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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

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ISO 22476-1 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 electrical cone penetration test (CPT) consists of pushing a cone penetrometer using a series of push rods 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. The test results can be used for interpretation of stratification, classification of soil type and evaluation of engineering soil parameters. Two International Standards define cone penetration tests: ISO 22476-1 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 in this part of ISO 22476, although “cone penetration resistance” is a more correct description of the process.

The test results of this part of ISO 22476 are specially suited for the qualitative and/or quantitative determination of a soil profile together with direct investigations (e.g. sampling according to ISO 22475-1 [2]) or as a relative comparison of other *in situ* tests.

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

- stratification;
- soil type;
- geotechnical parameters such as
  - soil density,
  - shear strength parameters, and
  - deformation and consolidation characteristics.

Geotechnical investigation and testing — Field testing —

Part 1:
Electrical cone and piezocone penetration test

1 Scope

This part of ISO 22476 deals with equipment requirements, the execution of and reporting on electrical cone and piezocone penetration tests.

NOTE 1 This part of ISO 22476 fulfills the requirements for electrical cone and piezocone penetration tests as part of geotechnical investigation and testing according to EN 1997-1 [3] and EN 1997-2 [4].

Within the electrical cone and piezocone penetration test, two subcategories of the cone penetration test are considered:

- electrical cone penetration test (CPT), which includes measurement of cone resistance and sleeve friction;
- piezocone test (CPTU), which is a cone penetration test with the additional measurement of pore pressure.

The CPTU is performed like a CPT with the measurement of the pore pressure at one or several locations on the penetrometer surface.

NOTE 2 CPT or CPTU can also be used without measurement of sleeve friction, but this is not covered in this part of ISO 22476.

This part of ISO 22476 specifies the following features:

a) type of cone penetration test, according to Table 1;

b) application class, according to Table 2;

c) penetration length or penetration depth;

d) elevation of the ground surface or the underwater ground surface at the location of the cone penetration test with reference to a datum;

e) location of the cone penetration test relative to a reproducible fixed location reference point;

f) pore pressure dissipation tests.

NOTE 3 This part of ISO 22476 covers onshore and nearshore CPT. For extra requirements for offshore CPT, see NORSOK G-001 [8].

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 any amendments) applies.

ISO 8503, *Preparation of steel substrates before application of paints and related products — Surface roughness characteristics of blast-cleaned steel substrates*

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

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

average surface roughness
Ra
average deviation between the real surface of the cone penetrometer and a medium reference plane placed along the surface of the cone penetrometer

3.1.2

cone
conical shaped bottom part of the cone penetrometer and the cylindrical extension

NOTE 1 When pushing the penetrometer into the ground, the cone resistance is transferred through the cone to the load sensor.

NOTE 2 This part of ISO 22476 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.

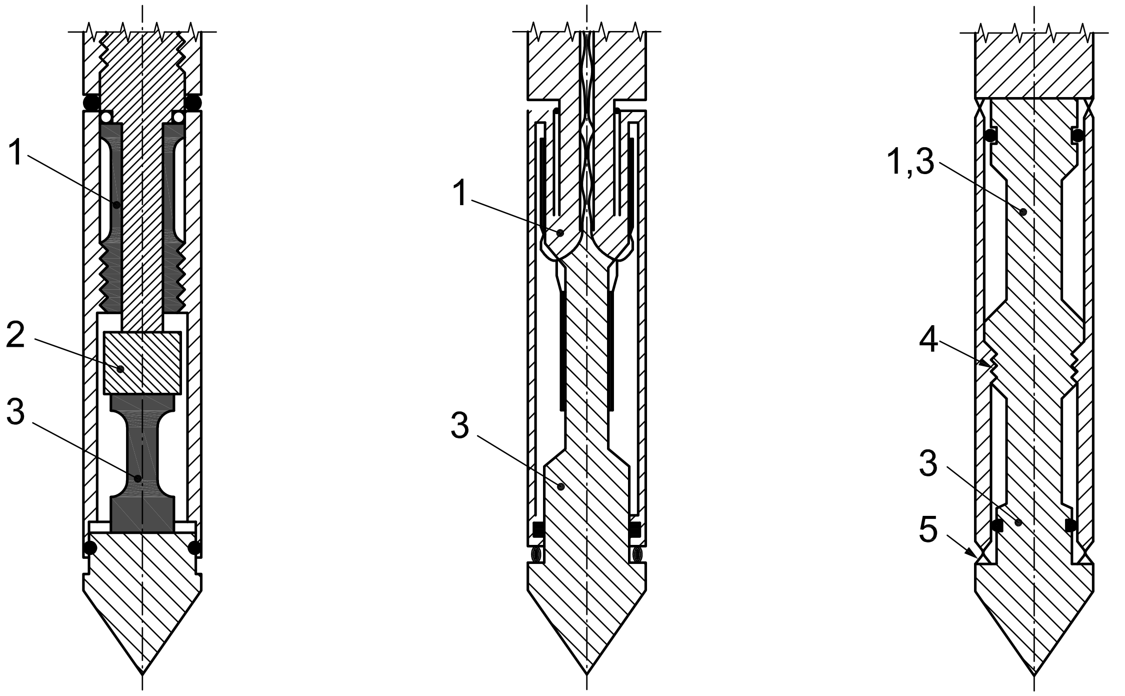
3.1.3

cone penetration test
CPT
pushing of a cone penetrometer at the end of a series of cylindrical push rods into the ground at a constant rate of penetration

3.1.4

cone penetrometer
assembly containing the cone, friction sleeve, any other sensors and measuring systems as well as the connection to the push rods

NOTE An example of a cone penetrometer is shown in Figure 1; for other filter locations, see Figure 2.



a) Cone resistance and sleeve friction load cells in compression

b) Cone resistance load cell in compression and sleeve friction load cells in tension

c) Subtraction type cone penetrometer

Key

1 sleeve load cell
2 point load cell overload protection device
3 cone load cell
4 thread
5 soil seal

Figure 1 — Cross section of an example of a cone penetrometer

3.1.5

cone resistance
cone penetration resistance

3.1.6

corrected cone resistance
q_t
measured cone resistance, q_c, corrected for pore pressure effects

3.1.7

corrected friction ratio
R_{ft}
ratio of the measured or corrected sleeve friction to the corrected cone resistance measured at the same depth

NOTE Usually the measured sleeve friction is used; however, if available, the corrected sleeve friction is used.

