INTERNATIONAL STANDARD

ISO 22476-5

First edition
2012-12-01

Geotechnical investigation and testing — Field testing —

Part 5: Flexible dilatometer test

Reconnaissance et essais géotechniques — Essais en place —

Partie 5: Essai au dilatomètre flexible

Reference number
ISO 22476-5:2012(E)

Contents

Page

Foreword

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

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

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

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

ISO 22476-5 was prepared by the European Committee for Standardization (CEN) Technical Committee CEN/TC 341, *Geotechnical investigation and testing*, in collaboration with Technical Committee ISO/TC 182, *Geotechnics*, Subcommittee SC 1, *Geotechnical investigation and testing*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

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

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

— *Part 2: Dynamic probing*

— *Part 3: Standard penetration test*

— *Part 4:Ménard pressuremeter test*

— *Part 5: Flexible dilatometer test*

— *Part 7: Borehole jack test*

— *Part 9: Field vane test*

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

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

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

Introduction

The results of dilatometer tests are used for deformation calculations provided that the range of stresses applied in the test are representative of the stresses to be applied by the proposed structure. Local experience normally improves the application of the results. In addition, for identification and classification of the ground, the results of sampling (according to ISO 22475-1) from each borehole are available for the evaluation of the tests. Identification and classification results (ISO 14688-1 and ISO 14689-1) are available from every separate ground layer within the desired investigation depth (see EN 1997-2:2007, 2.4.1.4(2)P, 4.1(1)P and 4.2.3(2)P).

Geotechnical investigation and testing — Field testing —

Part 5: Flexible dilatometer test

1 Scope

This part of ISO 22476 specifies the equipment requirements, execution of and reporting on flexible dilatometer tests.

NOTE This part of ISO 22476 fulfils the requirements for flexible dilatometer tests as part of geotechnical investigation and testing according to EN 1997-1 [1] and EN 1997-2 [2].

This part of ISO 22476 is applicable to tests in ground stiff enough not to be adversely affected by the drilling operation.

This part of ISO 22476 is applicable to four procedures for conducting a test with the flexible dilatometer.

This part of ISO 22476 applies to tests performed up to 1 800 m depth. Testing can be conducted either on land or off-shore.

2 Normative references

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

ISO 10012, *Measurement management systems — Requirements for measurement processes and measuring equipment*

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

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

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

EN 791, *Drill rigs — Safety*

EN 996, *Piling equipment — Safety requirements*

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

3 Terms, definitions and symbols

3.1 Terms and definitions

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

3.1.1
flexible dilatometer
cylindrical flexible probe which can be expanded by the application of hydraulic pressure or pressurized gas and which contains transducers for the measurement of the displacements of the flexible membrane and of the internal pressure

3.1.2
equipment for flexible dilatometer test
complete equipment which is necessary to carry out a flexible dilatometer test: the probe, a hydraulic pump or high-pressure gas in bottles, a measuring unit and cables to connect the probe to the measuring unit and the hydraulic pump or the gas bottle

NOTE The parts which are necessary to bring the flexible dilatometer probe to the testing point are not included.

3.1.3
dilatometer sounding
whole series of successive operations in a given borehole, i.e. forming dilatometer pockets and performing dilatometer tests in them

3.1.4
dilatometer test pocket
cylindrical cavity with circular cross-section drilled into the ground to receive the dilatometer probe

3.1.5
flexible dilatometer test
process of expanding the flexible dilatometer so as to press the flexible membrane against the pocket wall and so measure the associated expansion as a function of pressure and time (see Figure 1)

3.1.6
nominal diameter of the pocket
diameter of the pocket at the time of application of the seating pressure

3.1.7
seating pressure
pressure during the expansion of the dilatometer at which the dilatometer membrane contacts the pocket wall

3.1.8
pressure increment
fixed increase of pressure in the flexible dilatometer, according to a pre-determined programme and recorded in the control unit

NOTE It can also be a decrement.

3.1.9
diametral pocket displacement
displacement of pocket wall caused by an increase or decrease of any pressure

3.1.10
diameter increase/decrease
change in flexible dilatometer diameter and in pocket wall displacement caused by a pressure increment/decrement, and recorded in the measurement unit

3.1.11
flexible dilatometer curve
graphical plot of pressure versus the associated pocket wall displacement

3.1.12
flexible dilatometer shear modulus, G_{FDT}
shear modulus calculated from the slope over various intervals of pressure and pocket wall displacement

3.1.13
flexible dilatometer modulus, E_{FDT}
Young’s modulus calculated from the slope over various intervals of pressure and pocket wall displacement

3.1.14
depth of test
distance between the ground level and the centre of the expanding length of the dilatometer measured along the borehole axis (see Figure 2)

3.1.15
operator
qualified person who carries out the test

3.2 Symbols and abbreviations

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

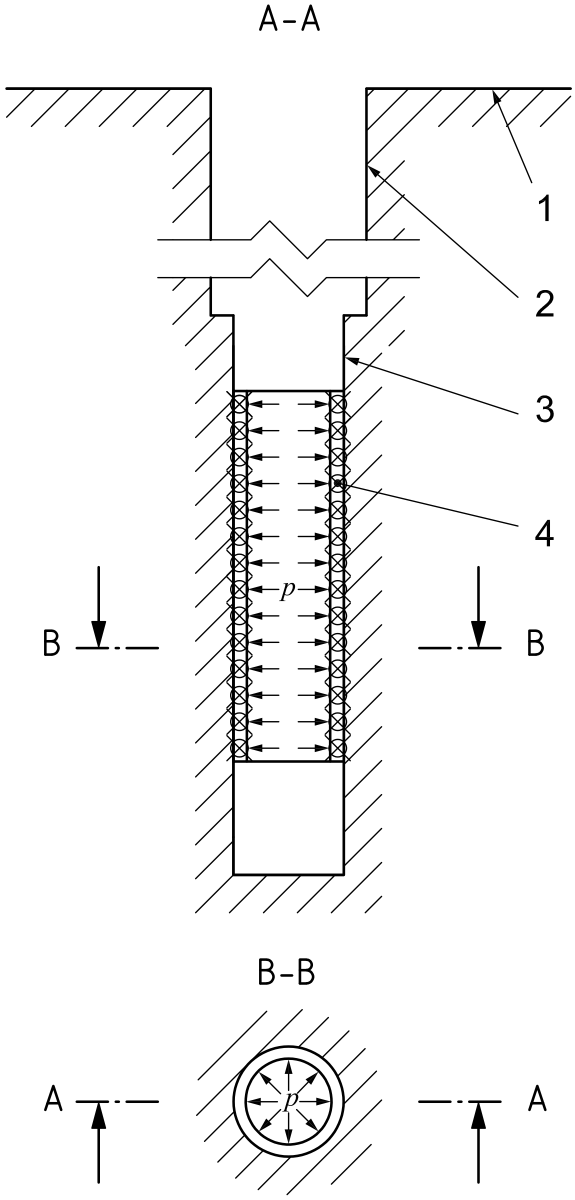
Table 1 — Symbols

Symbol	Description	Unit
a	Membrane compression coefficient in variant B dilatometer	$mm.MPa^{-1}$
d	Corrected pocket diameter	mm
d_1	Corrected pocket diameter at time t_1	mm
d_2	Corrected pocket diameter at time t_2	mm
d_c	Compression calibration cylinder diameter	mm
d_d	External diameter of the dilatometer	mm
d_r	Pocket diameter as read at the measuring unit	mm
d_s	Nominal diameter of the pocket after application of the seating pressure	mm
E_{FDT}	Young's Modulus of flexible dilatometer test	MPa
G_1	Loading shear modulus in procedure C	MPa
G_{FDT}	Shear modulus of flexible dilatometer test	MPa
G_L	Loading shear modulus of flexible dilatometer test	MPa
G_R	Reloading shear modulus of flexible dilatometer test	MPa
G_U	Unloading shear modulus of flexible dilatometer test	MPa
G_{UR}	Unloading/reloading shear modulus of flexible dilatometer test	MPa
k_f	Creep parameter	mm
L_{FD}	Length of the expanding part of the probe	mm
L_g	Axial distance between transducer or LVDT section and membrane clamping ring	mm
L_d	Length of the measuring segment of the dilatometer	mm
p	Applied pressure after correction	MPa
$p_{1.1}$	Constant full relief pressure for loops in procedure A	MPa
p_1	Pressure at reversal point at first loop	MPa
p_2	Pressure at reversal point at second loop	MPa
p_3	Pressure at reversal point at third loop	MPa
p_{max}	Maximum applied pressure during a test	MPa
p_m	Pressure loss associated with membrane stiffness	MPa
p_{Li}	Range of applied pressure in loading phase no. i	MPa
p_{Ri}	Range of applied pressure in reloading phase no. i	MPa
p_{Ui}	Range of applied pressure in unloading phase no. i	MPa
p_r	Pressure as read at the measuring unit	MPa
p_s	Seating pressure	MPa
p_y	Yield pressure during dilatometer test in procedure C	MPa
t	Time	min
t_1	Time 1 of a constant pressure test	min
t_2	Time 2 of a constant pressure test	min
z	Test depth	m
Δd_r	Increase of diametral displacement of the pocket	mm
Δd	Corrected increase of diametral pocket displacement	mm
Δp_r	Increment of applied pressure as read on the control unit	MPa
Δp	Corrected increment of applied pressure	MPa
ν	Poisson's ratio	–

4 Equipment

4.1 General

The test with the flexible dilatometer is performed by the expanding of a flexible dilatometer membrane placed in the ground (see Figure 1). The pressure applied to, and the associated expansion of the probe are measured and recorded so as to obtain a stress-displacement relationship for the ground as tested.

