INTERNATIONAL STANDARD

ISO 22476-7

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Geotechnical investigation and testing — Field testing —

Part 7:
Borehole jack test

Reconnaissance et essais géotechniques — Essais en place —

Partie 7: Essai au dilatomètre rigide diamétral

Reference number
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Foreword

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

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

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

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

ISO 22476-7 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 test*

— *Part 2: Dynamic probing*

— *Part 3: Standard penetration test*

— *Part 4: Ménard pressuremeter test*

— *Part 5: Flexible dilatometer test*

— *Part 7: Borehole jack test*

— *Part 9: Field vane test*

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

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

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

Introduction

The results of borehole jack tests are used for ground deformation calculations provided that the range of stresses applied in the test are representative of the stresses caused by the proposed foundation. Local experience normally improves the application of the results.

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. In addition, 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 7:
Borehole jack test

1 Scope

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

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

This part of ISO 22476 specifies the procedure for conducting a borehole jack test in ground stiff enough not to be adversely affected by the drilling operation. Two diametral cylindrical steel loading plates are placed in the ground and opened by pressure. Pressure applied to, and associated opening of the probe are measured and recorded so as to obtain a stress-displacement relationship of the ground for the range of the expected design stress.

This part of ISO 22476 applies to test depths of $\leq$ 100 m and to testing 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*

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

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
equipment for borehole jack test
borehole jack, hydraulic pump, measuring unit and cables to connect the borehole jack to the measuring unit and the hydraulic pump

3.1.2
borehole jack sounding
series of successive operations necessary to perform borehole jack testing at a given location, i.e. forming a borehole and performing borehole jack tests in this borehole

3.1.3
pocket for jack test
circular cylindrical cavity drilled in a borehole in which to insert the borehole jack device

3.1.4
borehole jack
circular cylindrical instrument in which two diametrically opposed curved plates on the outside are forced apart by the application of hydraulic pressure to one or more small jacks located between them

3.1.5
borehole jack test
process of jacking two cylindrical loading plates diametrically outwards against the borehole wall and measuring their associated expansion as a function of pressure and time

NOTE 1 See Figure 1.

NOTE 2 When testing in a borehole where the hydraulic head in the instrument supply line is likely to exceed the hydraulic head of the fluid in the borehole, consideration must be given to restricting the expansion of the instrument before it enters the pocket and at the conclusion of the test.

3.1.6
depth of test
distance between the ground level and the centre of the loading plates measured along the borehole axis

NOTE See Figure 2.

3.1.7
operator
qualified person who carries out the test

3.2 Symbols and abbreviations

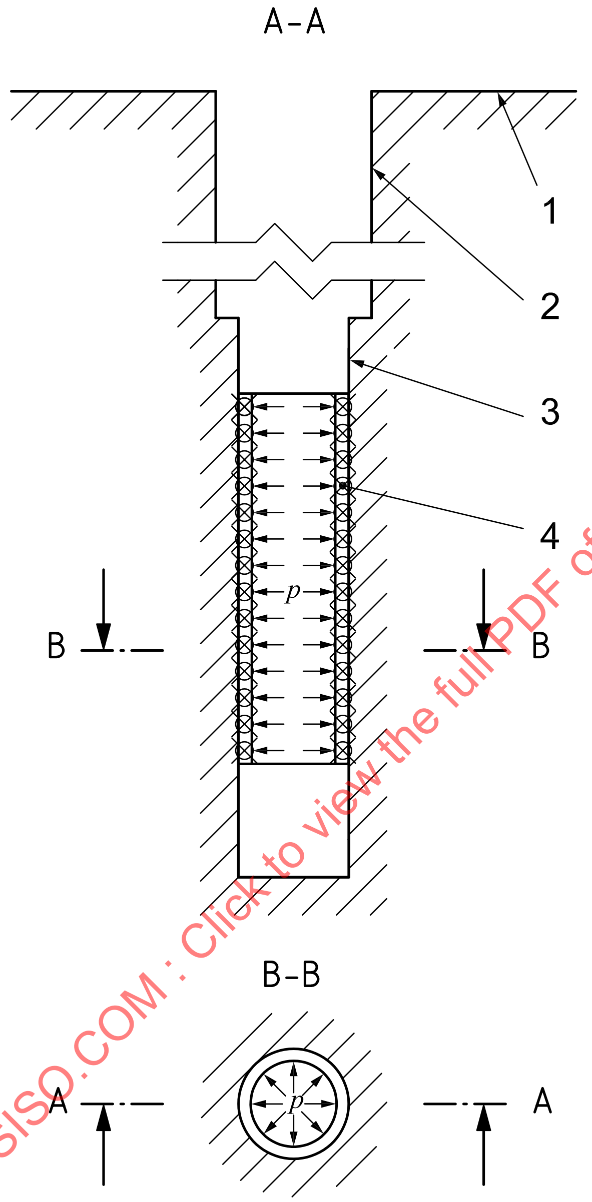
For the purposes of this International Standard the symbols and abbreviations of Table 1 apply.

