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Geotechnical investigation and testing — Field testing —

Part 4: Ménard pressuremeter test

Reconnaissance et essais géotechniques — Essais en place —
Partie 4: Essai au pressiomètre de Ménard

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 22476-4 was prepared by the European Committee for Standardization (CEN) Technical Committee CEN/TC 341, *Geotechnical investigation and testing*, in collaboration with Technical Committee ISO/TC 182, *Geotechnics*, Subcommittee SC 1, *Geotechnical testing*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

ISO 22476 consists of the following parts, under the general title *Geotechnical investigation and testing — Field testing*:

— *Part 1: Electrical cone and piezocone penetration test*

— *Part 2: Dynamic probing*

— *Part 3: Standard penetration test*

— *Part 4: Ménard pressuremeter test*

— *Part 5: Flexible dilatometer test*

— *Part 7: Borehole jack test*

— *Part 9: Field vane test*

— *Part 10: Weight sounding test* [Technical Specification]

— *Part 11: Flat dilatometer test* [Technical Specification]

— *Part 12: Mechanical cone penetration test (CPTM)*

Geotechnical investigation and testing — Field testing —

Part 4: Ménard pressuremeter test

1 Scope

This part of ISO 22476 specifies the equipment requirements, execution of and reporting on the Ménard pressuremeter test.

NOTE 1 This part of ISO 22476 fulfils the requirements for the Ménard pressurermeter test, as part of the geotechnical investigation and testing according to EN 1997-1 and EN 1997-2.

This part of ISO 22476 describes the procedure for conducting a Ménard pressuremeter test in natural soils, treated or untreated fills and in weak rocks, either on land or off-shore.

The pressuremeter test results of this part of ISO 22476 are suited to a quantitative determination of ground strength and deformation parameters. They may yield lithological information. They can also be combined with direct investigation (e.g. sampling according to ISO 22475-1) or compared with other *in situ* tests (see EN 1997-2:2007, 2.4.1.4(2) P, 4.1 (1) P and 4.2.3(2) P).

The Ménard pressuremeter test is performed by the radial expansion of a tricell probe placed in the ground (see Figure 1). During the injection of the liquid volume in the probe, the inflation of the three cells first brings the outer cover of the probe into contact with the pocket wall and then presses on them resulting in a soil displacement. Pressure applied to and the associated volume expansion of the probe are measured and recorded so as to obtain the stress-strain relationship of the soil as tested.

Together with results of investigations with ISO 22475-1 being available, or at least with identification and description of the ground according to ISO 14688-1 and ISO 14689-1 obtained during the pressuremeter test operations, the test results of this part of ISO 22476 are suited to the quantitative determination of a ground profile, including

— the Ménard E_M modulus,

— the Ménard limit pressure p_{LM} and

— the Ménard creep pressure p_{fM}.

This part of ISO 22476 refers to a probe historically described as the 60 mm G type probe. This part of ISO 22476 applies to test depths limited to 50 m and test pressure limited to 5 MPa.

NOTE 2 Ménard pressuremeter tests are carried out with other probe diameters and pocket dimensions such as shown below.

Probe		**Drilling diameter** (mm)	
Designation	**Diameter** (mm)	**min**	**max**
AX	44	46	52
BX	58	60	66
NX	70/74	74	80

Two alternative methods of measurement are provided as follows.

— Procedure A: data are recorded manually.

— Procedure B: data are recorded automatically.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14688-1, *Geotechnical investigation and testing — Identification and classification of soil — Part 1: Identification and description*

ISO 14689-1, *Geotechnical investigation and testing — Identification and classification of rock — Part 1: Identification and description*

ISO 22475-1, *Geotechnical investigation and testing — Sampling methods and groundwater measurements — Part 1: Technical principles for execution*

ENV 13005:1999, *Guide to the expression of uncertainty in measurement*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
pressuremeter
whole equipment which is used to carry out a Ménard pressuremeter test, excluding the means necessary to place the pressuremeter probe into the ground

NOTE 1 A pressuremeter includes a pressuremeter probe, a pressure and volume control unit, called CU, lines to connect the probe to the CU and, in the case of procedure B, a data logger which is either built into the CU or linked to it.

