Pressuremeter PMT

REFERENCE.

Mair RJ and Wood DM (1987). Pressuremeter testing – methods and interpretation.

CIRIA Ground Engineering Report. Butterworth

The Pressuremeter Test (PMT)

Test Equipment and Procedure

The pressuremeter is a cylindrical device designed to apply a uniform radial pressure to the sides of a borehole in which it is placed. There are two basic types:

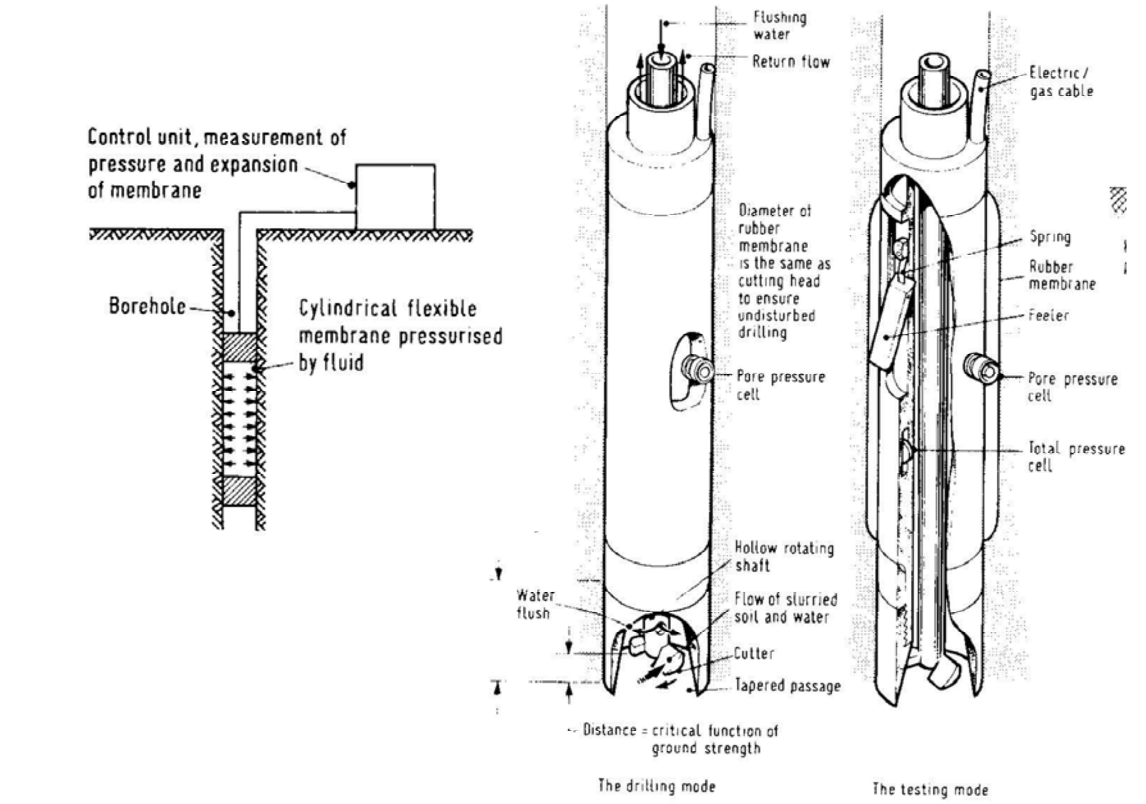
1. Menard pressuremeter – which is lowered into a preformed borehole
2. Self-boring pressuremeter – which forms its own borehole and thus less disturbance to the surrounding soil

