INTERNATIONAL STANDARD

ISO 22476-6

First edition
2018-09

Geotechnical investigation and testing — Field testing —

Part 6: Self-boring pressuremeter test

Reconnaissance et essais géotechniques — Essais en place —

Partie 6: Essai pressiométrique autoforé

Reference number
ISO 22476-6:2018(E)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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

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Geotechnical investigation and testing — Field testing —

Part 6:
Self-boring pressuremeter test

1 Scope

This document specifies the equipment requirements, execution of and reporting on self-boring pressuremeter (SBP) tests.

NOTE This document fulfils the requirements for self-boring pressuremeter test as part of the geotechnical investigation services according to EN 1997-1 and EN 1997-2.

Tests with the self-boring pressuremeter cover the measurement in situ of the deformation of soils and weak rocks by the expansion and contraction of a cylindrical flexible membrane under pressure.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 10012, *Measurement management systems — requirements for measurement processes and measuring equipment*

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

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
self-boring pressuremeter
SBP
equipment used to carry out a *self-boring pressuremeter test* (3.5), including the *self-boring head* (3.3) used to drill the test pocket into the ground and the *pressuremeter* (3.2) used to carry out the expansion

Note 1 to entry: An SBP includes a probe composed of a *self-boring head* (3.3) and a *pressuremeter* (3.2) , an hydraulic pump or other source of pressure, a test Control Unit (CU), pressure lines and wires to connect the probe to the CU and a data logger which is either built into the CU or attached to it. The SBP is drilled into the ground using the integral self-boring head at its lower end in such a way that the probe replaces the material it removes, creating its own test hole, and minimises the disturbance to the soil outside the instrument.

3.2
pressuremeter
cylindrical expanding part of the equipment used to carry out a pressuremeter test excluding the means necessary to place the pressuremeter probe into the ground

3.3
self-boring head
part of the equipment used to drill the test pocket as the probe is advanced into the ground

Note 1 to entry: A self-boring head includes a boring tool: i.e. a rotating cutter or a high pressure jet arrangement, housed in a cutting shoe attached at the probe end.

3.4
self-boring pressuremeter sounding
series of sequential operations necessary to perform self-boring pressuremeter testing at a given location

Note 1 to entry: See 3.1.

EXAMPLE Pushing the self-boring pressuremeter, activating the self-boring head (see 5.3) and then performing pressuremeter tests (see Clause 6).

3.5
self-boring pressuremeter test
process of expanding the self-boring pressuremeter probe so as to press the flexible membrane against the borehole wall and so measure the associated displacement as a function of pressure and time

3.6
self-boring pressuremeter curve
graphical plot of pressure versus the measured displacement

3.7
depth of test
distance between the ground level and the centre of the expanding length of the *self-boring pressuremeter* (3.1) measured along the borehole axis

Note 1 to entry: See Figure 1.

