



BSI Standards Publication

Geotechnical investigation and testing — Field testing

Part 1: Electrical cone and piezocone penetration test

National foreword

This British Standard is the UK implementation of EN ISO 22476-1:2023. It is identical to ISO 22476-1:2022. It supersedes BS EN ISO 22476-1:2012, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee B/526/3, Ground investigation and ground testing.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

European foreword

This document (EN ISO 22476-1:2023) has been prepared by Technical Committee ISO/TC 182 "Geotechnics" in collaboration with Technical Committee CEN/TC 341 "Geotechnical Investigation and Testing" the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2023, and conflicting national standards shall be withdrawn at the latest by July 2023.

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

This document supersedes EN ISO 22476-1:2012, EN ISO 22476-1:2012/AC:2013.

Any feedback and questions on this document should be directed to the users' national standards body/national committee. A complete listing of these bodies can be found on the CEN website.

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Endorsement notice

The text of ISO 22476-1:2022 has been approved by CEN as EN ISO 22476-1:2023 without any modification.

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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.

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

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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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).

This second edition cancels and replaces the first edition (ISO 22476-1:2012), which has been technically revised. It also incorporates the Technical Corrigendum ISO 22476-1:2012/Cor 1:2013.

The main changes are as follows:

- dimensional tolerances of cone penetrometer have been updated;
- application class scheme has been replaced by cone penetrometer class and test category classification scheme;
- introduction of temperature influence on measurements monitoring and requirements of internal temperature sensor for cone penetrometer class 0;
- requirements for the calibration of cone penetrometers have been added;
- minor updates to figures and text have been made.

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document establishes general principles equipment requirements, the execution of and reporting on cone and piezocone penetration tests.

The cone penetration test (CPT) consists of pushing a cone penetrometer using a series of pushrods into the soil at a constant rate of penetration. During penetration, measurements of cone resistance and sleeve friction are recorded. The piezocone penetration test (CPTU) also includes the measurement of pore pressures around the cone. Two International Standards define cone penetration tests: this document defines CPT and CPTU practice using electronic transducers; ISO 22476-12 defines CPT practice using mechanical measuring systems.

“Cone resistance” is the term used in practice and also in this document, although “cone penetration resistance” is a more correct description of the process.

The test results of this document are especially suited for the qualitative and/or quantitative determination of a soil profile together with other investigations (e.g. sampling according to ISO 22475-1 and identification ISO 14688-1) or as a relative comparison with in situ tests.

The results from a cone penetration test are typically used to evaluate:

- stratification;
- soil behaviour type;
- geotechnical parameters such as:
 - soil density;
 - shear strength parameters;
 - deformation and consolidation characteristics;
 - hydraulic conductivity and ground water pressure.

The results from a cone penetration test may also be used directly in geotechnical design calculations.

Geotechnical investigation and testing — Field testing —

Part 1:

Electrical cone and piezocone penetration test

1 Scope

This document establishes equipment, procedural and reporting requirements and recommendations on cone and piezocone penetration tests.

NOTE This document fulfils the requirements for cone and piezocone penetration tests as part of geotechnical investigation and testing according to the EN 1997 series.

This document specifies the following features:

- a) type of cone penetration test;
- b) cone penetrometer class according to [Table 2](#);
- c) test categories according to [Table 3](#);
- d) penetration length or penetration depth;
- e) elevation of the ground surface or the underwater ground surface at the location of the cone penetration test with reference to a datum;
- f) location of the cone penetration test relative to a reproducible fixed location reference point;
- g) pore pressure dissipation tests.

This document covers onshore and nearshore cone penetration test (CPT). For requirements for offshore CPT, see ISO 19901-8.

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/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Terms, definitions and symbols

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 Terms and definitions

3.1.1

average surface roughness

R_a
average deviation between the real surface of the *cone penetrometer* (3.1.6) and a medium reference plane placed along the surface of the cone penetrometer

3.1.2

base of the cone

cylindrical part of the *cone* (3.1.4) directly behind the conical part of the cone tip

3.1.3

calibration drift

difference between *reference reading* (3.1.34) before commencement of test and first *reference reading* (3.1.34) after calibration

3.1.4

cone

conical shaped bottom part of the *cone penetrometer* (3.1.6) and the cylindrical extension

Note 1 to entry: When pushing the penetrometer into the ground, the *cone resistance* (3.1.7) is transferred through the cone to the load sensor.

Note 2 to entry: This document assumes that the cone is rigid, so when loaded its deformation is very small relative to the deformation of other parts of the cone penetrometer.