NOTE 2 See Figure 2.

3.1.2
pressuremeter test pocket
circular cylindrical cavity formed in the ground to receive a pressuremeter probe

3.1.3
pressuremeter borehole
borehole in which pressuremeter pockets with circular cross sections are made in the ground, and into which the pressuremeter probe is to be placed

3.1.4
pressuremeter test
process during which a pressuremeter probe is inflated in the ground and the resulting pocket expansion is measured by volume as a function of time and pressure increments according to a defined programme

NOTE See Figure 4 and F.1.

3.1.5
pressuremeter sounding
whole series of sequential operations necessary to perform Ménard pressuremeter testing at a given location, i.e. forming pressuremeter test pockets and performing pressuremeter tests in them

NOTE See F.2.

3.1.6
pressuremeter pressure reading, p_r
pressure p_r as read at the CU elevation in the liquid circuit supplying the central measuring cell

3.1.7
pressure loss
difference between the pressure inside the probe and the pressure applied to the pocket wall

3.1.8
volume loss
difference between the volume actually injected into the probe and the volume read on the measuring device

3.1.9
raw pressuremeter curve
graphical plot of the injected volumes recorded at time 60 s, V_{60}, versus the applied pressure at each pressure hold, p_r

3.1.10
corrected pressuremeter curve
graphical plot of the corrected volume V versus the corrected pressure p

NOTE See Figure 5.

3.1.11
Ménard creep
difference in volumes recorded at 60 s and at 30 s at each pressure hold: $V_{60} - V_{30} = \Delta V_{60/30}$

3.1.12
corrected Ménard creep curve
graphical plot of the corrected Ménard creep versus the corrected applied pressure at each pressure hold

NOTE See Figure 5.

3.1.13
pressuremeter log
graphical report of the results of the pressuremeter tests performed in pockets at a succession of depths in the same pressuremeter borehole, together with all the information gathered during the drilling

NOTE See Annex F.

3.1.14
Ménard pressuremeter modulus, E_M
E-modulus obtained from the section between (p_1, V_1) and (p_2, V_2) of the pressuremeter curve

NOTE See Figure 5 and Annex D.

3.1.15
Ménard pressuremeter limit pressure, p_{LM}
pressure at which the volume of the test pocket at the depth of the measuring cell has doubled its original volume

NOTE See Annex D.

3.1.16
pressuremeter creep pressure, p_{fM}
pressure derived from the creep curve

NOTE See Annex D.

3.1.17
operator
qualified person who carries out the test

3.1.18
casing
lengths of tubing inserted into a borehole to prevent the hole caving in or to prevent the loss of flushing medium to the surrounding formation, above pocket location

3.2 Symbols

For the purposes of this document, the symbols given in Table 1 apply.