3.8
operator
qualified person who carries out the probe insertion and the test

4 Symbols

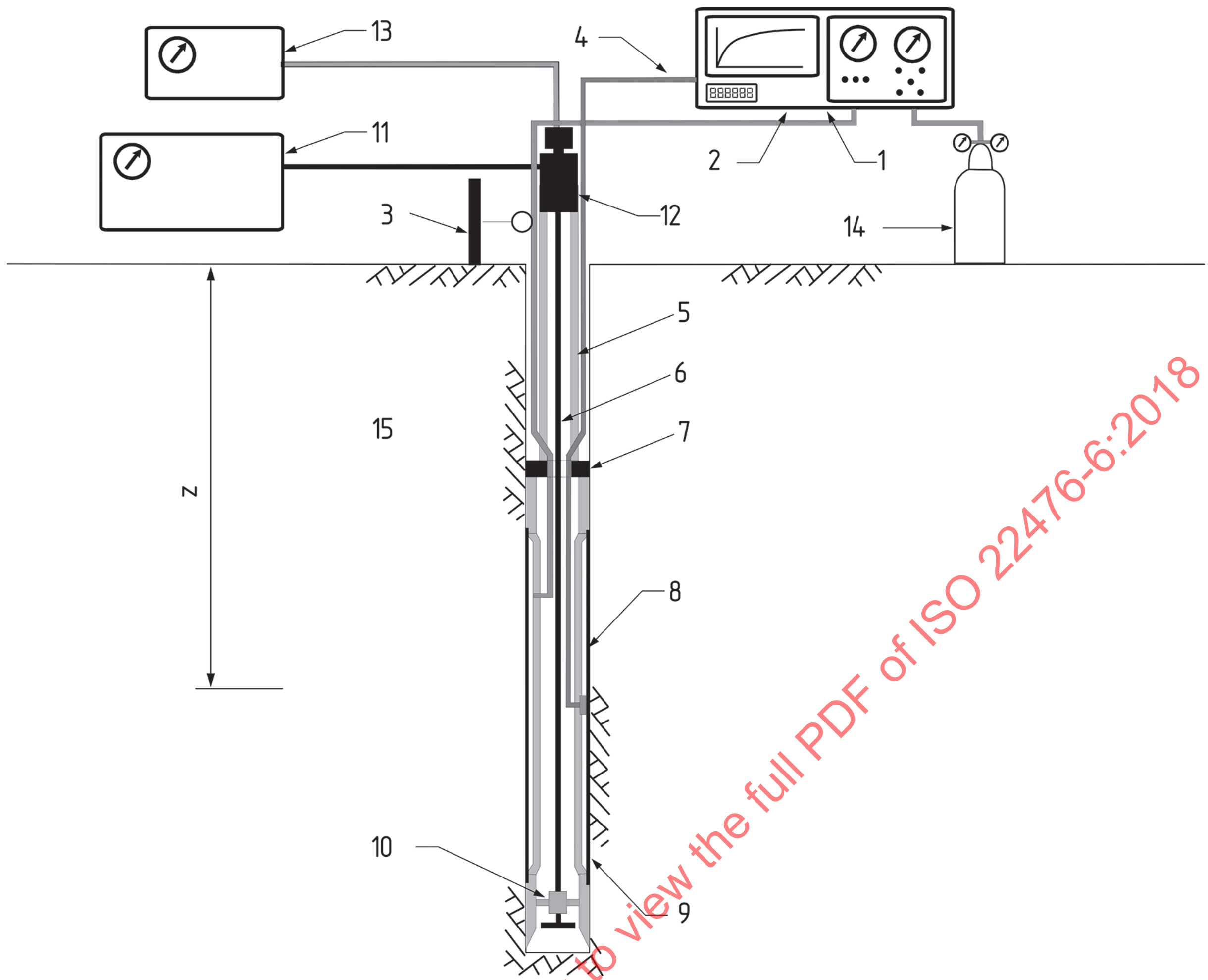
Symbol	Description	Unit
a	pressure coefficient of the displacement	mm.MPa^{-1}
b	membrane stiffness coefficient of the displacement	MPa.mm^{-1}
d	corrected displacement at the borehole wall	mm
d_a	apparent displacement during the membrane compression calibration	mm
d_c	calculated cylinder expansion during the membrane compression calibration	mm
d_i	internal diameter of the calibration cylinder	mm
d_p	outside diameter of the cutting shoe	mm
d_r	displacement as read at the measuring unit	mm
d_{so}	initial outside diameter of the measuring cell	mm
d_s	outside diameter of the measuring cell	mm
e	thickness of the calibration cylinder	mm
h	distance between the cutting tool and the cutting edge	mm
l_c	length of calibration cylinder	mm
l_g	distance between the displacement transducer and the membrane clamping ring	mm
l_s	expanding length	mm

Symbol	Description	Unit
p	applied pressure after correction	MPa
p_c	pressure at the origin of the segment exhibiting the slope b	MPa
p_{max}	maximum applied pressure	MPa
p_r	pressure as read at the measuring unit	MPa
r	measured cavity radius	mm
r_0	initial radius	mm
u_s	pore pressure	mm
t	time	s
V	measured cavity volume	mm^3
V_0	initial volume	mm^3
z	test depth	m
Δd	diametral displacement of the borehole wall	mm
Δp	change of the applied pressure	MPa
ε_v	volumetric strain	—
ε_r	radial strain	—
ν	Poisson’s ratio	—

5 Equipment

5.1 General

The self-boring pressuremeter equipment is shown in operation in Figure 1.



Key

1	CU	9	hollow probe body
2	acquisition, display and storage of the data	10	self-boring head
3	depth measurement system	11	power supply for the cutter drive unit (if required)
4	connecting lines	12	cutter drive unit (if required)
5	handling rods	13	flushing or jetting fluid supply
6	cutter drive rods (if required)	14	pressure source for expansion
7	probe to rod coupling	15	ground
8	central measuring cell	*z*	test depth

Figure 1 — Schematic diagram of the self-boring pressuremeter equipment

The CU includes:

— equipment to pressurize and so to inflate the probe;

— a device which permits the direct reading and the automatic recording of the parameters to be measured: time, pressure and volume or radial displacement.

