The pressuremeter set developed by MÉNARD is based on the idea of a lateral pressure device according to KÖGLER (1933) and consists on the one hand of a cylindrical probe, which can be extended laterally and is lowered into a borehole down to testing depth, and on the other hand of a measuring apparatus that remains on the surface. The probe, which consists of three cells, exerts a calculable uniform pressure on the bore-hole wall in the area of the central measuring cell. The displacement of the borehole wall caused by the loading is read off and recorded for each pressure stage as a function of time (Fig. 1).

The pressure and control mechanisms are based on pneumatic principles. Data concerning the deformation of the soil is transmitted hydraulically and appears on a high-precision volumeter. The sets can be equipped with a series of probes in diameters to match the most common boreholes and named according to their nominal diameter:

Code DCDMA	Probe diameter mm	Borehole diameter mm	
		min.	max.
EX	32	34	38
AX	44	46	52
BX	58	60	66
NX	(72) 74	(74) 76	80

The sets in current use belong to type G. They are characterised by two concentric connection lines for water and air (coaxial hose), which prevent parasitic extensions. Their use even in hard rock (modulus of elasticity ≥ 20.000 MPa) thus appears to be possible.

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In very soft soil characterised by a boundary pressure of less than 1.5 bar, it is advisable to use a membrane and protective sleeve made of very soft material (latex) with an intrinsic rigidity of less than 0.6 bar. This is the case with sludge and peat.

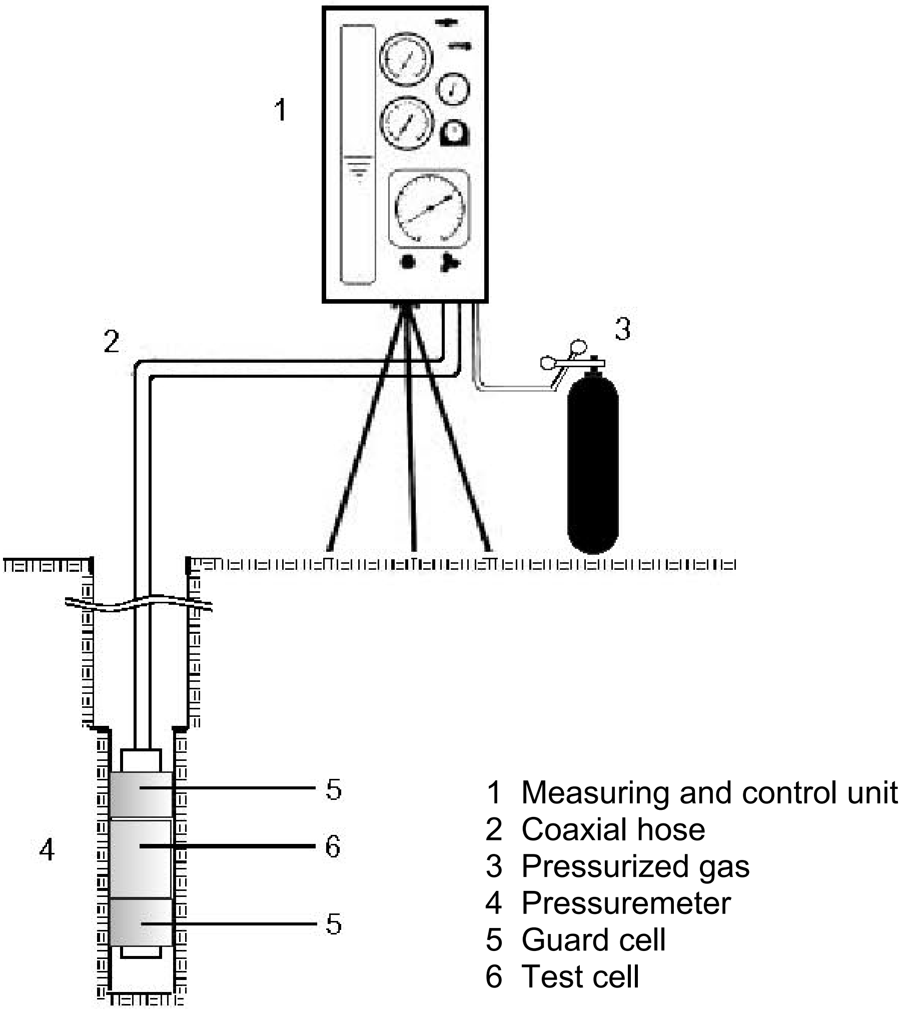

Fig. 1 Schematic test setup for the pressuremeter test according to MÉNARD

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For very high moduli (above 2.000 MPa), on the other hand, you must use highly resistant membranes and protective sleeves, which are calibrated in advance. These membranes are characterised by poorer but more uniform compression. If the change of volume caused by a 1 bar change in pressure turns out to be less than 0.5 cm³ (modulus higher than 400 MPa), you should use the changeover device on the volumeter, which increases the sensitivity of the readings a hundred-fold.