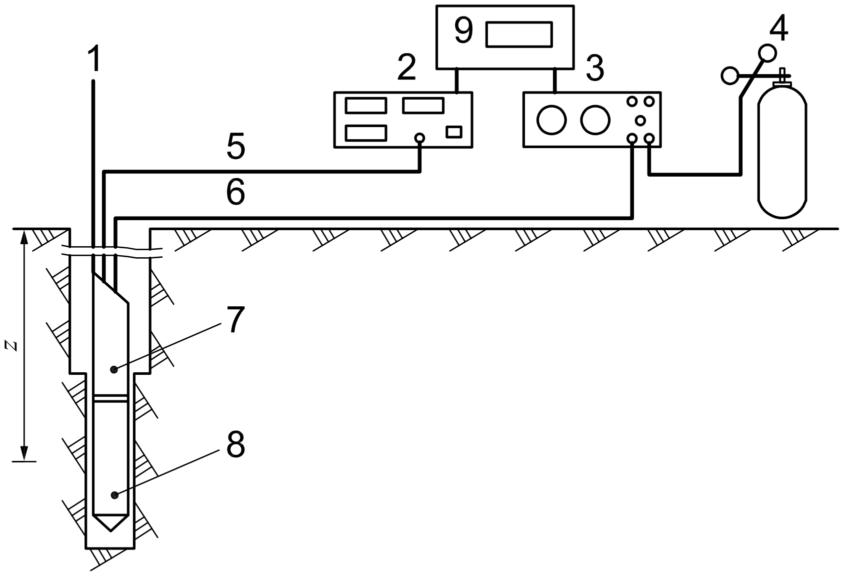


Key

1	ground surface
2	borehole wall
3	pocket
4	expanding dilatometer probe
p	applied pressure
A-A	axial section
B-B	cross section

Figure 1 — Example of a flexible dilatometer test

The equipment to carry out dilatometer tests shall consist of the components shown in Figure 2.



Key

1 setting rods (optional)
2 displacement measuring unit (obligatory)
3 pressure control unit (obligatory)
4 pressure source (obligatory)
5 signal cable (obligatory)
6 pressure line (obligatory)
7 sediment collection tube (optional)
8 flexible dilatometer probe (obligatory)
9 data logger (optional)
z test depth

Figure 2 — Schematic diagram of flexible dilatometer equipment

NOTE Sometimes, setting rods are necessary to push the probe into a tight pocket. They also allow orientation of the instrument. They are also needed in case it becomes difficult to extract the probe at the end of the test and hammering out is required.

Borehole diameters should be 76 mm, 96 mm, and 101 mm, according to ISO 22475-1.

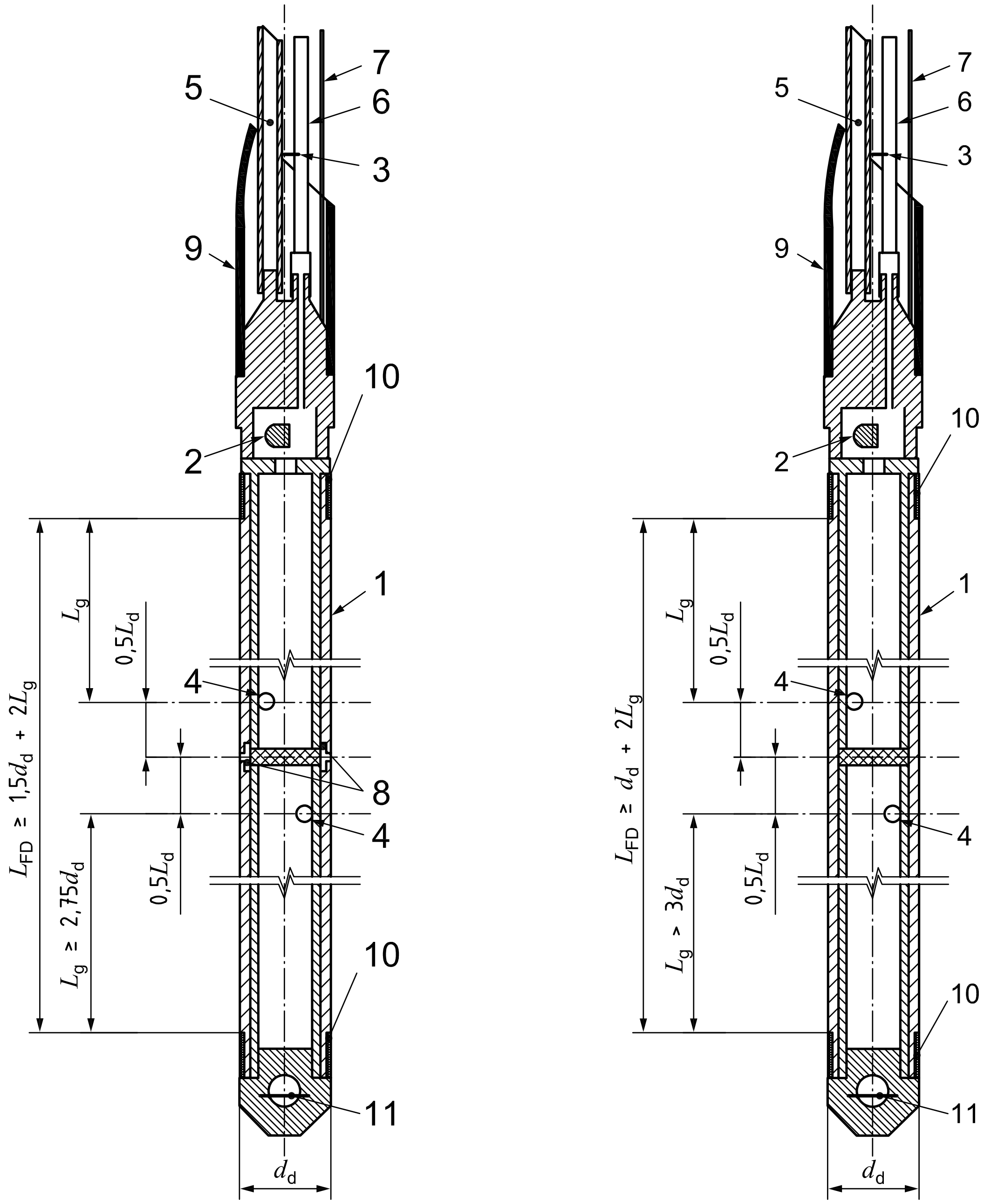
The external diameter d_d of the flexible dilatometer when deflated shall be some 3 mm to 6 mm smaller than the nominal diameter of the borehole.

The pressure applied to the membrane shall be measured by one or more electric transducers in the instrument (see Figure 3).

4.2 Dilatometer probe

The expansion of the borehole shall be monitored by three or more electric transducers.

In variant A, the diametral displacement shall be measured with electric transducers, which shall penetrate the membrane and shall directly bear on the borehole wall (Figure 3, left.). This variant shall be primarily used in rocks (Rock dilatometer, RDT, see EN 1997-2:2007, 4.5).



a) Variant A

b) Variant B

Key

1 membrane
2 pressure transducer
3 fluid or gas
4 displacement transducers
5 setting rod
6 pressure line
7 signal cable
8 metal insert at both ends of each displacement transducer (variant A)
9 sediment collection tube
10 membrane clamping ring
11 compass (if applicable)
d_d external diameter of the dilatometer
L_{FD} length of the expanding part of the dilatometer
L_g axial distance between transducer and clamping ring
L_d length of the measuring segment of the dilatometer

NOTE 1 On this sketch there are three displacement transducers (No. 4) at 120° from each other.