Table 1 — Symbols

Symbol	Description	Unit
a	Apparatus volume loss coefficient	cm^3/MPa
d_{ci}	Outside diameter of the inner part of the probe with slotted tube	mm
d_i	Inside diameter of the calibration cylinder used for the volume loss calibration	mm
d_c	Outside diameter of the central measuring cell, including any additional protection such as a slotted tube	mm
d_t	Drilling tool diameter	mm
e	Wall thickness of the calibration cylinder used for the volume loss calibration	mm
l_p	Length of the calibration cylinder used for the volume loss calibration	mm
l_g	Length of each guard cell	mm
l_{gs}	Length of each guard cell for a short central measuring cell pressuremeter probe	mm
l_{gl}	Length of each guard cell for a long central measuring cell pressuremeter probe	mm
l_m	Length along the tube axis of the slotted section of the slotted tube	mm
l_c	Length of the central measuring cell of the probe, measured after fitting the membrane	mm
l_{cs}	Length of the short central measuring cell after fitting the membrane	mm
l_{cl}	Length of the long central measuring cell after fitting the membrane	mm
m_E	Minimum value, strictly positive, of the m_i slopes	cm^3/MPa
m_i	Slope of the corrected pressuremeter curve between the two points with coordinates (p_{i}-1, V_{i}-1) and (p_i, V_i).	cm^3/MPa
p	Pressure applied by the probe to the ground after correction	MPa
p_e	Correction for membrane stiffness usually called pressure loss of the probe	MPa
p_E	Pressure at the origin of the segment exhibiting the slope m_E	MPa
p_{el}	Ultimate pressure loss of the probe	MPa
p_{fM}	Pressuremeter creep pressure	MPa
p_g	Gas pressure applied by the control unit indicator to the guard cells of the pressuremeter probe	MPa
p_h	Hydrostatic pressure between the control unit indicator and the central measuring cell of the pressuremeter probe	MPa
p_k	Gas pressure in the guard cells	MPa
p_{LM}	Ménard pressuremeter limit pressure of the ground	MPa
p_{LM}^*	Ménard net pressuremeter limit pressure of the ground	MPa
p_{LMH}	Ménard pressuremeter limit pressure as extrapolated by the hyperbolic best fit method	MPa
p_{LMDH}	Ménard pressuremeter limit pressure as extrapolated by the double hyperbolic method	MPa
p_{LMR}	Ménard pressuremeter limit pressure as extrapolated by the reciprocal curve method	MPa
p_m	Pressure loss of the central measuring cell membrane for a specific expansion	MPa
p_r	Pressure reading at the CU transducer elevation in the central measuring cell liquid circuit	MPa
p_c	Liquid pressure in the central measuring cell of the pressuremeter probe	MPa
p_t	Target pressure for each pressure hold according to loading programme	MPa
p_1	Corrected pressure at the origin of the pressuremeter modulus pressure range	MPa
p_2	Corrected pressure at the end of the pressuremeter modulus pressure range	MPa
t	Time	s
t_i	Time required for incrementing to the next pressure hold	s
t_h	Time the loading pressure level is held	s