3.1.5

cone penetration test

CPT

test in which a *cone penetrometer* (3.1.6) at the end of a series of *pushrods* (3.1.33) is pushed into the ground at a constant rate of penetration and forces are measured electrically in the cone penetrometer

3.1.6

cone penetrometer

assembly containing the *cone* (3.1.4), *friction sleeve* (3.1.16), any other sensors and *measuring system* (3.1.23) as well as the connection to the *pushrods* (3.1.33)

Note 1 to entry: An example of a cone penetrometer is shown in [Figure 1](#); for other filter locations, see [Figure 2](#).

3.1.7

cone resistance

cone penetration resistance

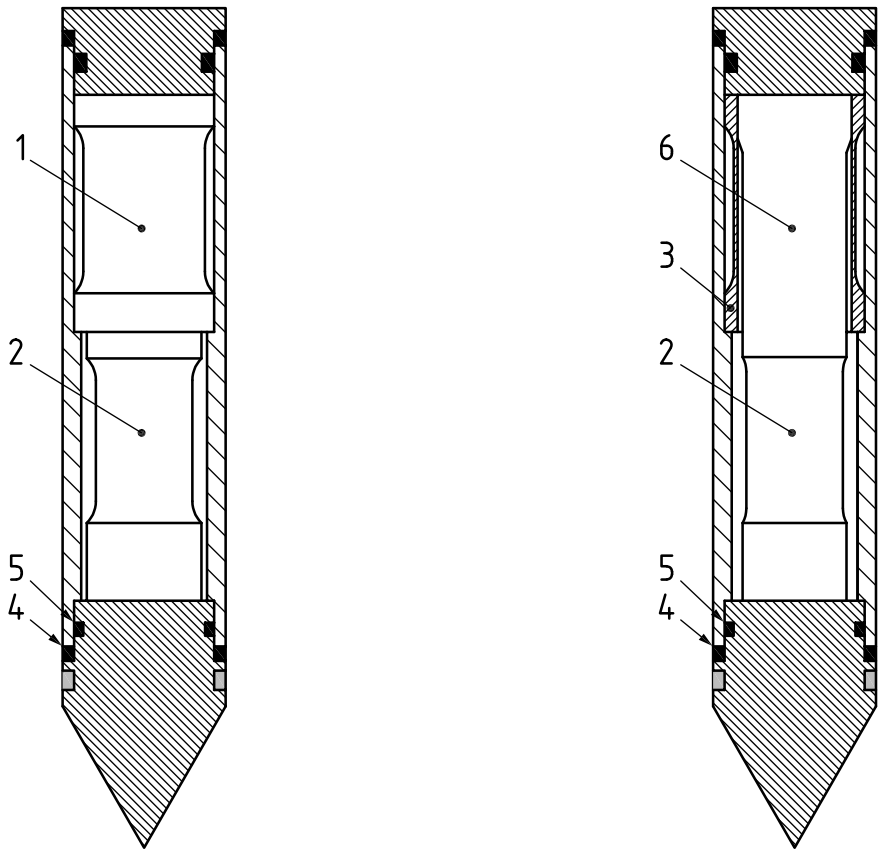
3.1.8

corrected cone resistance

total cone resistance

q_t

measured cone resistance (3.1.20), q_c , corrected for pore pressure effects



a) Cone resistance and sleeve friction load cells in compression

b) Subtraction type cone penetrometer

Key

- 1 sleeve load cell
- 2 cone load cell
- 3 thread
- 4 soil seal
- 5 water seal
- 6 load cell for combined axial forces acting on the cone and the friction sleeve

Figure 1 — Cross-sections of example cone penetrometers

**3.1.9
corrected friction ratio**

R_{ft}
ratio of the *measured sleeve friction* (3.1.22) or *corrected sleeve friction* (3.1.10) to the *corrected cone resistance* (3.1.8) measured at the same depth

Note 1 to entry: Usually, the measured sleeve friction is used; however, if available, the corrected sleeve friction is used.

**3.1.10
corrected sleeve friction**

f_t
measured sleeve friction (3.1.22), f_s , corrected for pore pressure effects

3.1.11

dissipation test

measurement of the pore pressure change with time, during a pause in pushing while holding the *cone penetrometer* (3.1.6) stationary

3.1.12

excess pore pressure

$\Delta u_1, \Delta u_2, \Delta u_3$

pore pressure in excess of the original *in situ pore pressure* (3.1.17) at the level of the filter caused by the penetration of the *cone penetrometer* (3.1.6) into the ground, see [Formulae \(1\)](#), [\(2\)](#) and [\(3\)](#):

$$\Delta u_1 = u_1 - u_0 \quad (1)$$

$$\Delta u_2 = u_2 - u_0 \quad (2)$$

$$\Delta u_3 = u_3 - u_0 \quad (3)$$

3.1.13

filter element

porous element in the *cone penetrometer* (3.1.6) that transmits the pore pressure to the pore pressure sensor, maintaining the geometry of the cone penetrometer

Note 1 to entry: Slotted filter may be used as the filter element for measurements of u_2 , in certain soil conditions.

