Pressuremeter Test (PMT)

- Pressuremeter is cylindrical devices designed to apply uniform pressure to the wall of a borehole by means of a flexible membrane. Both pressure and deformation at the cavity wall are recorded and interpretation is provided by cavity expansion theories under the assumption that the probe is expanded in a linear, isotropic and elastic-perfectly plastic soil. Although it can be used in different types of soil, however, its best applications are in relatively fine-grained sedimentary soil deposits.

- The original PMT was developed in the year 1956 by Louis Menard in an attempt to overcome the problem of sampling disturbance and to insure that the in-place soil structure is adequately represented.

- The device basically consists of a cylindrical rubber cell, usually of 58 mm in diameter and 535 cm^3 in volume, and two guard cells of the same diameter arranged coaxially. The probe length is usually 420 mm. The device is lowered into a carefully prepared (slightly oversize) borehole to the required depth.

- As recommended by ASTM, for diameters of 44, 58 and 74 mm, the required borehole diameter ranges are 45–53 mm, 60–70 mm and 76–89 mm, respectively.

- The central measuring cell is expanded against the borehole wall by means of water pressure, measurements of the applied pressure and the corresponding increase in volume being recorded. Pressure is applied to the water by compressed gas (usually nitrogen) in a controlled gas cylinder at the surface. The increase in volume of the pressure cell is determined from the movement of the water-gas interface in the other control cylinder (Figure 1a).

- Readings being normally taken at 15, 30, 60 and 120 s after a pressure increment has been applied. The process is continued until the total volume of the expanded cavity becomes as large as twice the volume of the original cavity, or, the pressure limit of the device is reached. A new test begins after the probe has been deflated and advanced to another depth. A version of Menard pressuremeter test is schematically shown in Figure 2.