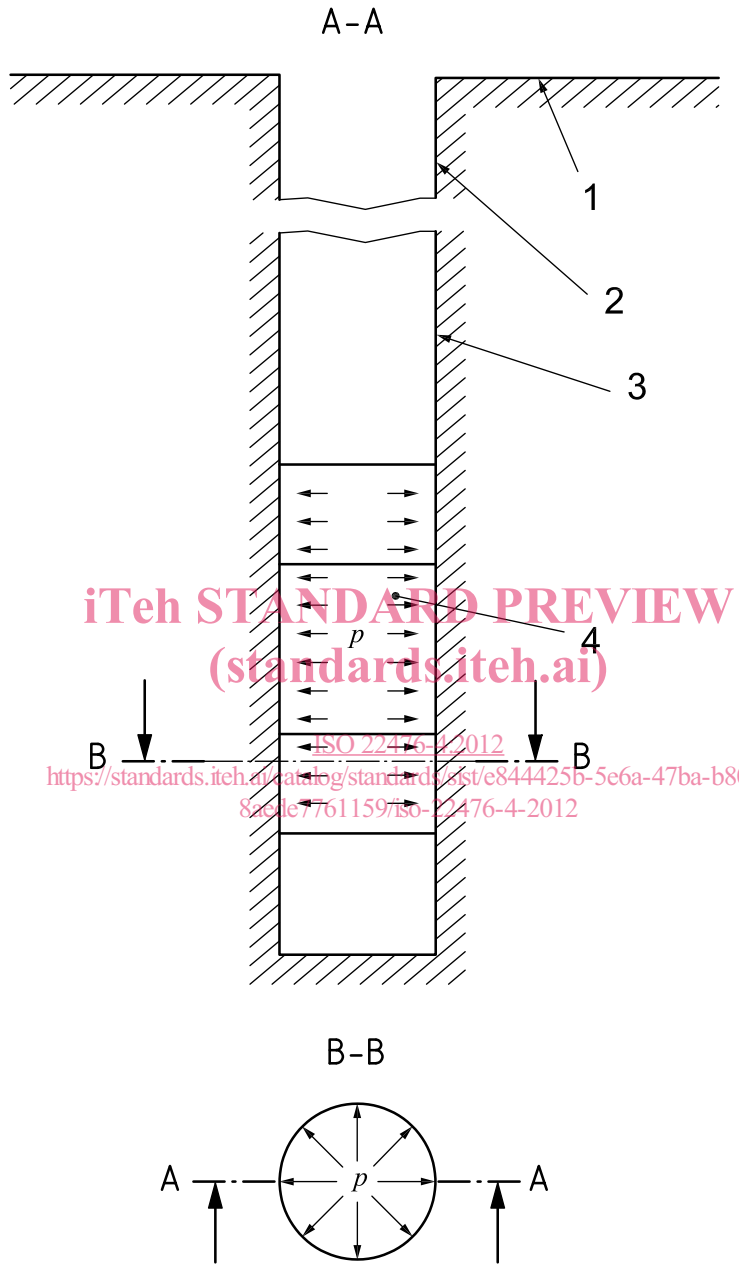
Table 1 *(continued)*

Symbol	Description	Unit
u_s	Pore water pressure in the ground at the depth of the test	MPa
z	Elevation, positively counted above datum	m
z_c	Elevation of the pressure measuring device for the liquid injected in the measuring cell	m
z_{cg}	Elevation of the pressure measuring device for the gas injected in the guard cells of the pressuremeter probe	m
z_N	Elevation of the ground surface at the location of the pressuremeter sounding	m
z_p	Elevation of the measuring cell centre during testing	m
z_w	Elevation of the ground water table (or free water surface in a marine or river environment)	m
CU	Pressure and volume control unit	—
E	Type of pressuremeter probe where the three cells are formed by three separate membranes in line	—
E_M	Ménard pressuremeter modulus	MPa
G	Type of pressuremeter probe where the central measuring cell is formed by a dedicated membrane over which an external membrane is fitted to form the guard cells (see Figure 2)	—
K_o	Coefficient of earth pressure at rest at the test depth	—
V	Value, after zeroing and data correction, of the volume injected in the central measuring cell and measured 60 s after starting a pressure hold	cm^3
V_c	Original volume of the central measuring cell, including the slotted tube, if applicable	cm^3
V_m	The average corrected volume between V_1 and V_2	cm^3
V_p	Volume obtained in the volume loss calibration test (see Figure B.2)	cm^3
V_E	Value, after data correction, of the volume injected in the central measuring cell for pressure p_E	cm^3
V_L	Value, after data correction, of the volume injected in the central measuring cell when the original volume of the pressuremeter cavity has doubled	cm^3
V_r	Volume injected in the probe as read on the CU, before data correction	cm^3
V_t	Volume of the central measuring cell possibly including the slotted tube	cm^3
V_1	Corrected volume at the origin of the pressuremeter modulus pressure range (see Figure 5)	cm^3
V_2	Corrected volume at the end of the pressuremeter modulus pressure range	cm^3
V_{30}	Volume injected in the central measuring cell as read 30 s after the beginning of the pressure hold	cm^3
V_{60}	Volume injected in the central measuring cell as read 60 s after the beginning of the pressure hold	cm^3
β	Coefficient used to determine the pressuremeter modulus pressure range	—
γ	Unit weight of soil at the time of testing	KN/m^3
γ_l	Unit weight of the liquid injected in the central measuring cell	KN/m^3
γ_w	Unit weight of water	KN/m^3
λ_g	Rate of change of pressure head of gas at p_k per metre depth	m^{-1}
ν	Poisson's ratio	—
σ_{vs}	Total vertical stress in the ground at test depth	kPa
σ_{hs}	Total horizontal stress in the ground at test elevation	kPa
Δp	Loading pressure increment	MPa
Δp_1	Initial pressure increment	MPa
$\Delta V_{60/30}$	Injected volume change from 30 s to 60 s after reaching the pressure hold − the Ménard creep	cm^3
$\Delta V_{60/60}$	60 s injected volume change between successive pressure holds	cm^3

4 Equipment

4.1 General description

The principle of the Ménard pressuremeter test is shown in Figure 1.