3.1.8

corrected sleeve friction

f_t

measured sleeve friction, f_s, corrected for pore pressure effects

3.1.9

dissipation test

measurement of the pore pressure change with time during a pause in pushing while holding the cone penetrometer stationary

3.1.10

electrical cone penetration test

cone penetration test where forces are measured electrically in the cone penetrometer

3.1.11

excess pore pressure

Δu_1, Δu_2, Δu_3

pore pressure in excess of the ambient pore pressure at the level of the filter caused by the penetration of the cone penetrometer into the ground:

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

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

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

3.1.12

filter element

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

3.1.13

friction ratio

R_f

ratio of the measured sleeve friction to the measured cone resistance at the same depth

3.1.14

friction reducer

local and symmetrical enlargement of the diameter of a push rod to obtain a reduction of the friction along the push rods

3.1.15

friction sleeve

section of the cone penetrometer where friction between the soil and the sleeve is measured

3.1.16

in situ equilibrium pore pressure

u_o

original *in situ* pore pressure at filter depth

3.1.17

inclination

angular deviation of the cone penetrometer from the vertical

3.1.18

initial pore pressure

u_i

measured pore pressure at the start of the dissipation test

3.1.19

measured cone resistance

q_c

division of the measured force on the cone, Q_c, by the projected area of the cone A_c:

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

3.1.20

measured pore pressure

u_1, u_2, u_3

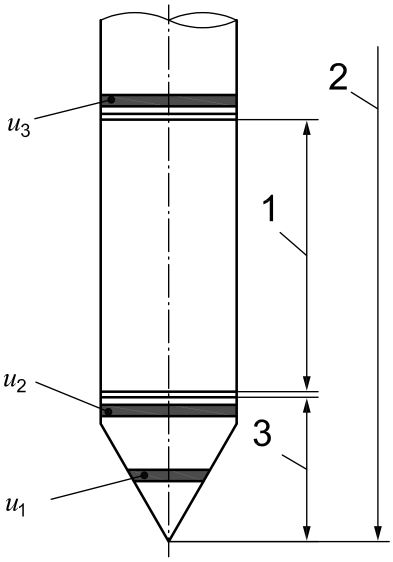
pressure measured in filter element during penetration and dissipation testing

NOTE 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 (preferably in the gap between the cone and the sleeve;

u_3 just behind the friction sleeve.



Key

1 friction sleeve
2 cone penetrometer
3 cone

Figure 2 — Locations of pore pressure filters

3.1.21

measured sleeve friction

f_s

division of the measured force acting on the friction sleeve, F_s, by the area of the sleeve, A_s:

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

3.1.22

measuring system

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

NOTE The measuring system normally includes components for measuring force (cone resistance, sleeve friction), pressure (pore pressure), inclination, clock time and penetration length.

3.1.23

net area ratio

a

ratio of the cross-sectional area of the load cell or shaft, A_{st}, of the cone penetrometer 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, A_c

NOTE See Figure 6.

3.1.24

net cone resistance

q_n

measured cone resistance corrected for the total overburden soil pressure

3.1.25

net friction ratio

R_{fn}

ratio of the sleeve friction to the net cone resistance measured at the same depth

3.1.26

normalized excess pore pressure

U

excess pore pressure during a dissipation test compared to the initial excess pore pressure

NOTE See 7.4.

3.1.27

penetration depth

z

vertical depth of the base of the cone, relative to a fixed point

NOTE See Figure 3.

3.1.28

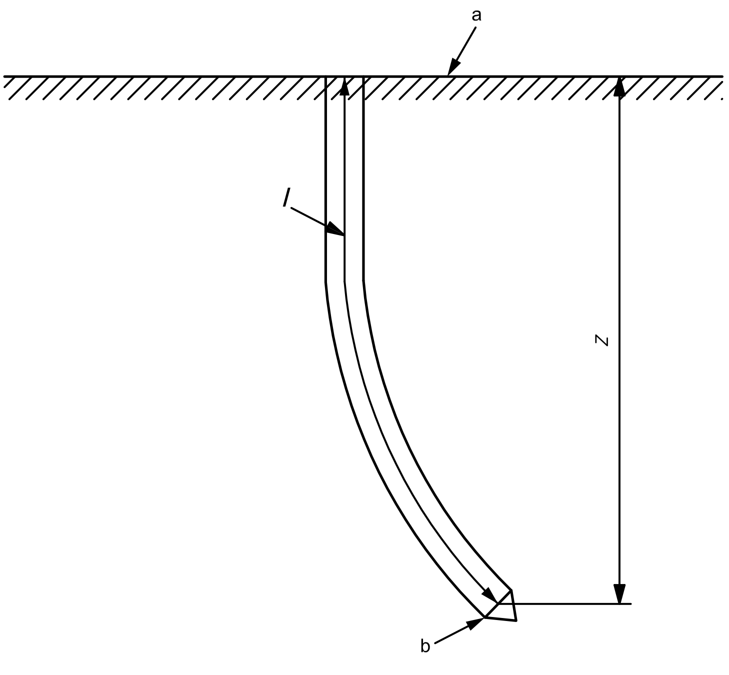
penetration length

l

sum of the lengths of the push rods and the cone penetrometer, reduced by the height of the conical part, relative to a fixed horizontal plane

NOTE 1 See Figure 3.

NOTE 2 The fixed horizontal plane usually corresponds to the level of the ground surface (on shore or off shore). 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)

3.1.29

piezocone penetration test
CPTU
electrical cone penetration test with measurement of the pore pressures around the cone

3.1.30

pore pressure ratio
B_q
ratio of the excess pore pressure at the u_2 filter position to the net cone resistance

3.1.31

push rod
part of a string of rods for the transfer of forces to the cone penetrometer

3.1.32

reference reading
reading of a sensor just before the penetrometer penetrates the ground or just after the penetrometer leaves the ground

NOTE 1 In offshore situations, it is the reading taken at the sea bed or at the bottom of a bore hole with water pressure acting.

NOTE 2 With tests starting on shore from the ground surface, the reference reading equals the zero reading.