NOTE 2 For variant A, the third No. 4 transducer is represented lengthwise with its metal inserts (No. 8) at both ends.

Figure 3 — Sketch of flexible dilatometer (not to scale)

The expanding length L_{FD} of the probe shall exceed ($5{,}5d_d + L_d$). The measuring segment L_d shall not exceed $1{,}5d_d$.

In variant B, the diametral displacement shall be measured by electrical transducers placed at the inner wall of the membrane (Figure 3 b). Because membrane compression influences the readings of pressure and displacement, proper corrections shall be determined by corresponding calibration (see A.3). Variant B shall be primarily used in soils (Soil dilatometer, SDT, see EN 1997-2:2007, 4.5).

4.3 Pressure control and displacement measuring units

The pressure control and displacement measuring units shall control the probe expansion and permit the reading of liquid or gas pressure and displacement as a function of time.

The pressurizing system (3 and 4 in Figure 2) shall allow:

— reaching a pressure at least equal to 20 MPa;

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

— stopping the injection when necessary.

4.4 Connecting lines

The pressure line and signal cable shall connect the pressure control and displacement measuring units to the probe. The pressure line shall convey the fluid to the probe either parallel or coaxial with the signal cable.

4.5 Measurement and control accuracy

4.5.1 Time

The accuracy of the device used to measure time must be one second.

4.5.2 Pressure and displacement

The maximum uncertainty of measurement of the devices measuring pressure and displacement shall be as specified in 5.4.

4.5.3 Display of readings

At the site the pressure control and displacement measuring units shall give a simultaneous and instantaneous display of the following readings: time, pressure of the fluid injected into the probe and diametral displacements.

4.5.4 Membrane compression calibration cylinder

The main dimensions of the steel cylinder serving the calibration for membrane compression shall be as follows:

— a known inside diameter which closely fits the deflated instrument;

— a wall thickness appropriate to the maximum pressure to be applied;

— a length appropriately greater than the expanding length of the instrument.

4.6 Data logging

If the data are not recorded manually, a data logging system shall be available to record the readings from the transducers, calibration data and the resulting readings of pressure and displacement.

5 Test procedure

5.1 Safety requirements

Regarding environmental protection, national standards and local regulations shall be applied as long as respective international standards are not available.

National safety regulations shall be followed, for instance for:

— personal health and safety equipment,

— clean air if working in confined spaces,

— ensuring the safety of the equipment.

Drill rigs shall be in accordance with EN 791 and EN 996.

5.2 Assembly of parts

The membrane and other parts of the probe shall be selected according to the expected ground conditions. Then the probe shall be linked to the control unit through the connecting line/cable.

The system shall be filled with the working fluid.

5.3 Calibration of the testing device and corrections of readings

5.3.1 Calibration of the testing device

Before testing, the equipment shall have been calibrated (see Annex A). The following components of the equipment shall be calibrated:

— displacement measuring system;

— pressure measuring system.

The calibration of the data logger system shall be conducted according to ISO 10012.

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

Copies of the calibration documents shall be available at the job site.

5.3.2 Correction of readings

Corrections as described in A.2 shall be performed for variant A and B probes, taking into consideration the maximum deformation expected in the test.

In the case of variant B, also the corrections as described in A.3 shall be applied.

5.4 Uncertainties of measurement

The following uncertainties shall be achieved in accordance with ISO 10012 (see also Annex D):

a) the distance between the centre of the membrane and the top of the pocket shall not exceed

— 0,1 m, or

— 1/200 of the length of the rod string,

whichever is the greater.

b) the resolution of each sensor used for the measurement of the additional diametral displacement Δd_r shall be

— 5 μm;

c) the resolution for pressures shall be

— ≤ 0,5 % of the measured pressure, or

— ≤ 20 kPa,

whichever is the greater;

d) the resolution for time intervals shall be

— 1 s.

5.5 Preparation for the sounding

The test location is usually determined from design requirements. The position of the borehole into which the probe is to be inserted shall be marked on a drawing and identified by its location details. When the borehole is inclined, its slope and direction should be recorded

For each borehole, the following parameters shall be recorded:

— reference to ISO 22476-5;

— sounding number;

— technique of borehole drilling ;

— soil/rock profile or at least the soil/rock type for each test pocket according to ISO 14688-1 and ISO 14689-1.

5.6 Pocket drilling and device placing

The pocket shall be drilled and the dilatometer probe placed in the test location with the minimum of disturbance to the borehole wall to be tested.

The pocket shall be drilled and samples taken according to ISO 22475-1. Identification and classification of the ground according to ISO 14688-1 and ISO 14689-1 shall be available from every separate ground layer within the desired investigation depth (see EN 1997-2:2007, 2.4.1.4(2) P, 4.1 (1) P and 4.2.3(2) P).

The borehole shall be advanced to within 1 m of the test depth. A pocket of about 3 m length shall then be cored at the nominal diameter for the instrument. The dilatometer probe shall be placed without delay. In all but hard rock, it shall be in position no later than 2 h after finishing the coring operation. If necessary, the instrument may be orientated in the pocket by rotating the setting rods. The instrument shall enter the pocket so that the top of the expanding length is at least 0,5 m from the pocket entry. The lower edges of the flexible dilatometer membrane shall not be closer than 0,5 m to the bottom of the pocket.

Careful attention shall be given to the effects of any sedimentation in the borehole.

Where no core has been recovered or when the stability of the borehole wall is not guaranteed, the decision of performing a test shall be evaluated by the operator.

When measures are taken to stabilize the borehole wall, their influence shall be considered when evaluating the test results.

5.7 Test execution

5.7.1 Test procedure and loading programmes

One of the following procedures, each representing a specific loading programme, may be chosen to carry out the test (see Annex B):

— Procedure A: load, unload and reload cycles. The data are recorded manually.

— Procedure B: load, unload and reload cycles. The data are recorded automatically.

— Procedure C: only one loading phase. The data are recorded manually.

— Procedure D: only one loading phase, followed by an unload/reload loop which is then followed by a pressure hold of an appreciable length of time during which the corrected pressure shall be maintained constant. The data are recorded manually.

The test procedure and its loading/unloading programme shall be selected according to the intended use of the test results.

5.7.2 Readings and recordings before and during the test

A comprehensive number of data (see 7) such as listed in 5.7.2.1 to 5.7.2.4 shall be reported.

5.7.2.1 Before the test

— test operator identification;

— type of probe;

— method of probe setting;

— calibration test references;

— depth (z) of the probe;

— if a data logger is used, its parameters:

  — pressurizing and read-out unit number;

  — memory card number or disk number;

— the initialization of the data logger if the data are not recorded manually;

— the initial reading of each transducer is checked and recorded;

— year, month, day, hour and minute of test.

5.7.2.2 During the test

At the end of each pressure hold:

— loading pressure or hold number in the series;

— any changes in the pressure and displacement occurring during the hold.

5.7.2.3 At test completion (see 5.8)

— date and time at completion of test;

— the uncorrected pressure versus displacement curve;

— the full print-out authentication by the operator, who signs and gives his full name in capital letters.

5.7.2.4 Data sheet and print out

Data sheets (see e.g. Annex C) or, in case of the use of a data logger, print outs shall be available for reporting the results.

5.8 End of loading

All tests stop when any of the following occur:

— the specified test programme has been carried out; or

— the maximum admissible expansion of the flexible dilatometer membrane is reached; or

— the measuring range of any of the transducers is exceeded.

5.9 Back-filling of borehole

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

6 Test results

6.1 Basic equations

The shear modulus of the flexible dilatometer test, G_{FDT}, is

$$G_{\mathrm{FDT}} = \Delta p\ [0{,}5\ d_{\mathrm{S}}/\Delta d] \qquad (1)$$

where

d_{S} is the nominal diameter of the pocket. All measurements of the borehole diameter are afterwards referred to d_{S}. It shall be determined as shown in Figures 4 and 5, that is by extrapolating the early linear portion of the expansion graph backwards to meet the horizontal line through the pressure axis at which the pocket expansion first begins (p_{S});

Δd is the additional diametral displacement of the borehole due to Δp;

Δp is the change of applied pressure above the contact pressure;

To calculate the flexible dilatometer modulus E_{FDT} from shear modulus G_{FDT}, the following equation shall be applied:

$$E_{FDT} = 2\, G_{FDT}\, (1 + \nu) \quad (2)$$

An assumption needs to be made for the Poisson's ratio ν.

