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International Standard

ISO 22476-16

Geotechnical investigation and testing — Field testing —

Part 16:
Borehole shear test

Reconnaissance et essais géotechniques — Essais en place —
Partie 16: Essai de cisaillement en forage

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Foreword

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

A list of all parts in the ISO 22476 series can be found on the ISO website.

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Introduction

The determination of the shear strength of soils is of paramount importance in geotechnical investigation and testing of soils. The shear resistance of soils and materials, characterised by the friction angle φ and the cohesion c, represents an important parameter for the geotechnical engineer while studying the stability of construction works and structures in relation with soils and materials. Usually, this resistance is measured in the laboratory using triaxial tests or direct shear tests carried out on field samples and only if sampling, conservation and preparation make it possible to consider the samples as non remolded and sufficiently representative of the soil in place.

Since the 1960's, various experimental devices have been designed and developed to determine the shear strength directly in situ from tests carried out in boreholes, in different soils at different depths.

The study of the bibliography literature shows that the majority of the existing borehole shear tests are based on the use of probes for applying and maintaining a normal pressure on the walls of the borehole and then to carry out a shear phase by a linear displacement of the probe on the soil against the walls of the borehole. The procedure is then repeated through a multistage increase of the normal pressure to obtain more values relating normal pressure and shear resistance.

The test equipment and apparatuses differ from each other by the geometry and size of the probes and by the shape of the friction part of these probes and by the procedure for applying normal pressure stages and shear phases.

One of the first devices of this kind is the Iowa Borehole Shear Tester (BST) developed in the USA.[13] The test is performed by placing a bilateral expandable probe, equipped with two diametrically opposed shear plates in a predrilled borehole, expanding the probe against the wall of the borehole and causing a shear failure in the soil by pulling the probe axially along the borehole. The size of the shear plates is relatively small (32,3 cm²) and does not allow testing of soils with coarse elements, which can somewhat limit its field of application.

In the early 1970s, H. Mori,[15] in Japan, developed an in situ shearing device called the IST which was used in many projects. The principle of the test is carried out by generating a shearing force while pulling upwards a cylindrical expandable probe provided with teeth driven into the wall of the borehole but it is not reported whether the IST test continues to be performed currently.

A self-boring in situ friction test (SBIFT), also developed in Japan,[14] allows the evaluation of soil characteristics as the initial horizontal at rest pressure, and deformation modulus and strength characteristics (cohesion and internal friction angle) of the soil. The SBIFT possesses a self-boring drilling functionality that can reduce the disturbance of the tested soil. However, very few data and results are available to currently validate this device and the characteristics of the soil it provides.

The same way as the SBIFT, a self-boring in situ shear pressuremeter (SBISP), was recently developed in China,[12] that allows the evaluation of pressuremetric characteristics as the initial horizontal at rest pressure, deformation yield pressure and modulus and also strength characteristics (cohesion and internal friction angle) of the soil. The SBISP possesses a self-boring drilling functionality that can greatly reduce the disturbance of the tested soil. However, very few data and results are available to currently validate this device and the characteristics of the soil it provides.

This document applies to the borehole shear test using the phicometer procedure, commonly named the phicometer borehole shear test (PBST). This test has been invented and developed by Gérard Philipponnat in the 1980's.[10]

This test has been the subject, between 1986 and 1992, of several applied research programs to design the apparatus and its components and to develop and optimize a common test procedure that can be used in a majority of soils. Various articles have been published as a result of these researches and since then PBST tests continue to be carried out currently, for the determination of the shear strength parameters from the test and to derive values for the undrained shear strength and an estimation of the drained effective shear resistance parameters.[9] The test has been standardized in France since 1997.

The borehole shear test using the phicometer covers a four-phases procedure consisting of drilling a borehole, lowering the probe to the test depth, inflating it into the borehole wall and shearing the soil by applying a series of steps of controlled radial pressure and simultaneously pulling out the probe with a constant displacement rate. The test sequences are shown in Figure 1.
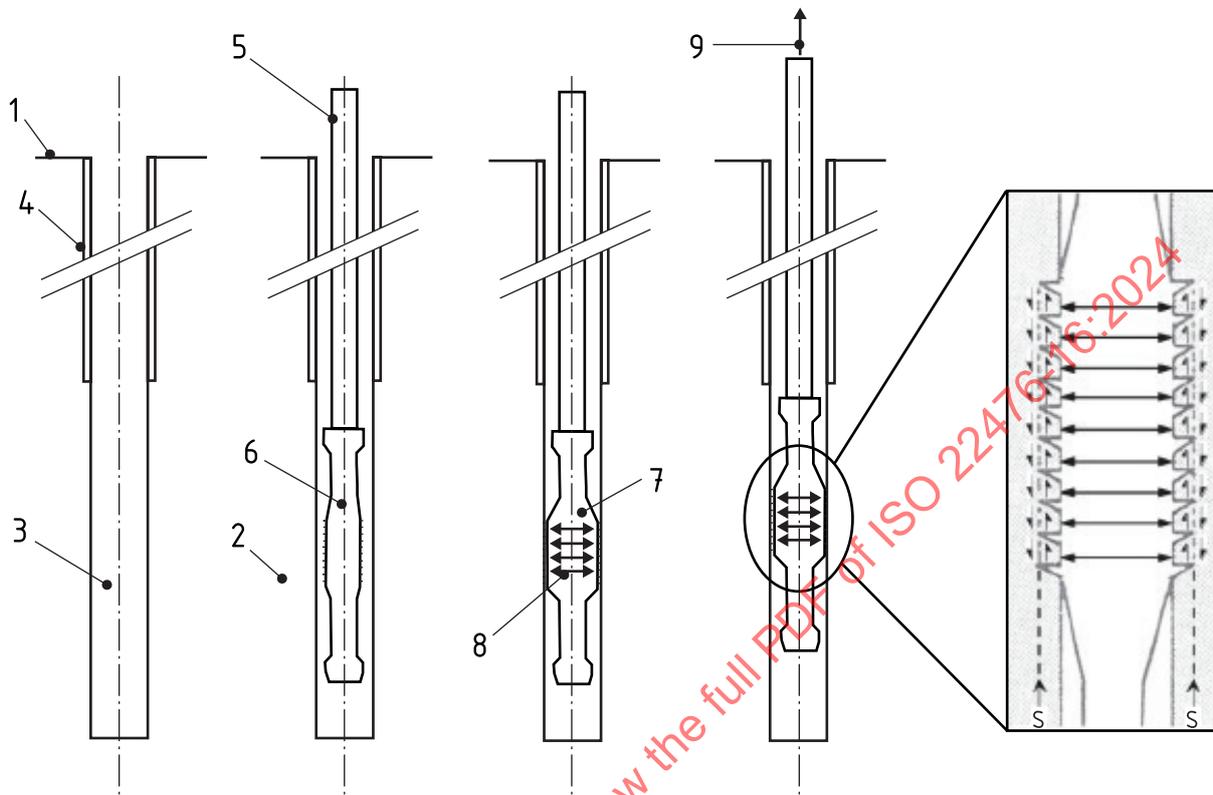
a) Borehole drilling phase: drilling a phico-meter borehole with casing (if necessary) and setting up the PBST test pocket in the borehole bottom

b) Probe placing phase: lowering the deflated probe to the test pocket depth

c) Teeth insertion phase: radial expansion of probe and insertion of the annular teeth in the borehole wall

d) Shearing phase: pull-ing on the probe inflated with a constant radial pressure at each multi-stage step

Key

1	ground surface	4	casing (if necessary)	7	probe (inflated state)
2	ground	5	string of rods	8	radial pressure
3	borehole	6	probe (deflated state)	9	pulling force
				S	cylindrical shear surface

Figure 1 — General arrangement and phases of the phicometer procedure borehole shear test

Geotechnical investigation and testing — Field testing —

Part 16:
Borehole shear test

1 Scope

This document is applicable to the borehole shear test using the phicometer procedure, commonly named the phicometer test (etymologically derived from phi for friction angle, co for cohesion and meter for measurement).

The test can be performed in all types of natural soils, fills and artificial soils, which can be saturated or not.

It does not apply to very soft fine soils, very loose coarse soils, medium strong to very strong rocks and natural or artificial soils with a predominance of cobbles having a particle diameter greater than 150 mm.

Generally, the test is applicable in soils with an order of magnitude of their in situ resistance characteristics as follows:

— Ménard pressuremeter limit pressure: 0,4 MPa < p_{lM} < 3,5 MPa approximately or more than 4 MPa in granular non-cohesive soils;

— CPT Cone resistance: 1,5 MPa <qc <15 MPa approximately, depending on the type of soil (see Annex E);

— SPT N: 8 <N <50 approximately, depending on the type of soil (see Annex E).

The test can also be carried out in soils presenting a resistance outside these application limits as long as the representativeness of the results is assessed or validated by the analysis of the PBST graphs (see Clause 8).

This document applies only to tests carried out at a depth less than or equal to 30 m.

The parameters derived from this test are the shear strength properties, as the cohesion and angle of friction.

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 the sampling of soil, rock and groundwater*

3 Terms, definitions and symbols

3.1 Terms and definitions

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

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

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

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

3.1.1
borehole shear test
process during which a special shearing probe is installed in a borehole at a defined depth and inflated against the borehole wall and pulled to determine the resulting shear resistance of the soil

Note 1 to entry: This process is repeated with a succession of increased maintained normal pressure steps so as to obtain a pressure versus shear stress relation of the soil.

3.1.2
phicometer borehole shear test
PBST
shear test performed in a *phicometer borehole* (3.1.4) with the *phicometer probe* (3.1.6) and the phicometer test procedure

Note 1 to entry: See Clause 5 for the phicometer test procedure.

3.1.3
phicometer
whole equipment which is used to carry out a *phicometer borehole shear test* (3.1.2)

3.1.4
phicometer borehole
part of a borehole in which the *phicometer test pocket* (3.1.5) is to be set up

Note 1 to entry: See 5.2.

3.1.5
phicometer test pocket
cylindrical cavity with a circular section made in a borehole and in which the *phicometer probe* (3.1.6) is placed, brought into contact and pulled upwards during the test phases

3.1.6
phicometer probe
cylindrical expandable probe with annular shearing teeth, used to carry out a *phicometer borehole shear test* (3.1.2)

Note 1 to entry: See 4.2 and Figure 3.