The standard test must be conducted within 24 hours of making the borehole; this does not apply to cast-in-situ probes, for which there is no fear of the soil being disturbed by the risk of water ingress in the borehole. If need be, intervals of several days may be allowed for boreholes without water flushing (hand auger, pneumatic drilling with pneumatic conveyance of the rock cuttings) above the ground water level.

The test itself is standardised and must be conducted using 10 identical pressure stages (6 to 14 pressure stages are permitted) until the failure limit is reached. Readings of the borehole deformation (volume increase) as a function of time are taken for each pressure after 15, 30 and 60 seconds of reaching the pressure (Fig. 2).

To obtain as exact a load curve as possible, the measured volume must equal 700 cm³ when $p_l < 8$ bar and 600 cm³ when 8 bar $< p_l <$ 15 bar. In the remaining cases the test must be continued at up to 20 - 25 bar pressure in soils and 50 - 70 bar in rock.

The chief mechanical properties of the soil, i. e. the deformation modulus (MÉNARD modulus E_M) and the limit pressure (failure limit p_l), are calculated from the load/volume diagrams (material stress-deformation diagram) for each depth level. The pressiometric modulus E_M is a shear modulus of the soil measured in a deviatoric field of stress. It characterises the pseudo-elastic phase of the test.

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By definition, the limit pressure p_l corresponds to the limit failure state of the soil when it is exposed to a uniformly increasing load acting on the wall of a cylindrical cavity.