The pressure applied to the membrane is measured by one or more electric transducers (see Figure 2). The pressure transducers are located:

— above the ground surface, or

— inside the probe, less than 1 m above the centre of the expanding length.

The displacement transducers for the membrane are located in the centre of the expanding length.

The outside diameter d_{s0} of the self-boring pressuremeter when deflated shall normally be the same as that of the cutting shoe d_p.

Use of an oversized cutting shoe shall be reported and taken into account during the analysis of the results.

One or more pore pressure transducers can be located through the membrane in the centre of the expanding length.

It is also necessary to have some means of measuring the depth of the test with appropriate accuracy.

5.2 Self-boring pressuremeter probe

The self-boring pressuremeter probe consists of a hollow core to allow the drill rods (if used) for self-boring operation and carry flush returns to the surface. Flexible hoses and passages are used to inject the proper fluids (gas or liquid) to inflate the central measuring cell whose expansion is monitored by three or more electronic transducers or volume measurement (Figure 2). The probe is fitted with a central cell membrane and may also be fitted with a Chinese lantern protective device to prevent damage from sharp inclusions in the soil. The probe shall be capable of a volumetric expansion of at least 25 % of the initial volume V_0.

The central measuring cell, with an outside diameter d_s and a length l_s, can expand radially in a borehole and apply a uniform pressure to the borehole wall. This central measuring cell shall have a minimum slenderness l_s/d_{s0} of 4,0[7][10]. This cell is inflated by injecting a liquid which is assumed to be incompressible or by gas pressure.

The probe also includes:

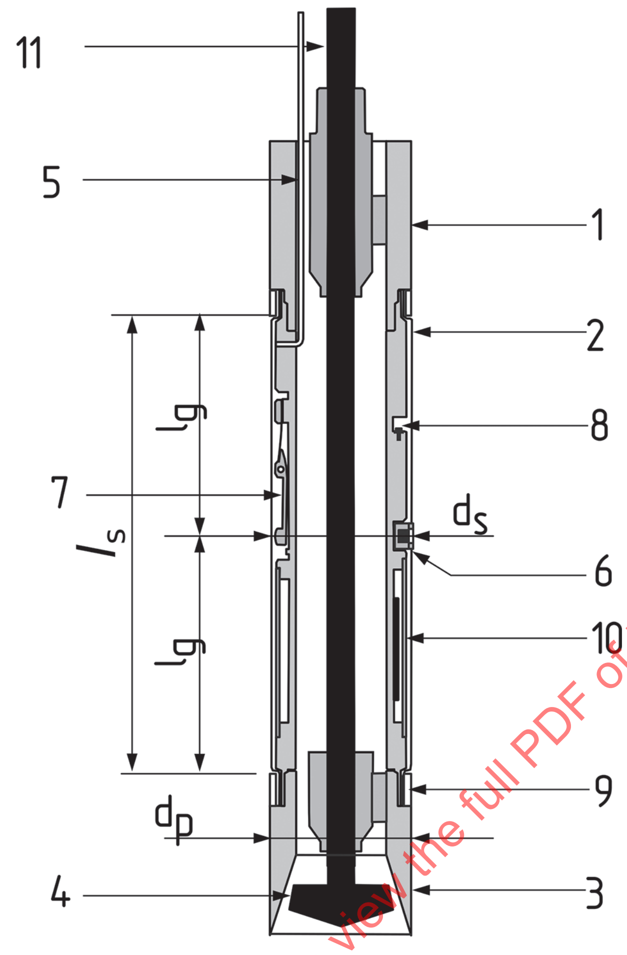
a) The core on its outside curved surface usually bears a pattern of grooves which distribute the liquid in the central cell under the flexible membrane. Over the core is fitted the membrane and the Chinese lantern protective cover. The top of the core is threaded and couples to the string of rods handling the probe from ground level.

b) The central cell membrane isolates the fluid from the space under the Chinese lantern protective cover.

c) Fluid lines connect the probe to the pressure and displacement CU.

d) The expansion of the membrane can be monitored by electric transducers. At least three displacement transducers should be available to monitor the mean surface but also any non-circular deformation of the membrane.

e) The pore pressure in the ground can be monitored by one or more electric transducers placed approximately at mid-height of the expanding length.