Table 1 — Symbols

Symbol	Description	Unit
A	Projected area of the cylindrical loading plates on the plane normal to the axis of expansion	m^2
A_c	Cross section area in one jack cylinder	m^2
b	Width of the loading plates	mm
d	Design diameter of the jack	mm
d_0	Initial diameter of test pocket	mm
d_c	Current diameter of test pocket	mm
d_s	Diameter of the pocket at the start of the test	mm
e	Associated loading plate expansion	mm
e_1	Loading plates expansion at time t_1 or pressure p_1	mm
e_2	Loading plates expansion at time t_2 or pressure p_2	mm
Δe_i	Loading plates expansion change equals diametral displacement of borehole wall	mm
E_B	Modulus of borehole jack test for loading condition	MPa
E_U	Modulus of borehole jack test for unloading condition	MPa
f	Specific device factor	–
k_f	time-dependent strain parameter	mm
l	axial length of loading plates	mm
l_T	transducer centre-to-centre length	mm
p	applied pressure	MPa
p_c	calculated average contact stress	MPa
p_{max}	maximum contact stress	MPa
p_s	initial contact pressure	MPa
p_1	pressure at time t_1	MPa
p_2	pressure at time t_2	MPa
q	hydraulic pressure in a jack	MPa
q_{max}	maximum hydraulic pressure to be used	MPa
q_s	starting pressure of the test	MPa
r_c	friction resistance in one jack cylinder	MPa
t	time	min
t_1	time 1 of a constant stress test	min
t_2	time 2 of a constant stress test	min
z	test depth	m
z_w	groundwater depth	m
α	tilt angle of the loading plates	°
β	opening angle of loading plates	°
Δp_c	change of calculated average contact stress	MPa
ν	Poisson's ratio	–

4 Equipment

The principle of the borehole jack test is shown in Figure 1.