3.1.7
phicometer test diagram
set of plots resulting from the *PBST* (3.1.2) test and allowing the determination of the shear resistance of the soil

Note 1 to entry: See Clause 8 and Figure 6.

3.1.8
phicometer cohesion
in situ cohesion c_i obtained from the *phicometer test diagram* (3.1.7)

3.1.9
phicometer angle of friction
in situ angle of shear friction φ_i obtained from the *phicometer test diagram* (3.1.7)

3.1.10
depth of test
distance between the ground level and the centre of the shearing zone of the phicometer probe measured along the borehole axis

3.1.11
operator
technician trained in carrying out PBST tests, in accordance with this document

3.2 Symbols

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

Table 1 — Symbols

Symbol	Description	Unit
T	Pulling force on the probe	kN
T_l	Maximum pulling force	kN
V	Volume injected into the measuring cell of the probe as read on the control unit	cm^3
V_d	Volume injected into the measuring cell of the probe at the beginning of the application of the pulling force ($V_d = V_{60}$)	cm^3
V_f	Volume injected into the measuring cell of the probe at the end of the application of pulling force	cm^3
V_{30}	Volume injected into the measuring cell of the probe after 30 s under a constant pressure phase	cm^3
V_{60}	Volume injected into the measuring cell of the probe after 60 s under a constant pressure phase	cm^3
d_{s0}	Initial diameter of the probe at rest in the shearing zone (see Figure 3)	mm
c_i	phicometer cohesion measured in situ by the PBST	kPa
d_s	Diameter of the probe in the shearing zone after injection of a volume V (see Figure 3)	mm
d_t	Diameter of the pocket at the level of the test	mm
d_c	Outside diameter of the measuring cell of the probe	mm
l_t	Slots length of the expansible shear tube	mm
l_c	Distance between the rings of the measuring cell of the probe	mm
l_s	Conventional length of the shearing zone (see Figure 3)	mm
N	Standard penetration test SPT Blow count (see ISO 22476-3)	-
p_c	Conventional radial pressure applied to the ground after corrections	kPa
p_e	Probe stiffness pressure loss determined by calibration	kPa
p_h	Pressure due to the injection liquid column in the probe (between z_c and z_s)	kPa
p_{IM}	Ménard pressuremeter limit pressure (see ISO 22476-4)	MPa
p_r	Pressure of the liquid injected into the phicometer measuring cell, read at the level z_c of the control unit (CU)	kPa
p_z	Pressure of the liquid at the centre of the measuring cell	kPa
q_c	Cone penetration resistance (see ISO 22476-1 or ISO 22476-12)	MPa
t	Time	s
v	Rate of axial displacement of the probe during the pulling phase	mm/min
z	Elevation, ascending above datum	m
z_0	Elevation of the ground surface level at the location of the test	m
z_c	Elevation of the pressure measuring device of the liquid injected into the phicometer measuring cell	m
z_e	Elevation of the drilling fluid in the borehole	m
z_{ei}	Initial level of water or mud measured in the borehole before the beginning of the test	m

Table 1 *(continued)*

Symbol	Description	Unit
z_{ef}	Final level of water or mud measured in the borehole after the end of the test	m
z_s	Elevation of the centre of the shearing zone of the phicometer probe at the beginning of the test	m
z_w	Elevation of the ground water table (or free water surface in a marine or river environment)	m
γ_l	Unit weight of the liquid injected into the measuring cell	kN/m^3
γ_w	Unit weight of water	kN/m^3
Δl	Axial displacement of the probe during shearing	mm
Δp	Loading pressure increment	kPa
Δt	Duration of a pressure hold at a loading stage	s
Δt_p	Duration of a loading pressure hold during the preliminary phase	s
ΔV	Injected volume change from 30 s to 60 s after reaching the pressure hold	cm^3
φ_i	Phicometer angle of friction measured in situ with the phicometer borehole shear test	°
τ	Shear stress	kPa
τ_l	Conventional limit shear stress	kPa

4 Equipment

4.1 General

The equipment to carry out phicometer borehole shear tests shall consist of the following components:

— phicometer probe,

— pressure – volume control unit (CU),

— a line to connect the probe to the CU,

— a pulling device placed on a reaction base on the ground surface and linked to the probe with pulling rods,

— a device to control the axial shearing displacement rate,

— means of measurement and display of pressure, volume, pulling force, axial displacement and the external diameter of the shearing zone of the probe.

The equipment can also include a data logger.

A phicometer borehole shear test (PBST) device assembly is shown in Figure 2.

An example of installation of the PBST equipment is shown in Annex H.
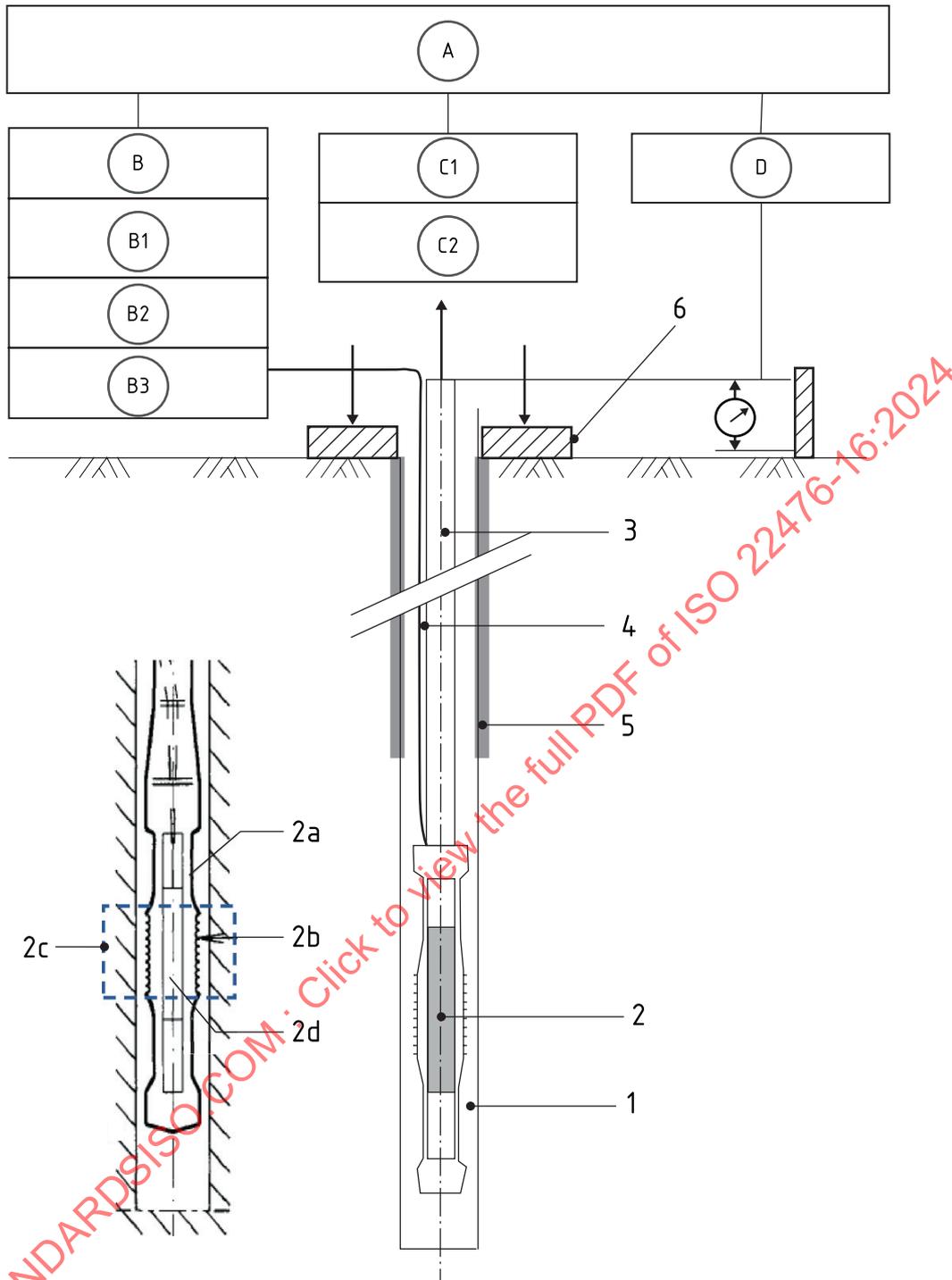
Key

1	borehole	3	string of rods	5	borehole casing (if necessary)
2	phicometer probe	4	connecting line	6	reaction base
		2a	expansible slotted tube	2c	shearing zone mobilized by the probe teeth
		2b	annular teeth	2d	inflatable measuring cell
A	data logger (optional)	B2	volume measurement	C2	pulling device with timer
B	pressure-volume control unit (CU)	B3	display of readings	D	axial displacement control
B1	pressure regulator & injection device	C1	measurement of pulling force		

Figure 2 — Diagram of the PBST test device assembly and its components

4.2   Phicometer probe

The phicometer probe is shown in Figure 3. It consists of a steel slotted device, called "expandable slotted shear tube" in which a radially expandable cylindrical cell called "measuring cell" is placed.

The expandable slotted shear tube is a hollow steel cylinder rigidly connected to the pulling rods to ensure its operation and to transmit the pulling force to the probe from the surface of the ground. It is designed with different parts featuring:

— a central shearing zone, made up of six initially jointed rigid plates, parallel to the axis of the probe and comprising ten annular teeth, regularly spaced vertically;

— two guard zones, made up of metal strips acting as a spring;

— an inflatable measuring cell placed at the level of the central shearing zone inside the expandable slotted shear tube and which is composed of a steel core, a deformable flexible membrane and a tube for liquid injection used to inflate this cell and to measure its volume.

The characteristics of the probe shall be as given in Annex A. Two types of deformable flexible rubber membranes exist:

— a standard membrane;

— a reinforced membrane.

The standard membrane is used for all soil types.

The reinforced membrane is exclusively used for aggressive soils where damaging and bursting of the cell probe occurs frequently.

4.3   Connection tube line and pulling rods

4.3.1   Connection tube line

The flexible tube line connecting the pressure volume control unit to the probe is used to inject the fluid in the measuring cell.

The expansion coefficient of this line shall be lower than 0,1 cm^3/MPa per meter of line.