Δd and Δp shall be corrected according to the calibration values obtained before testing (see 5.3.2).

NOTE 1 In many materials the moduli are strain- and path-dependent. A series of secant moduli taken from the pressure versus displacement graph can be used to define this variation.

NOTE 2 Formula (2) yields the Young's modulus for linearly elastic and isotropic materials only.

6.2 Loading test

6.2.1 General

For procedures A to C, test data shall be plotted as shown in Figures 4 to 6, in Annex B and in Annex C where results of procedure A tests are shown. The corrected pocket diameter shall be plotted as a function of the corrected applied pressure p. The shear modulus of flexible dilatometer test G_{FDT} is to be determined from Δd and Δp according to Formula (1).

When evaluating flexible dilatometer tests, Δp shall only be selected within a range of any one loading or unloading phase. Whichever is selected determines whether the modulus measured is a loading or an unloading one. Distinction shall be made between the first loading modulus and various reloading moduli (see Figures 4 and 5 and Table C.2). All moduli shall be derived and quoted individually. Modulus values should be quoted to three significant digits.

Tests according to procedure D shall be designed for specific purposes. To be able to correctly evaluate the time-dependent ground deformation at constant pressures on the borehole wall when the membrane deformation is large, action shall be taken to keep the corrected pressure constant between t_1 and t_2.

6.2.2 Determination of moduli

G shall be determined using the average value of the pocket diametral displacement measured at least in three diametral directions for a given load cycle. However, if the values differ much from each other indicating anisotropy of the rock or soil mass, the G value shall be determined separately for each direction and reported accordingly.

NOTE This method of evaluation applies to each of the four procedures A to D.

6.2.3 Procedure A

The moduli G shall be calculated as follows:

— first loading modulus G_{L1} from the tangent to the first load loop through the intersection of p_S and d_S (see Figure 4);

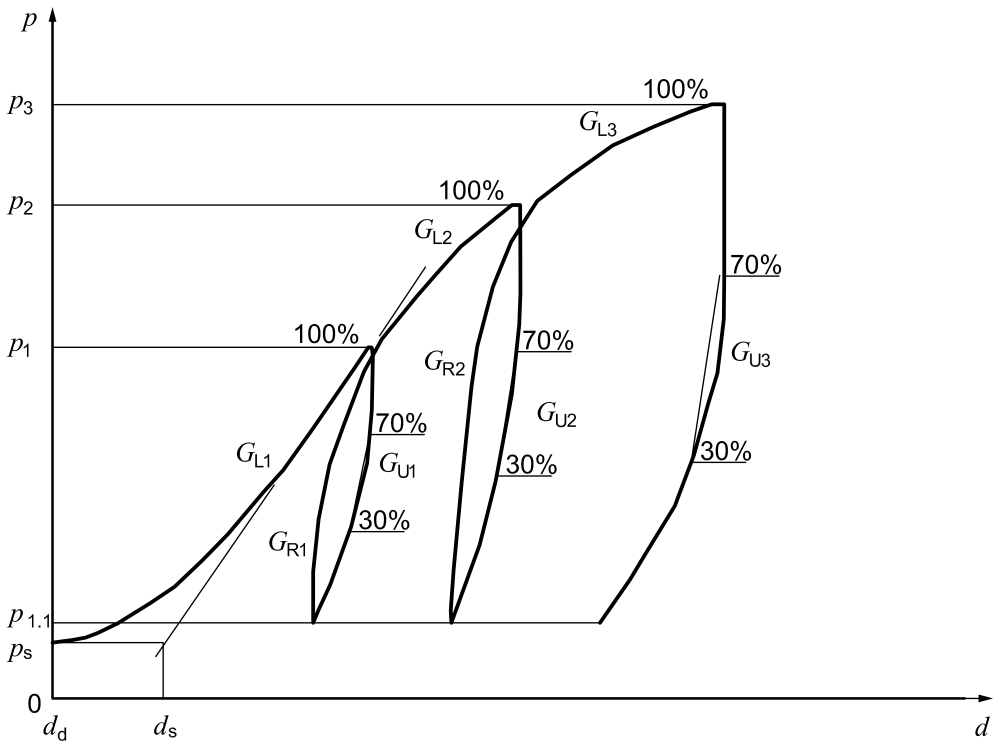
— the next first loading modulus G_{Li} from the slope of the secant between the upper reversal pressure (e.g. p_1 for G_{L2}) and the final pressure of the loading phase (e.g. p_2), see Figure 4;

— unloading moduli G_{Ui} for every unload path between 30 % and 70 % of the pressure range between upper reversal pressure (p_1 or p_2 or p_3) and full relief pressure $p_{1.1}$(0 %), see Table 2 and Figure 4;

— reloading moduli G_{Ri} for every reload path shall be calculated for every unload path between 30 % and 70 % of the pressure range between upper reversal pressure (p_1 or p_2 or p_3) and full relief pressure $p_{1.1}$ (0 %), see Table 2 and Figure 4.

Table 2 — Moduli of flexible dilatometer tests

First loading	Unloading (30 %–70 %)	Reloading
G_{L1}	G_{U1}	G_{R1}
G_{L2}	G_{U2}	G_{R2}
G_{L3}	G_{U3}	G_{R3}



Key for indices:

L = loading phase

U = unloading phase

R = reloading phase

1,2,3 = loop number

Key for examples:

G_{Li} = shear modulus in loading phase No. i

G_{Ui} = shear modulus in unloading phase No. i

G_{Ri} = shear modulus in reloading phase No. i

p_S = seating pressure

p_1, p_2, p_3 = pressures at reversal points of loops

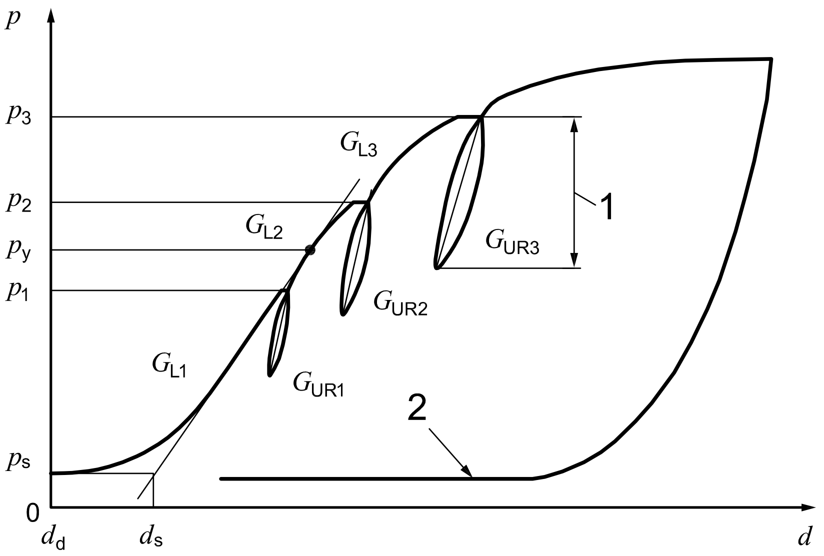
d_d = external diameter of the dilatometer

Figure 4 — Shear moduli G_{FDT} in procedure A

6.2.4 Procedure B

The first loading modulus G_{L1} shall be calculated from the tangent to the first load loop through the intersection of p_S and d_S (see Figure 5); the next loading moduli G_L shall be determined from the tangent to the d versus p curve (see Figure 5).

Unloading/reloading moduli G_U shall be calculated for every unload/reload loop by taking the gradient of the line through each individual loop as indicated in Figure 5.