Key

1	ground surface
2	ground
3	pocket
4	expanding pressuremeter probe
p	applied pressure
A–A	axial section
B–B	cross section

Figure 1 — Principle of a Ménard pressuremeter test

The pressuremeter as shown schematically in Figure 2 shall include:

— tri-cell probe;

— string of rods to handle the probe;

— control unit (CU);

— lines connecting the control unit to the probe.

The control unit (CU) shall include:

— equipment to pressurize, and so to inflate the probe, and to maintain constant pressures as required during the test;

— equipment to maintain an appropriate pressure difference between the central measuring cell and the guard cells;

— device which permits the direct reading and, in the case of procedure B, the automatic recording of the parameters to be measured: time, pressure and volume.

The pressure measuring devices for the liquid in the central measuring cell and for the gas in the guard cells shall be located either

— above the ground surface, or

— inside the probe, less than 1 m above the centre of the central measuring cell.

In the first case, the CU shall be provided with means to check the stabilized pressure value at the probe.

Some means of measuring the depth of the test with appropriate accuracy shall be provided.

4.2 Pressuremeter probe

Two types of probe shall be used according to ground type and condition:

— probe with a flexible cover;

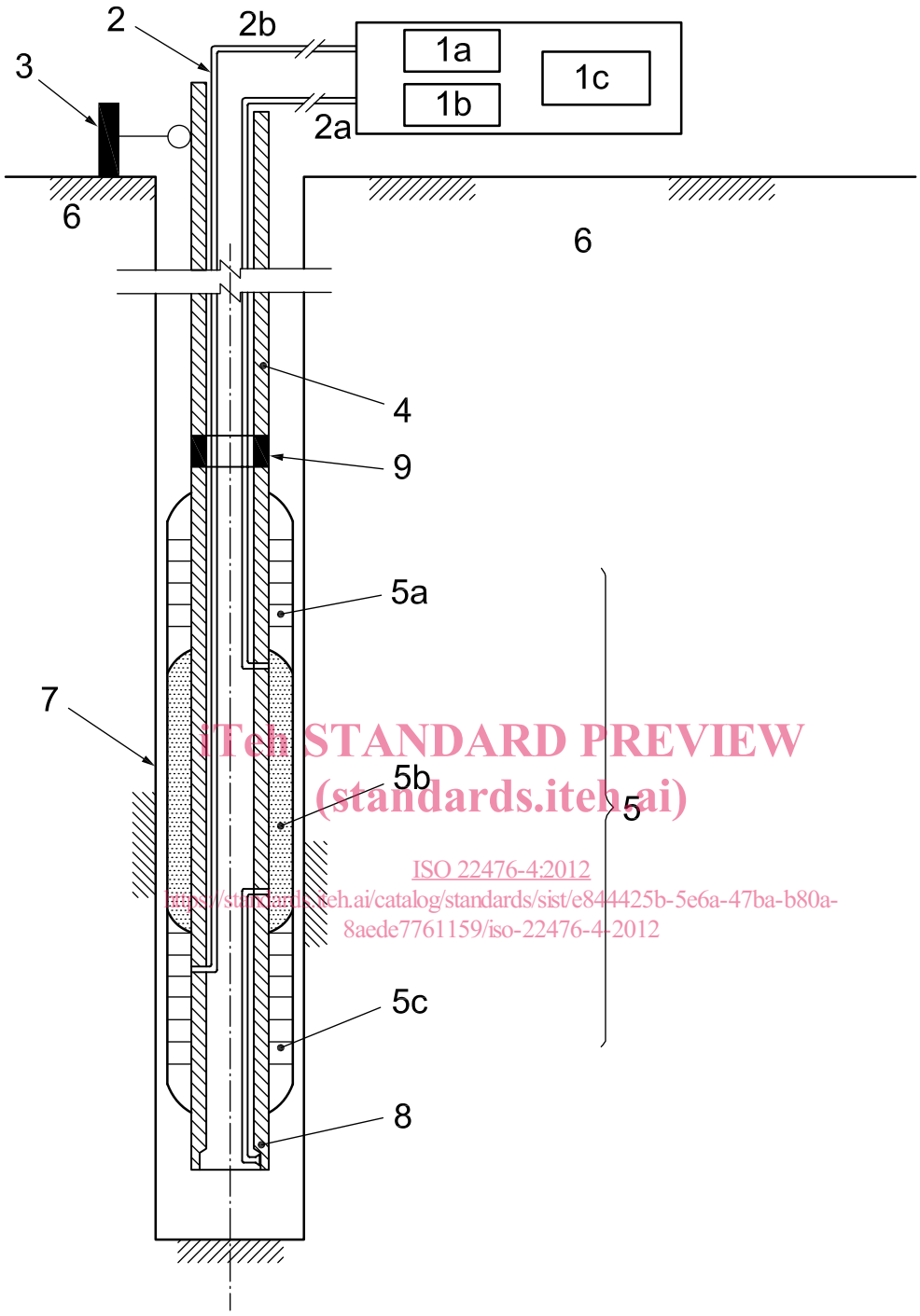
— probe with a flexible cover and either an additional more rigid protection or a slotted steel tube.