4.3.2   Pulling rods

A string of steel rods connects the probe to the equipment placed on the ground surface. The resistance of this string of rods shall withstand the efforts and stresses generated by the test during all its phases.

The elongation of the drill string shall remain less than 0,05 % of its total length.

The section of the rods and their fittings shall allow free sliding of the drill string in the borehole.

The part of the pulling rods above the ground surface is threaded over all its length, to allow the adjustment of the locking system of the string of rods on the pulling device (see 4.4.1).
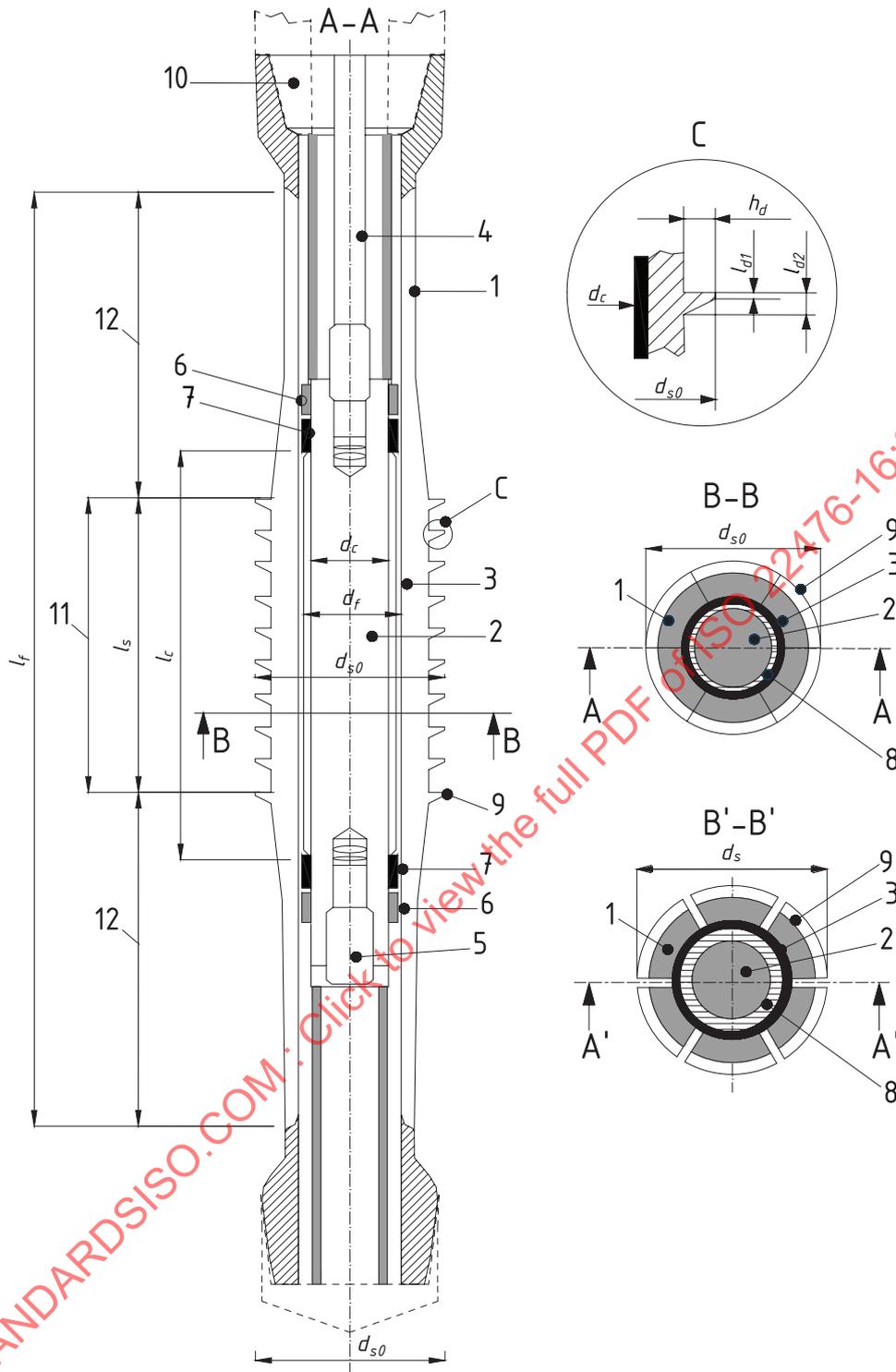
Key

1	expandable slotted shear tube	2	steel core of the inflatable measuring cell, placed between two spacers	3	measuring cell membrane
4	tube line for liquid injection	5	purge	6	rings for tightening of the membrane
7	joints	8	liquid for inflating the membrane	9	annular teeth of the shearing zone
10	rods-probe coupling system	11	probe shearing zone	12	probe guard zones

NOTE   The symbols in Figure 3 are defined in Table A.1.

Figure 3 — Phicometer probe

4.4   Equipment at ground surface

The equipment includes:

— a pulling device;

— a pressure-volume control unit (CU) allowing the pressurisation and the expansion of the probe;

— a regulation system to control the traction pulling speed of the probe.

4.4.1   Pulling device

The pulling device includes:

— A reaction base, with optional plates, for the distribution of loads on the ground surface.

— A hollow cylinder jack with a diameter hole allowing the upper end of the pulling rods string to pass freely and for axially tensioning the rods string and the connected probe.

— A device for locking the upper end of the pulling rods string above the hollow cylinder jack.

— A device that measures the pulling force. This device placed between the probe and the locking system can be either at the ground surface or in the borehole.

4.4.2   Pressure-volume control unit (CU)

Placed at the ground surface, the pressure-volume control unit allows to ensure the expansion of the probe and to measure, according to time, the pressure as well as the volume of the liquid injected in the measuring cell of the probe.

The pressurizing device of the CU shall enable to:

— reach a pressure of at least 1,5 MPa;

— keep constant the pressure in the measuring cell during the stages of the test;

— set and apply a pressure increment in less than 20 s.

NOTE   A pressure-volume control unit such as that used for the Ménard pressuremeter test (see ISO 22476-4) is appropriate. In that case, only the liquid circuit of the central measuring cell of this unit is used.

4.4.3   Regulation system of the traction speed of the probe

The regulation system is intended to obtain and to keep constant the rate of displacement of the pulling rods and the connected probe during the stages of shearing. The displacement is measured by comparison to a fixed reference mark.

4.5   Means of measurement and control

4.5.1   Time

The means used shall allow a measurement of time with an uncertainty lower than 2 s.

4.5.2   Pressure, volume and pulling force

The maximum uncertainties of the measuring instruments of pressure, of the volume and of the pulling force shall not exceed the values indicated in Annex F.

4.5.3 Axial displacement

The means used to measure the axial displacement shall allow a measurement of displacement with an uncertainty not exceeding the value indicated in Annex F.

4.5.4 Display of readings

On the site, the operators shall be able to have simultaneous real-time visualisation or display of the following measured readings: time, pressure, volume of the injected liquid in the measuring cell, shear displacement and pulling force.

4.5.5 Dimensions of the shearing zone of the probe

The external diameter d_s of the shearing zone of the probe is measured with a slide caliper at least at each calibration of the probe (see B.2.2), within a tolerance of 0,1 mm. The length l_s of the shearing zone of the probe and the dimensions of its annular teeth are defined in Table A.1.

5 Test procedure

The following operations shall be successively carried out, according to the flow chart shown in Figure 4.

In Figure 4:

— a pressure hold corresponds to a step during when the pressure p_r is maintained constant;

— a loading stage corresponds to a stage where the pressure in the probe is set and regulated to a given value as defined in 5.4 and Table 2 during the loading phase;

— a loading phase corresponds to the successive loading stages and pressure holds applied either during the teeth insertion phase or during the shearing phases;

— a shearing stage corresponds to the stage of pulling up the inflated phicometer probe at a constant speed of 2 mm/min, under a constant pressure during the shearing phase;

— the shearing phase corresponds to the successive application of the shearing stages as defined in Table 2 in function of p_{lM} and p_h.

5.1 Checks and measurements before insertion of the probe in the ground

Before inserting the probe into the borehole, the calibrations and controls of correct operation described in Annex B shall have been carried out.

The level of water or drilling mud in the borehole is recorded right before the insertion of the probe.

5.2 Borehole drilling phase, probe placing phase and zero setting

To carry out a borehole shear test with the phicometer procedure, it is necessary to create a cylindrical test pocket, by performing a preliminary drilled phicometer borehole descending below the test level.

The drilling techniques of the phicometer borehole for the installation of the phicometer probe shall meet the specifications of Annex C.

The choice between the different drilling techniques and tools is made according to the soil type, in order to achieve a cylindrical test zone on the borehole wall with minimum disturbance and create the phicometer test pocket. The direct driving of the phicometer probe into the soil is not allowed.

The distance between the top of the phicometer borehole and the centre of the phicometer test pocket (i.e. the center of the shearing zone of the phicometer probe) shall not be less than 1,0 m.

The drilling above the phicometer borehole can be carried out in a diameter greater or equal to the phicometer borehole diameter.

In most cases, it remains necessary to support the borehole walls by using drilling mud and/or by placing a casing.

In the case where two successive close tests are to be carried out in the same borehole (see 5.3), the depth of the bottom of the phicometer borehole for the first test shall not exceed the depth of the first test by more than 0,8 m, to avoid any disturbance of the second test pocket zone.

The diameter of the test pocket d_t shall be:

62 mm ≤ d_t ≤ 65 mm

The test elevation or the depth of test z_s corresponds to the middle of the shearing zone of the probe (at the moment of the installation).

Once the probe has been lowered to the level of the test, it is essential to check that the system slides in the borehole and to take into account the forces due to the weight of the drill string and the probe and the parasitic forces due to possible friction on the borehole walls.

To this end, the drill string and the attached probe are lifted and raised by a few centimetres in order to suspend the probe and the drill string and follow the variation of the corresponding necessary raising force. This force shall stabilize between 1 cm and 5 cm of uplift and correspond roughly to the theoretical weight of the hanged rods and the probe.

This raising force T_0 is noted. It is then taken as the origin value for the measuring of the effort of pulling.

NOTE 1   This origin value can also be reset to zero in order to read the neat effort of pulling acting on the probe.

NOTE 2   In order to minimize in the measurements, the part of the parasitic force on the pulling rods, the pulling force measuring device can be placed in the borehole on the top of the probe.