Key

1 hollow probe body
2 membrane
3 cutting shoe
4 cutting tool
5 pressure line
6 one pore pressure transducer
7 displacement transducers
8 pressure transducer
9 membrane clamping ring
10 electronic signal conditioning
11 setting and cutter drive rods

Figure 2 — Example of a self-boring pressuremeter probe

5.3 Self-boring head

The self-boring head is the lower part of the probe with an outside diameter d_p. It has a sharp cutting edge with the taper on the inside and as the probe is steadily and slowly advanced into the ground by pushing, the soil that enters it is cut up and removed to the surface through the interior of the probe body by the action of either (Figure 3):

— a rotating cutter,

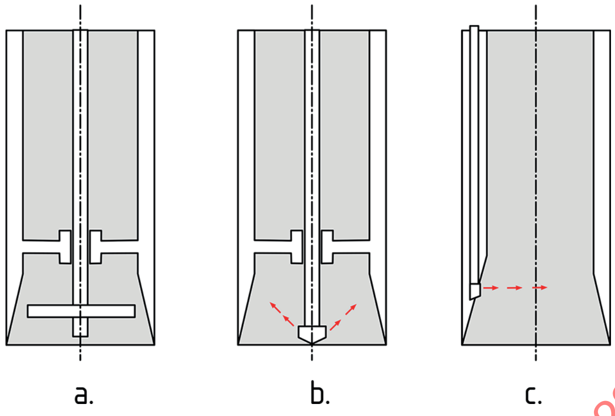
— an upward pressurised water jet, or

— a lateral pressurised water jet.

The rotating cutter can be in a shape of a rock roller bit, a full face cutter, a flat blade or a stirring paddle (disc).

Use of percussion on rotating cutter shall be reported.

To identify the influence of tool wear on SBP tests, it may be appropriate to check and report the status of the initial and final wear of the tool and/or shoe. For this purpose, the dimensions of the tools at the beginning and end of the drilling can be measured, where feasible, and reported (according to ISO 22476-15). The change or replacement of any equipment shall be reported as well.



Key

a. rotating cutter

b. upward pressurised water jets

c. lateral pressurised water jets

Figure 3 — Self-boring head

The distance h between the cutting tool or the nozzle and the cutting edge is a function of the nature of the soil (Figure 4) as defined in Annex B.

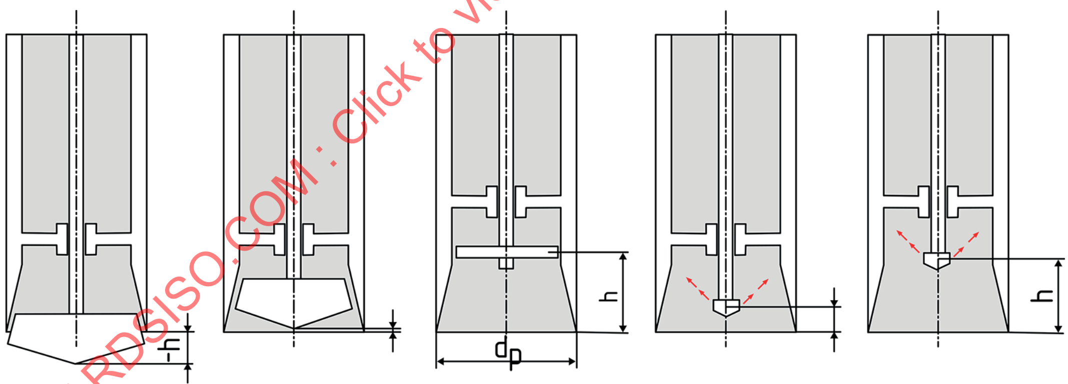


Figure 4 — Distance between the cutting tool and the cutting edge

When the ground becomes stiffer a lower value of h is used (see Annex B). For hard soils and soft rocks, a negative value of h may be used, hence the rotating tool protubing from the cutting edge. The tool shall not be entirely outside of the cutting shoe.

NOTE The influence of ratio h/d_p is highlighted in References [7],[8] and[9].

5.4 Pressure and displacement CU

The pressure and displacement CU permits the reading of liquid or gas pressure and displacement as a function of time and controls the probe expansion and contraction. The pressure may be controlled manually or automatically.

The pressurizing device shall permit:

— reaching a pressure p_r at least equal to 4 MPa;

— keeping a constant pressure in the measuring cell;

— imposing cycles of pressure and displacement at several constant rates.

5.5 The connecting lines

The flexible lines connect the pressure and displacement CU to the probe. They transmit the pressurized liquid or the gas to the measuring cell and may be parallel or coaxial.