These probes are described in Figure 3 a) and Figure 3 b), respectively, and their geometrical features are given in Table A.1.

When the probe is driven or pushed into the ground (see C.3), it shall be fitted with the more rigid protection or a slotted tube together with a extension tube completed by either a point or a cutting shoe.

NOTE If no slotted tube is involved, the probe body must be designed to withstand driving or pushing.

The probe shall be capable of a volumetric expansion of at least 700 cm^3 (550 cm^3 for a probe with a short central measuring cell within a slotted tube).



Key

1 control unit (CU):
1a pressurization, differential pressurization and injection devices
1b pressure and volume measuring devices
1c acquisition, storage and printing out of the data (required for procedure B)
2 connecting lines:
2a line for liquid injection
2b line for gas injection
3 depth measurement system
4 rods
5 pressuremeter probe:
5a upper guard cell
5b central measuring cell
5c lower guard cell
6 ground
7 pressuremeter test pocket
8 probe body, hollow
9 probe rod coupling

Figure 2 — Diagram of a Ménard pressuremeter

4.2.1 Probe with flexible cover

The probe shall be made up of three cylindrical cells of circular cross-section along the same axis (see Figure A.1). During a test these cells shall expand simultaneously against the pocket wall. The probe includes:

— one central measuring cell, with an outside diameter d_c and a length l_c (l_{cl} for a “long probe” or l_{cs} for short probe – see Table A.1), which shall expand radially in a pocket and shall apply a uniform stress to the pocket wall. This cell shall be inflated by injecting a liquid which is assumed to be incompressible;

— two guard cells with an outside diameter d_g and a length l_g (l_{gl} or l_{gs}) located above and below the central measuring cell. These cells shall be designed to apply to the pocket wall a stress close to, but not greater than, the stress induced by the central measuring cell. These cells shall be inflated by gas pressure.

The probe shall consist of a hollow steel core with passages to inject the proper fluids to inflate the cells. The probe shall be fitted with a central measuring cell membrane and a flexible cover sleeve. The steel core, on its outside curved surface, shall usually bear a network of grooves which uniformly distribute the liquid in the central measuring cell under the membrane. To this core shall be fixed the membrane and the flexible cover. The top of the core shall be threaded and coupled to the string of rods handling the probe from ground level; the central measuring cell membrane shall isolate the fluid in the central measuring cell from the gas of the guard cells. The flexible cover which overlies the central measuring cell membrane shall give form to the guard cells. A flexible protection made of thin steel strips usually 17 mm wide either overlapping (up to half-way) or isolated, running between fixing rings (see Figure A.1) may be added over the cover. Fluid lines shall connect the probe cells to the pressure and volume control unit (CU). The drain tap of the measuring cell shall protrude from the bottom of the steel core.