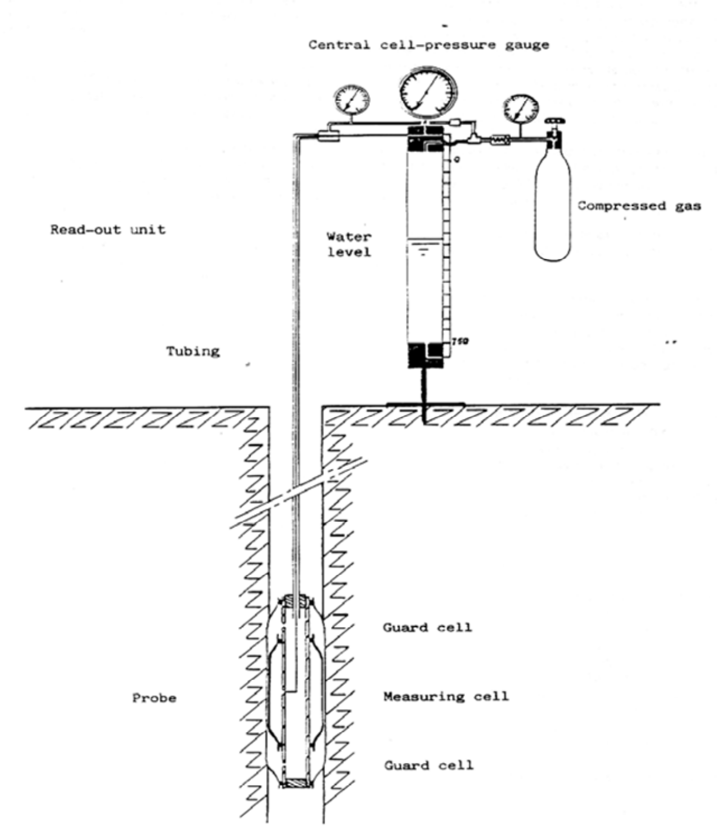
In both cases the pressuremeter test involves applying a known pressure to the device to expand the borehole in a radial direction. The applied pressure and resulting soil deformation can be interpreted using cavity expansion theory, ie doesn't rely on empirical correlations. This approach to interpretation is more appealing than empirical methods used for the SPT or CPT.

The figure shows a general arrangement of the equipment.

The fluid inside the flexible rubber membrane is pressurised. The outside of the rubber membrane is protected by steel strips. The volume of expansion is determined by either measuring the volume of fluid required to cause expansion or by using local displacement transducers at the cavity wall and in the horizontal plane.

Schematic diagrams of PM test a) General arrangement b) Self-boring pressuremeter





Schematic of a pressuremeter test in a borehole (from Gambin and Rousseau, 1988).

Pressuremeters are designed for maximum pressures: 2.5-10MPa for soils and 10-20MPa for very stiff soils or weak rocks.

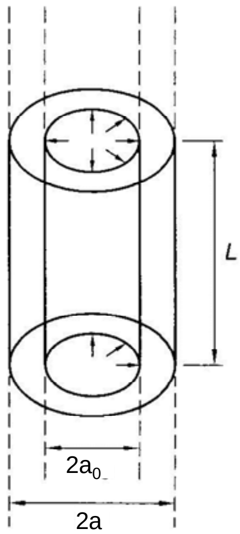
Typically they have a length to diameter ratio of 6, although the cavity expansion theory assumes the cylindrical cavity is infinitely long. Differences between theory and tests can be attributed to slight 'end effects'.

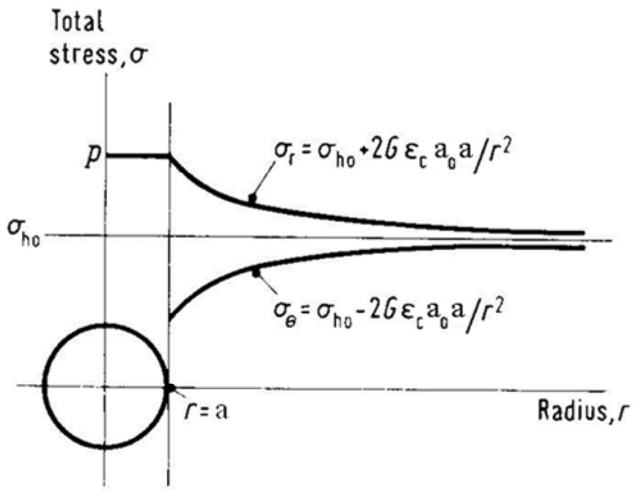
Corrections must be made during testing to account for:

- compressibility of fluid and pipe network,
- differences in elevation between pressuremeter and pressure transducer
- stiffness of the rubber membrane.

For a Menard PMT there is likely to be soil disturbance in the borehole in which the pressuremeter is placed such that it is not in direct contact with the sides of the borehole. This difference is reflected in the data from the early stage of the test. A high quality self-boring PMT will have good contact between the borehole sides and pressuremeter.