The signal cable connects the transducers of the instrument to the data logging system.

5.6 The injected fluid

The fluid injected into the measuring cell may be gas, water, oil or a liquid of similar viscosity. It shall not freeze in the conditions of use.

5.7 Means of measurement and control

5.7.1 Data acquisition

The data logging system shall be so designed and constructed as to ensure that all the data required for a complete analysis of the test is fully and permanently recorded at the time of the test.

Measurements may also be made periodically during probe insertion while boring.

The accuracy of the measuring systems time, pressure, volume and displacement shall be as specified in Annex C.

5.7.2 Display of readings

At the site the pressure and volume CU shall give a simultaneous and immediate display of the following readings: pressure of the fluid injected into the measuring cell, radial displacement or volume of the fluid injected, pore pressure (if applicable), and jetting pressure (if applicable).

6 Test procedure

6.1 Selection of equipment and procedures

The membrane of the probe and the self-boring head used in a self-boring sounding shall be selected according to the expected ground conditions. The probe is then linked to the CU through the connecting lines and cables and the whole system is filled with the working fluid.

6.2 Calibration of the testing device and corrections of readings

Before testing, the equipment shall have been calibrated. Copies of the calibration documents shall be available at the job site. The calibrations shall be done according to ISO 10012 on:

— the displacement measuring systems, and

— the pressure measuring systems.

Corrections as described in Annex A shall be performed taking into consideration the maximum pressure and displacement expected during the test.

If any part of the system is repaired or exchanged, the calibration shall be verified.

The calibrations shall also be verified on completion of a self-boring pressuremeter testing programme.

6.3 Probe placing

The choice of cutting shoe and cutting tool or nozzle should meet the specifications in Annex B. Pressure of the flushing fluid and the force needed to push the probe shall be controlled during boring to ensure that there is no clogging inside the probe. Comparison between the pressure of the flushing fluid and the pore pressure can be used to check the quality of the boring.

NOTE 1 A borehole or other in situ operation can affect the soil properties for a distance as much as 30 times the borehole diameter.

No rotation of the self-boring pressuremeter shall be permitted. Rotation of the probe in the ground during insertion shall be reported and taken into account during the analysis of the results.

In any borehole, the minimum spacing between two subsequent tests shall not be less than 0,75 m.

NOTE 2 The usual spacing between the locations of the central section of the probe for two subsequent tests is 1 m.

As a rule, the minimum depth for a test in a borehole is 0,75 m. This depth may be reduced but the distance should ensure that the membrane is fully supported within the pocket when the pressuremeter pocket is drilled from the bottom of a larger borehole as long as the diameter of this larger borehole is less than or equal to 0,6 m.

Successive SBP tests shall not be carried out upward in the borehole.

6.4 Relaxation

After boring, the CU is used to determine the total horizontal stress of the ground at rest, by keeping the volume constant in the measuring cell.

An assumed equilibrium pore pressure (if applicable) and total stress shall be reached before the beginning of the loading programme. Use of a predefined delay period shall be justified. Total stress and pore pressure shall be read and recorded according to the capability of the data logger (Figure 5).

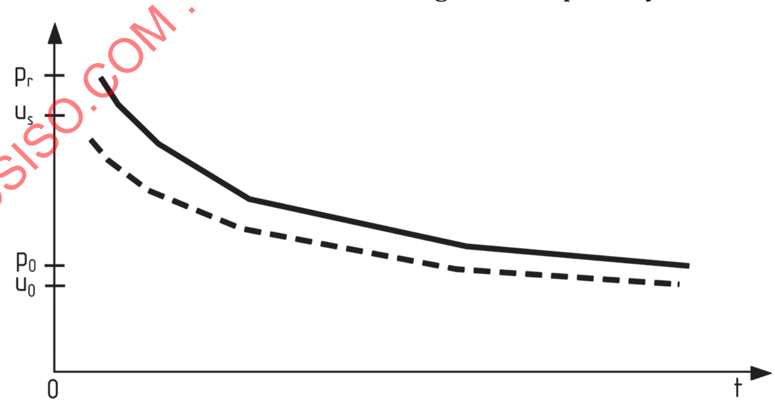


Figure 5 — Example of relaxation results

6.5 Loading program

6.5.1 General

A pressuremeter test is either stress controlled or strain controlled or a combination of the two. The method of control shall be clarified in the project specification. Tests are normally conducted with the initial stages and unload reload loops performed with stress control. As the soil yields, the strain rate may be then regulated at 1 % per minute.