NOTE The flexible protection may be added to reduce damage to the cover from sharp fragments protruding from the pocket wall.

4.2.2 Probe with slotted tube

This probe shall consist of two parts:

— an inner part which shall be an assembly of three cylindrical cells of circular cross-section along the same axis; and

— an outer part which shall be made of a slotted steel tube (see Figure A.1). When this slotted tube is pushed or driven into the soil it shall be fitted with an extension pipe ending with a point or a cutting shoe.

The inner part includes:

— one central measuring cell, with an outside diameter d_c and a length l_c (l_{cl} for a “long probe” or l_{cs} for short probe – see Table A.1), which shall expand radially in the slotted tube and shall apply a uniform stress to the tube wall. This cell shall be inflated by injecting a liquid which is assumed to be incompressible;

— two guard cells with an outside diameter d_g and a length l_g (l_{gl} or l_{gs}), located above and below the central measuring cell. These cells shall be designed to apply to the slotted tube wall a stress close to, but not greater than, the stress induced by the central measuring cell. These cells shall be inflated by gas pressure.

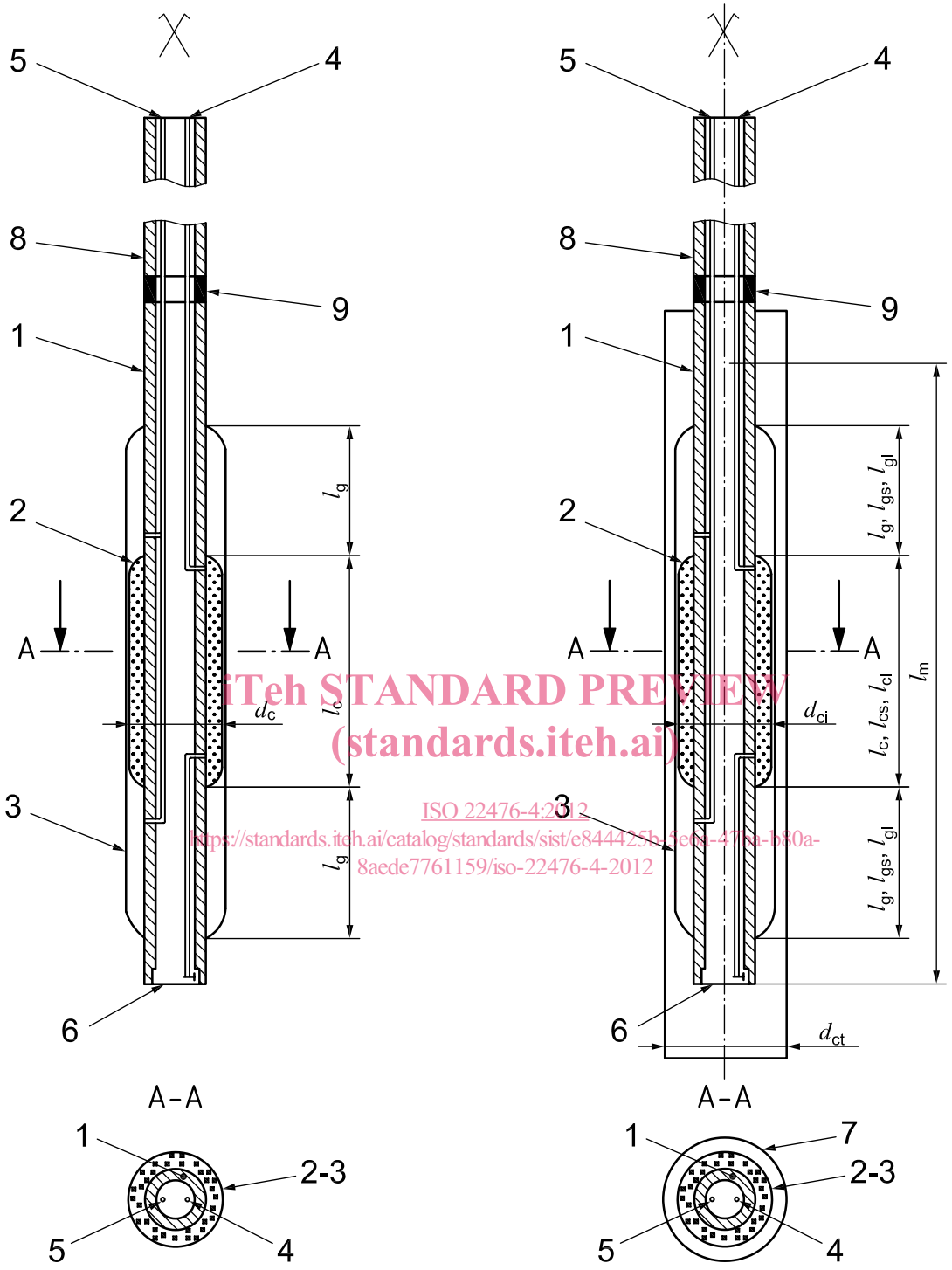
During a test these cells shall act simultaneously on the inside wall of the slotted tube, which shall transfer the stresses to the pocket wall.