Stresses around expanding cylindrical cavity in elastic soil
(Mair and Muir Wood 1987)





Cavity volumetric strain:
$\Delta V/V = (V - V_0)/V$ where V is the current volume and V_0 is the initial volume

Cavity radial strain:
$\varepsilon_c = \Delta a/a_0 = (a - a_0)/a_0$ where a is the current cavity radius and a_0 is the initial cavity radius

from theory of elasticity at r = a

$$p - \sigma_{h0} = 2G\varepsilon_c a_0/a$$

and $G = \dfrac{dp}{2d\varepsilon_c} = V\dfrac{dp}{dV}$

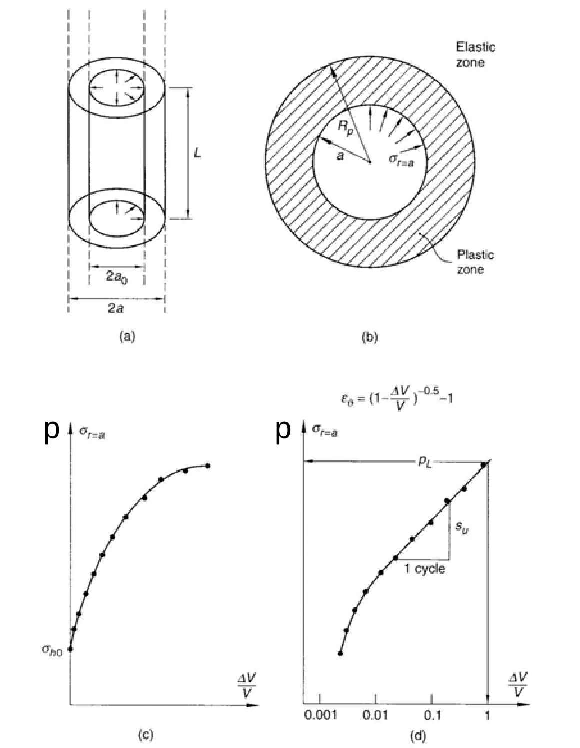


Figure 7.30 Interpretation of a pressuremeter test.

Cavity volumetric strain:

$\Delta V/V = (V - V_0)/V$ where V is the current volume and V_0 is the initial volume

Cavity radial strain:

$\varepsilon_c = \Delta a/a_0 = (a - a_0)/a_0$ where a is the current cavity radius and a_0 is the initial cavity radius

note $\varepsilon_c = \dfrac{\Delta a}{a_0} = \dfrac{1}{\sqrt{1-\dfrac{\Delta V}{V}}} - 1$

In the elastic phase:

The shear modulus G may be obtained from a linear part of a plot of *p vs* ε or *p vs V*

$$G = \frac{dp}{2d\varepsilon_c} = V\frac{dp}{dV}$$

Elastic-plastic phase in clays:

The limit pressure p_L may be obtained by plotting of *p vs ln(ΔV/V)* and hence the undrained strength c_u may be determined

$$p = p_L + c_u.\ln(\Delta V/V)$$

$$V = \pi a^2 L \qquad V_0 = \pi a_0^2 L \qquad d\varepsilon_c = \frac{da}{a_0} \qquad d\varepsilon_v = \frac{dV}{V} = \frac{2\pi a L \times da}{\pi a^2 L} = \frac{2da}{a} = 2d\varepsilon_c$$

$$\varepsilon_v = \frac{\Delta V}{V} = \frac{\pi L\left(a^2 - a_0^2\right)}{\pi L a^2} = 1 - \frac{a_0^2}{a^2} \qquad so\ \frac{a_0^2}{a^2} = 1 - \frac{\Delta V}{V}$$

$$\varepsilon_c = \frac{\Delta a}{a_0} = \frac{a}{a_0} - 1 \quad so\ \varepsilon_c = \frac{1}{\sqrt{1-\dfrac{\Delta V}{V}}} - 1 = \frac{1}{\sqrt{1-\varepsilon_v}} - 1$$