Key for Indices:

L = loading phase

U = unloading phase

R = reloading phase

1,2,3 = loop number

Key for examples:

G_L = Shear modulus in loading phase

G_{UR} = Shear modulus in unloading/reloading phase

p_s = seating pressure

d_s = nominal diameter of the pocket

p_1, p_2, p_3 = pressures at reversal points, loops No. 1, 2 and 3.

p_y = yield pressure of the ground

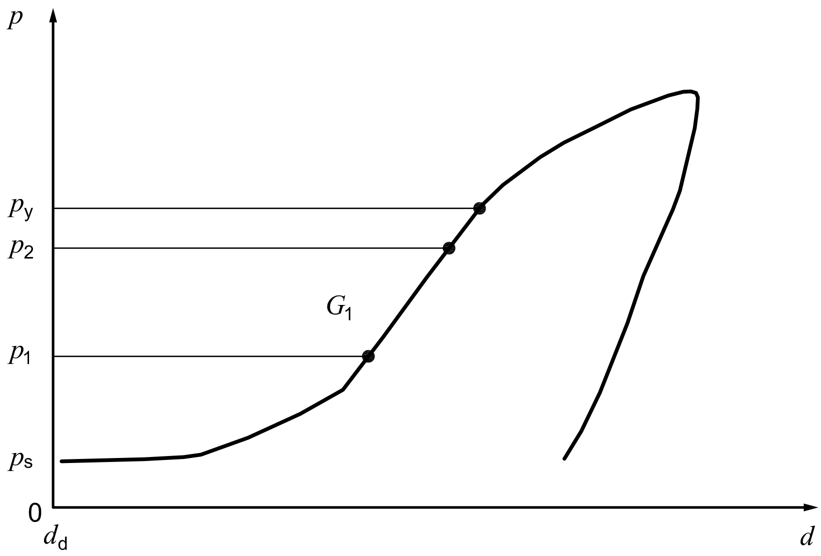
1 = pressure drop, typically $p_i/3$

2 = membrane collapsing at head of water

Figure 5 — Shear moduli G_{FDT} in procedure B

6.2.5 Procedure C

The loading modulus G_1 shall be calculated by taking the gradient between the points corresponding to, for example, p_1 and p_2 in Figure 6, i.e. at 30 % and 70 % of the pressure range of the linear part of the curve, up to the pressure p_y.



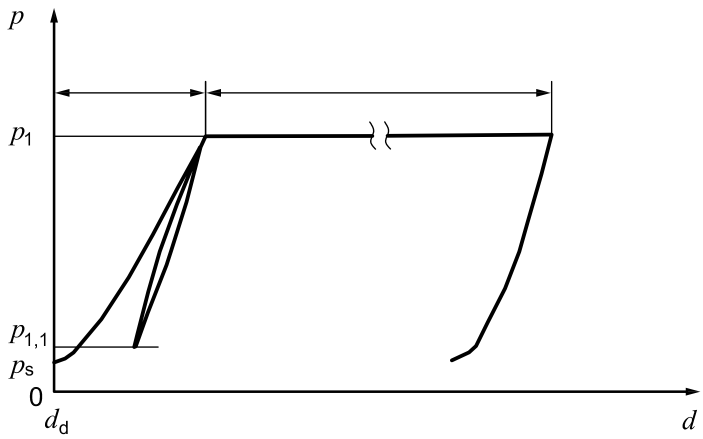
Key

p_y yield pressure of the ground

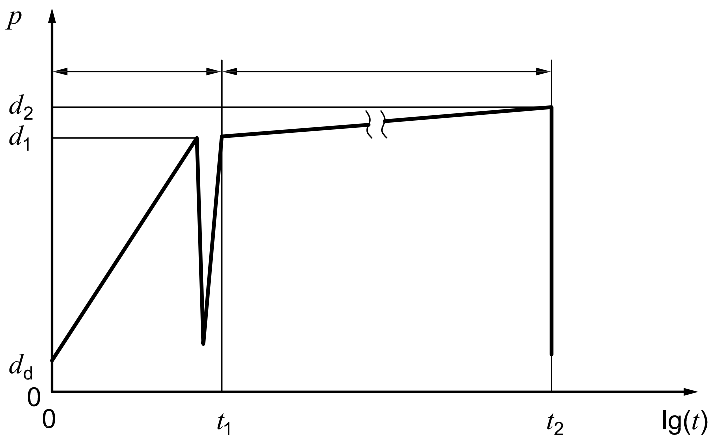
Figure 6 — Shear modulus G_1 in procedure C.

6.3 Constant pressure tests (procedure D)

After starting the test with a loading phase followed by a unload/reload cycle, p_1 shall be held constant during a given period of time [see Figure 7 a)].



(a) Displacement versus pressure



(b) Displacement versus time

Figure 7 — Constant pressure tests

The corrected pocket diameter shall be plotted in semi-log form as a function of elapsed time as indicated in Figure 7 b), the plot showing a nearly linear curve.

The creep parameter k_f corresponding to the slope between t_1 and t_2 characterizing the time-dependent deformation characteristics of the material shall be determined for the given pressure level from Formula (3):

$$k_f = \frac{d_2 - d_1}{\lg\left(t_2/t_1\right)} \quad (3)$$

where

d_2 is the corrected pocket diameter at time t_2;

d_1 is the corrected pocket diameter at time t_1.

6.4 Uncorrected and corrected graphs

d_r as a function of p_r shall be used to plot the uncorrected flexible dilatometer curve:

$$d_r = f\,(p_r) \quad (4)$$

d as a function of p shall be used to plot the corrected flexible dilatometer curve:

$$d = f\,(p) \quad (5)$$

where the applied pressure corrected for membrane pressure loss and stiffness (A.2) is given by

$$p = p_r\,(d_r) - p_e\,(d_r) \quad (6)$$

where the corrected pocket diameter d is given by

$$d = d_r - a\,p_r \quad (7)$$

and a is determined by the method described in A.3.

For a variant A dilatometer probe, the membrane compression coefficient a is zero.

7 Test report

7.1 General

In the presentation of test results, the information should be easily accessible, for example in tables or as a standard archive scheme. Presentation in digital form is permissible for easier data-exchange.

7.2 Reporting of test results

7.2.1 to 7.2.5 indicate which information shall be in

— the field record of test results;

— the test report;

— every table and every plot of test results.

The field report, completed at the project site, and the test report shall include the information given here.

The test results shall be reported to enable a third party to check and understand the results.

Particulars observed during the test or deviations from this part of ISO 22476 which can affect the results of the measurements shall be recorded and reported.

All dilatometer tests shall be analysed and reported in a manner permitting their verification by a third person.

7.2.1 General information		Field report	Test report	Every plot
1.a	Reference to this part of ISO 22476 and to ISO 22475-1	–	x	–
1.b	Company executing the test	x	x	x
1.c	Name and signature of the equipment operator executing the test	x	–	–
1.d	Name and signature of the field manager responsible for the project	–	x	–
1.e	Depth to the groundwater table (if recorded) and date and time of recording	x	x	–
1.f	Description of the material cuttings according to ISO 14688-1 and ISO 14689-1	x	x	–
1.g	Type and composition of any medium used to support the borehole wall	x	x	–
1.h	Depth and possible causes of any stoppages in the dilatometer testing	x	x	–
1.i	Stop criteria applied, i.e. target pressure, maximum pressure, maximum diameter	x	x	–
1.j	Observations during the test, for example drops of pressure, diameter or volume, incidents, changes in zero/reference readings, etc.	x	x	–
1.k	Borehole back-filled according to ISO 22475-1	x	–	–

7.2.2 Location of the test		Field report	Test report	Every plot
2.a	Test No.	x	x	x
2.b	Depth of test	–	x	x
2.c	Local or general coordinates	–	x	x
2.d	Coordinate reference system and tolerances	–	x	–
2.e	Elevation of ground surface referred to a stated datum	–	x	x

7.2.3 Test equipment		Field report	Test report	Every plot
3.a	Dilatometer type	x	–	x
3.b	Geometry and dimensions	x	x	–
3.c	Description of the drilling and sampling works according to ISO 22475-1	x	–	–
3.d	Identification of dilatometer	x	x	x
3.e	Measuring ranges of the sensors	–	x	–
3.f	Date of last calibration of the sensors (recommended)	–	x	–
3.g	If applicable (variant B dilatometer), inside diameter, wall thickness and material of the calibration cylinder.	x	–	–

7.2.4 Test procedure		Field report	Test report	Every plot
4.a	Test type (A, B, C, D or deviation)	x	x	–
4.b	Test specifications	x	x	–
4.c	Method of test control (pressure controlled or displacement controlled)	x	x	–
4.d	Date of the test	x	x	x
4.e	Starting time of the test	x	x	–
4.f	Clock time of the events during the test	x	x	–
4.g	Depth of the dilatometer test, measured to the centre of the expanding length	x	x	x
4.h	Fluid (water or drilling mud) level in the borehole	x	x	–

7.2.5 Measured and calculated parameters		Field report	Test report	Every plot
5.a	Applied pressures and pocket diameter with time	x	x	–
5.b	Zero and/or reference readings of pressure, and diameter before and after the test	x	x	–
5.c	Zero drift (in engineering units)	–	x	–
5.d	Corrections applied during data processing (e.g. drifts, system compliance, etc.)	–	x	–
5.e	Calibration data for system compliance and membrane stiffness	x	x	–
5.f	Flexible dilatometer moduli and the methods used to obtain them	–	x	–
5.g	Applied pressures and pocket diameter with time	x	x	–

7.3 Choice of axis scaling

All graphical results shall be presented at a scale which results in the graph sensibly filling the space on the paper.

