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Geotechnical investigation and testing — Field testing —

Part 1: Electrical cone and piezocone penetration test

Reconnaissance et essais géotechniques — Essais en place —

Partie 1: Essais de pénétration au cône électrique et au piézocône

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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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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— application class scheme has been replaced by cone penetrometer class and test category classification scheme;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.

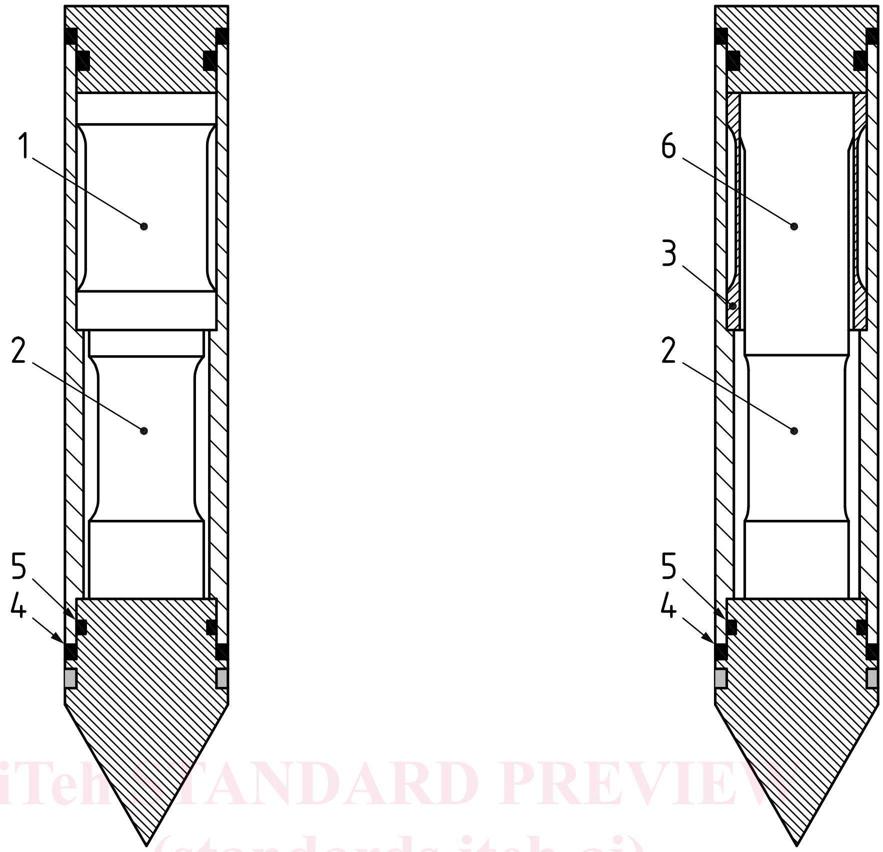
3.1.5
cone penetration test
CPT
test in which a *cone penetrometer* (3.1.6) at the end of a series of *pushrods* (3.1.33) is pushed into the ground at a constant rate of penetration and forces are measured electrically in the cone penetrometer

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
Δu_1, Δu_2, Δu_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_o
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):

$$q_c = Q_c / A_c \tag{4}$$

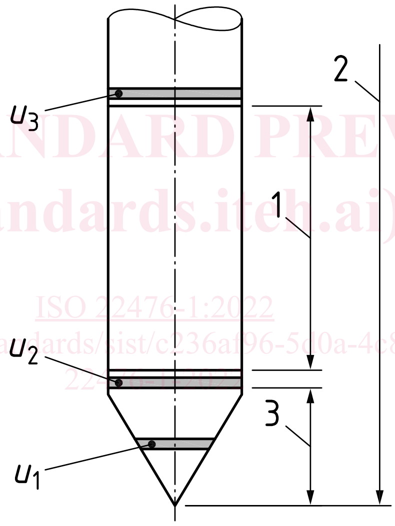
3.1.21
measured pore pressure
u_1, u_2, u_3
pressure measured in *filter element* (3.1.13) during penetration, *dissipation test* (3.1.11) and pore pressure observation test

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):

$$f_s = F_s / A_s \tag{5}$$

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.

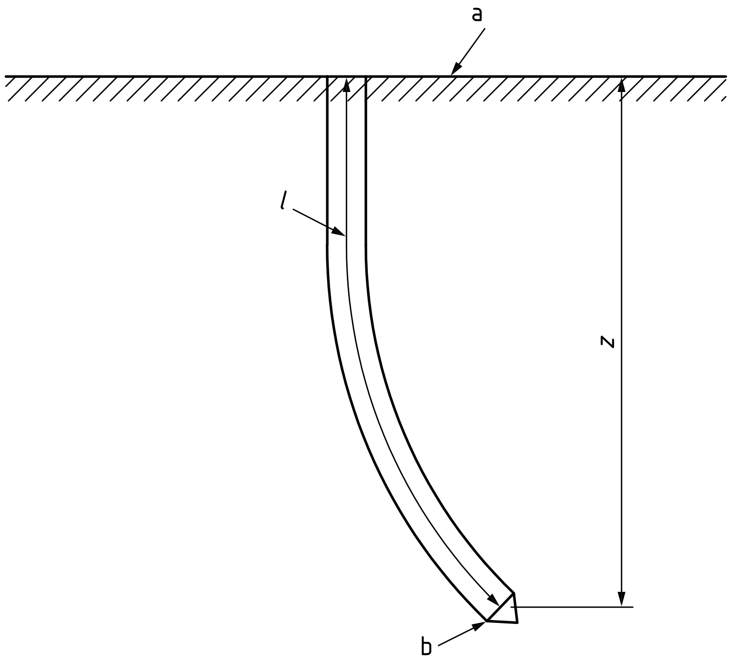
3.1.29
penetration depth
z
vertical depth of the *base of the cone* (3.1.2), relative to a fixed point

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 $F_{rqc \text{ or }} F_{rfs}$)	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