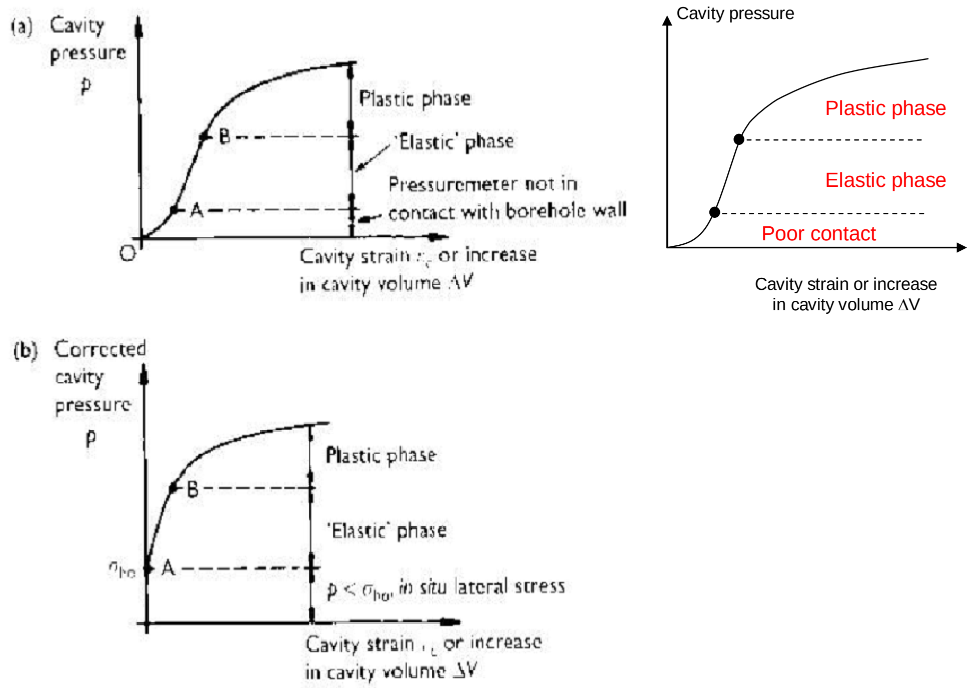
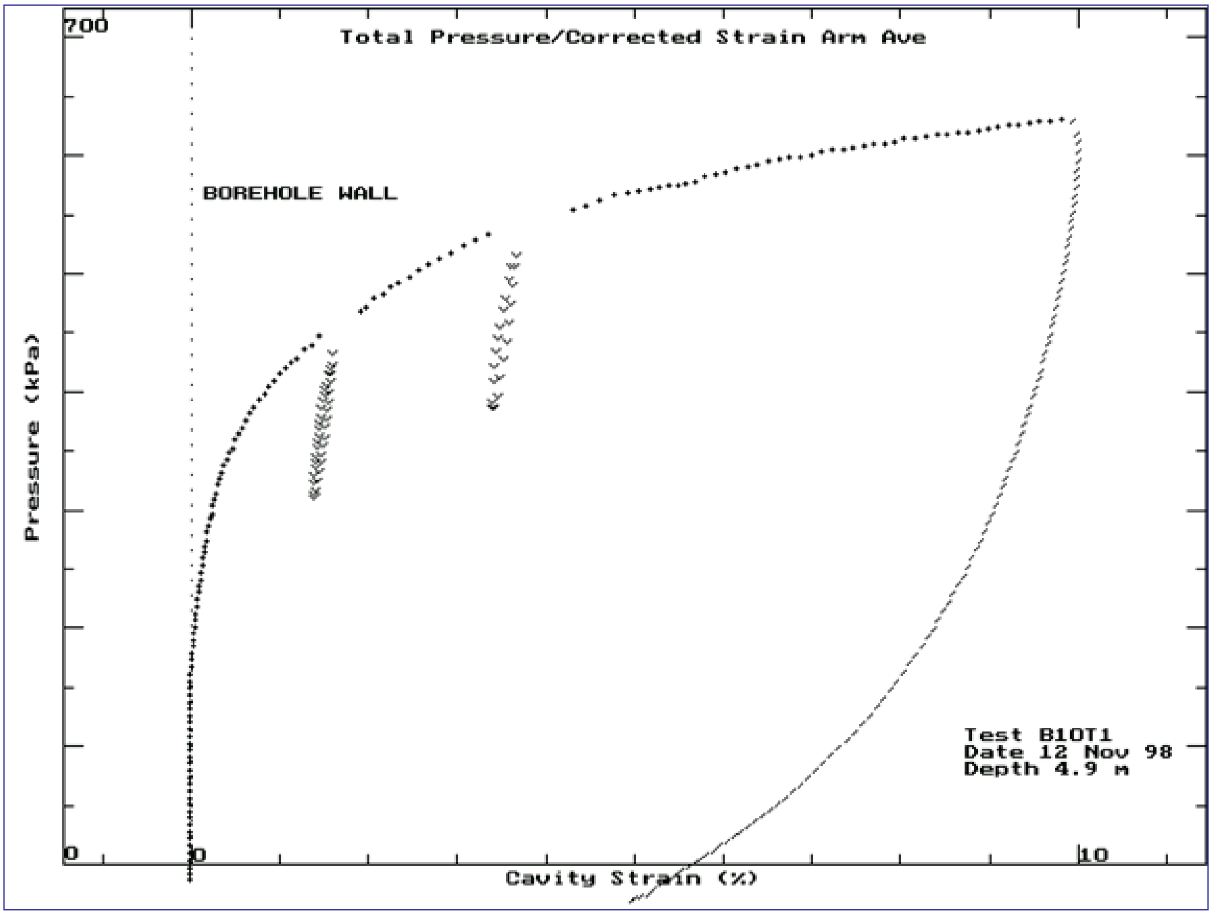