3.1.33

thrust machine
equipment that pushes the cone penetrometer and rods into the ground at a constant rate of penetration

3.1.34

total overburden stress
σ_vo
stress due to the total weight of the soil layers at the depth of the base of the cone

3.1.35

zero drift
absolute difference between the zero readings (or reference readings) of a measuring system at the start and after completion of the cone penetration test

3.1.36

zero reading
stable output of a measuring system when there is zero load on the sensors, i.e. the parameter to be measured has a value of zero, while any auxiliary power supply required to operate the measuring system is switched on

3.2 Symbols

Symbol	Name	Unit
A_c	cross-sectional projected area of the cone	mm^2
A_n	cross-sectional area of load cell or shaft	mm^2
A_s	surface area of 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	
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
$\Delta u_{1,\,2,\,3}$	excess pore pressure at filter locations 1, 2 and 3	MPa
F_s	axially measured force on the friction sleeve	kN
f_s	measured sleeve friction	MPa
f_t	corrected sleeve friction	MPa
h_c	height of the conical section of the cone	mm
h_e	length of the cylindrical extension of the cone	mm
l	penetration length	m
l_s	length of the friction sleeve	m
Q_c	axially measured force on the cone	kN
q_c	measured cone resistance	MPa
q_n	net cone resistance	MPa
q_t	corrected cone resistance	MPa
Ra	average surface roughness	μm
R_f	friction ratio	%
R_ft	corrected friction ratio	%

Symbol	Name	Unit
R_{fn}	net friction ratio	%
t	time	s
t_{50}	time needed for 50 % excess pore pressure dissipation	s
U	normalized excess pore pressure	
u	pore pressure	MPa
u_i	pore pressure at the start of the dissipation test	MPa
u_t	pore pressure at time t during a dissipation test	MPa
u_o	*in situ*, initial 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
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	°
σ_{vo}	total overburden stress	MPa

4 Equipment

4.1 Cone penetrometer

The cone penetrometer has 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. An internal inclinometer is included for measurement of the inclination of the penetrometer to meet the requirements of the application classes 1, 2 and 3 as given in Table 2.

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 approaching 1, 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.

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.

4.2 Tolerances

The dimensional tolerances are operational tolerances. Manufacturing tolerances should be stricter.

The tolerance on surface roughness is a manufacturing tolerance.

4.3 Surface roughness

The surface roughness as mentioned in 4.4 and 4.5 refers to average roughness, Ra, determined by a surface profile comparator according to ISO 8503, or equivalent. The intention of the surface roughness requirement is to prevent the use of an “unusually smooth” and “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. It is believed that the surface roughness requirement will usually be met in practice for common types of steel used for penetrometer manufacture and for common ground conditions (sand and clay). The effort required for metrological confirmation can thus be limited in practice.

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 mm^2, which corresponds to a diameter of 35,7 mm.

Depending on ground conditions, cones with a diameter between 25 mm ($A_c = 500$ mm^2) and 50 mm ($A_c = 2\ 000$ 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. The use of a cone with $A_c \neq 1\ 000$ 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 length 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:

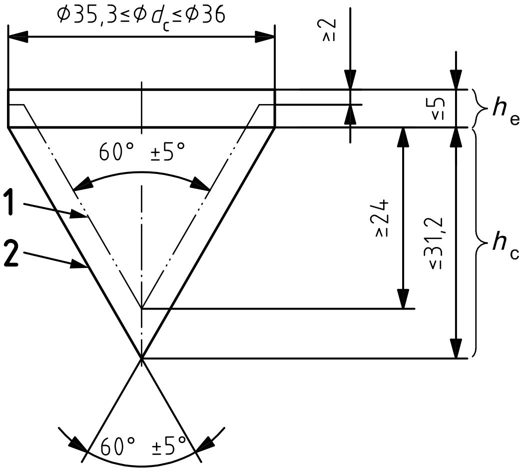
$24,0 \text{ mm} \leq h_c \leq 31,2 \text{ mm}$

If a filter is put at position u_2, the diameter of the filter element itself may be larger than the required dimensions (see also 4.5 and 4.4).

The cone should be manufactured to a surface roughness of $Ra < 5$ µm.

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

Dimensions in millimetres



Key

1 minimum shape of the cone after wear

2 maximum shape of the cone

Figure 4 — Tolerance requirements for use of 1000 mm^2 cone penetrometer

4.5 Friction sleeve

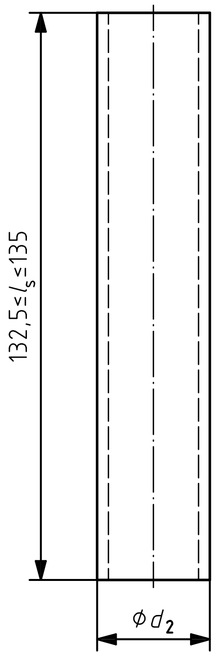
The friction sleeve shall be placed just above the cone. The distance due to gaps and soil seals shall not be more than 5,0 mm.

The nominal surface area shall be 15 000 mm^2. 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 ratio of the length and the diameter should preferably be 3,75. Ratios of 3 to 5 are allowable.

The diameter of the friction sleeve, d_2, shall be equal to the diameter of the cone, d_c, with a tolerance of 0 mm to +0,35 mm.

Dimensions in millimetres



Key

l_s length of friction sleeve

d_2 diameter of friction sleeve

[a] $d_2 \geq d_c$; $d_2 < (d_c + 0{,}35)$; $d_2 < 36{,}1$

[b] $A_s = 15\,000\ \text{mm}^2$

Figure 5 — Geometry and tolerances of friction sleeve

The geometry and tolerances of the friction sleeve shall be within the tolerance requirement as shown in Figure 5:

$$d_c \leq d_2 < (d_c + 0{,}35)\ \text{mm}$$

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 $Ra = 0{,}4\ \mu\text{m} \pm 0{,}25\ \mu\text{m}$, 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.

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 like in Figure 2. Other filter locations can be accepted.

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

NOTE 3 This might not always be possible; in these circumstances other methods like prepushing, preboring or changing saturating fluid can be necessary.

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

NOTE 4 The following types of material have been used with good experience in soft normally consolidated clay: sintered stainless steel or bronze, carborundum, ceramics, porous PVC and HDPE.

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 5.4).

NOTE 5 With regard to the choice of saturating liquid, saturation of pore pressure measurement system, and use of slot filters, see Annex D.

Filters should be replaced before each test.