7.4 Presentation of test results

Presentation of the results of a flexible dilatometer test shall include data according to 7.2:

a) specifications of the displacement and pressure measuring systems (type, manufacturer, serial number);

b) specifications of the flexible dilatometer (type, manufacturer, serial number);

c) table and graphs of applied pressures p_r versus pocket diameter d_r ;

d) table of all moduli calculated from the test results;

e) table and graphs of corrected pressure p versus corrected pocket diameter d (Figures 4–7);

f) plot of the corrected pressure p as a function of time t (time-load diagram).

Annex A
(normative)

Calibration and corrections

A.1 Measuring devices

All the control and the measuring devices shall be periodically checked and calibrated to show that they provide reliable and accurate measurements.

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

A.2 Membrane stiffness

The pressure loss p_m due to the stiffness of the membrane shall be obtained from an inflation test according to the procedures described in A.2.1 and A.2.2.

The calibrations described below shall be carried out as follows:

— at each change of flexible dilatometer membrane;

— otherwise at intervals appropriate to the use the probe has received but at least once a year.

A.2.1 Preparation of flexible dilatometer for membrane pressure loss test

The flexible dilatometer probe shall be connected by a short line (less than 2 m) to a pressure source. The membrane shall then be inflated at least three times by injecting fluid up to the maximum deformation.

For this operation the pressure control unit shall be fitted 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 shall be inflated as if it was in the ground, using pressure increments small enough to properly define the complete range of diameters of the membrane.

If a liquid is used to pressurize the flexible dilatometer, the difference in elevation between the probe and the measuring unit shall be taken into account.

The pressure versus probe diameter curve shall be plotted as in Figure A.1 showing the increase of diameter with increase of pressure. For the correction for membrane stiffness of the pressure p_r of an actual test as read at the measuring unit, the procedure shall be as follows. The pressure given in Figure A.1 corresponding to the increase in diameter measured during the actual test shall be subtracted from the test pressure reading to give the pressure acting on the ground.

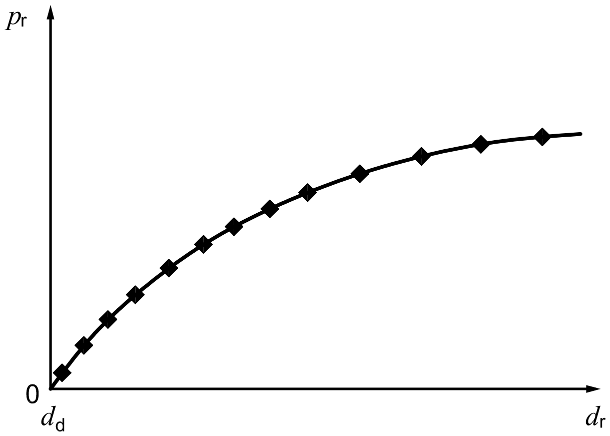


Figure A.1 — Membrane stiffness plot for flexible dilatometer

A.3 Membrane compression coefficient for variant B dilatometer

The calibrations described below shall be carried out as follows:

— at each change of flexible dilatometer membrane ;

— otherwise at intervals appropriate to the use the probe has received but at least once a year.

The probe shall be placed into the compression calibration cylinder (see 4.5.4).

The probe shall be pressurized by increments Δp_r initially of 100 kPa and then by pressure steps appropriate to define the curve up to the full pressure rating of the instrument. For each pressure hold, the probe diameter shall be recorded (see Figure A.2).

In Figure A.2 the difference between the upper parts of curves 1 and 2, each approximated by a straight line, shall be used in correcting for the effect of membrane compression. The procedure to obtain the membrane compression coefficient a between two pressure holds p_1 and p_2 is as follows.

On the calibration graph corresponding to Figure A.2, two horizontal lines at ordinates p_1 and p_2 shall be drawn and the intersection points with curves 1 and 2 shall be reported as:

— d_{11} and d_{12} on the d axis for pressure p_1;

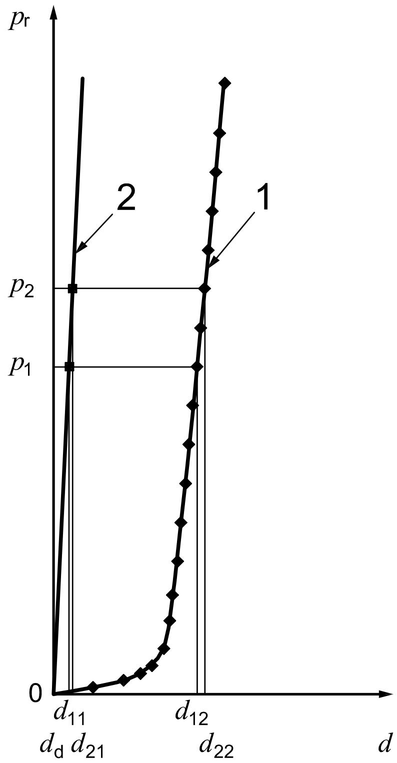
— d_{21} and d_{22} on the d axis for pressure p_2.

The membrane compression coefficient between the pressure holds p_1 and p_2 is given by

$$a = \frac{(d_{22} - d_{21}) - (d_{12} - d_{11})}{p_2 - p_1}$$

This coefficient shall be calculated once for all, as long as the two curves exhibit straight line portions in the part where they are used.

For instruments with multiple displacement transducers, the mean value of a shall be used in the calculation above.



Key

Curve 1 diameter d_r as read

Curve 2 calibration cylinder diameter d_c expansion under pressure, to be obtained either by calculation from elastic properties of the material or by direct measurement

Figure A.2 — Determination of the membrane compression coefficient – Example

Annex B
(normative)

Performing the test

The procedures A, B, C and D as described in this Annex B shall be adhered to.

B.1 Load–unload–reload procedures

B.1.1 Procedure A (see Figure B.1)

Both the loading and unloading parts shall be carried out in steps with pressure holds at each step. In addition, the minimum pressure in each reload loop shall be the same pressure $p_{1.1}$. After having reached the maximum pressure, the load shall be decreased in steps with readings continued as before.

B.1.2 Procedure B (see Figure B.2)

The unloading and reloading phases of each loop shall be carried out either by steps or continuously.

NOTE The loop sizes are normally smaller than in the case of procedure A..

The size of the unloading phases shall be selected according to the design specifications of the test.

B.1.3 Common to procedures A and B

The maximum applied pressure p_{max} to be used during the test shall be decided by considering the maximum stress expected to be applied to the ground by the structure proposed. In both procedures, a minimum of three reload loops should be carried out. The programme for these unload/reload loops should be either given in the specifications for the test or decided according to the observed progress of the test.

Before commencing the descent phase of a reload loop, enough time shall be allowed for time-dependent effects to become insignificant.