Figure 11.12 Corrected pressuremeter test data plotted as cavity pressure vs. cavity strain or volume change: (a) Menard pressuremeter; (b) self-boring pressuremeter.

Estimation of In-Situ Horizontal Stress

The cavity pressure at point A in Figure 11.12 represents the in-situ horizontal *total* stress σ_{ho} in the ground. This is also referred to as the 'lift off' pressure. Its determination for the Menard pressuremeter requires care and experience, because the soil around the borehole is unloaded prior to the test. Mair and Wood (1987) summarise an iterative procedure suggested by Marsland and Randolph (1977) to determine σ_{ho} from Menard PMTs that partly overcomes this problem.

A short linear region is often observed between points A and B, referred to as the 'elastic' region, although in some tests is almost non-existent. From point B onwards the curves are non-linear as the soil deformation is made up of 'elastic' and 'plastic' components. A limit pressure is approached as the cavity strain is increased to large values.



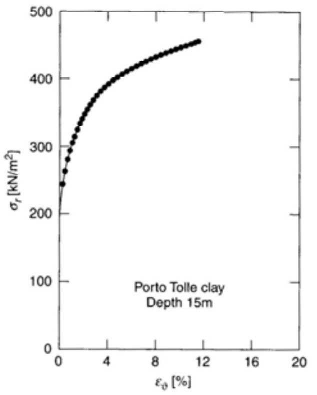


Figure 7.31 Example of expansion curve from a pressuremeter test.

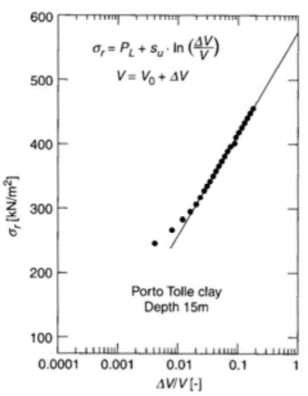
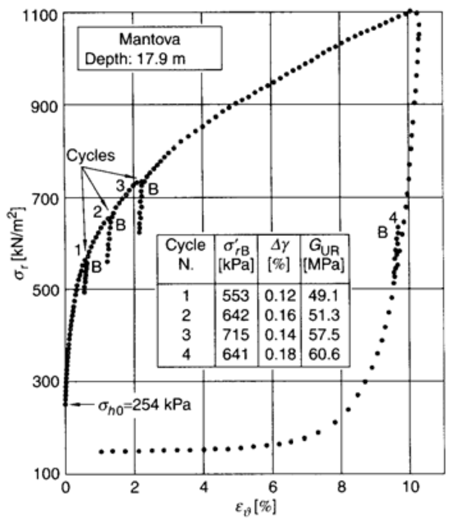