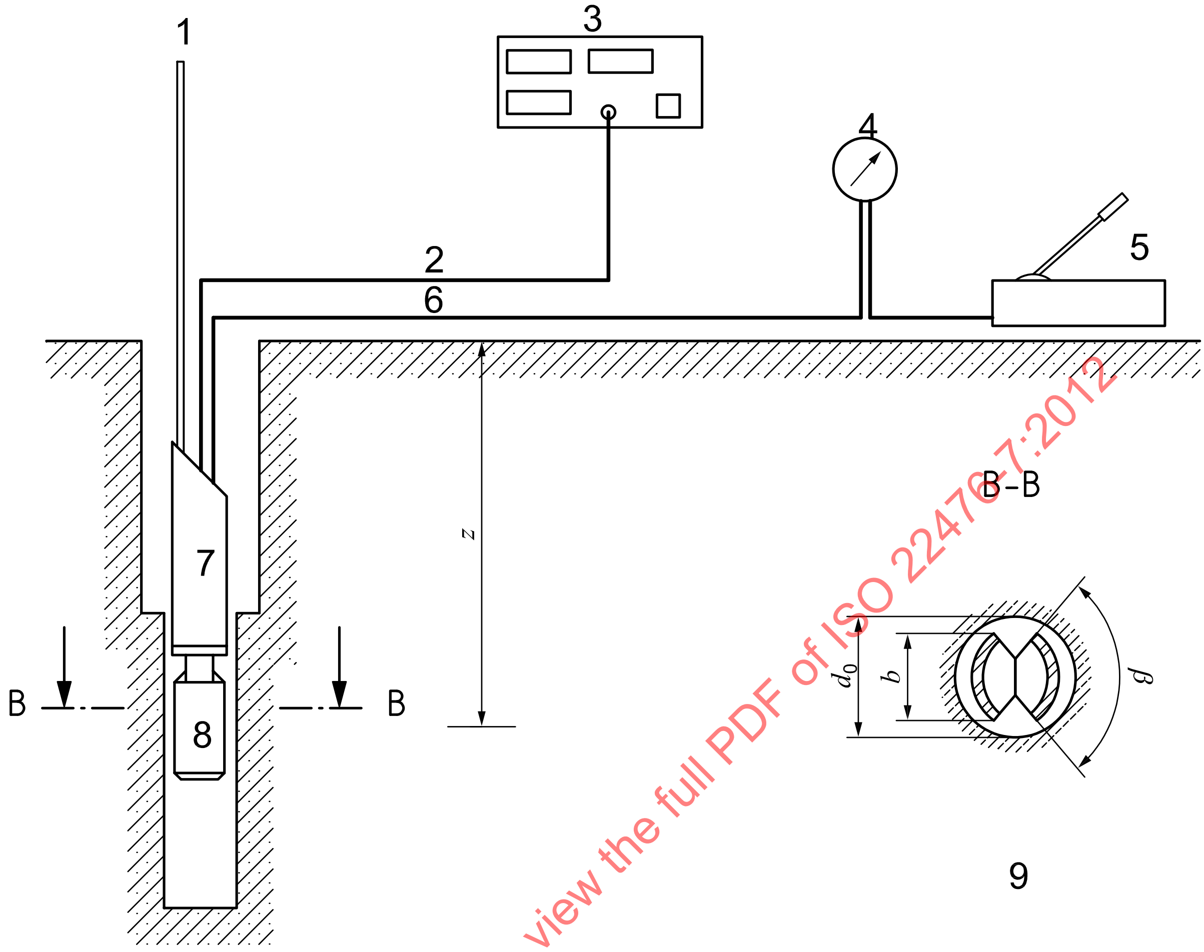


Key

1 ground surface
2 borehole
3 test pocket
4 loading plates
p applied pressure
A-A axial section
B-B cross section

Figure 1 — Example of a borehole jack test

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



Key

1	setting rods	8	borehole jack
2	signal cable	9	loading plate
3	measuring unit	β	opening angle
4	pressure gauge	d_0	initial diameter of test pocket
5	hydraulic pump	b	width of loading plate
6	pressure line	z	test depth
7	sediment collection tube	B-B	cross section

Figure 2 — Diagram of borehole jack equipment (depth less than 100 m)

The following components are obligatory:

— borehole jack (No. 8 in Figure 2);

— pressure line (No. 6 in Figure 2);

— signal cable (No. 2 in Figure 2);

— measuring unit (No. 3 in Figure 2);

— hydraulic pump (No. 5 in Figure 2);

— pressure gauge (No. 4 in Figure 2);

The following components are recommended:

— sediment collection tube to protect from caving (No. 7 in Figure 2);