B.1.4 Single loading procedure C (see Figure B.3)

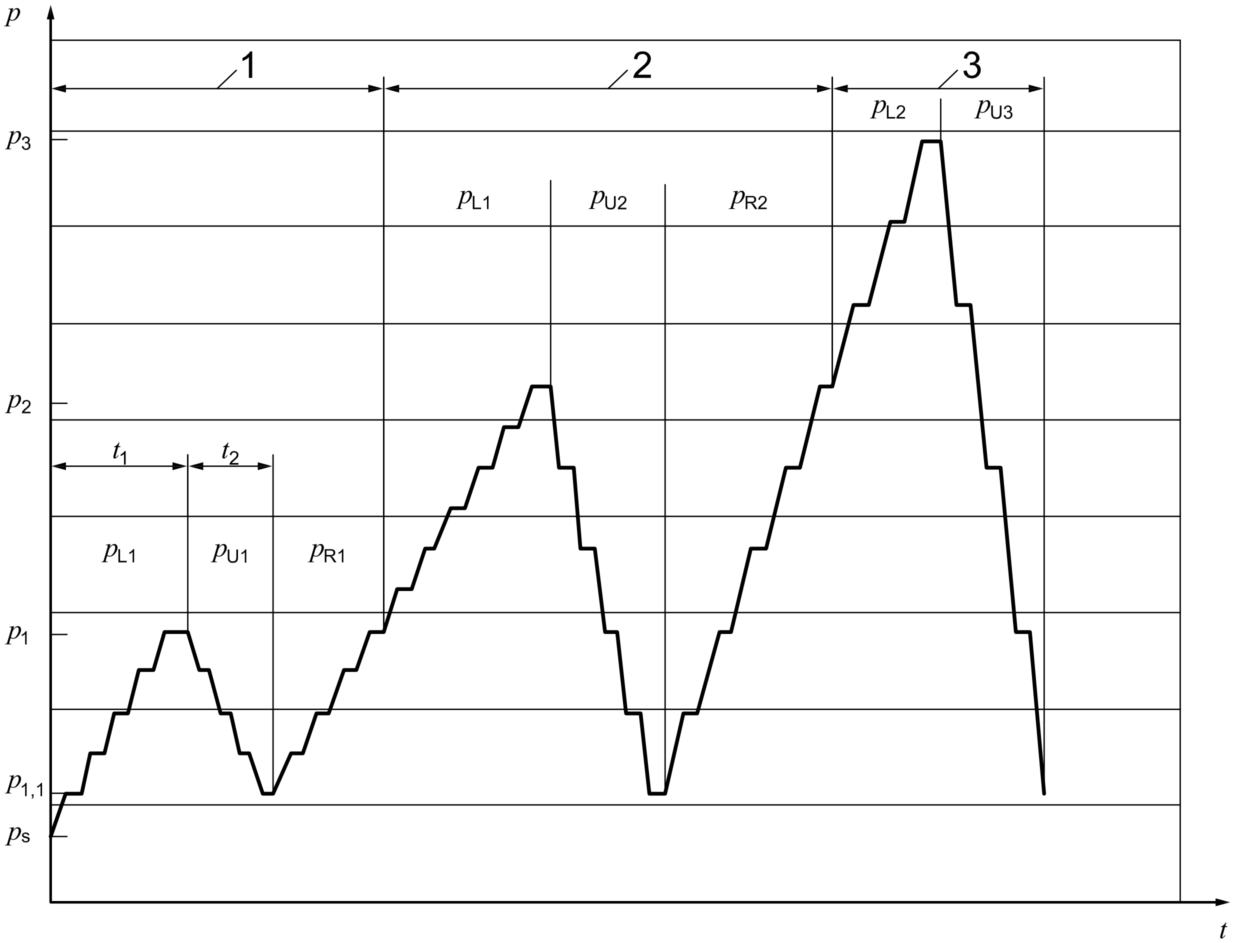
At each step, the pressure shall be held until either the maximum specified pressure or the displacement capacity of the equipment is reached.

B.2 Details of procedure A

The flexible dilatometer membrane shall be expanded until it contacts the pocket wall indicated by an abrupt rise in pressure, i.e. the seating pressure p_S. Further pressure shall then be applied until it equals approximately 2 % to 5 % of the expected maximum pressure.

Starting the test from this pressure p_S, the soil or rock shall be loaded by stepped increments of pressure. The duration of the pressure holds should be between 1 min and 3 min. Simultaneous readings of pressure and pocket diameter shall be recorded.

Loading and unloading phases are shown in Figure B.1.



Key for indices:

L = loading phase

U = unloading phase

R = reloading phase

1,2,3 = loop number

n = step number

Key for examples:

p_{Li} = range of applied pressure in loading phase No. i

p_{Ui} = range of applied pressure in unloading phase No. i

p_{Ri} = range of applied pressure in loading or reloading phase No. i

p_i = pressure at reversal point at loop No. i

p_s = seating pressure

Figure B.1 — Example of loading test programme (procedure A)

The following details shall be observed:

a) First loop:

— the first loading shall be carried out at least in five equal steps. The position of the first load reversal point shall be decided by reference to the magnitude of the seating pressure;

— unloading to $p_{1.1}$ shall be carried out at least in four steps. The pressure steps shall be the same as those used for the loading.

— reloading to p_1 shall be carried out with the same steps as the unloading and shall take the same time;

— the duration t_2 of the unloading phase of any reload loop shall not take less than half of the duration t_1 of the loading phase.

b) Following loops:

— loading to p_2 such as 1,5 $p_1 < p_2 < 2p_1$ shall be carried out with equal steps;

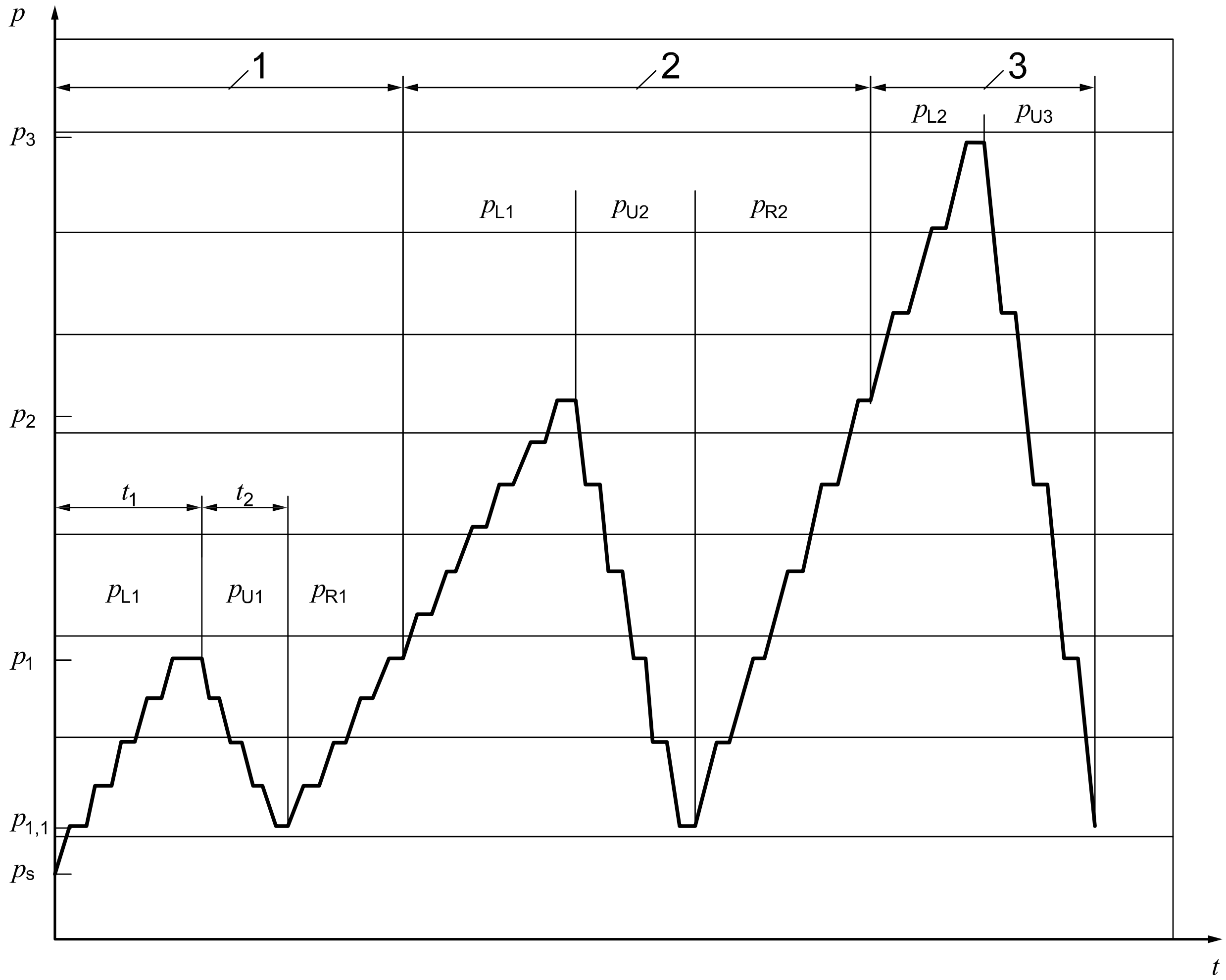
— unloading to $p_{1.1}$ shall be carried out in four equal steps;

— reloading to p_2 shall be carried out using the same size steps in both pressure and time as the preceding unloading.