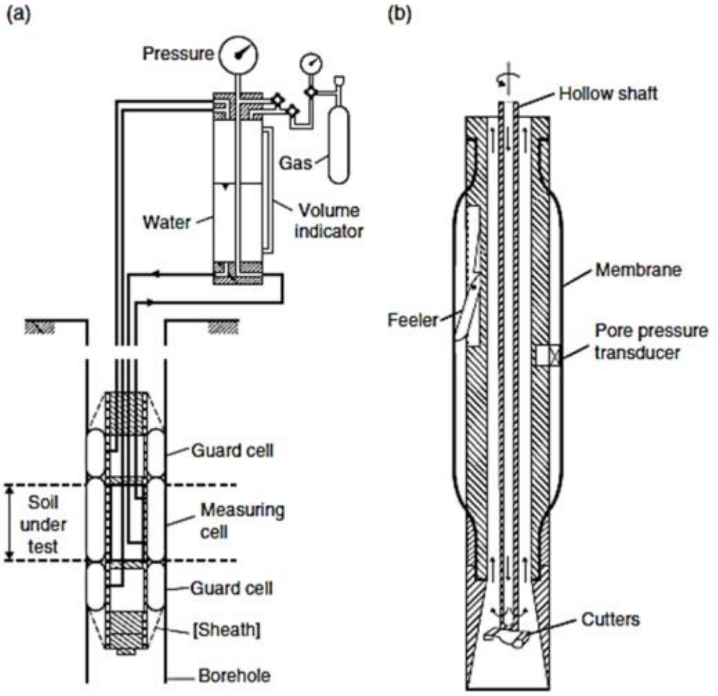
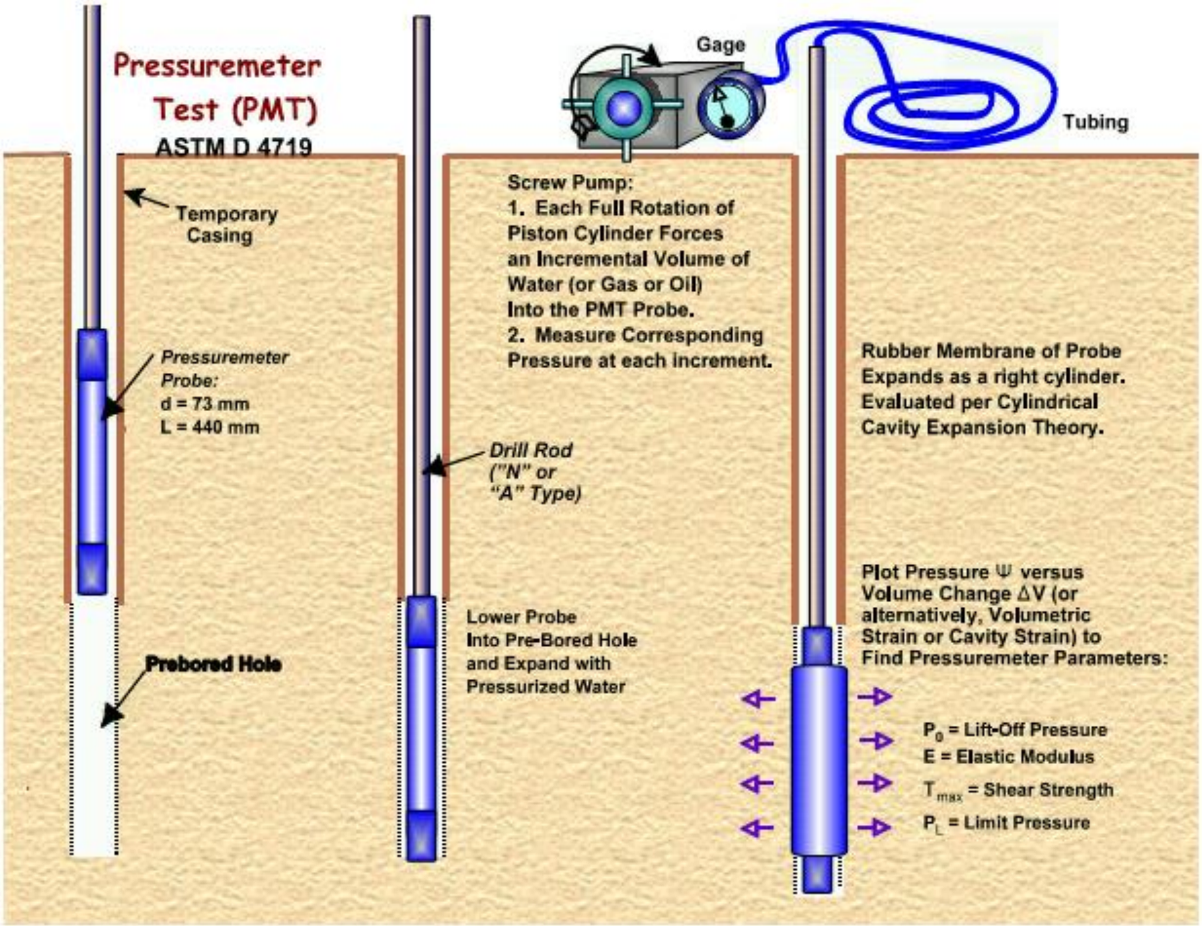


Figure1: Basic features of (a) Menard pressuremeter and (b) self-boring pressuremeter



Screw Pump:
1. Each Full Rotation of Piston Cylinder Forces an Incremental Volume of Water (or Gas or Oil) Into the PMT Probe.
2. Measure Corresponding Pressure at each increment.

Lower Probe Into Pre-Bored Hole and Expand with Pressurized Water

Rubber Membrane of Probe Expands as a right cylinder. Evaluated per Cylindrical Cavity Expansion Theory.

Plot Pressure Ψ versus Volume Change ΔV (or alternatively, Volumetric Strain or Cavity Strain) to Find Pressuremeter Parameters:

P_0 = Lift-Off Pressure
E = Elastic Modulus
T_{max} = Shear Strength
P_L = Limit Pressure

Figure 2:Basic components of the pressuremeter.

Types of Pressuremeter

There are three types of pressuremeter:

1. **Pre-Bored Pressuremeter (PBP).**

   The probe is simply lowered into a pre-bored hole to the test depth where the membrane is inflated. The Ménard-type pressuremeter (MPM) is the most widely used tool in this group. The pressuremeter has a slightly smaller outside diameter than the diameter of the hole. Pressure applied by gas is recorded by a gauge placed at the surface, while displacements are determined by measuring the change in volume of a water-filled central cell. This central cell is protected by upper and lower guard cells that are inflated with gas to ensure that the central cell expands predominantly in the radial direction as a circular cylinder.