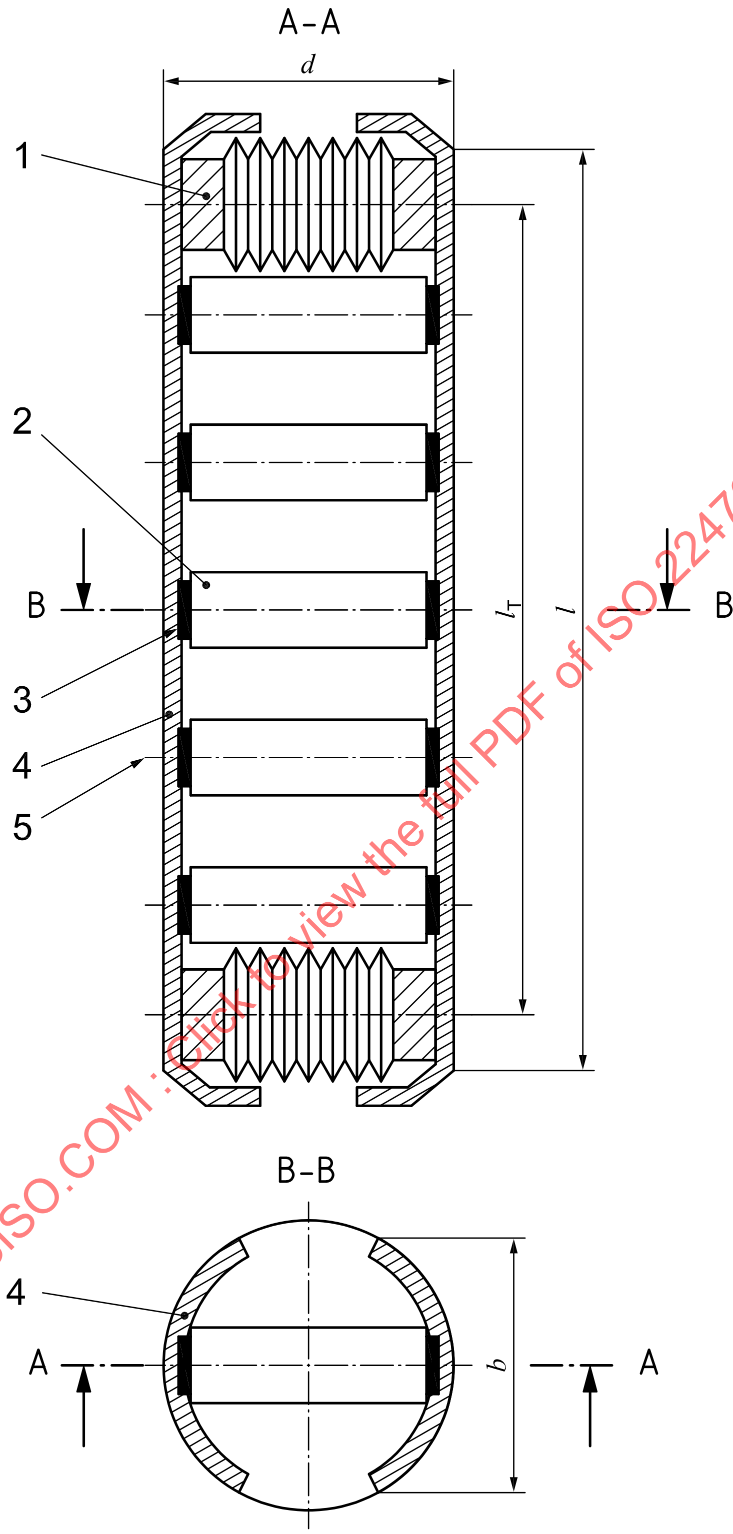
— setting rods (No. 1 in Figure 2).

The nominal diameter of the borehole shall be some millimetres larger than the external diameter of the closed borehole jack.

NOTE In the case of a borehole diameter of 101 mm, a borehole jack with an external diameter of 95 mm has been shown to be suitable.

Annex A shows the geometrical parameters for various instruments.

The hydraulic pressure applied to the jacking cylinders between the loading plates shall be measured by an electric transducer in the instrument (see Figure 3). The pressure may be recorded by a suitable measuring device at the ground surface.



Key

1 displacement transducer
2 hydraulic cylinders (variable No.)
3 spherical bearing surface
4 loading plate
5 axis of cylinder expansion
b width of the loading plate
d design diameter of the jack
l axial length of loading plates
l_T centre-to-centre distance of transducers
A-A axial section
B-B cross section

Figure 3 — Sketch of expanded borehole jack: axial section and cross section

The expansion of the loading plates shall be monitored by one or more electric transducers. If the loading plates are moved by hydraulic cylinders connected in parallel, at least two such transducers should be provided so that any tilt of the loading plates is recorded. If the plates cannot tilt then a single transducer is sufficient.