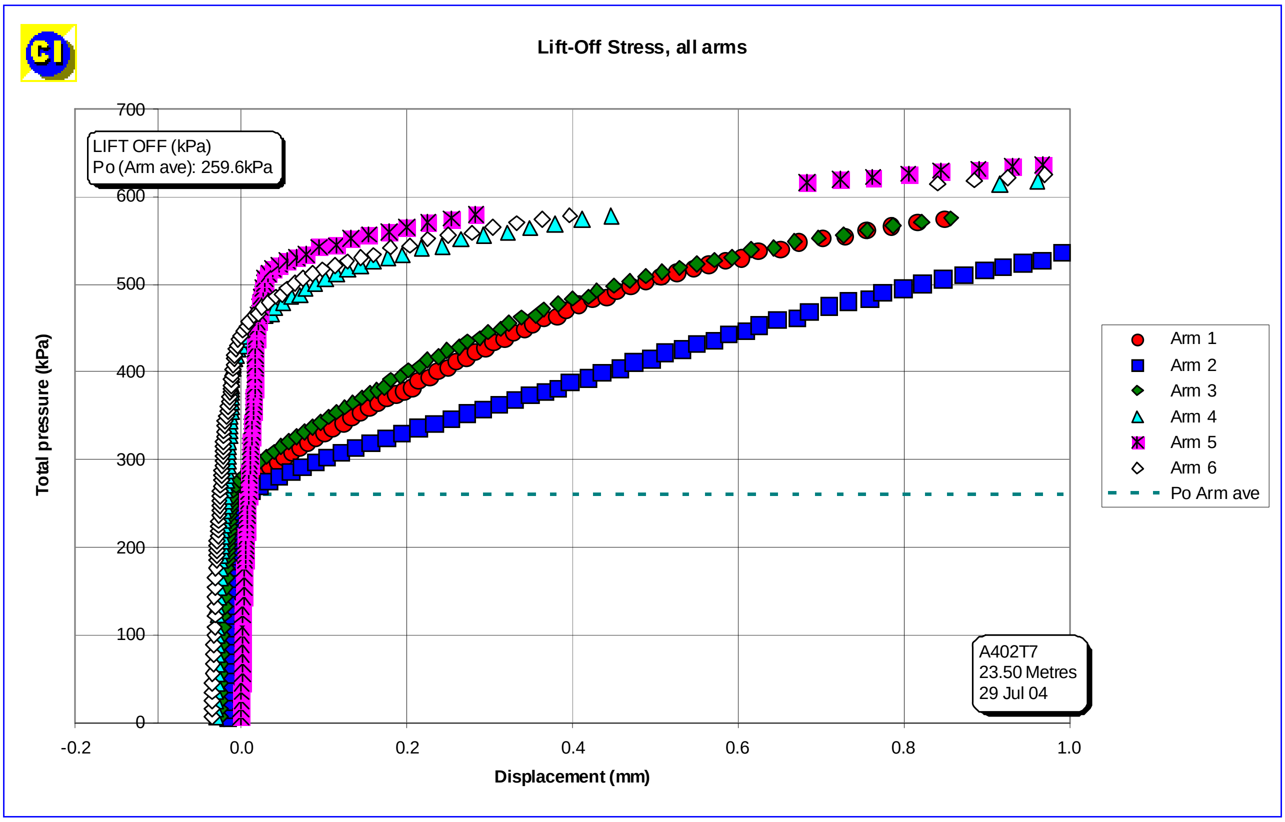
Figure 7.32 Interpreting a pressuremeter test according to Windle and Wroth (1977) procedure.

Some test data in clay and sand



Cycle N.	σ'_{rB} [kPa]	$\Delta\gamma$ [%]	G_{UR} [MPa]
1	553	0.12	49.1
2	642	0.16	51.3
3	715	0.14	57.5
4	641	0.18	60.6

Figure 7.38 Example of a pressuremeter test in Po river sand (Bellotti *et al.*, 1986).



Assessment of horizontal stresses in the ground

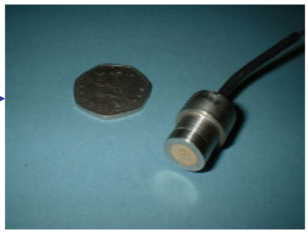
The horizontal stress and K_0 in the ground are difficult to determine but knowledge of their distribution is essential for the analysis of soil-structure interaction around tunnels and excavations. The horizontal stress cannot be calculated without *a priori* knowledge of K_0.

There are several ways to determine σ_h and K_0 including:

Total stress measurement with spade cells;

Lift-off pressures with pressuremeter (SBPM);

Suction measurements on high quality samples.