4.6.2 Pore pressure u_1

The surface of the filter shall fit the shape of the cone: it shall not protrude more than 0,5 mm and shall not recess.

The deviation of 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 test shall correspond to the diameter of the cylindrical part of the cone and the friction sleeve, with a tolerance limit of 0,0 mm to +0,2 mm. The filter can be larger, but shall never be smaller than the diameter of the cylindrical part of the cone. The filter shall not have a larger diameter than the friction sleeve:

$$d_2 - 0{,}2\ \text{mm} \le d_{\text{fil}} \le d_2$$

$$d_c \le d_{\text{fil}} \le (d_c + 0{,}2)\ \text{mm}$$

To correct for 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 0,0 mm to 0,2 mm, i.e. the diameter of the filter shall not be smaller than the diameter of the friction sleeve:

$$d_2 \leq d_{\text{fil}} \leq d_2 + 0{,}2 \text{ mm}$$

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 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 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.

4.8 Push rods

The push rods 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 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 push rods shall be determined as specified in A.1.1, at the intervals given in Table A.1.

Friction along the push rods can be reduced by a local increase in the rod diameter (friction reducer). The friction can also be reduced by lubrication of the push rods, 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 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 push rods should be guided by rollers, a casing or similar device to reduce the risk of buckling. The push rods may also be guided by a casing in water or soft strata to avoid buckling.

The push rods should be chosen with respect to the data signal transmission system chosen.

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

4.9 Measuring system

4.9.1 Accuracy

The resolution of the measuring system shall be better than one-third of the required accuracy applicable to the application class given in Table 2.

Uncertainties in the measuring system, including temperature effects, are described in Annex E.

4.9.2 Sensors for cone resistance and sleeve friction

The load sensor shall be compensated for possible eccentricity of axial forces. The sensor for recording the side friction force shall be constructed so that it measures the friction along the sleeve, and not the earth pressure against it.

NOTE Normally strain gauged load cells are used for recording cone resistance and sleeve friction.

4.9.3 Sensor for pore pressure

The sensor should not show significant deformation during loading. The sensor communicates with the porous filter on the surface of the cone penetrometer via a liquid-filled chamber. The measuring system should be as rigid as possible (see 5.4) to obtain a good response.

NOTE 1 The pore pressure sensor is normally a pressure transducer of the membrane type.

NOTE 2 This system measures the pore pressure in the surrounding soil during penetration.

4.9.4 Sensor for inclination

The inclinometer shall normally have a measuring range of at least ±15° relative to the vertical axis.

Other measuring ranges may be used, but these can affect the maximum penetration which can be achieved (see 4.9.5).

An inclination sensor is not required where the target penetration is less than 5 m and for application class 4.

4.9.5 Measuring system for penetration length

The measuring system shall include measurement of the penetration length.

If relevant, the measurement system for depth shall also include a procedure for correction of measurements if upward movements of the push rods occur relative to the depth sensor, caused by a decrease in force on the push rods.

4.9.6 Raw data

The test data may be recorded as raw data.

NOTE It is preferable to record the data as raw data so they are available for future processing. Raw data is the unprocessed data as the output of the sensors.

4.10 Thrust machine

The cone penetrometer shall be able to penetrate at a standard rate of penetration of 20 mm/s ± 5 mm/s, and the equipment shall be loaded or anchored to limit movements of the thrust machine relative to ground level while the penetration occurs. Hammering or rotation of the penetration rods during measurements is not allowed.

Required reaction (counterweight) for the thrust machine may be supplied by dead weight and/or soil anchors.

The pushing equipment shall give a stroke of at least 1 m. Other stroke lengths may be used in special circumstances.

5 Test procedures

5.1 Selection of cone penetrometer

Select a cone penetrometer to fulfil the requirements of the penetration test according to Table 1.

Table 1 — Types of cone penetration test

Type	Measured parameter
TE1	Cone resistance and sleeve friction
TE2	Cone resistance, sleeve friction and pore pressure
NOTE Cone penetration tests with measurements of pore pressures at more than one location are variants of type TE2.	

Inclination measurement should be included depending on application class; see Table 2.

5.2 Selection of equipment and procedures

The required accuracy is meant to be a function of what the results are to be used for. Application classes have been developed to give guidance on selecting type of CPT, required accuracy and logging frequency. For given soil profiles and use of CPT results, the application class specifies the needed minimum accuracy and the maximum length between measurements, with an associated degree of uncertainty. The use of CPT results is stated in terms of profiling, material identification and definition of soil parameters.

Equipment and procedures shall be selected according to the required application class given in Table 2.

Application classes are defined as follows:

- Application class 1 is intended for soft to very soft soil deposits. Class 1 penetration tests are normally not apt for mixed bedded soil profiles with soft to dense layers (although pre-drilling through stiff layers can overcome the problem). Tests can only be performed with use of the CPTU.

- Application class 2 is intended for precise evaluation for mixed bedded soil profiles (see note 1) with soft to dense layers, in terms of profiling and material identification. Interpretation in terms of engineering properties is also possible, with restriction to indicative use for the soft layers. Penetrometer type to be used depends on project requirements.

- Application class 3 is intended for evaluation of mixed bedded soil profiles (see Note 1) with soft to dense soils, in terms of profiling and material identification. Interpretation in terms of engineering properties is achievable for very stiff to hard and dense to very dense layers. For stiff clays or silts and loose sands, only an indicative interpretation can be given. Penetrometer type to be used depends on project requirements.

- Application class 4 is only intended for indicative profiling and material identification for mixed bedded soil profiles with soft to very stiff or loose to dense layers. No appreciation in terms of engineering parameters can be given. Tests are to be performed with an electrical cone penetrometer (type TE1) and inclination measurement may be omitted.

If all possible sources of errors are added, the accuracy of the recorded measurements shall be better than the largest of the values given in Table 2. The inaccuracy analyses shall include internal friction, errors in the data acquisition, eccentric loading, temperature (ambient and transient) effects and dimensional errors.

Metrological confirmation applicable to a cone penetration test shall be according to ISO 10012.

The actual cross-sectional area of the base of the cone and the actual external cylindrical surface area of the friction sleeve shall be determined and recorded for application class 1.

NOTE 1 Mixed bedded soil profiles refer to soil conditions containing typically dense and compact soils, but possibly also including soft layers.

