THE PRESSUREMETER TEST

PRINCIPLE
1. **PRINCIPLE OF THE MENARD PRESSUREMETER TEST**

In 1957, Louis MENARD, a French civil engineer, developed a simple equipment to test the soil in place. He also proposed to directly use the parameters as found for designing foundations. These improvements led to new trends in the cost effective design of foundations.

**PRINCIPLE:**

This test is a so-called "in-situ" test, as opposed to the laboratory tests. The principle is to introduce a cylindrical probe with a flexible cover which can expand radially in a borehole (see Fig. T1).

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**CYLINDRICAL DEFORMATION**

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**BOREHOLE**

**SOIL**

**PROBE**

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T1
A pressure is applied by the probe on the walls of the hole, and the soil deformation is measured, through the acquisition of the hole volume increase (see Fig. T2).

**PRESSUREMETER TEST**

![Graph of PRESSUREMETER TEST](image)

- **This stress-strain curve is divided into different parts:**
  - Inflation of the probe cover so as to obtain the contact between the probe and the walls of the hole.
  - Pseudo-elastic reaction of the soil against probe pressure.
  - Large displacements of the soil against probe pressure.

**The Pressuremeter parameters are:**

- **\( E_m \):** the Ménard Modulus used for the calculation of the settlement of foundations.
- **\( P_l \):** the Limit Pressure used for the calculation of the bearing capacity of the soil with regards to a specified foundation.
- **\( P_f \):** the Creep Pressure which is the boundary between the pseudo-elastic type of reaction of the soil and the large displacements type of reaction, for the pressuremeter stress path.
2. **EQUIPMENT DESCRIPTION**

- The radial expansion is obtained using a steel cylinder, covered by a rubber membrane.
- The applied pressure is obtained using a neutral gas (Nitrogen), a cheap and simple source of energy.
- The control of the applied pressure and the measurement of the radial deformation is obtained through the MENARD monitoring box.

**APAGEO SEGELE MENARD PRESSUREMETER**

![Diagram of equipment with labels: PVC, Volume Control, Pressure Gauge, Monitoring Box, Compressed Gas (Nitrogen), Tubing, Soil, G Probe.]

Fig. T3
THE PROBE:

In the simple case of the monocell probe 32 mm O.D., the rubber cover is tightened using 2 steel rings which press the rubber cover against O-rings (see Fig. T4).

MONOCELL PROBE 32 mm O.D.  

Fig. T4

Theoretically, the expansion is such that the rubber cover remains cylindrical. In fact, we notice that we may observe some "end effects" (see Fig. T5).

END EFFECTS  

Fig. T5
Two guard cells are necessary for the probe to impose a radial strain which is constant in amplitude all along the measuring cell. Further, these 2 guard cells will help confining the measuring cell length.

The guard cells are not used to measure the volume increase, and they can be filled with gas or water: this was the "E PROBE" (see Fig. T6).
In fact, the "G PROBE" which has now been used for 30 years was developed by Louis MENARD for practical and economical reasons. It is based on the same principle, but the guard cells boundaries do not physically exist: they are in fact bounded between the central measuring cell membrane, the rubber cover of the probe and the probe steel core.

The cover is thicker, and often reinforced by various means.

**EXPANDED G PROBE**

**CENTRAL MEASURING CELL**

![Diagram of EXPANDED G PROBE]

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*The G PROBE advantages:*

- 2 tubes (gas + water) are only used, instead of up to 4 tubes
- Easy assembling and disassembling

*Various fittings are available:*

- Various types of rubber covers exist, in order to adapt the probe to the soil type. Most commonly, either covers with steel strips or steel reinforced covers are used.

- When the reinforcement of the cover is not resistant enough for the type of soil considered, a "slotted casing" can be used: this is a steel tube into which the probe is placed. This tube can be easily expanded, thanks to long slots located all along the tube.
THE PRESSUREMETER:

The monitoring box allows to set the pressure step by step, and to measure the soil deformation, i.e. the volume of water injected into the central cell of the probe.

The access to every internal component is very easy. All gas and water leads to the probe are in Rilsan™.

Fig. T8

THE CONNECTING TUBES:

The tubes are used to inject the water and the gas into the probe. Originally, the tubing used to be a coaxial one, the external tube transmitted the gas pressure, and the inside tube was used to inject water.