Strain-controlled pressuremeter tests shall have a defined rate of constant volumetric strain or constant radial strain, as applicable.

Stress controlled tests shall be performed at a continuous rate of pressure application.

Tests may contain unload-reload and reload-unload cycles (Figure 6). These cycles shall be performed according to agreed specifications.

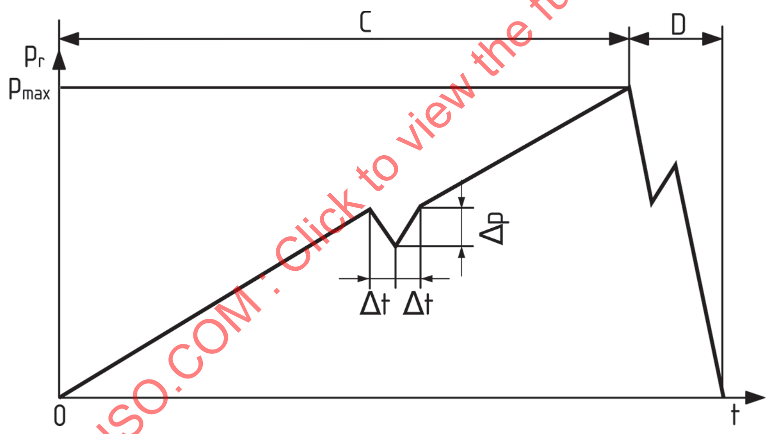
The maximum applied pressure p_{max} and strain or volume to be used are decided by the maximum capacity of the pressuremeter and considerations of the maximum stress expected to be applied to the ground by the structure proposed. The maximum applied pressure should also take into account limits to avoid damage to the equipment (primarily membrane bursting) based on observations of the test behaviour by the operator.

The loading, unloading and reloading phases of each test shall be carried out continuously and in the way specified jointly by the operator and the user of the test results. Adjustments to the loading programme shall be decided according to the observed progress of the test.

The whole descent phase from p_{max} is carried out continuously, without steps and may contain one or more reload-unload loops. These loops are carried out in a similar manner to unload/reload loops.

Departures from the specified loading program shall be fully reported (i.e. test with loading steps).

Before commencing the descent phase of a reload loop enough time should be allowed for time dependant effects to become insignificant (holding period) where this is feasible without creating changes in soil properties (e.g. allowing consolidation effects).



Key

p_r	applied pressure	*C*	loading phase
t	time	*D*	unloading phase
Δt	duration of a unloading phase		
Δp	pressure drop		

Figure 6 — Loading programme for a self-boring pressuremeter test

During both boring and testing the data is recorded automatically. Pressure applied to, and the associated expansion of the probe are measured and recorded so as to obtain the stress-displacement relationship for the soil as tested (see Figure 7). For a good definition of reload loops data should be recorded not less frequently than at 10 s intervals. A loop should contain a minimum of 20 data points and displayed according to 5.7.2. A pressure drop of about a third of the pressure at the start of the reload loop, or a maximum of two times the undrained shear strength is commonly used. Care should be taken to prevent failure of the ground during unloading cycles.

In deciding the proper rate of pressure change consideration shall be given to rate effects and drainage in the material being tested.

6.5.2 End of test

The test stops when:

— the specified test programme has been carried out,

— the maximum admissible expansion of the pressuremeter membrane is reached,

— the measuring range of one of the transducers is exceeded, or

— in the operator's opinion, continuation of the test could result in damage to the equipment.

In the event of membrane bursting, the test ceases.

The volume in the measuring cell or the radius shall be decreased until:

$$d_s = d_{so}$$

which allows probe removal or further self-boring (see 5.4) and testing.

6.6 Backfilling of the borehole

After completion of all the tests in a bore, the borehole shall be back-filled and the site restored according to the specifications given in ISO 22475-1.

7 Test results — Interpretation of tests

The result of the tests is the digital data file from which the pressuremeter curve below is plotted together with any information recorded such as pore water pressures.

The measured pressure and the corresponding volume or radius shall each be converted to applied pressure and volumetric or radial strain[10].

NOTE 1 Annex A gives guidance on the calculation of the corrected values of volume or radius from the readings and on the calculation of the applied pressure from the measured pressure.

NOTE 2 Conversions between volumetric strain and radial strain are given in Annex D.