The pressure line and the signal cable shall connect the downhole instrument to the measuring and control units at the surface. The pressure line shall be connected to a hydraulic pump and a pressure gauge. The signal cable shall connect the transducers in the instrument to the measuring unit.

5 Test procedure

5.1 Calibration of the testing device

Before testing, the equipment shall have been calibrated and applicable corrections determined (see Annex B). Copies of the calibration documents shall be available at the job site. The following components of the equipment shall be calibrated:

— displacement measuring system;

— pressure measuring system.

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

5.2 Pocket drilling and device placing

A sample shall be recovered according to ISO 22475-1 at the test depth before the borehole jack test is carried out.

In unstable boreholes, a casing with a suitable diameter shall be placed down to a level 1,0 m above the desired test location. A central hole or pocket of about 3 m in length shall then be cored at the nominal diameter for the instrument.

The pocket shall be drilled and the downhole instrument shall be placed in the test location with the minimum of disturbance to the ground to be tested (see Annex E). Careful attention should be paid to the possible effects of any sedimentation in the borehole.

The borehole jacking device shall be set into the pocket without delay. If necessary the instrument may be orientated in the pocket by rotating the setting rods. The instrument shall enter the pocket so that the upper edges of the jacking plates are at least 0,5 m from the pocket entry. The lower edges of the loading plates shall not be closer than 0,5 m from the bottom of the pocket.

Borehole jack tests should not be carried out in ground where the stability of the borehole wall is not guaranteed.

5.3 Loading programme

5.3.1 General

The maximum hydraulic pressure, q_{max}, to be used shall be decided considering the maximum stress expected to be applied to the ground by the proposed structure.

Two procedures may be chosen from to carry out the test:

— tests including load, unload and reload phases;

— tests in which time-dependent effects are important. These tests shall be individually designed according to the exact data requirements.

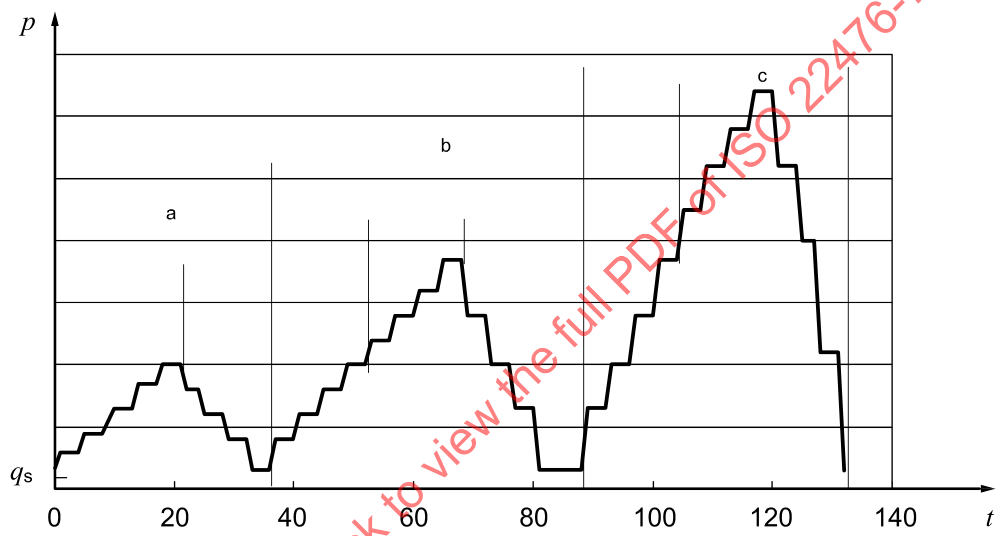
In the first procedure, at least three unload/reload loops shall be carried out during the loading phase of operation. The programme for these unload/reload loops shall be either given by the specifications for the test or decided according to the observed progress of the test. The position of the first load reversal point has to be decided by reference to the initial contact stress (see 6.1.1). Before commencing the descent phase of a reload loop, enough time shall be allowed for time-dependent effects to become insignificant.