3.1.14

friction ratio

R_f

ratio of the *measured sleeve friction* (3.1.22) to the *measured cone resistance* (3.1.20) at the same depth

3.1.15

friction reducer

device used to reduce friction along the *pushrod* (3.1.33)

3.1.16

friction sleeve

section of the *cone penetrometer* (3.1.6) where friction between the soil and the sleeve is developed and the load is transferred to the sleeve load cell

3.1.17

in situ pore pressure

u_0

original pressure of groundwater held within the soil

3.1.18

inclination

angular deviation of the *cone penetrometer* (3.1.6) from the vertical

3.1.19

initial pore pressure

u_i

measured pore pressure (3.1.21) at the start of the *dissipation test* (3.1.11)

3.1.20

measured cone resistance

q_c

quotient of the measured force on the cone, Q_c , and cross-sectional projected area of the cone A_c , see [Formula \(4\)](#):

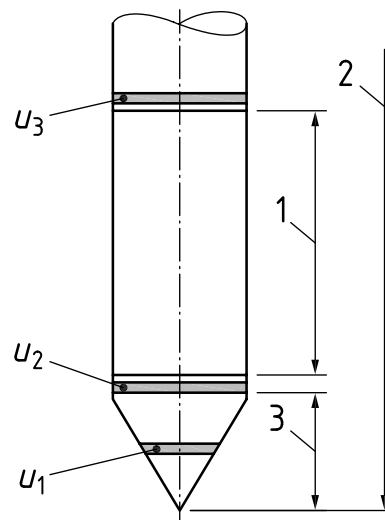
$$q_c = Q_c / A_c \quad (4)$$

3.1.21 measured pore pressure

u_1, u_2, u_3
pressure measured in *filter element* ([3.1.13](#)) during penetration, *dissipation test* ([3.1.11](#)) and pore pressure observation test

Note 1 to entry: The pore pressure can be measured at several locations as follows (see [Figure 2](#)):

- u_1 on the face of the cone;
- u_2 on the cylindrical section of the cone (in the gap between the cone and the sleeve);
- u_3 just behind the *friction sleeve* ([3.1.16](#)).



Key

- 1 friction sleeve
- 2 cone penetrometer
- 3 cone

Figure 2 — Locations of pore pressure filters

3.1.22 measured sleeve friction

f_s
division of the measured force acting on the *friction sleeve* ([3.1.16](#)), F_s , by the area of the sleeve, A_s , see [Formula \(5\)](#):

$$f_s = F_s / A_s \quad (5)$$

3.1.23

measuring system

all sensors and auxiliary parts used to transfer and/or store the electrical signals generated during the *cone penetration test* (3.1.6)

Note 1 to entry: The measuring system normally includes components for measuring force (*cone resistance* and sleeve friction), pressure (pore pressure), *inclination* (3.1.18), clock time and *penetration length* (3.1.30).

3.1.24

net area ratio of the cone

a

ratio of the cross-sectional area of shaft, A_n , of the *cone penetrometer* (3.1.6) above the cone at the location of the gap where fluid pressure can act, to the nominal cross-sectional area of the *base of the cone* (3.1.2), A_c

Note 1 to entry: See Figure 6.

3.1.25

net area ratio of the friction sleeve

b

ratio of the difference between cross-sectional area of the bottom of the sleeve friction, A_{sb} , and the top of the sleeve friction, A_{st} , to the area of *friction sleeve* (3.1.16), A_s

3.1.26

net cone resistance

q_n

measured cone resistance (3.1.20) corrected for the total overburden soil pressure and pore pressure

3.1.27

net friction ratio

R_{fn}

ratio of the sleeve friction to the *net cone resistance* (3.1.26) measured at the same depth

3.1.28

normalized excess pore pressure

U

excess pore pressure (3.1.12) during a *dissipation test* (3.1.11) compared to the initial excess pore pressure

Note 1 to entry: See 7.3.

3.1.29

penetration depth

z

vertical depth of the *base of the cone* (3.1.2), relative to a fixed point

Note 1 to entry: See Figure 3.