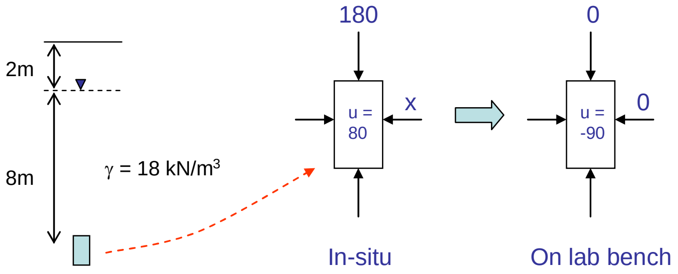
Analysis of stress changes during sampling to find K_0

from Skempton's analysis of pore pressure changes resulting from total stress changes under undrained conditions :

$\Delta u = B.(\Delta\sigma_3 + A.(\Delta\sigma_1 - \Delta\sigma_3))$ where *A* and *B* are pore pressure parameters

for an isotropic elastic material A = 1/3

Example



Lab measurements show that the suction in the sample is 90 kPa

Estimate $K_0 = \sigma'_3/\sigma'_1$ in-situ

$\Delta u =$

$\Delta\sigma_1 =$

$\Delta\sigma_3 =$

so x = kPa

$$K_0 = \frac{(\sigma_3 - u)}{(\sigma_1 - u)} =$$

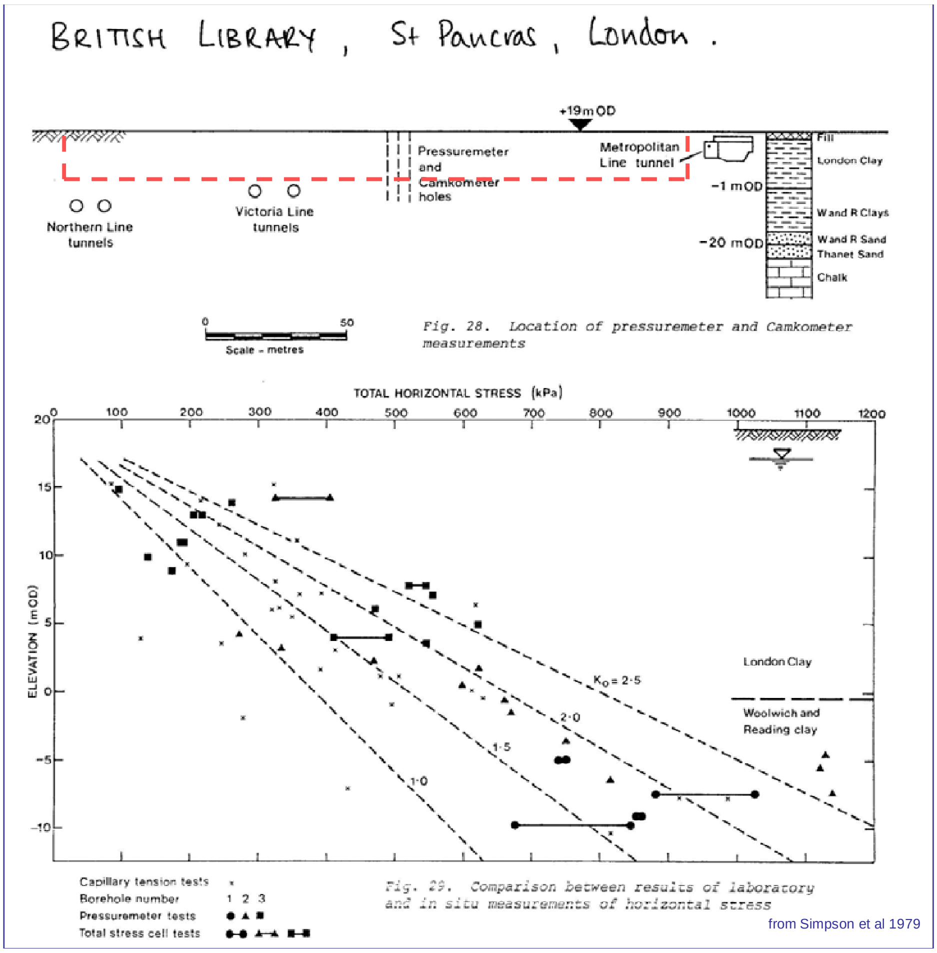


Fig. 28. Location of pressuremeter and Camkometer measurements

Fig. 29. Comparison between results of laboratory and in situ measurements of horizontal stress

Conclusions

The PMT can be used to measure various soil parameters directly including:

Shear stiffness G_{hh}

Lateral stresses and Coefficient of earth pressure at rest K_0

Undrained shear strength of clays c_u

Angle of shearing resistance of granular soils ϕ'

It is a specialist equipment and requires careful calibration, operation and interpretation.

Geophysics methods – crosshole and down hole tests