5.3.2 Loading phase

When starting the test, the loading plates shall be jacked slowly until they contact the wall of the test pocket. This contact is indicated by an abrupt rise in the hydraulic pressure. This shall be the initial contact pressure, p_S. Further pressure shall then be applied until it equals q_S, which shall be chosen between 2 % and 5 % of the planned maximum pressure (see Figure 4).

Starting from this initial pressure, the soil or rock shall be loaded by stepped increments of pressure. The duration of these pressure holds shall be chosen to be between 1 min and 3 min. Simultaneous readings of pressure and loading plate expansion are recorded. Each loading phase shall be performed in five to eight increments. Before the start of each unload in an unload/reload loop, the pressure shall be held constant until time-dependent effects have declined to an acceptable value.

Deviations from the test procedure shall be reported in each individual case and their influence on the test results shall be explained.



Key

a First loading phase.

b Second loading phase.

c Third loading phase.

Figure 4 — Example of a loading test programme

5.3.3 Unloading phase

After having reached the maximum hydraulic pressure of the loading phase, the load shall be decreased in steps with pressure and loading plate expansion being recorded.

The hydraulic pressure in an unloading phase shall never fall below q_S. The exact design of a reload loop shall either be given by the specifications for the test or decided according to the observed progress of the test. Sufficient data points shall be available in a reload loop to give a good definition of the whole loop.

5.3.4 End of loading

The loading phase shall be stopped when either:

— the maximum hydraulic pressure is reached; or

— the maximum admissible expansion of the loading plates is reached; or

— the tilt angle α of the loading plates is more than 3°. The tilt angle is defined as:

$$\tan\alpha = \frac{\text{difference between transducers 1 and 2}}{l_T}$$

5.4 Back-filling of borehole

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

5.5 Safety requirements

National safety regulations shall be followed; e.g. for:

— personal health- and safety equipment;

— clean air if working in confined spaces;

— ensuring the safety of the equipment.

6 Test results

6.1 Basic equations

6.1.1 Calculation of average contact stress

The average contact stress, p_c, between the loading plates and the borehole wall shall be determined by

$$p_c = \frac{F}{A} \tag{1}$$

where

A is one loading plate projected area;

F is the force exerted by the jacks on one loading plate:

$$F = nA_c\,(q - r_c) \tag{2}$$

where

n is the number of cylinders;

q is the hydraulic pressure;

A_c is the cross-section area of one cylinder of the jack;

r_c is a friction-effect correction which must be determined by a calibration (see B.4).

6.1.2 Modulus of borehole jack test, E_B

The modulus of the jack test, E_B, shall be determined by the general formula

$$E_B = f \cdot \frac{d_c}{\Delta e_i} \cdot \Delta p_i \tag{3}$$

where

f is the specific device factor dependent on the opening angle of the loading plates β and on Poisson's ratio ν;

NOTE Device specific factors f for instruments in use are given in Annex A.

d_c is the current diameter of the pocket;

Δe_i is the loading plates expansion change due to Δp_i;

Δp_i is the change of calculated average contact stress;

E_B is always specific to the stress range considered.

6.2 Loading tests

The test data shall be plotted as shown in Figure D.1. The loading plate expansion, e, is plotted as a function of the calculated average contact stress, p_c. The loading modulus of jack test, E_B, shall be determined from the test data Δe and Δp_c according to Formula (3).

When evaluating borehole jack tests, Δp_c shall only be selected within a range of any one loading or unloading phase. Whichever phase is selected determines whether the modulus measured is a loading or an unloading one. There is a further distinction between the first loading modulus and various reloading moduli (see Table D.1 and Figure D.2). All moduli shall be calculated and reported individually (Table D.1). Modulus values shall be reported to three significant figures.

6.3 Constant load test

To evaluate the time-dependent ground deformation at constant stress ($p_1 = p_2$), the measured loading plate expansion shall be plotted as a function of the logarithm of time. The slope corresponds to a time-dependent strain parameter k_f. Analytically, k_f can be determined according to Formula (4) for a stated stress level p:

$$k_f = \frac{e_2 - e_1}{(\lg t_2 - \lg t_1)} \qquad (4)$$

where

e_2 is the loading plate expansion at time t_2;

e_1 is the loading plate expansion at time t_1;

with $p_1 = p_2$

7 Reporting

7.1 General

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

Subclause 7.2 describes 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 in 7.2.