NOTE 2 The achievable penetration length or penetration depth depends on the soil conditions, the allowable penetration force, the allowable forces on the push rods and push rod connectors and the application of a friction reducer and/or push rod casing and the measuring range of the cone penetrometer.

If dissipation tests are required (see 5.9), equipment of TE2 type tests shall be selected depending on the project requirements.

NOTE 3 For uncertainties in cone penetration testing, see Annex E.

Table 2 — Application classes

Application class	Test type	Measured parameter	Allowable minimum accuracy[a]	Maximum length between measurements	Use	
					Soil[b]	Interpretation / evaluation[c]
1	TE2	Cone resistance	35 kPa or 5 %	20 mm	A	G, H
		Sleeve friction	5 kPa or 10 %			
		Pore pressure	10 kPa or 2 %			
		Inclination	2°			
		Penetration length	0,1 m or 1%			
2	TE1 TE2	Cone resistance	100 kPa or 5 %	20 mm	A B C D	G, H* G, H G, H G, H
		Sleeve friction	15 kPa or 15 %			
		Pore pressure[d]	25 kPa or 3 %			
		Inclination	2°			
		Penetration length	0,1 m or 1 %			
3	TE1 TE2	Cone resistance	200 kPa or 5 %	50 mm	A B C D	G G, H* G, H G, H
		Sleeve friction	25 kPa or 15 %			
		Pore pressure[d]	50 kPa or 5 %			
		Inclination	5°			
		Penetration length	0,2 m or 2 %			
4	TE1	Cone resistance	500 kPa or 5 %	50 mm	A B C D	G* G* G* G*
		Sleeve friction	50 kPa or 20 %			
		Penetration length	0,2 m or 2 %			

NOTE For extremely soft soils, even higher demands on the accuracy can be needed.

[a] The allowable minimum accuracy of the measured parameter is the larger value of the two quoted. The relative accuracy applies to the measured value and not the measuring range.

[b] According to ISO 14688-2 [1]:

A homogeneously bedded soils with very soft to stiff clays and silts (typically q_c < 3 MPa)
B mixed bedded soils with soft to stiff clays (typically q_c ≤ 3 MPa) and medium dense sands (typically 5 MPa ≤ q_c < 10 MPa)
C mixed bedded soils with stiff clays (typically 1,5 MPa ≤ q_c < 3 MPa) and very dense sands (typically q_c > 20 MPa)
D very stiff to hard clays (typically q_c ≥ 3 MPa) and very dense coarse soils (q_c ≥ 20 MPa)

[c] G profiling and material identification with low associated uncertainty level
G* indicative profiling and material identification with high associated uncertainty level
H interpretation in terms of design with low associated uncertainty level
H* indicative interpretation in terms of design with high associated uncertainty level

[d] Pore pressure can only be measured if TE2 is used.

5.3 Position and level of thrust machine

The distance between the test location and the location of previous investigation points should be sufficient to prevent interaction effects.

Between cone penetration tests, a distance of 2 m is normally sufficient. The distance to a previous borehole should be at least 20 times the borehole diameter. Some borehole techniques, such as air drilling, can require larger distances. Nearby excavations should be avoided.

The thrust machine shall push the push rods so that the axis of the pushing force is as close to vertical as possible. The deviation from the intended axis should be less than 2°. The axis of the penetrometer shall correspond to the loading axis at the start of the penetration.

5.4 Preparation of the test

For cone penetrometers with measurement of pore pressure, the filter element and other parts of the pore pressure system shall be saturated with a liquid before field use. Appropriate measures should be taken to preserve saturation during the test.

Usually de-aired, distilled water is used when testing is carried out in saturated soils. If performing penetration tests in unsaturated soils, dry crust, dilative soils (e.g. dense sands) or when the groundwater table is located at large depths, the filter should be saturated with glycerine or a similar fluid.

Saturation of the cone penetrometer before penetration starts or during operation in a predrilled hole can be maintained by applying a rubber membrane around the filter. During saturation and mounting of the rubber membrane, the penetrometer will be subjected to small stresses, so that the sensors can show values different from zero.

NOTE 1 See Annex E in case a slot filter is used.

NOTE 2 When penetrating coarse materials, predrilling may be used in parts of the profile if the penetration stops in dense, coarse or stone-rich layers. Predrilling may be used in coarse top layers, sometimes in combination with casings to avoid collapse of the borehole. In soft or loose soils, predrilling can be used to penetrate the crust to reach the groundwater table. Predrilling can be done by ramming a dummy-rod of (45 to 50) mm diameter through the dense layer to provide an open hole and reduce the penetration resistance.

The zero readings of the cone resistance, the penetration length the sleeve friction and, if applicable, the pore pressure and inclination of the cone penetrometer relative to the vertical axis shall be recorded.

In order to obtain the required accuracy, depending on application class, it can be necessary to ensure that cone temperature is at or near ground temperature before commencing testing. Zero readings of all sensors should be taken with the cone penetrometer unloaded and temperature-stabilized ideally at ground temperature. Required accuracies are given in Table 2. Annex A contains maintenance, checks and calibration procedures.

NOTE 3 When the cone penetrometer is lowered into the ground or in the water, small temperature gradients will occur if the air temperature is different from the ground temperature, which will influence the sensors. Therefore, it is important that the penetrometer is left to come to equilibrium so that the temperature gradients can be reduced to zero before the penetration starts. Usually, the largest gradients will occur after 2 min to 3 min. The cone penetrometer will usually be completely temperature-stabilized after 10 min to 15 min.

5.5 Pushing of the cone penetrometer

During the penetration test, the cone penetrometer shall be pushed into the ground at a constant rate of penetration of (20 ± 5) mm/s. The rate shall be checked by recording time and penetration length.

NOTE 1 The penetration is regarded as continuous even if the penetration is stopped regularly for a new stroke or mounting of a new push rod. Some thrust machines can carry out true continuous penetration without any stops and this can be an advantage, particularly in layered silt and clay deposits.

NOTE 2 The penetration is regarded as discontinuous if larger stops are introduced, such as dissipation tests (see 5.9) or due to unforeseen malfunctions of the equipment.

NOTE 3 In dense sands and gravels, penetration rates less than the "standard" can be acceptable, to prevent damage to the cone and cone rods.