The liquid pressure in the control unit (CU) is set to zero before the beginning of the test.

5.3   Minimum spacing between tests

The distance between two consecutive tests in a same borehole shall not be less than 1,2 m. The distance between two phicometer boreholes shall not be less than 20 times the initial borehole diameter.

Figure 4 — Flow chart and phases of the PBST test
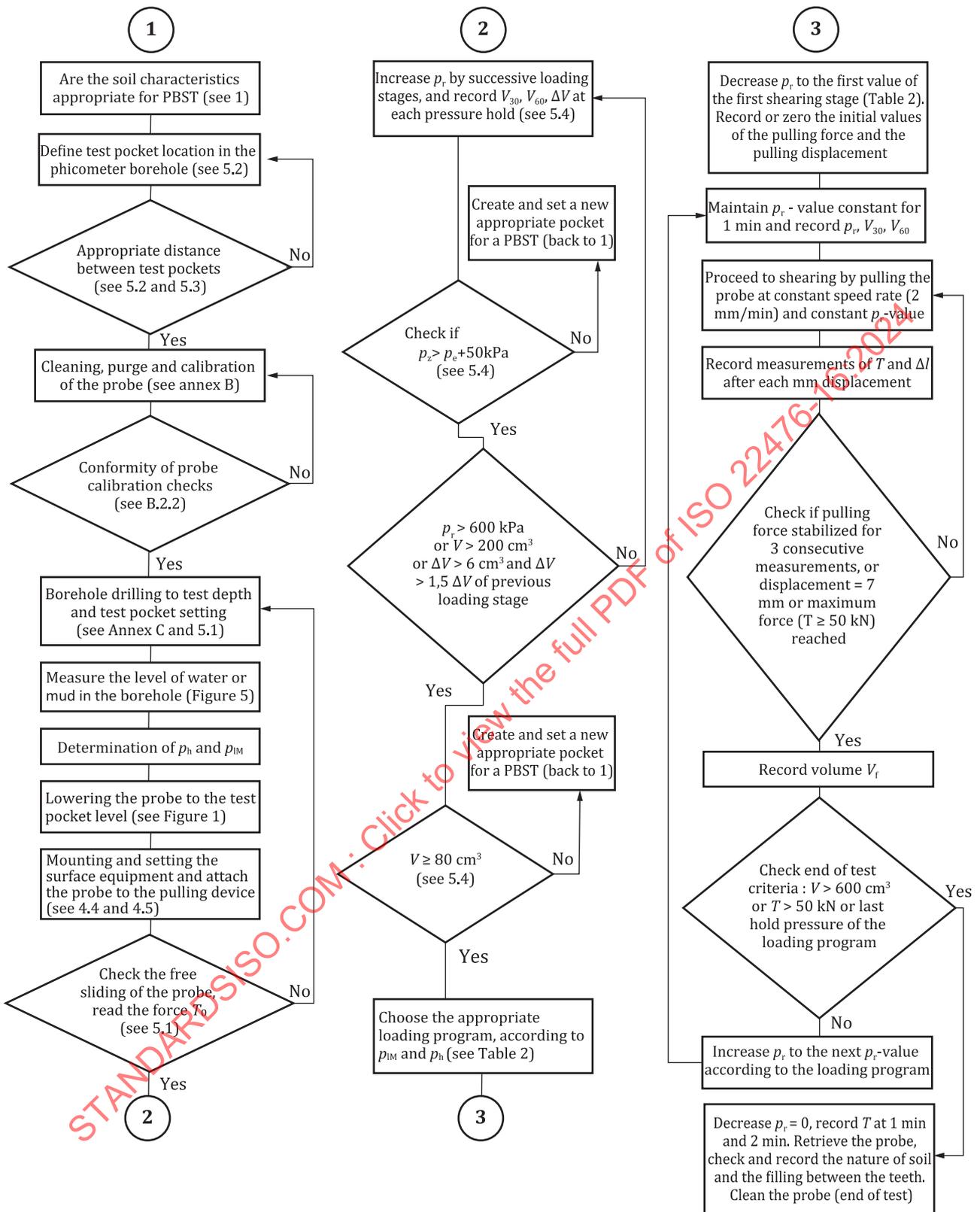
Key

①   borehole drilling and probe placing phases
②   teeth insertion phase
③   shearing phase

5.4 Teeth insertion phase

After the insertion of the probe in the ground (see 5.2), the probe is inflated by successive loading stages during which the pressure p_r is kept constant to ensure the insertion of the annular teeth into the soil on the borehole wall.

The pressure p_r is increased gradually by pressure increments Δp, as follows:

— Δp = 50 kPa for poorly to fairly consistent soils with a Ménard pressuremeter limit pressure p_{lM} ranging between 0,4 MPa and 1,0 MPa;

— Δp = 100 kPa for consistent and compact soils with a Ménard pressuremeter limit pressure p_{lM} higher than or equal to 1,0 MPa;

NOTE   In the case where the Ménard limit pressure values of the soils are not available, Annex E provides correlations to estimate p_{lM} from other common soil resistance parameters. These correlations are given only for information and to allow the use of this document.

The pressure is maintained constant at each loading stage for a Δt_p duration of 60 s.

At each stage, the applied pressure p_r is noted as well as the volume injected into the measuring cell at the following times: t = 30 s (V_{30}) and t = 60 s (V_{60}) and the volume difference ($V_{60} - V_{30}$).

The pressure p_z applied to the level of the probe is conventionally given by:

$$p_z = p_r + p_h$$

where p_h is calculated, as appropriate (see Figure 5), by the following formulae:

— If the test level is located above the level of water or mud in the borehole (z_w and $z_e < z_s$):

$$p_h = (z_c - z_s) . \gamma_l$$

— If the test level is located below the level of water or mud in the borehole (z_w or $z_e > z_s$):

$$p_h = (z_c - z_e) . \gamma_l \text{ or } p_h = (z_c - z_w) . \gamma_l$$

The specific weight of water or mud γ_l is taken conventionally equal to 10 kN/m^3 and z_e is conventionally defined by:

$$z_e = (z_{ei} - z_{ef}) / 2$$

where z_{ei} and z_{ef} are respectively the initial and final levels of water or mud measured in the borehole before the beginning and after the end of the test, the probe being extracted.

At each pressure hold, the curve representing the volume V_{60} as a function of p_z is drawn progressively on the test sheet (see Table 3) and is compared with the calibration pressure loss curve of the probe $V(p_e)$, in accordance with Annex B.
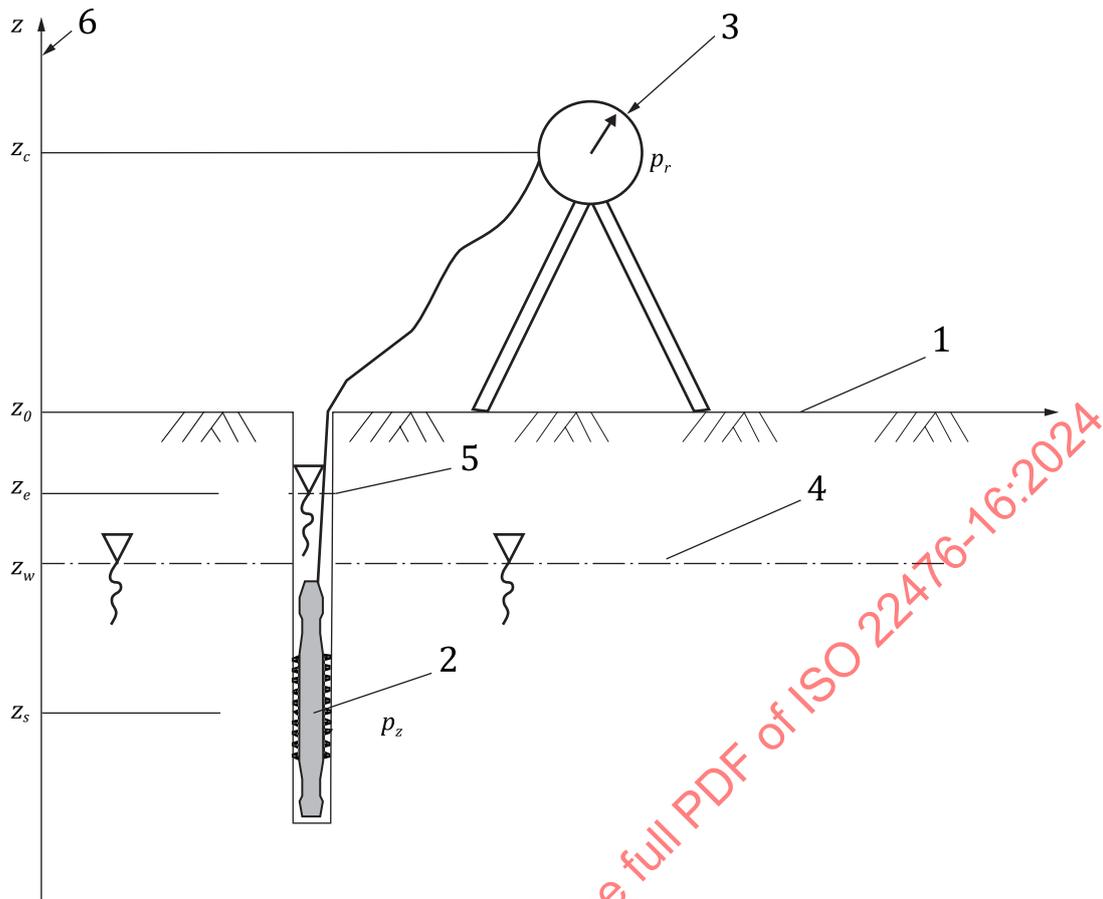
Key

1	ground surface level	4	ground water table level	p_r	pressure read on the control unit
2	PBST probe	5	level of water or mud in the borehole	p_z	pressure in the probe ($p_z = p_r + p_h$)
3	liquid pressure reading device	6	elevation		

Figure 5 — Location of the probe and the liquid pressure reading device and definition of levels during a test

In order to ensure beforehand that the probe comes into contact with the borehole wall, it is necessary during this expansion phase that the pressure in the probe p_z be at least 50 kPa higher than the pressure loss p_e given for the same volume by the pressure loss calibration curve of the probe.