2. **Self-Boring Pressuremeter (SBP)**

   The pressuremeter is pushed hydraulically from the surface while the soil inside the sharp cutting edge of the tapered shoe is removed by a rotating cutting mechanism supplied with flush fluid that jets soil particles to the surface as the probe is advanced. The aim of SBP is to reduce the soil disturbance caused by forming a borehole.

   The factors affecting the amount of soil disturbance caused by insertion are:

   i. soil type;
   ii. distance of the cutter back from the lower edge of the cutting shoe;
   iii. diameter of cutting shoe relative to the uninflated outside diameter of the pressuremeter membrane;
   iv. the downward force applied during drilling; and
   v. the amount of vibration during drilling.

3. **Push-in Pressuremeter (PIP)**

The PIP has many advantages over the self-boring pressuremeter. Installation is achieved by pushing the pressuremeter module from the bottom of a borehole or by inserting a pressuremeter module mounted behind a cone tip. The cone pressuremeter prototype (CPMT) is pushed into the ground using a standard cone truck as part of the cone penetration test operation, with the cone driven into the soil at a constant penetration rate of 20 mm/s.

Calibration Procedure

pressuremeter is designed for maximum pressures in the ranges 2.5–10.0 MPa in soils and 10–20 MPa in very stiff soils and weak rocks. Corrections must be made to the measured pressure, volume change and cavity deformation in order to account for: (a) the head difference between the water level in the cylinder and the test level in the borehole (or between the pressure transducer and the element), (b) the pressure required to stretch the rubber cell (i.e. for stiffness of the membrane) and (c) the expansion of the control cylinder and tubing under pressure. The two other guard cells are expanded under the same pressure as in the measuring cell but using compressed gas. The increase in volume of the guard cells is not measured. The function of the guard cells is to eliminate end effects, insuring a state of plane strain.

Test Method

The probe consists of three cells. The outer two cells are known as ‘guard cells’ and are normally filled with pressurized gas. The central, measuring cell is filled with water, and is connected to a sight tube, which records volume change, in the pressure-volumeter. Pressure is provided by means of a CO_2 bottle.

The pressure of both gas and water is increased in equal increments of time, and approximately equal increments of pressure. Resulting changes in measuring-cell volume are recorded at 15 s, 30s, 60s and120s after each pressure increment is applied.

The number of increments actually achieved will depend upon the accuracy of the operator’s prior estimate of the limit pressure. Between 5 and 14 increments are normally considered acceptable.

The results of a Menard pressuremeter test are represented by a graphical form of corrected pressure (P) against total volume (V), as shown in Figure 3. Zone I of the figure represents the reloading stage during which the soil around the borehole is pushed back into the original state (the at-rest state before drilling the borehole). At this state the cell initial volume (V_o) has been increased to ($V_o + v_o$), and the cell pressure (p_o) approximately equals to the in situ lateral earth pressure (p_h), depending on procedure and insertion disturbance. Zone II represents an assumed elastic zone in which the cell volume versus cell pressure is practically linear. In this stage, within the linear section of the $P - V$ plot, the shear modulus of the soil may be considered equal to slope (dp/dV) multiplied by volume V. Pressure (p_f) represents the yield (or creep) pressure. Zone III is the plastic (or creep) zone, and the pressure (p_l) represents the limit pressure.