3.1.30

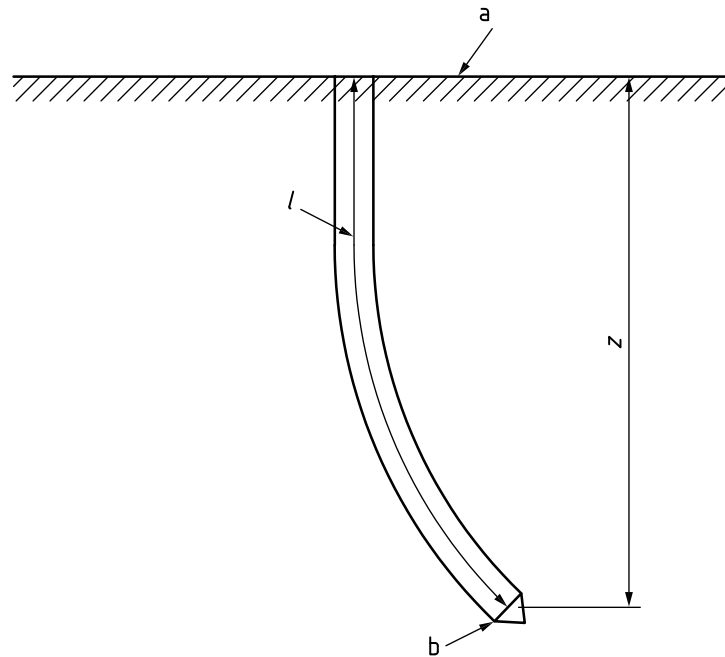
penetration length

l

sum of the lengths of the *pushrods* (3.1.33) and the *cone penetrometer* (3.1.6), reduced by the height of the conical part, relative to a fixed horizontal plane

Note 1 to entry: See Figure 3.

Note 2 to entry: The fixed horizontal plane usually corresponds to the level of the ground surface (on shore or nearshore). This can be different from the starting point of the test.

**Key**

- a Fixed horizontal plane.
- b Base of conical part of cone.
- l penetration length
- z penetration depth

Figure 3 — Penetration length and penetration depth (schematic only)

3.1.31**piezocone penetration test****CPTU**

cone penetration test (3.1.5) with measurement of the pore pressures around the cone

3.1.32**pore pressure ratio**

B_q

ratio of the *excess pore pressure* (3.1.12) at the u_2 filter position to the *net cone resistance* (3.1.26)

3.1.33**pushrod**

part of a string of rods for the transfer of forces to the *cone penetrometer* (3.1.6)

3.1.34**reference reading**

stable output of a *measuring system* (3.1.23) reading of a sensor just before the penetrometer penetrates the ground or just after the penetrometer leaves the ground

Note 1 to entry: With tests starting onshore from the ground surface, the reference reading equals the zero reading.

3.1.35**thrust machine**

equipment that pushes the *cone penetrometer* (3.1.6) and *pushrods* (3.1.33) into the ground at a constant rate of penetration

3.1.36

total overburden stress

σ_{vo}

stress due to the total weight of the soil layers at the depth of the *base of the cone* (3.1.2)

3.1.37

zero drift

absolute difference between the *reference readings* (3.1.34) of a *measuring system* (3.1.23) at the start and after completion of the *cone penetration test* (3.1.5)

3.2 Symbols

Symbol	Name	Unit
A_c	cross-sectional projected area of the cone	mm ²
A_n	cross-sectional area of the load cell or shaft	mm ²
A_s	surface area of the friction sleeve	mm ²
A_{sb}	cross-sectional area of the bottom of the friction sleeve	mm ²
A_{st}	cross-sectional area of the top of the friction sleeve	mm ²
a	net area ratio of cone	
b	net area ratio of sleeve	
b'	repeatability error without rotation	
B_q	pore pressure ratio	
C_{inc}	correction factor for the effect of the inclination of the cone penetrometer relative to the vertical axis	
d_{cone}	diameter of the cone at a specified height	mm
d_c	diameter of the cylindrical part of the cone	mm
d_{fil}	diameter of the filter	mm
d_2	diameter of the friction sleeve	mm
$d_{2l;\theta}$	diameter of the lower one fifth of the friction sleeve at rotational position θ	mm
$d_{2m;\theta}$	diameter of the middle one fifth of the friction sleeve at rotational position θ	mm
$d_{2u;\theta}$	diameter of the upper one fifth of the friction sleeve at rotational position θ	mm
$d_{c;\theta}$	diameter of the cylindrical at rotational position θ	mm
$d_{fil;\theta}$	diameter of the filter element at rotational position θ	mm
$\Delta u_{1,2,3}$	excess pore pressure at filter locations 1, 2 and 3	MPa
F_{fs}	sleeve friction force output	kN
F_N	the range between maximum and the minimum value of calibration range	kN
F_{qc}	cone resistance force output	kN
F_{qc+fs}	force measured by the sensor for combined cone resistance and sleeve friction	kN
F_r	reference axial force applied during calibration (can be F_{rqc} or F_{rfs})	kN
F_{rfs}	reference sleeve friction force	kN
F_{rqc}	reference cone resistance force	kN
F_s	axially measured force on the friction sleeve	kN
f_s	measured sleeve friction	MPa
$f_{s;a}$	apparent sleeve friction	kN
$f_{s;ac}$	temperature-corrected apparent sleeve friction	kPa
$f_{s;r}$	reference sleeve friction	kN
f_t	corrected sleeve friction	MPa
h_c	height of the conical section of the cone	mm
$h_{c;\theta}$	height of the conical section at rotational position θ	mm