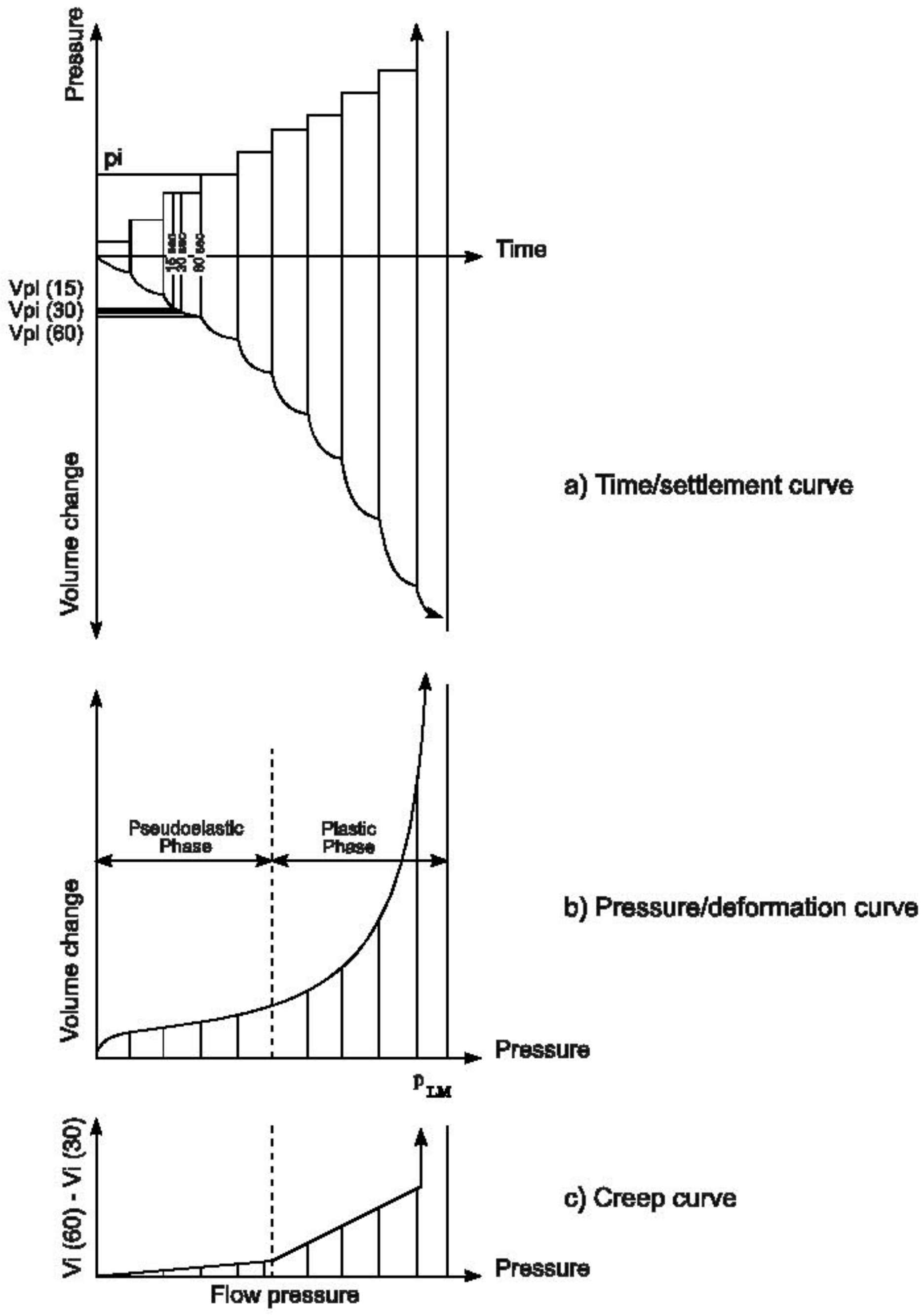

Fig. 2 Schematic test recording of a MÉNARD test

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To calculate the pressiometer modulus (E_M) you proceed from the basic formula according to LAMÉ for the expansion Δr of a cylindrical cavity with radius r and the effect of an increasing pressure Δp:

$$\frac{\Delta r}{r}=\frac{1+\nu}{E}\Delta p \qquad \text{or} \qquad E=(1+\nu)\frac{r}{\Delta r}\Delta p$$

where ν is Poisson's ratio. If the volume change Δv is used instead of the radius change Δr, the formula is:

$$E = 2\,(1+\nu)\,v\,\frac{\Delta p}{\Delta v}$$

The pressiometer modulus E_M is:

$$E_M = K\,\frac{\Delta p}{\Delta v}$$

where K is a geometric constant of the pressiometer probe. Δp and Δv are the related changes of pressure and volume in the pseudo-elastic phase of the test (Fig. 2b). The lower limit of the range of fluctuation Δp should always be higher than the horizontal earth pressure at rest p_h.

It can be shown that:

$$K = 2.66\,(v_o + v_m)$$

where

v_o	is the volume of the measuring cell at rest
v_m	is the volume of liquid which is filled into the measuring cell on account of the applied mean pressure p_m

Poisson's ratio *v* is normally taken as 0.33.

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The limit pressure p_l is derived from the position of the asymtote on the pressiometric curve and can be read off the absciss directly in the diagram.

The following typical values are listed to provide an idea of the magnitude of E_M and p_l:

Soil type	E_M [MPa]		p_l [bar]	
Sludge and peat	0.2 to	1.5	0.2 to	1.5
Soft clays	0.5 to	3.0	0.5 to	3.0
Plastic clays	3.0 to	8.0	3.0 to	8.8
Stiff clays	8.0 to	40.0	6.0 to	20.0
Marl	5.0 to	60.0	6.0 to	40.0
Silty fine sands	0.5 to	2.0	1.0 to	5.0
Silts	2.0 to	10.0	1.0 to	15.0
Gravelly sands	8.0 to	40.0	12.0 to	50.0
Fine sands	7.5 to	40.0	10.0 to	50.0
Calcareous rock	80.0 to	20,000	30.0 to	above 100
New fills	0.5 to	5.0	0.5 to	3.0
Old fills	4.0 to	15.0	4.0 to	10.0

Due to the fact that the LAMÉ equation disregards the absence of the tensile strength of the examined soil, a modulus two or three times smaller than the modulus determined by other customary methods is determined with the MÉNARD test. That's why the result of the pressuremeter test is also named MÉNARD modulus E_M. This modulus is only used in a specific proceeding to dimension a foundation or piles.

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