct and indirect contributions to the geotechnical community related to the pressuremeter test, one can mention:

- The International Symposium on Pressuremeters, ISP, having completed 7 editions so far (from 1982 to 2015)
- The international journal Sols-Soils, edited from 1962 to 1980
- The first foundation design rules established in the so-called "D60" technical note (Ménard, 1967), which were incorporated into a national French design recommendation in the 70's (LCPC-SETRA, 1972)
- The rules now included in the French standards applying Eurocode 7 (AFNOR 2012, 2013b). For details on the design methods, see Frank *et al*. (2022)
- A joint industry-academia research project, ARSCOP, launched in 2016 dedicated to the improvement of the ground investigation techniques using the pressuremeter and to the design methods based on the results of the test (Burlon and Reiffsteck, 2015)

Several textbooks dedicated exclusively to the pressuremeter test and/or its use for foundation engineering are available internationally. The reader interested in learning more about the test can refer to the following works: Baguelin et al. (1978), Mair and Wood (1987), Briaud (1992), Clarke (1995), Frank *et al*. (2022).

Interview

This contribution to the Time Capsule Project includes an interview with Professor Roger Frank, who devoted his whole career to the Central Laboratory of the French Bridges and Highways Administration, the LCPC and to the Engineering School of the same administration, *Ecole Nationale des Ponts et Chaussées*. Professor Frank was involved in many aspects of the pressuremeter testing during his career.

Want to learn more, visit the Time Capsule Project page on the CFMS web site and watch the interview!

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