Once this criterion is reached, the teeth insertion phase is continued until obtaining one of the following criteria:

— the volume V_{60} of the probe is at least 200 cm^3; or

— the read pressure has reached 600 kPa; or

— the beginning of the creep of the soil. This beginning of creep can be detected by the variation of volume between 30 s and 60 s when it reaches 6 cm^3 and 1,5 times the same variation measured in the previous stage.

If at the end of the teeth insertion phase, the volume of the probe is less than 80 cm^3, it is recommended to carry out a check to verify that there is no soil that has fallen or collapsed above the probe in the borehole. In this case, the test should be repeated at another depth in the same borehole or at the same depth in a new borehole drilled nearby.

At the end of the teeth insertion phase, the pressure p_r is then reduced to the first pressure hold value according to Table 2 and the shearing phase is immediately carried out.

5.5 Shearing phase

5.5.1 Loading program – applied hold pressures in the probe

The shearing phase is carried out by successive stages of pulling the probe while keeping constant, for each stage, the pressure p_r measured with the pressure gauge.

The pressure holds of the loading program of the shearing phase are given in Table 2 according to the estimated Ménard limit pressure p_{lM} of the soil and for different values of p_h.

NOTE   In the case where the Ménard limit pressure values of the soils are not available, Annex E provides correlations to estimate p_{lM} from other common soil resistance parameters. These correlations are given only for information and to allow the use of this document.

5.5.2 Successive shearing stages under pressure holds

After the selection of the appropriate loading program as a function of p_{lM} and p_h, the pressure p_r is set with the value defined for the first stage, according to Table 2.

The values indicated by the measurement devices of the pulling force and pulling displacement are noted or set to zero.

During the first minute of the first pressure hold, the volume of the measuring cell shall be read and recorded at t = 30 s, and at t = 60 s. This last volume value corresponds to V_d.

The pressure p_r being maintained constant, shearing is then generated by pulling the probe with the pulling device from the ground surface, at a constant rate of displacement of 2 mm/min. The pulling force is then recorded at least each 30 s or each mm of displacement.

This shearing stage is stopped when the pulling force is stabilized after at least 4 mm of displacement or when a maximum displacement of 7 mm is reached. The stabilization is assumed to be obtained when the difference between three consecutive measurements is less or equal to 5 %. The volume V_f at the end of the stage is then recorded.

The process is then repeated for the next shearing stages and pressure holds according to Table 2.

Table 2 — Values of the pressure hold p_r of the loading program for the shearing stages 1 to 8

Estimated Ménard p_{lM} MPa	p_h MPa	Pressure during stages 1 to 4 MPa				Pressure during stages 5 to 8 MPa				
		No.1	No.2	No.3	No.4	Check condition	No.5	No.6	No.7	No.8
$0,4 \leq p_{lM} < 1,0$	$p_h < 0,10$	0,20	0,25	0,30	0,35	$V_f > 350$ cm^3	0,40	0,45	0,50	0,55
						$V_f \leq 350$ cm^3	0,45	0,55	0,65	0,75
	$0,10 \leq p_h \leq 0,15$	0,10	0,15	0,20	0,25	$V_f > 350$ cm^3	0,30	0,35	0,40	0,45
						$V_f \leq 350$ cm^3	0,35	0,45	0,55	0,65
	$0,15 < p_h \leq 0,20$	0,05	0,10	0,15	0,20	$V_f > 350$ cm^3	0,25	0,30	0,35	0,40
						$V_f \leq 350$ cm^3	0,30	0,40	0,50	0,60
	$0,20 < p_h \leq 0,30$	0,05	0,10	0,15	0,20	$V_f > 350$ cm^3	0,25	0,30	0,35	0,40
						$V_f \leq 350$ cm^3	0,30	0,40	0,50	0,60

Table 2 *(continued)*

Estimated Ménard p_{IM} MPa	p_h MPa	Pressure during stages 1 to 4 MPa				Pressure during stages 5 to 8 MPa				
		No.1	No.2	No.3	No.4	Check condition	No.5	No.6	No.7	No.8
$P_{IM} \geq 1{,}0$	$p_h < 0{,}10$	0,25	0,30	0,35	0,40	$V_f > 350$ cm^3	0,45	0,55	0,65	0,75
						$V_f \leq 350$ cm^3	0,55	0,70	0,85	1,00
	$0{,}10 \leq p_h \leq 0{,}15$	0,15	0,20	0,25	0,30	$V_f > 350$ cm^3	0,35	0,45	0,55	0,65
						$V_f \leq 350$ cm^3	0,45	0,60	0,75	0,90
	$0{,}15 < p_h \leq 0{,}20$	0,10	0,15	0,20	0,25	$V_f > 350$ cm^3	0,30	0,40	0,50	0,60
						$V_f \leq 350$ cm^3	0,40	0,55	0,70	0,85
	$0{,}20 < p_h \leq 0{,}30$	0,05	0,10	0,15	0,20	$V_f > 350$ cm^3	0,25	0,35	0,45	0,55
						$V_f \leq 350$ cm^3	0,35	0,50	0,65	0,80

5.5.3 End of the test

The shearing phase is led until:

— either, the eight stages of shearing given by Table 2 are carried out; or

— the volume injected into the measuring cell of the probe exceeds 600 cm^3; or

— the maximum pulling force exceeds 50 kN.

The pressure in the probe is then completely released to zero and the residual forces of pulling after a hold period of $t = 60$ s and $t = 120$ s are recorded.

After complete deflation of the probe volume, the pulling rods and the probe are then extracted from the borehole.

The level of water or mud in the borehole z_{ef} is noted immediately after extracting the probe.

The nature of the soil filling the spaces between the annular teeth of the retrieved probe, and the degree of filling (total filling, partial filling or no filling) are noted.

6 Back-filling of the phicometer borehole

The method of back-filling of the borehole resulting from the PBST tests shall be agreed and carried out in accordance with ISO 22475-1, taking into consideration national regulations, technical or authority requirements.

If a backfilling of the borehole is required, then it shall be documented in the test report.

7 Safety requirements

It is assumed that national safety and health regulations are followed, for example for:

— personal protection equipment;

— clean air if working in confined spaces;

— ensuring the safety of personnel and equipment.

8 Test results

8.1 General

The data reduction and the exploitation of the measurements shall be carried out in accordance with Annex D. It consists in determining from the PBST results, the in situ shear strength parameters:

— phicometer angle of friction measured in situ φ_i;

— cohesion measured in situ c_i.

To achieve this, the following procedure and steps shall be observed:

— determination of the calibration characteristics of the probe in order to correct the radial pressure p_c and the shear strength τ according to B.2.2.4;

— determination for each stage of the corrected radial pressure p_c, according to the method described in D.1.1;

— determination of the limit shear stress τ_l, according to the method described in D.1.2;

— layout of the following graphs of the test:

— graph of the shearing curve [see Figure 6 a)], representing $\tau_l\,(p_c)$;

— associated graph of the creep [see Figure 6 b)], representing $V_f - V_d\,(p_c)$;

— associated graph of the injected volume [see Figure 6 c)], representing the injected volume $V\,(p_c)$;

— determination from the graphs of the significant zone of adjustment (see Figure 6);

— adjustment and determination of the in situ phicometer angle of friction φ_i and the in-situ cohesion c_i from the $\tau_l(p_c)$ curve (see D.2.2).

8.2 Shearing curve graph — Shear strength parameters φ_i and c_i

In a graph having the radial pressure p_c for X-coordinates and the limit shear stress τ_l for Y-ordinates, the points $\tau_l(p_c)$ of all the stages of the shearing phase are represented.

The X and Y axes of the diagram shall be linear with the same scale. An example of this graph is represented in Figure 6 a).

8.3 Associated graphs

Two other graphs are associated with the shearing curve graph. They represent:

— the creep expansion curve of the probe which represents the difference in volume injected into the probe between the beginning and the end of each stage of the pulling phase $(V_f - V_d)$ against p_c [see Figure 6 b];

— the injected volume curve, representing the injected volume in the probe V against p_c [see Figure 6 c)].

8.4 Adjustment and determination of the in situ phicometer angle of friction φ_i and the in situ phicometer cohesion c_i

The test diagram in Figure 6 includes three graphs [a), b) and c)]. They represent the results of all the shear stages performed during the test.

In general, three zones can be identified on each of these graphs:

— the initial zone (zone 1), corresponding to the first shear stages, where the points indicate that the penetration of the teeth into the borehole wall, initiated during the teeth insertion phase (see 5.4) is achieved and that the contact of the soil, trapped beneath the teeth, with the undisturbed ground is reached at the end of this first zone;

— the central zone (zone 2), where shear stages with low creep values ($V_f - V_d$) can be identified and where the succession of these representative points in graphs a) and b) is quasi linear;

— the final zone (zone 3) which indicates the shear stages of the test where the creep [graph b)] and the rate of change of the volume [graph c)] increase.

Only the points in the central zone are used for the linear fitting adjustment of a straight line representing the shear failure envelope or the Coulomb envelope. The slope of this line on the shearing curve graph [see Figure 6 a)] is the tangent of the angle of friction φ_i and the ordinate at the origin of this line is the cohesion c_i measured in situ with the PBST.

NOTE   An estimation of the undrained shear resistance parameters φ_u and c_u and the effective shear resistance parameters φ' and c' from the in-situ angle of friction φ_i and cohesion c_i can be obtained by guidelines published in Reference [9].

8.5   Examples of adjustment and determination of the in-situ angle of friction φ_i and cohesion c_i

For information, examples of adjustment of measurement points are given in Annex G.

They show for different typical cases how to determine the adjustment zone and the corresponding φ_i and c_i values obtained.