Symbol	Name	Unit
h_e	height of the cylindrical extension of the cone	mm
$h_{e;\theta}$	length of the cylindrical extension of the cone at rotational position θ°	mm
i_a	apparent inclination	°
i_{fi}	X_i corresponding to $F_r = 0$ after applying a series i	kN
i_r	reference inclination	°
i_{0i}	X_i corresponding to $F_r = 0$ before applying a series i	kN
k	coverage factor	
l	penetration length	m
$l_{gl;\theta}$	length of the gap between the cylindrical part of the cone and the lower end of the friction sleeve at rotational position θ	mm
$l_{gu;\theta}$	length of the gap above the upper end of the friction sleeve at rotational position θ	mm
l_s	length of the friction sleeve	m
$l_{s;\theta}$	length of the friction sleeve at rotational position θ	mm
Q_c	axially measured force on the cone	kN
q_c	measured cone resistance	MPa
$q_{c;a}$	apparent cone resistance	MPa
$q_{c;ac}$	temperature-corrected apparent cone resistance	MPa
$q_{c;amax}$	maximum value of $q_{c;a}$ for a predefined time period	MPa
$q_{c;amin}$	minimum value of $q_{c;a}$ for a predefined time period	MPa
$q_{c;r}$	reference cone resistance	MPa
q_n	net cone resistance	MPa
$q_{c;max}$	is the maximum value of cone resistance measured during the penetration phase of the test	MPa
q_t	corrected cone resistance	MPa
r	resolution of the sensor	
R_a	average surface roughness	µm
R_f	friction ratio	%
R_{ft}	corrected friction ratio	%
R_{fn}	net friction ratio	%
S	equal to A_c for q_c , and equal to A_f for f_s	mm ²
t	time	s
t_{50}	time needed for 50 % excess pore pressure dissipation	s
U	normalized excess pore pressure	
u	pore pressure	MPa
u_a	apparent pore pressure	MPa
U_{Ac}	expanded measurement uncertainty for the cross-sectional area of the cone	mm ²
u_{Ac}	combined standard uncertainty for the cross-sectional area of the cone	mm ²
u_{ac}	temperature-corrected apparent pore pressure	MPa
U_{As}	expanded measurement uncertainty for the area of the friction sleeve	mm ²
u_{As}	combined standard uncertainty for the area of the friction sleeve	mm ²
U_c	expanded measurement uncertainty for calibration of cone resistance and sleeve friction	kPa
u_c	combined standard uncertainty for calibration	kN
$u_{c,dim}$	combined standard uncertainty of u_c and u_{dim}	kPa
U_{cfs}	expanded measurement uncertainty for calibration of sleeve friction	kPa
U_{class}	measurement uncertainty for the determination of cone penetrometer class	kPa