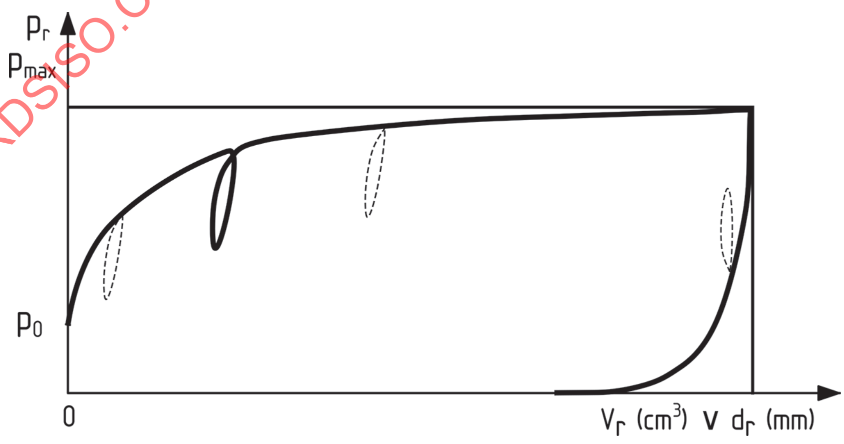


Figure 7 — Example of a self-boring pressuremeter test result

8 Self-boring pressuremeter test report

In the presentation of test results the information shall be easily accessible, preferably in tables and graphs, in a standard archive scheme or in a digital form.

1 General information	Field report	Test report
1.a. Reference to this document (ISO 22476-6)		x
1.b. Company executing the test	x	x
1.c. Equipment operator executing the test	x	
1.d. Field manager executing the test		x
1.e. Depth to the groundwater table (if recorded) and date and time of recording	x	x
1.f. Depth and possible causes of any interruptions in the pressuremeter tests	x	x
1.g. End criteria applied, i.e. target pressure, maximum pressure, maximum radius, etc.	x	x
1.h. Observations during the test, for example drops of pressure, radius or volume, incidents, buckled rods, abnormal wear or changes in zero load readings	x	x

2 Location of the test	Field report	Test report
2.a. Identification of the test	x	x
2.b. Elevation of the pressuremeter test related to a known datum		x
2.c. Local or general coordinates		x
2.d. Geodetic reference system and tolerances		x

3 Test equipment	Field report	Test report
3.a. Pressuremeter type and rating	x	x
3.b. Geometry and dimensions (d_{SO}, l_S...) of the SBP	x	x
3.c. Type of thrust machine used, pushing capacity, associated jacking and anchoring systems	x	x
3.d. Identification number of the SBP	x	x
3.e. Measuring ranges of the sensors (recommended)		x
3.f. Pore pressure cell type	x	x
3.g. Test reference number and date of last calibration of the sensors (recommended)		x
3.h. If applicable, calibration cylinder inner diameter	x	

4 Boring information	Field report	Test report
4.a. Self-boring head type	x	x
4.b. Self-boring cutting shoe diameter d_p	x	x
4.c. Cutter type, dimension and position h		x
4.d. Flushing fluid type	x	x
4.e. Flushing or jetting fluid pressure		x

4.f. Thrust force	x	x
4.g. Drilling start and end times	x	x
4.h. Drilling distance	x	x
4.i. Pore pressures recorded during boring	x	x
4.j. Orientation of the probe	x	
4.k. Drilling comments		x

5 Test procedure	**Field report**	**Test report**
5.a. Test specifications of additional test stages	x	x
5.b. Method of test control (stress controlled or strain controlled)	x	x
5.c. Pressure at the start and pressure drop of loops	x	x
5.d. Date of the test	x	x
5.e. Starting time of the test	x	x
5.f. Clock time during the test	x	x
5.g. Depth of the pressuremeter test	x	x
5.h. Strain rates, pressure rates	x	x

6 Measured parameters	**Field report**	**Test report**
6.a. Time in seconds, applied pressure in MPa and volumetric or radial displacement measurements	x	x
6.b. Zero load readings of pressure and volume or radius at ground level, before and after drilling and before and after the test	x	x
6.c. Corrections applied during data processing (e.g. membrane stiffness, compressibility etc.)		x
6.d. If applicable, calibration data of system compliance, membrane pressure loss and compressibility	x	

7 Pressuremeter curves	**Field report**	**Test report**
7.a. corrected pressuremeter curve shall be obtained by plotting readings *V* or *d* versus *p*		x
7.b graphical representation of the pressuremeter parameters as a function of depth, with a depth scale		x

Annex A
(normative)

Calibration and corrections

A.1 Measuring devices

All the measuring devices shall be periodically checked and calibrated according to the project specification and/or relevant standards to show that they provide reliable and accurate measurements (see also Reference [6]). Calibrations at the start and end of a project should normally be carried out, with intermediate calibrations every 10 or 20 tests, according to the type of testing and use of the equipment.