Annex G also gives examples of tests that are difficult to interpret. These examples are not exhaustive.
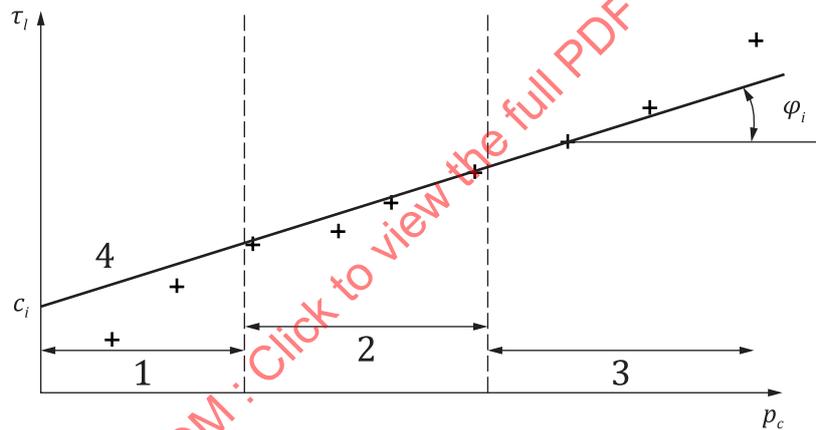
a) Shearing curve graph with shear strength parameters
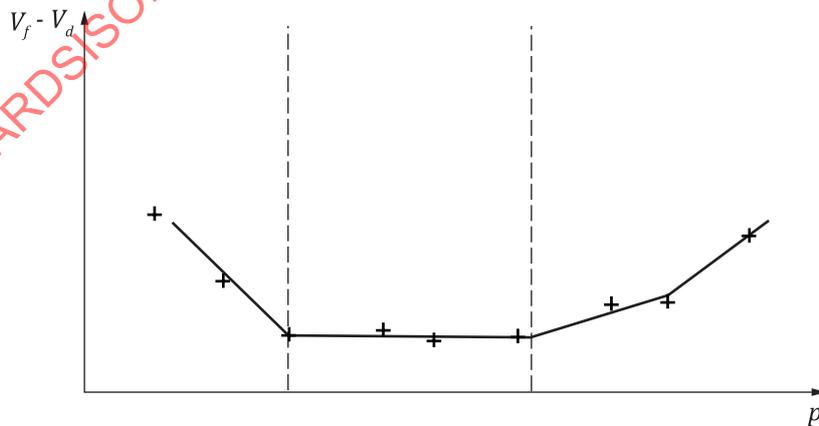
b) Creep expansion curve
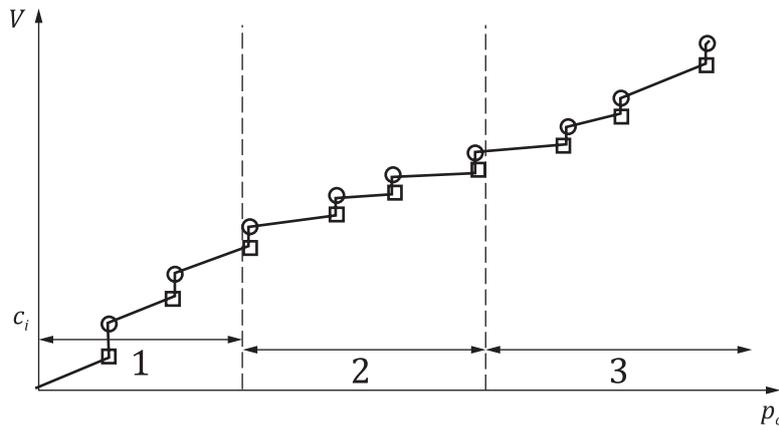
c) Injected volume

Key

1	zone 1: initial zone	2	zone 2: significant zone of adjustment	3	zone 3: final zone
4	shear failure envelope (coulomb line)				
○	V_f				
□	V_d				

Figure 6 — Example of a PBST test-results diagram

9 Reporting

9.1 General

The test report is the key deliverable from the on-site testing operations and shall provide sufficient information such that all relevant aspects of the preparation of the pocket and the execution of the test are available to the reader. The report shall also provide an interpretation of the results with supporting graphical presentation of the results.

The test results shall be reported in such a fashion that third parties are able to check and fully understand the results.

9.2 Field report

The field report shall contain all data collected in the field during the four test sequences shown in Figure 1. It shall also enable to identify the operator in charge.

The PBST test field report shall include the following minimal indications:

— a reference to this document, i.e. ISO 22476-16:2024;

— the identification number of the borehole in which the test was carried out;

— the depth of test in reference to the top of borehole ($z_0 - z_s$);

— the name of the company and the name of the operator in charge of the test;

— the identification references of the equipment used (at least the pressure volume control unit and the pulling device), and the corresponding calibration references;

— the drilling methods and tools used to prepare the test pocket;

— the date and time of the beginning of the test;

— the distance between the top of the borehole and the pressure measuring device $(z_c - z_0)$;

— the depths of water or drilling mud in the borehole, measured before lowering the probe and measured after extraction of the probe;

— the type of membrane (normal or reinforced);

— the table of the volume and pressure readings during the teeth insertion, taken at 30 s and 60 s at each loading stage;

— the table of the readings taken during the successive stages of the shearing phase, including: the pressure hold value and the corresponding volume injected within 30 s and 1 min (V_d), the readings of the pulling force T taken at each mm of the axial displacement of the probe Δl, the final volume injected V_f at the end of the phase of pulling;

— the state of filling between the annular teeth of the probe after its extraction and a description of the ground between the teeth.

An example of PBST test sheet is given in Tables 3 and 4. The probe calibration sheet (see example in Table B.2) or file data corresponding to the test sheets shall be available.

Table 3 — Example of a PBST test sheet — Teeth insertion phase

Company:_____		Phicometer borehole shear test according to this document: teeth insertion phase	
File no.:_____ _____	Location:_____ Job site:_____	Borehole no.:_____	
Drilling technique:_____ _____	Drilling tool:_____ _____	Drilling before testing: between _____ m and _____m	
Elevation of control unit z_c =_____m	Test elevation: z_s =_____m	Fluid elevation in the borehole Before the beginning of test: z_{ei} =_____m	After the end of test: z_{ef} =_____m
Probe calibration no._____ Date: ____/____/____		Test date: ____/____/____ Hour:_____:_____	
Placement and phase of dilation of the probe			
If: $z_s \leq z_e$ then: p_h=10 $(z_c - z_e)$, in kPa If: $z_s > z_e$ then: p_h=10 $(z_c - z_s)$, in kPa		Pulling suspension force of the drill string and the probe at the test level: T_0 =_____ kN	

p_h = _____kPa

Pressure increments

$0,4 \leq p_{IM} < 1,0$ MPa	Δp = 50 kPa ☐
$p_{IM} \geq 1,0$ MPa	Δp = 100 kPa ☐

Pressure hold no.	Pressure p_r	Injected volume		ΔV_{30}^{60} (cm³)
		V_{30} (cm³)		
		V_{60} (cm³)		

$p_z = p_r + p_h$

Calibration curve of the probe

ISO 22476-16:2024(en)

Table 4 — Example of a PBST test sheet — Phase of shearing stages

Company:_____ _____	Phicometer borehole shear test according to this document: shearing phase		
File no:_____ _____	Location:_____ Job site:_____	Borehole no:_____	
Control unit device Reference:_____	Last calibration date:_____ Reference:_____	Elevation of test: _____ m	
Pulling force measuring device Reference:_____	Last calibration date:_____ Reference:_____	Elevation of liquid pressure reading device: _____ m	

Shearing phase of the test under pressure holds values in Table 2.

$p_z = p_r + p_h$ with (see preliminary phase) p_h =_____

Hold (1)	Δl mm	T	Hold (2)	Δl mm	T	Hold (3)	Δl mm	T
p_r	1		p_r	1		p_r	1	
p_z	2		p_z	2		p_z	2	
$V_{(30s)}$	3		$V_{(30s)}$	3		$V_{(30s)}$	3	
$V_{d(60s)}$	4		$V_{d(60s)}$	4		$V_{d(60s)}$	4	
V_f	5		V_f	5		V_f	5	
V_f-V_d	6		V_f-V_d	6		V_f-V_d	6	
_	7		_	7		_	7	
Hold (4)	Δl mm	T	**Hold (5)**	Δl mm	T		Δl mm	Δl mm	T
p_r	1		p_r	1		p_r	1	
p_z	2		p_z	2		p_z	2	
$V_{(30s)}$	3		$V_{(30s)}$	3		$V_{(30s)}$	3	
$V_{d(60s)}$	4		$V_{d(60s)}$	4		$V_{d(60s)}$	4	
V_f	5		V_f	5		V_f	5	
V_f-V_d	6		V_f-V_d	6		V_f-V_d	6	
_	7		_	7		_	7	
Hold (7)	Δl mm	T	**Hold (8)**	Δl mm	T			
p_r	1		p_r	1		Degree of soil filling between the teeth: _____		
p_z	2		p_z	2				
$V_{(30s)}$	3		$V_{(30s)}$	3		Nature of soil in annular teeth:_____		
$V_{d(60s)}$	4		$V_{d(60s)}$	4				
V_f	5		V_f	5				
V_f-V_d	6		V_f-V_d	6		Observations:_____		
_	7		_	7				

Units	Volume in:_____		End of the shearing phase		Observations:_____
	Pressure in:_____	$p_r = 0$	1 min	$T =$	Operators:_____ _____
	Pulling force in:_____		2 min	$T =$	

9.3 Test report

The phicometer borehole shear (PBST) test report, presented in the form of a graphic document, shall contain the following information:

Written information:

— a reference to this document, i.e. ISO 22476-16:2024;

— the reference of the location of the borehole and, if available, the planimetric coordinates of the borehole;

— the identification number of the borehole in which the test was performed;

— the test depth elevation or the depth of test from the top of the borehole;

— the type of borehole drilling technique and drilling tool used;

— the elevation or depth of water or mud in borehole (probe being extracted);

— the soil type identified between the annular teeth.

Graphical information:

— a graph representing the values of the limit shear stress τ_l against the corrected radial pressure p_c obtained for each shearing stage and the representation of the linearly fitted straight line of the shearing envelope [see Figure 6 a)];

— best fitted values of the in situ phicometer angle of friction φ_i and in situ phicometer cohesion c_i [see Figure 6 a)];

— a graph representing the volume dilation of the probe $(V_f - V_d)$ at each shearing stage against the corrected radial pressure p_c [see Figure 6 b)];

— a graph representing the evolution of the probe volume V against the corrected radial pressure p_c during the successive stages of shearing [see Figure 6 c)].

The test report shall be signed by the representative field responsible expert.

9.4 Tests log

The phicometer borehole shear (PBST) tests carried out in a same borehole can be represented as a log. A PBST tests log shall include as a minimum in addition to the written information of the test report:

— information on the ground strata met during drilling (e.g. nature of the grounds, colour, depth of the layers, resistance to the drilling progression);

— a representation of the following numerical values with the depth:

— in situ phicometer angle of friction φ_i value, rounded to the nearest degree;

— in situ phicometer cohesion c_i value, expressed in kilopascals with two significant digits;

— comments on the test procedure, mishaps and any other information or event that can have influenced or affected the test results.