Symbol	Name	Unit
U_{cqc}	expanded measurement uncertainty for calibration of cone resistance	kPa
u_{d2}	combined standard uncertainty for diameter of the friction sleeve	mm ²
u_{dc}	combined standard uncertainty for cone diameter	mm ²
u_{dim}	combined standard uncertainty equal to u_{Ac} for q_c , and equal to u_{As} for f_s	mm ²
$U_{fs:class}$	measurement uncertainty for sleeve friction for the determination of cone penetrometer class	kPa
u_i	initial excess in pore pressure (t=0) during a dissipation test	kPa
u_i	each of the uncertainty contributions consider for the calculation of the combined standard uncertainty	
U_{inc}	expanded measurement uncertainty for cone penetrometer inclination	°
u_{inc}	combined standard uncertainty for cone penetrometer inclination	°
u_{ls}	combined standard uncertainty for length of the friction sleeve	mm
$U_{qc:class}$	measurement uncertainty for cone resistance for the determination of cone penetrometer class	kPa
u_r	reference pressure applied during calibration	MPa
u_{ref}	standard uncertainty of the reference measuring device	
u_t	pore pressure at time t during a dissipation test	MPa
U_u	expanded measurement uncertainty for pore pressure	kPa
$U_{u:class}$	measurement uncertainty for pore pressure for the determination of cone penetrometer class	kPa
u_o	in situ pore pressure	MPa
u_1	pore pressure measured at location 1	MPa
u_2	pore pressure measured at location 2	MPa
u_3	pore pressure measured at location 3	MPa
v	relative reversibility error of the sensor	
X_a	computed value of deflection calculated from the interpolation formula	
X_i	deflection output value for a calibration step from series i	
X_N	value of F_{qc} (or F_{fs}) corresponding to F_N	kN
$\overline{X_r}$	average of the values of X_i	kN
$\overline{X_{wr}}$	average of the values of X_i without rotation	kN
z	penetration depth	m
α	measured total angle between the vertical axis and the axis of the cone penetrometer	°
β_1	measured angle between the vertical axis and the projection of the axis of the cone penetrometer on a fixed vertical plane	°
β_2	measured angle between the vertical axis and the projection of the axis of the cone penetrometer on a vertical plane that is perpendicular to the plane of angle β_1	°
Δb_{fs}	bending influence on sleeve friction	kPa/N
Δb_{qc}	bending influence on cone resistance	kPa/N
Δb_u	bending influence on pore pressure	kPa/N
Δa_{fs}	ambient temperature stability for sleeve friction	kPa/°C
Δa_{fsc}	ambient temperature stability for corrected sleeve friction	kPa/°C
Δa_{qc}	ambient temperature stability for cone resistance	kPa/°C
Δa_{qcc}	ambient temperature stability for corrected cone resistance	kPa/°C
Δa_u	ambient temperature stability for pore pressure	kPa/°C
Δa_{uc}	ambient temperature stability for corrected pore pressure	kPa/°C
Δt_{fs}	transient temperature stability for sleeve friction	kPa/°C

Symbol	Name	Unit
Δt_{fsc}	transient temperature stability for corrected sleeve friction	kPa/°C
Δt_{qc}	transient temperature stability for cone resistance	kPa/°C
Δt_{qcc}	transient temperature stability for corrected cone resistance	kPa/°C
Δt_u	transient temperature stability for pore pressure	kPa/°C
Δt_{uc}	transient temperature stability for corrected pore pressure	kPa/°C

4 Equipment

4.1 General

4.1.1 Tolerances

The dimensional tolerances are operational tolerances.

The tolerance on surface roughness is a manufacturing tolerance.

4.1.2 Gaps and soil seals

Gaps between the different parts of the cone penetrometer shall not exceed 5 mm in height. A soil seal shall protect the gap to prevent soil particles from affecting the measurement.

The soil seal shall deform easily relative to the load cell and other elements in the penetrometer, to prevent the transfer of significant forces through the gap.

4.2 Cone penetrometer

The cone penetrometer shall have internal load sensors for the measurement of force on the cone (cone resistance), side friction on the friction sleeve (sleeve friction) and, if applicable, pore pressure at one or several locations on the surface of the cone penetrometer.

NOTE 1 Other sensors can be included in the cone penetrometer.

The axis of all parts of the cone penetrometer shall be coincident.

Cone penetrometers should ideally have a net area ratio of the cone approaching 1 and a net area ratio of the sleeve approaching 0, taking into account the robustness of the cone penetrometer.

NOTE 2 Net area ratio, a , varies between 0,5 and 0,9 for commonly used cone penetrometers.

4.3 Surface roughness and hardness

The cone and friction sleeve of the cone penetrometer shall be manufactured to a minimum hardness of 45 HRc. Hardness Rockwell scale C is defined in ISO 6508-1:2016.

The surface roughness, as mentioned in 4.4 and 4.5, refers to the average roughness, R_a , determined by a surface profile comparator according to ISO 8503, or equivalent.

NOTE The surface roughness requirement intends to prevent the use of an “unusually smooth” or “unusually rough” cone or friction sleeve. Steel, including hardened steel, is subject to wear in soil (in particular sands); and the friction sleeve develops its own roughness with use. It is therefore important that the roughness at manufacture approaches the roughness acquired upon use.

4.4 Cone

The cone consists of a conical part and a cylindrical extension. The cone shall have a nominal apex angle of 60° . The cross-sectional area of the cone shall be $1\,000\text{ mm}^2$, which corresponds to a diameter of $35,7\text{ mm}$.

Depending on ground conditions, cones with a diameter between 25 mm ($A_c = 500\text{ mm}^2$) and 50 mm ($A_c = 2\,000\text{ mm}^2$) may be used for special purposes, without the application of correction factors. In this case, the geometry of the cone shall be adjusted proportionally to the diameter. The geometry of the friction sleeve should be adjusted to obtain comparable results. Use of a cone with $A_c \neq 1\,000\text{ mm}^2$ shall be reported.