The outside steel tube shall carry at least six axial or helical slots evenly distributed round the circumference (Figure 3 b).The tube slotted length l_m is measured along the tube axis. This length shall be the greater of:

$$1,3\ (l_c + 2\ l_g) \text{ or } 800 \text{ mm}$$

Before and after expansion, the opening of each slot of the tube shall be less than or equal to 0,4 mm. After expansion the slotted tube and the slots shall be able to recover their original shape and size.

The assembly within the slotted tube shall be located by flexible spacers so as to allow the probe to expand radially with a minimum of resistance.



a) pressuremeter probe with flexible cover **b) pressuremeter probe with slotted tube**

Key

1 hollow probe body
2 measuring cell membrane
3 external sleeve or flexible cover
4 liquid inlet to the measuring cell
5 gas inlet to the guard
6 measuring cell drain outlet
7 slotted tube
8 rods
9 probe–rod coupling

Dimensions are given in Annex A.

Figure 3 — Pressuremeter probe (diagrammatic)

4.3 Pressure and volume control unit (CU)

The control unit (CU) shall be built around a cylindrical volumeter fitted with a pressurizing device and a set of measuring devices. The CU shall control the probe cell expansion and permit the simultaneous reading of liquid and gas pressures and injected liquid volume as a function of time.

The pressurizing device shall allow:

— reaching the pressuremeter limit pressure or a pressure p_r at least equal to 5 MPa;

— holding constant each loading pressure level in the measuring cell and in the guard cells during the set time;

— implementing a pressure increment of 0,5 MPa in less than 20 s as measured on the CU;

— controlling the pressure difference between the measuring cell and the guard cells;

— injecting a volume of liquid in the measuring cell larger than 700 cm^3.

Further, in the control unit a valve between the volumeter and the pressure measuring device shall allow stopping the injection.

4.4 Connecting lines

The flexible lines shall connect the pressure and volume control unit (CU) to the probe. They shall convey the liquid to the measuring cell and the gas to the guard cells. They may be parallel or coaxial. When the lines are coaxial the central line shall convey the liquid and the outer line the gas.

4.5 Injected liquid

The liquid injected into the measuring cell is either water or a liquid of similar viscosity and shall not freeze under the conditions of use.

4.6 Measurement and control

4.6.1 Time

The accuracy of the device used to measure time shall be in accordance with Annex E.

4.6.2 Pressure and volume

The resolution of measurement of the devices measuring pressure and volume shall be in accordance with Annex E.

4.6.3 Display of readings

At the site the pressure and volume control unit (CU) shall give a simultaneous and instantaneous display of the following readings: time, pressure of the liquid injected into the measuring cell, volume of the liquid injected and pressure of the gas in the guard cell circuit.

4.6.4 Volume loss calibration cylinder

The main features of this steel cylinder (Figure B.1) shall be as follows:

— measured inside diameter d_i not more than 66 mm;

— wall thickness e not less than 8 mm;

— length l_p more than 1 m or the slot length l_m, whichever is greater.