5.6 Use of friction reducer

The use of a friction reducer (see 3.1.14) is permissible. The cone penetrometer and, if relevant, the push rod shall have the same diameter for at least 400 mm measured from the base of the cone before the introduction of the friction reducer if applicable.

5.7 Frequency of logging parameters

The minimum logging frequency of parameters shall be in accordance with Table 2. Logging shall include (clock)time for application classes 1 and 2 of Table 2.

The logging interval for the various measured values can also be chosen depending on the detail required in the profile, e.g. detection of thin layers. Usually the same reading interval is used for registration of cone resistance, sleeve friction and pore pressure.

If the values are measured more frequently than the required reporting intervals according to Table 2, then the average value calculated can be reported. Other methods, however, can also be applicable. The method used shall be reported.

5.8 Registration of penetration length

The level of the base of the conical part of the cone shall be determined according to the requirements in Table 2, relative to the ground level or another fixed reference system (not the thrust machine). The resolution of the penetration length measurement shall be at least 10 mm.

The penetration length shall also be checked and recorded at least every 5 m for tests according to application class 1 of Table 2. For other application classes, the penetration length shall be checked and recorded at the end of the test. Penetration length shall be checked without using the depth sensor.

The penetration of the cone penetrometer and the push rods shall be terminated when one of the following events occurs.

- The desired penetration length or penetration depth has been reached, see also EN 1997-2:2007, 4.2.2 (3)P.
- The inclination of the cone penetrometer relative to the vertical axis exceeds the measuring range, or 15°.
- The agreed maximum thrust or maximum capacity of the cone penetrometer or measuring systems is reached.

Possible damage to the equipment can also be a valid reason to end the test.

NOTE The measured parameters for a cone penetrometer with a large inclination can deviate from the values that would have been measured if the cone penetrometer was vertical.

The penetration depth should be calculated from penetration length and inclination measurements as in Annex B.

5.9 Dissipation test

If the drainage and/or consolidation characteristics of the soil are to be evaluated, dissipation tests may be carried out at pre-selected depths in the deposit. In a dissipation test, the pore pressure decay is obtained by recording the values of pore pressure with time. In fine, low permeability soils, the pore pressure record is used to evaluate the coefficient of consolidation.

NOTE 1 A dissipation test may be used to estimate the *in situ* pore pressure.

Pore pressure and cone resistance shall be measured with time. It is particularly important to take frequent readings at the beginning of the dissipation test. The dissipation shall be performed with the rods unclamped.

If the weight of the equipment is greater than the total resistance of the soil, the dissipation test may be performed with clamped rods. If the rods are clamped during the dissipation test, this shall be recorded as a deviation from this part of ISO 22476 (7.2.1. d).

NOTE 2 The required depth and minimum duration of a dissipation test depends on the soil conditions and the purpose of the measurement. A maximum duration is also a common reference condition for avoiding inappropriately long interruptions.

The logging frequency should be at least 1 Hz for the first minute of the dissipation test, but may be halved for every log(time) cycle thereafter.

The duration of the dissipation test should normally correspond to at least t_{50}, the time needed for 50 % pore pressure dissipation ($u_t \leq u_o + 0{,}5 \times \Delta u_i$), since t_{50} is the time used in most interpretation methods.

If u_o is not known, a cautious estimate of the value should be made.

NOTE 3 Variation in cone resistance is unavoidable in practice and will depend on factors such as type of equipment and soil conditions.

5.10 Test completion

The penetration of the cone penetrometer and the push rods shall be terminated when

- the required penetration length has been reached, or
- the agreed maximum thrust or maximum capacity of the measuring system has been reached.

Possible damage to the equipment can also be a valid reason to end the test.

The reference readings of the measured parameters shall be recorded after extraction of the cone penetrometer from the soil and, if necessary, after cleaning of the cone penetrometer. If the zero drift of the measured parameters is larger than the allowable minimum accuracy according to the required application class of Table 2, then the results should be neglected, or the test can be assigned to a lower class. After completion of the test, inspect the cone penetrometer and note any excessive wear or damage.

NOTE The zero drift determined from zero load output before test and after cleaning is a measure of the correct functioning of the equipment and is used to evaluate if the requirements of Table 2 can be fulfilled. The zero load outputs from the uncleaned cone are important for the interpretation of test results.

Measured parameters can be corrected for zero drift, if appropriate.

5.11 Equipment checks and calibrations

The overall equipment shall undergo regular maintenance, checking and calibration procedures as specified in Annex A. The calibration interval shall be such that the accuracy required for the application class can be verified.

NOTE Verification of the required accuracy can be based on the track record.

5.12 Safety requirements

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.

6 Test results

6.1 Measured parameters

The following parameters shall be determined:

f_s measured sleeve friction;

l penetration length;

q_c measured cone resistance;

u pore pressure, one or more of the following (for TE 2):

  u_1 pore pressure in the face of the cone,

  u_2 pore pressure at the cylindrical extension of the cone,

  u_3 pore pressure measured above the friction sleeve.

α measured total angle between the vertical axis and the axis of the cone penetrometer.

6.2 Correction of parameters

Recorded values that are not representative due to penetration interruption shall be ignored.

NOTE 1 The surrounding water pressure will influence the measured cone resistance and sleeve friction. This is explained by the effect of the water pressure in the gaps between the cone and the friction sleeve, and in the gap above the friction sleeve.

When water pressure is measured using a filter element at the cylindrical extension of the cone (u_2), measured cone resistance shall be corrected by using Formula (6):

$$q_t = q_c + u_2 \times (1 - a) \quad (6)$$

where

q_t is the corrected cone resistance, in MPa;

q_c is the measured cone resistance, in MPa;

u_2 is the pore water pressure in the cylindrical part of extension of the cone (assumed equal to the pore pressure in the gap between the cone and the sleeve), in MPa;

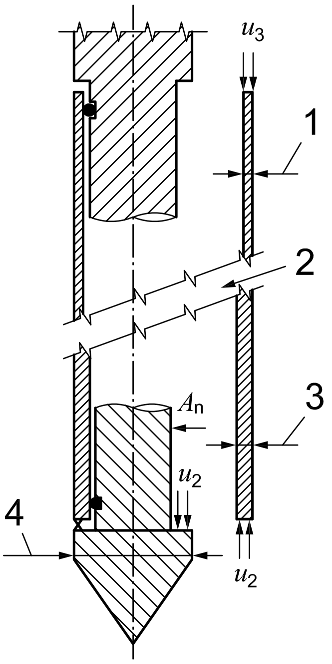
a is the net area ratio:

$a = A_n / A_c$

where

A_c is the cross-sectional projected area of the cone (see Figure 6), in mm^2;

A_n is the cross-sectional area of load cell or shaft (see Figure 6), in mm^2.