The diameter of the cylindrical part shall be within the tolerance requirement, as shown in [Figure 4](#):

$$35,3\text{ mm} \leq d_c \leq 36,0\text{ mm}$$

The height of the cylindrical extension shall be within the following tolerance requirement:

$$7,0\text{ mm} \leq h_e \leq 10,0\text{ mm}$$

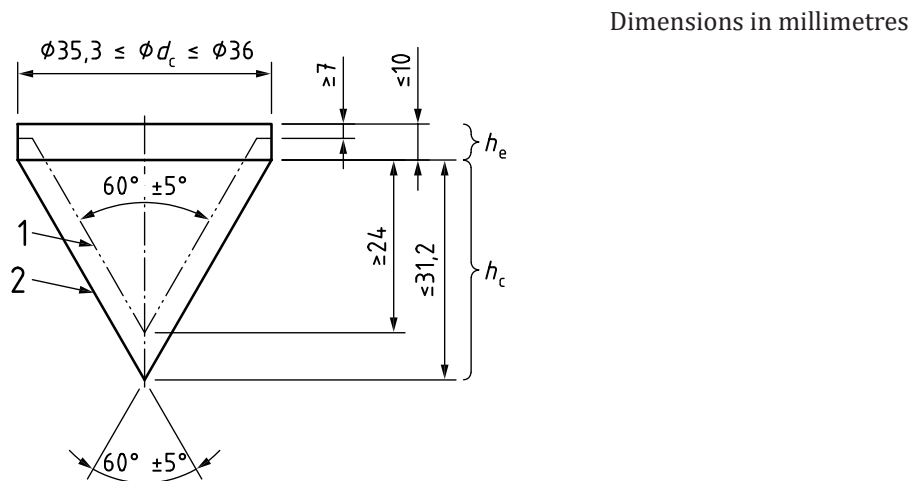
The height of the conical section shall be within the following tolerance requirement:

$$24,0\text{ mm} \leq h_c \leq 31,2\text{ mm}$$

If a filter is put at position u_2 , the diameter of the filter element itself shall be equal to the diameter of the cone, d_c , with a tolerance of $-0,1\text{ mm}$ to 0 mm (see also [4.5](#) and [4.6](#)).

The cone shall be manufactured to a surface roughness of $R_a < 5\text{ }\mu\text{m}$.

The cone shall not be used if an additional visual check indicates that it is asymmetrically worn or unusually rough, even if it otherwise fulfils the tolerance requirements.



Key

- 1 minimum shape of the cone after wear
- 2 maximum shape of the cone

Figure 4 — Tolerance requirements for the use of $1\,000\text{ mm}^2$ cone penetrometer

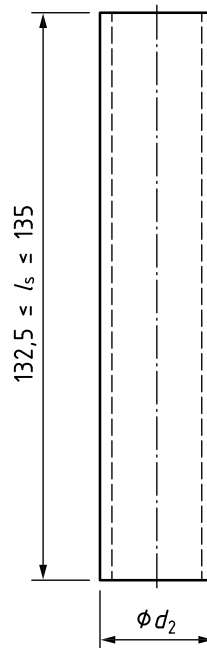
4.5 Friction sleeve

The friction sleeve shall be placed just above the cone. The distance due to gaps and soil seals shall not be more than 5,0 mm.

The surface area, A_s , shall be 15 000 mm². Tolerance requirements are shown in [Figure 5](#).

Friction sleeves with an external diameter between 25 mm and 50 mm may be used for special purposes, if used with cones of the corresponding diameter without the application of correction factors. The nominal ratio of the length and the diameter should preferably be 3,75. Ratios of 3 to 5 are allowable.

Dimensions in millimetres



Key

l_s length of the friction sleeve

d_2 diameter of the friction sleeve

Figure 5 — Geometry and tolerances of the friction sleeve

The geometry and tolerances of the friction sleeve shall be within the tolerance requirement, as shown in [Figure 5](#).

The diameter of the friction sleeve, d_2 , shall be equal within the following tolerance requirement:

$$d_c \leq d_2 < (d_c + 0,25) \text{ mm}$$

and

$$d_2 < 36,1 \text{ mm}$$

The length of the cylindrical part shall be within the following tolerance requirement:

$$132,5 \text{ mm} < l_s \leq 135,0 \text{ mm}$$

The friction sleeve shall be manufactured to a surface roughness of $R_a = 0,4 \mu\text{m} \pm 0,25 \mu\text{m}$, measured in the longitudinal direction.