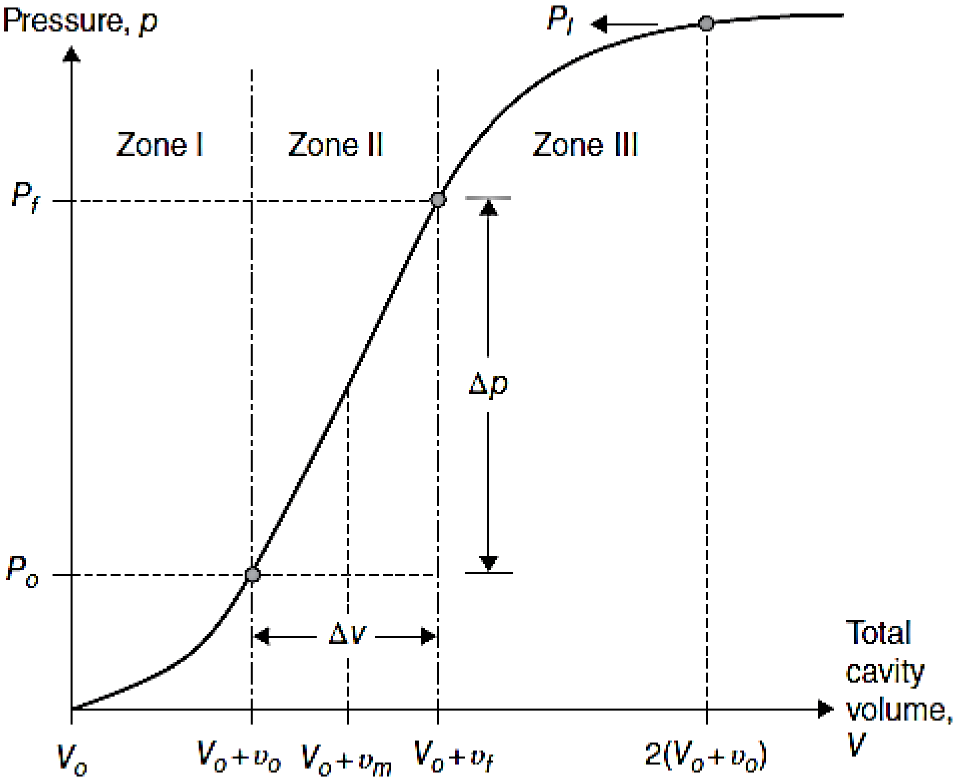


Figure 3:Pressuremeter test curves

Results and Interpretation

The principal differences between the classes of pressuremeter lie in the stresses applied to the probe at the start of the test.

a. PBP starts from a horizontal total stress level close or equal to zero.
b. SBP starts their test at approximately the horizontal total stress level in the ground before insertion.
c. PIP starts with a horizontal total stress which can be expected to be much greater than originally existed in the ground.

Results of a pressuremeter test can be used in solving the following equations:

$$E_{sp} = 2(1 + \mu_s)(V_o + v_m)\left(\frac{\Delta p}{\Delta v}\right)$$

where:

E_{sp} = pressuremeter modulus

$v_m = \dfrac{v_o + v_f}{2}$ (for a pre-drilled borehole using Menard pressuremeter)

$v_m = \dfrac{v_f}{2}$ (for a self-boring pressuremeter)

$$\Delta p = p_f - p_o,\ \Delta_v = v_f - v_o$$

μ_s = Poisson's ratio of soil; Menard recommended $\mu_s = 0.33$, but other values can be used.

$\Delta p/\Delta v$= slope of the linear section of the P–V plot Figure 3

According to Ohya et al. (1982):

$$E_{sp}\left(\mathrm{kN/m^2}\right) = 1930\,N_{60}^{0.63} \qquad \text{(for clays)}$$

$$E_{sp}\left(\mathrm{kN/m^2}\right) = 908N_{60}^{0.66} \qquad \text{(for sands)}$$

$$E_{sp} = 2(1 + \mu_s)G_{sp}$$

$$G_{sp} = (V_o + v_m)\left(\frac{\Delta p}{\Delta v}\right)$$

where:

G_{sp} = pressuremeter shear modulus

$$\frac{\Delta V}{V} = 1 - (1 + \varepsilon_c)^{-2}$$

$\dfrac{\Delta V}{V}$ = volumetric strain of soil

where ε_c = circumferential strain

= (increase in cavity radius Δr/radius r_o)

$$K_o = \frac{p_h}{\sigma_o} \approx \frac{p_o}{\sigma_o}$$

where K_o = at-rest earth-pressure coefficient.
σ_o = total vertical stress

According to Kulhawy and Mayne (1990):

$$\sigma'_c = 0.45\, p_l$$

where σ'_c = Preconsolidation pressure

On the basis of the cavity expansion theory, Baguelin et al. (1978) proposed that:

$$c_u = \frac{(p_l - p_o)}{N_p}$$

where

c_u = undrained shear strength of a clay

$N_p = 1 + \ln\left(\frac{E_p}{3c_u}\right)$

Typical values of Np vary between 5 and 12.

In the case of saturated clays, it is possible to obtain the value of cu by iteration from the following expression:

$$p_l - p_o = c_u\left[\ln\left(\frac{G_{sp}}{c_u}\right) + 1\right]$$