Key

1 cross sectional area (top) A_{st}

2 friction sleeve surface area A_s

3 cross sectional area (bottom) A_{sb}

4 cross sectional area A_c

Figure 6 — Correction of cone resistance and sleeve friction due to the unequal end area effect

Measurements should only be corrected if u_2 is measured.

NOTE 2 u_2 can be estimated from u_1 or u_3 by empirical relations, to obtain an approximately corrected cone resistance. In soft clays and silts, the correction can get substantial, and u_2 should preferably be measured and corrections carried out if the cone resistance recordings are used for interpretation of mechanical parameters.

The area ratio cannot be determined from geometrical considerations alone, but should be determined by tests in a pressure chamber or similar.

NOTE 3 The measured sleeve friction is influenced by surrounding water pressure. Since it is not standard practice to measure the pore pressure u_3 above the friction sleeve, the uncorrected sleeve friction f_s is commonly used. A possible correction method for the recorded sleeve friction is given in Annex C.

Various other corrections can be necessary to meet the requirements of the application class, like temperature effects, cross-sectional area of cone, compression of the push rods and rebound of the thrust machine.

6.3 Calculated parameters

The following parameters shall be calculated, based on the measured parameters:

R_f friction ratio

z penetration depth

Correction for inclination, like calculation of penetration depth from penetration length, shall be carried out for application classes 1 and 2 according to the procedure given in Annex B.

The following parameter shall be calculated, based on the corrected parameters:

R_{ft} corrected friction ratio

7 Reporting

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.

Subclause 7.2 indicates the information required in

- the **field record** of test results,
- the **test report**, and
- 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 cone penetration test, particulars or deviations from this part of ISO 22476 should be recorded, which can affect the results of the measurements and the corresponding penetration length.

7.2 Reporting of test results

7.2.1 General information

	Field report	Test report	Every plot
a) Reference to this part of ISO 22476	–	x	x
b) Application class	x	x	x
c) Test type (TE1 or TE2)	x	x	x
d) Particulars or deviations from this part of ISO 22476	x	x	–
e) Company executing the test	–	x	x
f) Name and signature of equipment operator executing the test	x	–	–
g) Name and signature of field manager responsible for the project	–	x	–
h) Depth to the groundwater table (if recorded)	x	x	–
i) Pore pressure information (for instance from piezometers) if relevant and available	–	x	–
j) Depth of predrilling or trenching depth	x	x	x
k) Type of materials encountered (if possible)	x	x	–
l) Depth of penetration and possible causes of any interruptions (like dissipation tests)	x	x	–

7.2.1 General information

	Field report	Test report	Every plot
m) Stop criteria applied, like target depth, maximum penetration force or inclination	x	x	–
n) Method of back filling the hole, if applicable	x	–	–
o) Observations done in the test, for example: — presence of stones, — noise from the pushing rods, — incidents, — buckled rods, — abnormal wear, — significant changes in zero or reference readings	x	x	–
p) Specific arrangements that deviate from common set up of thrust machine (like a jack-up platform)	x	x	–

7.2.2 Location of the test

	Field report	Test report	Every plot
a) Identification of the test	x	x	x
b) Elevation of the cone penetration test	–	x	x
c) Local or general coordinates	–	x	x
d) Reference system and tolerances	–	x	–
e) Reference elevation to a known datum	–	x	x

The contract shall specify who is responsible for providing the coordinates and levels of investigation points.

7.2.3 Test equipment

	Field report	Test report	Every plot
a) Cone penetrometer type	x	–	x
b) Geometry and dimensions cone penetrometer	x	–	–
c) Type of thrust machine used, pushing capacity, associated jacking and anchoring systems	x	–	–
d) Manufacturer of cone penetrometer	x	x	–
e) Identification number of the penetrometer	x	x	–
f) Measuring ranges of the transducers	x	x	–
g) Date of last calibration of sensors	x	x	–
h) Filter location	x	–	x
i) Net area ratio	x	–	–

7.2.4 Test procedure

	Field report	Test report	Every plot
a) Date of the test	x	x	x
b) Starting time of the test	x	x	–
c) Clock time during the test	x	x	–
d) Depth of the start of penetration with reference to the ground surface	–	x	x
e) Saturation fluid used in pore pressure system (if piezocone)	x	x	–

7.2.5 Test results (depending on application class)

	Field report	Test report	Every plot
a) Measured and calculated parameters according to 6.1 and 6.3	x	x	x
b) Corrected parameters according to 6.2	–	x	–
c) Zero and/or reference readings of measured cone resistance, sleeve friction and, if applicable, pore pressure before and after the test and zero drift (in engineering units), for application classes 1 and 2.	x	x	–
d) Corrections applied during data processing (e.g. zero drifts)	–	x	–
e) *In situ* pore pressure measurements (if recorded)	x	x	–
f) Inclination of the cone penetrometer to the vertical axis, for a maximum penetration depth interval of 1 m, if applicable	–	x	–

7.3 Presentation of test results

In the graphical presentation of test results, the following axis scaling should be used:

- Penetration depth z: 1 scale unit = 1 m;
- Cone resistance q_c, q_t: 1 scale unit = 2 MPa or 0,5 MPa;
- Sleeve friction f_s, f_t: 1 scale unit = 0,05 MPa;
- Pore pressure u: 1 scale unit = 0,2 MPa or 0,02 MPa;
- Friction ratio R_f, R_{ft}: 1 scale unit = 2 %;
- Pore pressure ratio B_q: 1 scale unit = 0,5.

One scale unit should be 1 cm.

A different scaling may be used in the presentation if the recommended scaling is used in an additional plot. The recommended scaling can for example be used for general presentation, whereas selected parts may be presented for detailed studies, using a different scaling. In clays, and where the test results are to be used for interpretation of soil parameters (application classes 1 and 2, see Table 2), it is particularly important to use enlarged scaling in the presentation of test results.

The axis scaling for dissipation test results (cone resistance q_c, pore pressure u and time t) shall suit the measured values.