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

During the test, particulars or deviations from this part of ISO 22476 which can affect the results of the measurements shall be recorded and reported.

7.2 Reporting of test results

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	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 borehole jack testing	x	x	
1.i	Stop criteria applied, i.e. target pressure, maximum pressure, maximum diameter	x	x	
1.j	Observations done in the test: 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 (if applicable)	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	Borehole jack type	x		x
3.b	Geometry and dimensions	x	x	
3.c	Description of the drilling works according to ISO 22475-1	x		
3.d	Identification of borehole jack	x	x	x
3.e	Measuring ranges of the sensors		x	
3.f	Date of last calibration of the sensors (recommended)		x	
3.g	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	x	x	
4.b	Test specifications	x	x	
4.c	Method of test control	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 borehole jack test, measured to the centre of the expanding plates	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 p and diametral displacements of borehole wall Δe 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	Borehole jack moduli and the methods used to obtain them		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 borehole jack 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 borehole jack (type, manufacturer, serial number);

c) table and graphs of applied pressures and related diametral pocket displacements (see Annex D);

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

e) plot of the diametral displacement, Δe, against the corrected pressure, p;

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

Annex A
(normative)

Dimensions of borehole jacks and related device factors

The standardized dimensions of borehole jacks and related device factors are given in Table A.1.

NOTE These factors were established from finite element calculations (FEM). For further information on the device factors see Bibliography [3] and [4].

Table A.1 — Dimensions of borehole jacks and related device factors

Type No.	Opening angle β (°)	Load plate length l (m)	Design diameter d (m)	Specific device factor f for $\nu = 0{,}25$	Specific device factor f for $\nu = 0{,}3$	Specific device factor f for $\nu = 0{,}4$
1	120	0,195	0,146	0,792	0,785	0,749
2	120	0,220	0,146	0,827	0,822	0,785
3	120	0,490	0,146	0,960	0,949	0,898
4	130	0,490	0,146	0,894	0,885	0,834
5	120	0,785	0,146	1,017	1,005	0,946
6	130	0,340	0,096	0,820	0,808	0,748
7	120	0,490	0,101	0,986	0,972	0,904

Annex B
(normative)

Calibration and correction

B.1 Measuring devices

All the control and measuring systems shall be checked every time they are used. Full calibration against reference standards in accordance with ISO 10012 shall be performed before and after each contract.

B.2 Displacement transducers

The resolution of the displacement transducer must be 10 μm or better.

B.3 Hydraulic pressure

The allowable error is 0,5 % of the indicated pressure or 0,1 % of the full scale pressure, whichever is the greater.

B.4 Friction effect

The hydraulic cylinders actuating the loading plates are subject to friction which reduces the forces acting on the ground. This represents a pressure correction, r_c, which must be determined by a calibration.

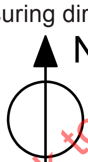
The instrument shall be supported vertically in free air and with the cylinders fully closed. The pressure shall be then increased gradually until the cylinders start to move. The pressure, r_c, at which this happens represents the friction resistance and must be subtracted from all subsequent pressure readings.

A check shall also be made that the friction effect at large expansion does not differ significantly from the value determined above.

Annex C
(normative)

Field report example

While the content of the report contains normative minimum requirements, the format may be freely chosen.

<table>
<tr><td colspan="6">Borehole jack test field report</td></tr>
<tr><td colspan="2">Contractor:</td><td colspan="2">File number:</td><td colspan="2">Enclosure:</td></tr>
<tr><td colspan="6">Client/name of project:</td></tr>
<tr><td colspan="2">Coordinate:</td><td colspan="2">Job site:</td><td colspan="2">Borehole No.:
Date:</td></tr>
<tr><td colspan="2">Drilling rig:</td><td colspan="2">Drilling tool:</td><td colspan="2">Drilling completed between ____ m and ____ m</td></tr>
<tr><td colspan="2">Test date:
Starting time:</td><td colspan="2">Test depth
$z =$ ____ m</td><td colspan="2">Formation:
Type of soil/rock:</td></tr>
<tr><td colspan="2">Type No.
(see Table A.1):
Device serial No.:</td><td colspan="2">Test specification:
Loading test ☐
Constant pressure test ☐</td><td colspan="2">Pilot hole from ____ m to ____ m
back-filling (if applicable) ☐</td></tr>
<tr><td colspan="2"></td><td colspan="2">Measuring direction:

</td><td colspan="2">Groundwater level
$z_w =$ ____ m
Date:</td></tr>
<tr><td rowspan="2">Time
min</td><td rowspan="2">Average contact stress
MPa</td><td colspan="3">Loading plate expansion</td><td rowspan="2">Difference between transducers No. 1 and No. 2
mm
(maximum allowable loading plate expansion difference)</td></tr>
<tr><td>Transducer No. 1 mm</td><td>Transducer No. 2 mm</td><td>Mean value mm</td></tr>
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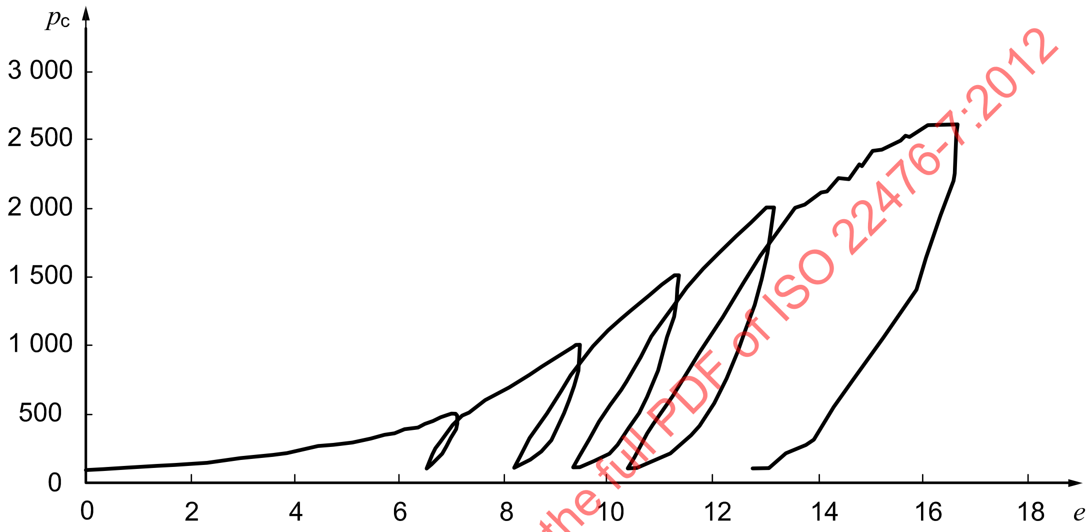
<tr><td colspan="6">Remarks (cause of any stoppages, stop criteria, incidents):
Name and signature of the operator in charge:</td></tr>
</table>

Annex D
(informative)

Test example

The result of a borehole jack test is shown in Figure D.1.



Key

p_c average contact stress (kPa)

e loading plate expansion (mm)

Figure D.1 — Result of a borehole jack test; expansion diagram; average contact stress, p_c, versus loading plate expansion, e

The corresponding moduli E_B for the example test result are given in Table D.1.

Table D.1 — Calculated moduli, E_B

Loading phase No.	Range of applied pressure [kPa]	Moduli, E_B [MPa]		
		First loading	**Reloading**	**Unloading 70 %/30 %** (see Figure D.2)
1	100 to 500	2,24	–	–
	500 to 100	–	–	26,2
2	100 to 500	–	20,8	–
	500 to 1 000	8,82	–	–
	1 000 to 100	–	–	27,4
3	100 to 1000	–	22,4	–
	1 000 to 1 500	12,1	–	–
	1 500 to 100	–	–	26,9
4	100 to 1 500	–	22,9	–
	1 500 to 2 000	13,2	–	–
	2 000 to 100	–	–	26,2
5	100 to 2 000	–	22,5	–
	2 000 to 2 600	7,8	–	–
	2 600 to 100	–	–	24,8