The friction sleeve shall not be used if a visual check indicates that it is scratched, asymmetrically worn or unusually rough, even if it otherwise fulfils the tolerance requirements.

The cross-sectional area of the top end of the friction sleeve shall not be smaller than the cross-sectional area of the lower end.

4.6 Filter element

4.6.1 General filter location

A filter position in or just behind the cylindrical extension of the cone is recommended, see [Figure 2](#).

NOTE 1 Measurements at different filter locations in addition to the recommended ones can give valuable information about the ground conditions.

NOTE 2 The measured pore pressure is influenced by soil type, in situ pore pressure and filter location on the surface of the cone penetrometer. The pore pressure consists of two components: the original in situ pore pressure and the additional or excess pore pressure caused by the penetration of the cone penetrometer into the ground.

The filter shall not influence the measured cone resistance or sleeve friction.

Tolerances on filter dimensions are tolerances at the start of a test.

The pore pressure measuring system shall be saturated at the start of the test.

The filter should remain saturated, even when the cone penetrometer is penetrating an unsaturated layer. This is not always possible; in these circumstances, other methods like pre pushing, pre boring or changing saturating fluid can be necessary.

Porous filters should have a pore size between 2 μm and 20 μm , matching a hydraulic conductivity between 10^{-4} m/s and 10^{-5} m/s. Filter materials that get clogged should be avoided.

NOTE 3 The following types of material have been used with good experience in soft normally consolidated clay: sintered stainless steel, carborundum, ceramics, porous PVC (Poly vinyl Chloride), HDPE (High Density Poly Ethylene) and porous brass filter.

The use of slotted filter shall fulfil the same purpose and general requirements as a porous filter.

The cone penetrometer shall be designed in such a way that it is easy to replace the filter and that the liquid chamber is easy to saturate (see [5.3](#)).

NOTE 4 With regard to the choice of saturating liquid, saturation of pore pressure measurement system, and use of slot filters, see [Annex F](#).

4.6.2 Pore pressure u_1

The surface of the filter shall fit the shape of the cone: it shall not protrude and shall not recess more than 0,1 mm.

The deviation from the surface of the filter to the surface of the cone should be assessed visually.

The filter element should be positioned in the middle third of the conical part.

4.6.3 Pore pressure u_2

The filter element shall be placed in or just behind the cylindrical part of the cone. The diameter of the filter at the start of the test shall equal to the diameter of the cylindrical part of the cone and the friction sleeve, with a tolerance limit of $-0,1$ mm to 0 mm.

$$(d_2 - 0,1) \leq d_{\text{fil}} \leq d_c$$

For correction of pore pressure effects on cone resistance, the filter element should be located in the gap between the cone and the friction sleeve. Since this is not possible in practice, the filter should be located in the cylindrical part of the cone as close as possible to the gap.

4.6.4 Pore pressure u_3

The diameter of the filter shall correspond to the diameter of the friction sleeve with a tolerance limit of $-0,1$ mm to 0 mm, i.e. the diameter of the filter shall be smaller or equal to the diameter of the friction sleeve:

$$(d_2 - 0,1) \leq d_{\text{fil}} \leq d_2$$

The filter element should be placed immediately above and as close as possible to the gap between the friction sleeve and the shaft of the cone penetrometer.

4.7 Pushrods

The pushrods shall have the same diameter as the cone for at least 400 mm measured from the base of the cone for cones with a base area of $1\,000\text{ mm}^2$. For other size cones, this distance shall be scaled linearly in proportion to the diameter.

Prior to each use, the straightness shall be checked visually. The straightness of the pushrods shall be determined as specified in [B.1.1](#), at the intervals given in [Table B.1](#).

Friction along the pushrods can be reduced by a local increase in the rod diameter (friction reducer). The friction can also be reduced by lubrication of the pushrods, for instance by mud injection during the test. The injection point should be at least 400 mm above the base of the cone for cones with a base area of $1\,000\text{ mm}^2$. For other size cones, this distance shall be scaled linearly in proportion to the diameter of the cone.

Above the ground level, the pushrods should be guided by rollers, a casing or similar device to reduce the risk of buckling. The pushrods may also be guided by a casing in water or soft strata to avoid buckling.

The pushrods shall be chosen with respect to the data signal transmission system chosen.

NOTE The pushrods can also be used to support and/or protect parts of the measuring system. With the acoustic transfer of CPT results, the rods are also used for transmission of data.

4.8 Measuring system

4.8.1 Accuracy

The resolution of the measuring system shall be better than one-third of the maximum allowable uncertainty applicable to the cone penetrometer class given in [Table 2](#).

Uncertainties in the measuring system are listed in [5.1.2](#), and the required calculations are described in [Clause B.2](#).