Since 1986, APAGEO SEGELM developed a new type of tubing, made of twin tubes, side by side, with completely independent circuits. Connecting and disconnecting the tubing became very simple, thanks to specific quick coupling connectors.

Note: When dealing with high pressure values, a slight expansion of the tubing itself occurs. In order to take this phenomenon into account, a calibration test is necessary, as explained here after.
3. **OPERATION OF THE EQUIPMENT**

3.1. **PROBE BLEEDING**:

The first operation is to bleed the air which can be contained in the probe. This is realised before performing the test itself.

3.2. **PRESSURE LOSS TEST**:

The rubber cover fitted on the probe presents a slight resistance which increases with the expansion. This resistance must be determined in order not to assimilate it to the soil resistance.

This resistance is then subtracted from the pressure values acquired during the test, for each recorded volume expansion.

This "**Pressure Loss Test**" is carried out as follows: the probe is placed besides the Pressuremeter, in the open air; it is then inflated step by step with increasing pressure, as for a normal test; the volume versus pressure curve is acquired (see Fig. T9).

**OPEN-AIR PRESSURE LOSS TEST**

![Diagram of open-air pressure loss test](image)

**Fig. T9**
3.3. VOLUME LOSS TEST:

As already mentioned, the slight expansion of the whole water conduit, due to the pressure increase, is read in addition to the soil cavity volume increase, resulting into a slightly too large measure. The principle of this calibration is to measure the inflation of this conduit alone, at increasing pressures, in order to later reduce the test data.

This "Volume Loss Test" is realised as follows: the probe is introduced in a heavy steel tube, which can be considered as being rigid. The probe is then inflated, and the volume versus pressure curve which is recorded will clearly indicate this volume loss.

PROBE VOLUME LOSS TEST:

![Diagram of probe volume loss test](image)

Fig. T10
3.4. **DIFFERENTIAL PRESSURE, OR PRESSURE LAG:**

We describe here the difference of pressure between the central cell (water) and the guard cells (gas), and its effects on the probe (see Fig. T11).

### 3.4.1. Pressure lag at probe elevation:

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\text{P}_{\text{gas}} - \text{P}_{\text{water}} = 2 \times \text{P}_{\text{membrane}} \quad \text{P}_{\text{gas}} \gg \text{P}_{\text{water}} \quad \text{P}_{\text{water}} \gg \text{P}_{\text{gas}}
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<table>
<thead>
<tr>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Fig. T11</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="Case 1 Diagram" /></td>
<td><img src="image2.png" alt="Case 2 Diagram" /></td>
<td><img src="image3.png" alt="Case 3 Diagram" /></td>
<td><img src="image4.png" alt="Figure T11" /></td>
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In order to obtain a valid test, the central cell has to be in contact with the soil (case 1) over its full length.

We can see on Fig. T11 that, when the pressure is similar in the guard cells and the central cell, or if it is higher in the guard cells (case 2), then the central membrane will not be able to expand, that is to be in contact with the soil.

On the contrary, if the pressure is much higher in the central cell (case 3), we will have "end effects" on the central cell, affecting the real radial expansion value.

We can conclude that in order to be in case 1, we need to keep a slightly lower pressure in the guard cells, as compared with the central cell, using a differential pressure regulator.

To estimate this differential pressure value, it is necessary to measure the pressure which is needed to obtain full inflation of the central rubber membrane. This can be performed as a pressure loss test which we already described. Maximum pressure resistance of the standard membrane being 50 kPa (it can vary from 30 to 60 kPa, or 0.3 to 0.6 bar), experience has led to adopt a pressure lag of 100 kPa (1 bar) at probe elevation.

*This differential pressure must be checked at all time during the test.*
3.4.2. Pressure lag at monitoring box elevation:

Then another phenomenon should be taken into account, which is the increasing pressure of water in the central cell due only to the increasing depth of the probe.

As you know, in a column of water, the pressure increases with depth.

As you see from example Fig. T12, with the tap water supply: the tallest is the water tank, the highest is the pressure at your tap. 10 meters will increase the pressure value by 100 kPa (1 bar).

This pressure only depends on the height of the water level, or, in our case, of the depth of the probe.

This depth is measured between the middle of the monitoring box, and the middle of the probe (see Fig. T13).