Annex A
(normative)

Characteristics of the phicometer probe

The geometrical specifications (see Figure 3) for the manufacturing of the main components of the phicometer probe are given in Table A.1.

Table A.1 — Specifications of the expansible shear tube, measuring cell and the phicometer probe

Characteristic		References	Symbols	Units	Value	Tolerance
Expansible shear tube	Shearing zone	Length	l_s	mm	225	+1 −1
		Outside diameter	$d_{s,0}$	mm	58	+1 −1
		Annular teeth number		(-)	10	0
		Depth of teeth	h_d	mm	5	+0,2 −0,2
		Thickness of teeth at edge	$l_{d,1}$	mm	1,0	+0,0 −0,2
		Thickness of teeth at base	$l_{d,2}$	mm	3,5	+0,2 −0,2
	Guard zone	Slot length (along tube axis)	l_t	mm	710	+10 −0
		Internal diameter	d_f	mm	33	+2 −2
Measuring cell	Steel core	Distance between rings	l_c	mm	328	+10 −0
		Outside diameter	d_c	mm	31,5	+0,5 −0,5
Phicometer probe with Standard membrane	for V=200 cm³	Pressure loss	p_e	kPa	≤ 180	-
		Outside diameter	d_s	mm	68≤ d_s ≤ 72	-
	for V=500 cm³	Pressure loss	p_e	kPa	≤ 260	-
		Outside diameter	d_s	mm	79≤ d_s ≤ 84	-
Phicometer probe with Reinforced membrane	for V=200 cm³	Pressure loss	p_e	kPa	≤ 220	-
		Outside diameter	d_s	mm	68≤ d_s ≤ 72	-
	for V=500 cm³	Pressure loss	p_e	kPa	≤ 380	-
		Outside diameter	d_s	mm	80≤ d_s ≤ 85	-

Annex B
(normative)

Calibration, checks and corrections

B.1 Measuring devices

All control and measuring devices shall be periodically checked and calibrated against reference standards to show that they provide reliable and accurate measurements. The calibration interval shall be such that the resolution required can be verified, and should be less than one year.

NOTE   Verification of the required resolution can be based on the record of previous calibrations.

The uncertainties of measurements summarized in Annex F shall be considered. The device for volume measurement shall be calibrated with a length of tube line lower than 1 m.

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

A copy of the latest calibration test report or a proof of this calibration shall be available at the job site.

B.2 Calibrations and checks of correct operation to be carried out on job site

B.2.1 Means of measurement

Every month or all the 100 tests and during each period of freezing, the proof of the accuracy of the pressure gauges, dynamometers or of the pressure pick-ups shall be made, for example by using a material of reference or working measurement standards. The corresponding reports are filed in accordance with the rules in force in the firm to demonstrate the metrological traceability.

B.2.2 Phicometer probe

The standard cell membrane of the phicometer probe is used for all soil types. The reinforced membrane is exclusively used for aggressive soils where damaging and bursting of the cell probe occurs frequently.

The operations described in B.2.2.1, B.2.2.2 and B.2.2.3 shall be carried out as follows:

— at each change of the phicometer probe configuration or component replacement;

— at each change or modification of the connecting lines between the probe and the control unit;

— at intervals adapted to the use that the probe has received, for example a daily interval for regular daily use of the probe.

These operations shall be undertaken only when the probe is ready to be inserted into the ground for the PBST test, i.e. when the suitable length of connecting line is fitted and after having purged the measuring cell and the liquid circuit from all gas bubbles.

B.2.2.1 Checks of the geometrical characteristics of the probe in use

A probe in good condition of use shall present a teeth depth h_d not less than 4 mm and shall comply with the characteristics given in Table B.1.

B.2.2.2 Probe pre-inflation

The probe is inflated at least three times in the open air by injecting 600 cm^3 of liquid. Then the probe is placed vertically near the control unit so that the centre of the measurement cell is at the level of the pressure transducer. After that, the volume measuring device shall be zeroed by adjusting the volume of liquid in the circuit. The initial reading of each transducer shall then be checked.

B.2.2.3 Geometrical features, pressure loss and volume-diameter relation of the phicometer probe

The probe is placed near the pressure regulator, i.e. out of the ground, as shown on Figure B.1.

Key

z	elevation	z_s	phicometer probe level	z_c	elevation of control unit

Figure B.1 — Location of the probe and the pressure regulator during the calibration

The volumeter is regulated successively to inject in the probe a volume ranging from 200 cm^3 to 600 cm^3 by steps of 100 cm^3. At each step of injected volume, the liquid circuit is closed and the corresponding liquid pressure is measured and recorded as p_e. The outside diameter d_s of the probe is measured on the outer edge of the fifth tooth (starting from the top) of the probe, by means of a slide caliper. Table B.2 presents an example of a calibration sheet. The probe shall fulfill the criteria given in Table B.1.

Table B.1 — Criteria to check the state of the phicometer probe

Volume injected cm^3	Standard membrane	Reinforced membrane
0 (at rest)	$56 \leq d_s \leq 61$ mm $p_e \leq 10$ kPa	$56 \leq d_s \leq 61$ mm $p_e \leq 10$ kPa
200 ± 2	$68 \leq d_s \leq 72$ mm $p_e \leq 180$ kPa	$68 \leq d_s \leq 72$ mm $p_e \leq 220$ kPa
500 ± 2	$79 \leq d_s \leq 84$ mm $p_e \leq 260$ kPa	$80 \leq d_s \leq 85$ mm $p_e \leq 380$ kPa

Table B.2 — Calibration of the probe – Example

Company:_____			
File no:_____	Location:_____ Site:_____		Calibration
Date:_____ Hour:_____		Probe calibration no.: ☐ normal ☐ reinforced	
Observation:		z_c=_____m	operator
		z_s=_____m	
		$p_e = p_r + 10(z_c\text{-}z_s)$ p in kPa and z in m	

Probe calibration (see Figure B.2)				Control criteria (see Figure B.3)				
injected volume V cm³	pressure		outside diameter of probe d_s measured at the 5th annular tooth counted downward mm	injected volume V cm³	standard «N» membrane		reinforced «R» membrane	
	read p_r kPa	calculated p_e kPa			d_s mm	p_e kPa	d_s mm	p_e kPa
0				200	$68 \le d_s \le 72$	≤180	$68 \le d_s \le 72$	≤220
200								
300				500	$79 \le d_s \le 84$	≤260	$80 \le d_s \le 85$	≤380
400								
500				— if p_e higher than the values above the probe is out of service				
600				— disassemble the probe if for V = 500 cm³ the diameter d_s is higher than the values above.				

If, for a volume V of 500 cm³:

— the probe diameter is higher than the values given in Table B.1, it is necessary to disassemble the probe, to clean it and start again the calibration;

— the probe diameter is lower than the values given in Table B.1, the probe should be rejected.

B.2.2.4   Exploitation and analysis of the calibration results

From the calibration measurements, two curves are plotted:

— the curve pressure-volume: $V = f(p_e)$ which is plotted (see Figure B.2) after correction if necessary (i.e. when the probe was not placed on the same level as the pressure transducer) of pressure p_h due to the hydraulic head between z_c and z_s (see Figure B.1).

The pressure loss of the probe p_e is, after corrections:

$$p_e = p_h + p_r$$

where

p_h is the hydraulic head correction;

p_r is the pressure read with the pressure gauge.

— the curve volume-diameter: $V = g(d_s)$ is also plotted (see Figure B.3).

The curve $V = f(p_e)$ is adjusted by the least squares fitting method such as:
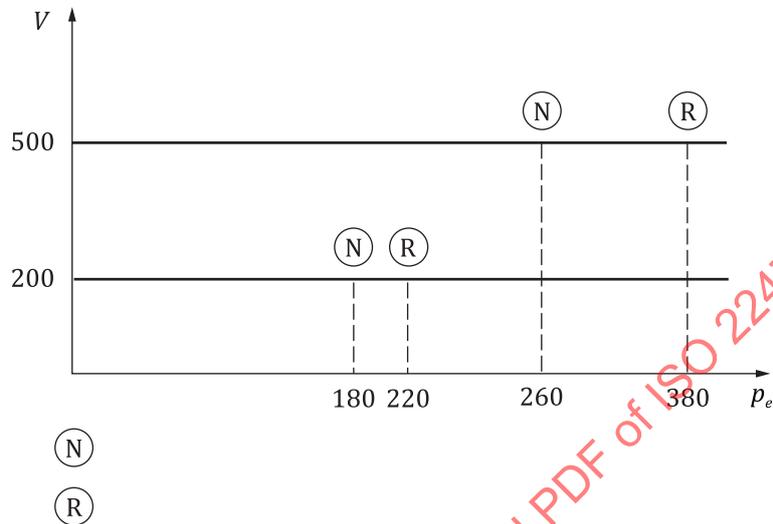
$$V = a \cdot (p_e)^b$$

a and *b* being the coefficients of the adjustment.

The curve $V = g(d_s)$ in the same way is adjusted with a linear law, such as:

$V = c \cdot d_s + d$

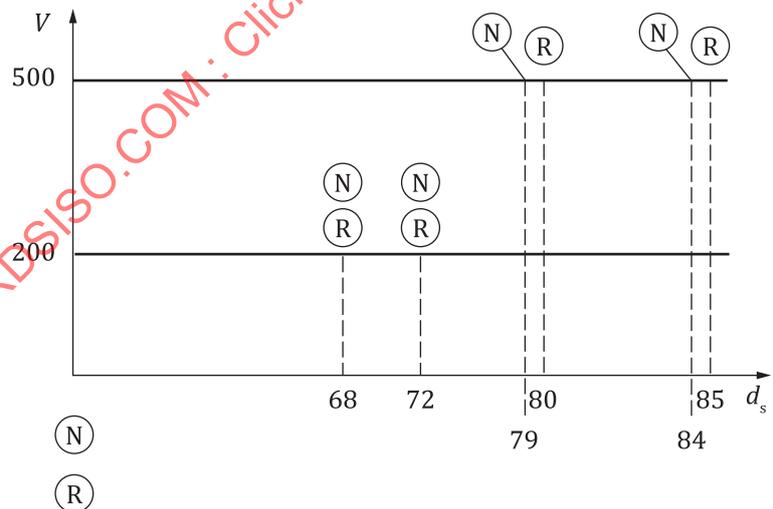*c* and *d* being the coefficients of the adjustment.