B.3 Details of procedure B

The whole descent phase from p_{max} shall be carried out continuously without steps except that one or more reload/unload loops are permitted (Figure B.2). These loops shall be carried out in a similar manner to unload/reload loops. For good resolution of reload loops, data should be recorded not less frequently than at 10 s intervals. A loop should contain about 20 data points. A pressure drop of about a third of the pressure at the start of the reload loop is recommended.

Loading and unloading phases are shown in Figure B.2.



Key for indices:

L = loading phase

U = unloading phase

R = reloading phase

1,2,3 = loop number

n = step number

Key for examples:

p_{Li} = range of applied pressure in loading phase No. i

p_{Ui} = range of applied pressure in unloading phase No. i

p_{Ri} = range of applied pressure in reloading phase No. i

p_i = maximum applied pressure at reversal point No. i

p_S = seating pressure

Figure B.2 — Example of loading test programme (procedure B)

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

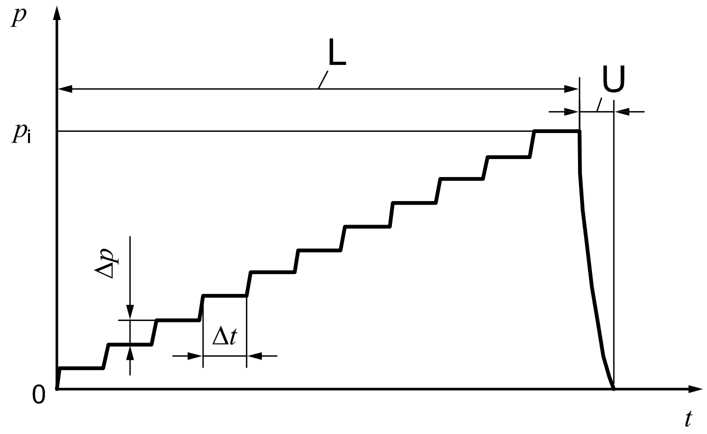
B.4 Details of procedure C

Pressure shall be increased in steps until either the ground fails or the capacity of the equipment is reached (Figure B.3).

The first pressure increment Δp_1 to be used shall be decided either by the operator or by instruction. Once the initial readings have been recorded, the operator shall observe the stability trend during a pressure hold and as a result may change the pressure increment so as to

— obtain enough points to evaluate the pseudo-elastic behaviour during the test, and

— record at least three pressure holds beyond this behaviour.



Key

L = loading phase

U = unloading phase

Figure B.3 — Example of loading test programme (procedure C)

B.5 Details of procedure D

Tests in which time-dependent effects are important shall be individually designed according to the precise data requirements.

Annex C
(normative)

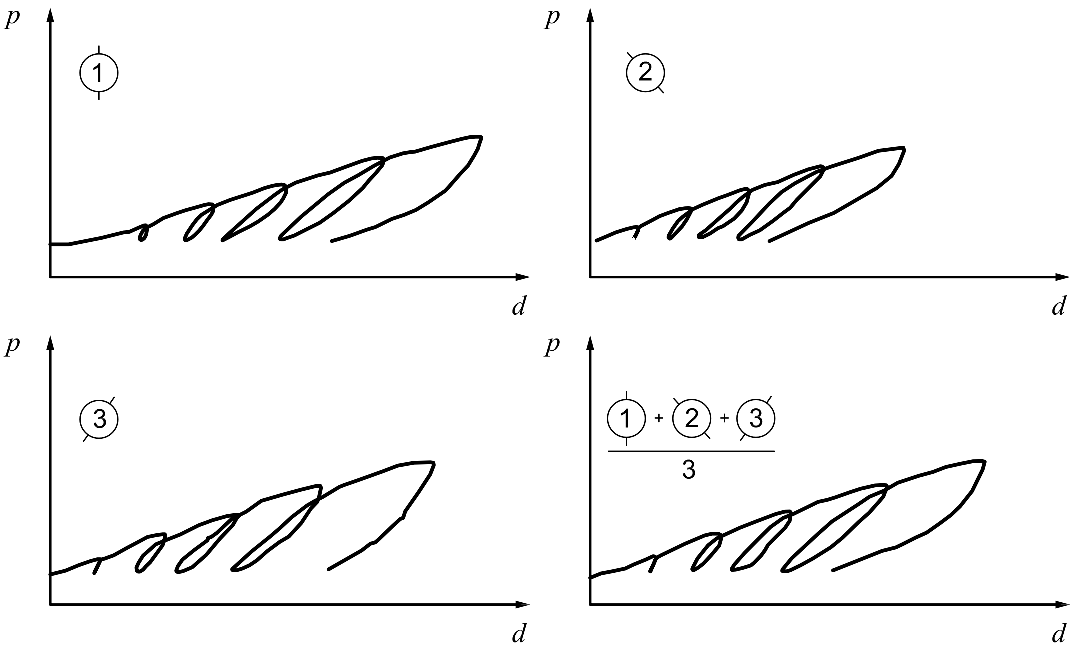
Field report and G_{FDT} results

The format of reporting the data may be freely chosen whereas the content of Table C.1 is mandatory (see 7.2). An example of plotted data is given in Figure C.1. An example of shear moduli G_{FDT} obtained is given in Table C.2.

Table C.1 —Test data sheet

Commissioner:		Order number:		Annex:	
Object:				Date:	
Borehole:		Mud type:		Time:	
Test depth:		Formation:		Soil/Rock:	
Device serial No.:		Groundwater level under surface .... m		Pocket from .... m To .... m	
Measuring direction:		Remark:		Test operator:	
Time min	Pressure, p_r MPa	Displacement, d_{r1} mm	Displacement, d_{r2} mm	Displacement, d_{r3} mm	Mean, d_r mm

Data may be plotted according to Figure C.1. Corrected diameter d versus corrected applied pressure p in the three measuring directions is shown on three different graphs and the mean values of d are given on a fourth graph. Then various values of the ground shear modulus G_{FDT} can be calculated for various ranges of pressures during loading and unloading (Table C.2) based on the data plotted on a figure similar to Figure 4.



Key

1–3: plot of test data for each transducer

$(1+2+3)/3$: average of the 3 plots

Figure C.1 — Plot of test readings in a procedure A test.

Table C.2 — Shear moduli G_{FDT} associated with data plots similar to Figure 4

Load cycle (No.)	Range of applied pressure (MPa)	Shear moduli G_{FDT} Displacement transducer No. 1 (MPa)	Displacement transducer No. 2 (MPa)	Displacement transducer No. 3 (MPa)	Mean value (MPa)
		First loading			
1-1	0,50 to 1,00	42	91	96	76
1-2	1,00 to 1,50	72	105	60	79
1-3	1,50 to 2,00	62	82	57	67
1-4	2,00 to 2,50	48	58	48	52
1-5	2,49 to 3.02	48	56	47	50
		Reloading			
2-1	0,50 to 1,00	210	220	400	277
2-2	0,50 to 1,50	200	196	196	198
2-3	0,50 to 2,00	164	169	196	176
2-4	0,50 to 2,49	136	142	158	146
		Unloading (30/70)			
3-1	1,00 to 0,50	337	255	616	404
3-2	1,50 to 0,50	243	220	251	238
3-3	2,00 to 0,50	192	186	244	208
3-4	2,50 to 0,50	157	159	199	172
3-5	3.02 to 0,50	140	144	172	152

Annex D
(normative)

Accuracy and uncertainties

D.1 Accuracy of the measuring devices

The accuracy of the measurements depends on the equipment and the type of measuring devices of pressure and displacement included in this equipment. The rules given in 5.4 shall be adhered to.

Because the readings for pressure and displacement are either recorded manually or by transducers, their resolution depends on either the display or the data logger. In both cases, the accuracy depends on how the various devices are calibrated. Therefore, the measuring devices shall be calibrated as close as possible to their measuring range increased by 10 % to 20 %.

D.2 Uncertainties of the measurements

The uncertainties of the measurements depend not only on the equipment. It is defined as the variability of the measurements obtained while measuring any magnitude. The higher the dispersion is, the higher is the uncertainty of the result.

The uncertainty is defined as the interval in which the real measurement of the magnitude is occurring; it is related to the repeatability of the measurements. It shall be calculated according to ENV 13005.

Bibliography

[1] EN 1997-1 *Eurocode 7: Geotechnical design — Part 1: General rules*

[2] EN 1997-2:2007, *Eurocode 7: Geotechnical design — Part 2: Ground investigation and testing*

[3] ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ICS 93.020

Price based on 31 pages