If any part of the system is repaired or exchanged, calibration shall be verified.

A copy of the latest calibration test report shall be available at the job site.

A.2 Stiffness of cell membranes

Due to the stiffness of the cell membranes there is a pressure loss value p_m associated with each membrane. This is obtained from an inflation test.

The membrane pressure loss is obtained by the procedure described in A.2.1 and A.2.2.

A.2.1 Preparation of the self-boring pressuremeter for a membrane pressure loss test

The self-boring pressuremeter probe is connected by a short connecting line to the CU (less than 2 m for probes using liquid for expansion). The membrane is then inflated at least three times by injecting fluid up to the maximum deformation.

For this operation the pressurizing and read-out unit shall be used with a pressure measuring device accurate to better than 10 kPa.

A.2.2 Membrane stiffness correction test

The probe is placed upright, in the open air. The probe is inflated as if it was in the ground, with pressure increments small enough properly to cover the complete range of displacement of the membrane.

If a liquid is used to pressurise the self-boring pressuremeter the elevation difference between the probe and the measuring unit shall be taken into account.

The pressure versus displacement curve, d_r (or V_r) = f(p_r) is plotted after data reduction (Figure A.1). The values shown on this graph give the membrane stiffness correction as a function of the membrane displacement.

The membrane stiffness coefficient of displacement b is defined as

$$b = \Delta p_r / \Delta d_r \text{ (or } b = \Delta p_r / \Delta V_r\text{)} \tag{A.1}$$

in MPa/mm (or MPa/cm^3) for the linear part of the curve.

The corrected pressure p is given by:

$$p = p_r\,(d_r) - b.d_r - p_c \text{ (or } p = p_r\,(V_r) - b.V_r - p_c\text{)} \tag{A.2}$$

Use of the entire curve for correction should be reported.

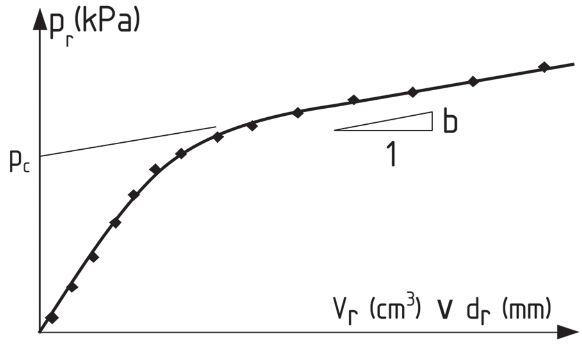


Figure A.1 — Stiffness plots for the self-boring pressuremeter

A.3 Membrane compression

A.3.1 The calibration cylinder

The main features of this cylinder shall be as follows (see Figure A.2):

— A measured inside diameter d_i not more than d_{so} + 5 mm.

— A wall thickness e suitable to the maximum pressure required.

— The length of the cylinder l_c is a function of the dimension of the active part of the probe.

A.3.2 Membrane compression test

The probe is placed into the compression calibration cylinder. This is a metal cylinder of known elastic properties and strong enough to resist several times the maximum working pressure of the self-boring pressuremeter.

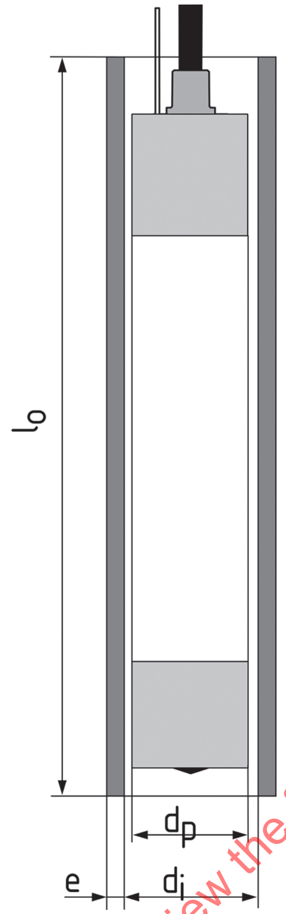


Figure A.2 — Compression calibration cylinder for the self-boring pressuremeter

The probe is pressurised by increments Δp initially of 100 KPa and then by appropriate pressure steps up to the full pressure rating of the instrument. For each pressure increment the displacement is recorded (see Figure A.3).