The volume loss of the circuit is neglected.

Key

N   standard membrane of the inflatable measuring cell
R   reinforced membrane of the inflatable measuring cell

Figure B.2 — Pressure loss calibration curve $V(p_e)$ plot

Key

N   standard membrane of the inflatable measuring cell
R   reinforced membrane of the inflatable measuring cell

Figure B.3 — Volume-diameter relation of the phicometer probe $V(d_s)$ plot

Annex C
(normative)

Execution of the PBST borehole

C.1 Drilling the phicometer borehole

The drillings techniques depend on type of soils, their state and the existence or not of a water table. Table C.1 presents various usual methods with their condition of uses.

Table C.1 — Drilling techniques for phicometer boreholes

Soil Type	Preboring								
	By rotary drilling[a]						By driving		
	HA	HAM	CFA	OHDM	RCD	RPM	OS-TKWH	VDT	OS-T/W-P
Medium stiff clay	R	R	○	R	○	○	■	■	■
Stiff clay and marl	NA	○	R	R	R	○	■	■	■
Silt: — above ground water table	R	R	R	○	○	○	○	○	○
— below water table	■	○	■	○	○	○	■	■	■
Loose sand: — above ground water table	R	R	○	○	○	○	■	■	■
— below water table	■	R	■	■	■	○	■	■	■
Medium dense and dense sand	R	R	R	R	○	○	○	○	NA
Coarse soils: gravels, cobbles, boulder clay	NA	NA	○	○	○	R	○	○	NA
Weathered rock Soft rock	NA	NA	○	R^0	R	○	○	○	NA

R	Recommended	HA	Hand auger	RPM	Rotary percussion with mud
○	Permitted	HAM	Hand auger with mud circulation		
■	Not permitted	CFA	Continuous flight auger	OS-TKWH	Driven tube - Hammered
NA	Not adapted				
0	Possible without mud	OHDM	Open hole rotary drilling with mud	VDT	Vibro driven sampler/tube
		RCD	Rotary Core drilling with mud	OS-T/W-P	Thin wall pushed sampler /tube

° Mud circulation: pressure should not exceed 500 kPa or the flow exceed 15 l/min.

[a] Tool diameter not be more than 1,13 d_{s0}.

C.2 Length of borehole before inserting the probe

The length of the phicometer borehole to be drilled before placing the phicometer probe, is such that it shall not exceed the depth of test (centre of the probe) of more than 1,5 m.

Only one test is carried out for each phicometer borehole drilling stage. After each test, the probe is retrieved from borehole in order to be cleaned.

In the case where two successive tests distant of 1,2 m are to be carried out, the depth of the phicometer borehole for the first test should not exceed the depth of test by more than 0,8 m.

C.3   Membrane choice selection

The reinforced membrane is used only in soils containing coarse grain with asperities being likely to cause burstings or puncture of the standard membrane during the test. In all the other cases, a standard membrane shall be used.

C.4   Time between drilling and testing

The test shall be executed immediately after completion of drilling.

Annex D
(normative)

Determination of the shear strength parameters

D.1 Determination of the values of τ and p_c

For each stage of shearing, the values of the conventional limit shear stress of the ground τ_l and the conventional radial stress p_c, are determined as follows.

D.1.1 Corrections of the radial pressure

During a test to a given elevation z_s, the neat radial pressure p_c being applied by the probe on the ground is equal to the pressure p_r read with the pressure regulator, increased by the hydrostatic pressure p_h as defined in 5.4 and decreased by the pressure loss of the probe p_e for the corresponding injected volume (see B.2.2.3):

$$p_c = p_r + p_h - p_e$$

D.1.2 Calculation of the limit shear stress τ_l of each shearing stage

The shear stress τ_l is given by the formula

$$\tau_l = \frac{T_l}{\pi \cdot l_s \cdot d_s}$$

Where, for each stage of shearing at a given pressure hold:

— T_l is the limit pulling force, corresponding to the maximum value of the pulling force measured during each shear stage, after elimination of any aberrant or non-representative values;

— l_s is the conventional length of the shearing zone of measurement of the probe, taken as $l_s = 23$ cm;

— d_s is the diameter of the probe corresponding to the volume injected at the end of the stage V_f. It results from the calibration curve $V = g(d_s)$ (see B.2.2.3).

D.2 Determination of the shearing curve of the soil

D.2.1 Determination of the significant zone of the shearing curve

The three graphs described in 8.2 and 8.3 are plotted (see Figure 6).

If values of $(V_f - V_d)$ for first shearing stages go decreasing significantly and if the corresponding points of the graph $V = f(p_c)$ form a curve with the concavity directed towards the axis of p_c values, that means that the penetration of the teeth in the intact ground is insufficient and the corresponding points of these first stages should not be considered for the fitting of the Coulomb envelope.

If, for the last shearing stages, the general shape of the curve $V = f(p_c)$ has a concavity directed towards the axis of τ, this shows that a creep of soil under the exerted radial pressures is occurring and that the corresponding points should also not be considered for the fitting.

D.2.2 Determination of the in situ shearing parameters φ_i and c_i

The line of shearing is adjusted by the least squares method of fitting on the remaining significant zone of adjustment where the points of the curve $\tau_1 = f(p_c)$ correspond to a variation of $V_f = f(p_c)$ having a linear form. For a correct fitting of the Coulomb envelope and determination of the shearing parameters, it is necessary to have at least three significant points remaining in the zone of adjustment.

The in situ angle of friction φ_i measured by the phicometer borehole shear test is defined by the slope of the Coulomb linear envelope.

In situ cohesion c_i, measured by the phicometer borehole shear test is the ordinate at the origin of this linear envelope.

The formulae corresponding to the least squares method of linear fitting, giving φ_i and c_i are:

$$\varphi_i = \tan^{-1}\left[\frac{\left(n\sum_1^n p_c \cdot \tau_1\right) - \left(\sum_1^n p_c \cdot \sum_1^n \tau_1\right)}{\left(n\sum_1^n p_c^2\right) - \left(\sum_1^n p_c\right)^2}\right]$$

$$c_i = \frac{\left(\sum_1^n \tau_1 \cdot \sum_1^n p_c^2\right) - \left(\sum_1^n p_c \cdot \left(\sum_1^n p_c \cdot \tau_1\right)\right)}{\left(n\sum_1^n p_c^2\right) - \left(\sum_1^n p_c\right)^2}$$

Where n is the number of significant points taken into account for the fitting.

In the case where the linear regression fitting leads to a cohesion value close to zero, but negative, it is then possible to consider $c_i = 0$ and to determine the value of φ_i by using the fitting method based on the average values, as follows:

$$\varphi_i = \tan^{-1}\left[\frac{\sum_1^n \frac{\tau_1}{p_c}}{n}\right]$$

Annex E
(informative)

Correlations to estimate p_{lM} from other soil resistance parameters q_c and N

In the case where the Ménard limit pressure p_{lM} values of the soils to be tested by the phicometer borehole shear test are not available, Figure E.1 provides correlations to estimate p_{lM} for different types of soil, from the mechanical CPT cone resistance q_c or from the SPT N value of the soil.

These correlations are given only for information and to allow the execution of the PBST test using this document.
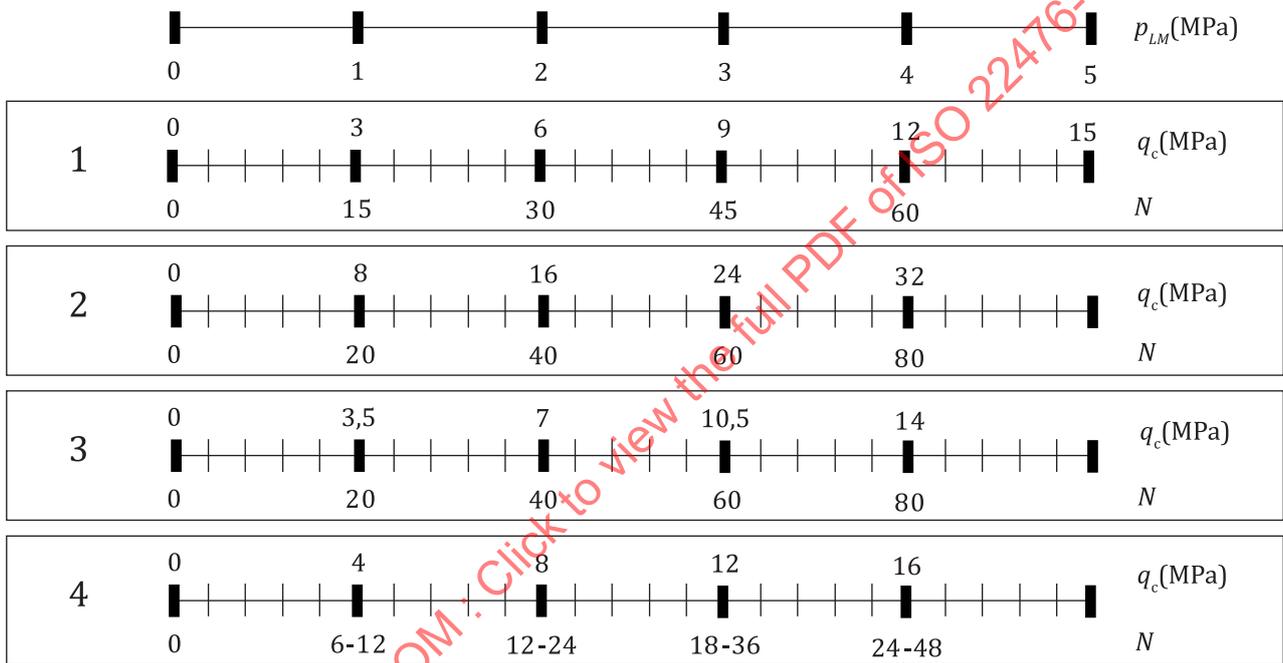
Key

1 clay and clayey silt

2 sand and gravel

3 marl

4 chalk

SOURCE   Reference [11], reproduced with the permission of the authors.

Figure E.1 — Example of correlations to estimate p_{lM} from q_c and N for different types of soil[11]