NOTE A common presentation format is to use linear scales for q_c and u and a logarithmic scale for t.

7.4 Presentation of test results and calculated parameters

The test results shall be presented as continuous profiles as a function of the penetration depth (for application classes 1, 2 and 3) or penetration length (for application class 4).

The test results (according to the application class and test type) that shall be presented are:

- Cone resistance - depth/length q_c (MPa) - z (m);
- Sleeve friction - depth/length f_s (MPa) - z (m);
- Measured pore pressure - depth/length $u_{1,2,3}$ (MPa) - z (m);

- Inclination - depth/length α (°) - z (m) or tabulated, as function of depth.

Penetration depth is the measured length corrected for the measured inclination.

The units used may be kilopascals (kPa), depending on the scale of measured parameters.

Presentation of the results of cone penetration tests according to application classes 1 and 2 shall, if required, include at least tabular data according to 7.1.

For application class 1, corrected cone resistance (q_t) shall be plotted in addition and the corrected sleeve friction (f_t) may be plotted in addition. The corrected parameters should be used in further processing of the data. An exception is made for testing of coarse-grained materials, where the effect of the end area correction is negligible.

In situ pore pressure can be estimated from the location of the groundwater table, or preferably by local pore pressure measurements. It can also be evaluated from the test results by performing dissipation tests in permeable layers. The total overburden stress profile can be determined from density measurements *in situ* or from undisturbed samples in the laboratory. If adequate information is lacking, an estimate of the density may be obtained by use of a classification chart based on the results from the cone penetration test and local experience.

For further processing of the measured data, the following relationships should be used, if appropriate:

- Excess pore pressure $\Delta u = u - u_o$;
- Net cone resistance $q_n = q_t - \sigma_{vo}$;
- Friction ratio $R_f = (f_s/q_c) \times 100$ %;
- Corrected friction ratio $R_{ft} = (f_s/q_t) \times 100$ % (if known, f_t shall be used instead of f_s);
- Pore pressure ratio $B_q = (u_2 - u_o)/(q_t - \sigma_{vo}) = \Delta u_2/q_n$;
- Normalized excess pore pressure $U = (u_t - u_o)/(u_i - u_o)$;

Knowledge of the following parameters is required for processing of the test results:

- *In situ*, initial pore pressure versus depth u_o (MPa) versus z (m);
- Total overburden stress versus depth σ_{vo} (MPa) versus z (m).

These parameters, or additional calculated values, can be used for both identification of strata and classification of soil types, and as basic input values for evaluation in terms of engineering parameters.

The friction ratio shall be presented on the plot. Presentation of the other calculated parameters is optional because they are dependent on interpretation.

Annex A
(normative)

Maintenance, checks and calibration

A.1 Maintenance and checks

A.1.1 Linearity of push rods

Before the test is carried out, the linearity of the push rods should be checked by one of the following methods:

- holding the rod vertically and rotating it. If the rod appears to wobble, the straightness is not acceptable;
- rolling the rods on a plane surface. If the rod appears to wobble, the straightness is not acceptable;
- sliding a straight hollow tube which is slightly longer than the rod over the rod. If the rod can pass through the tube without jamming, the straightness is acceptable.

If any indications of bending appear, the use of the rods should be suspended.

Other methods of checking of the straightness may be used.

NOTE In application class 4 there is no inclinometer, so it is more important to control the straightness of the rods.

A.1.2 Wear of the cone penetrometer

The wear of the cone and the friction sleeve shall be checked regularly (see Table A.1) to ensure that the geometry satisfies the tolerances (see 4.4 and 4.5). A standard geometrical pattern similar to a new or unused cone penetrometer may be used in this control.

A.1.3 Gaps and seals

The seals and gaps between the different parts of the cone penetrometer shall be checked regularly (see Table A.1). In particular, the seals should be checked for intruding soil particles and cleaned. The penetrometer shall be cleaned before storage.

A.1.4 Pore pressure measuring system

If pore pressure measurements are carried out, the filter should have sufficient permeability for satisfactory response (see 4.6.1). The pore pressure system should be completely saturated before the penetration starts, and this saturation should be maintained until the cone penetrometer reaches the groundwater surface or saturated soil. For maintenance intervals, see Table A.1.

Before each test the filter needs to be checked visually for damage, wear and clogging. Preferably before each test, the filter should be replaced and the saturation procedure should be carried out.

A.1.5 Maintenance procedures

For maintenance and calibration of the equipment, the check scheme in Table A.1 shall be followed, along with the manufacturer's manual for the particular equipment.

Table A.1 — Control scheme for maintenance routines

Checking routine	Start of test	End of test	Every sixth month
Verticality of thrust machine	x	–	–
Depth sensor	–	–	x
Push rods	x	–	–
Wear	x	x	–
Gaps and seals	x	x	–
Zero value	x	x	–
Calibration	–	–	x[a]
Filter element	x	x	–
Penetration rate	–	–	x
Safety functions	–	–	x

[a] and at intervals during long term testing, see A.2.1.

A.2 Calibration

A.2.1 General procedures

A new cone penetrometer shall be calibrated with respect to:

- the net area ratios, used for correction of measured cone resistance and sleeve friction;
- influence of internal friction – restriction to movement of the individual parts;
- possible interference effects (electrical cross talk, etc.);
- ambient temperature effects.

The calibrations and checks are specific to each cone penetrometer. They will show variations during a penetrometer's life caused by small changes in the function and geometry of the cone penetrometer. In such cases, a re-calibration of the cone penetrometer should be carried out. Calibration should be carried out regularly, at least every six months. If it appears from a track record that no significant deviations are registered, a longer period between calibrations can be applicable. Depending on application class requirements and zero drift at zero load, more frequent calibration can be required. During long term testing, calibration may be carried out more frequently.

The calibrations should include the whole measurement system, i.e. mounted transducers, data acquisition system, cables, etc. Preferably calibration is performed as "system calibration", i.e. carried out using the same data acquisition system, including cables, as in the field test, representing a check of possible inherent errors of the system. During the fieldwork, regular function controls of the equipment should be carried out. These should be carried out at least once per location and/or once per day. Furthermore, a function control and possibly a re-calibration should be carried out if the operator suspects overloading of the load sensors (loss of calibration).

In general, the requirements of ISO 10012 should be followed.

A.2.2 Calibration of cone resistance and sleeve friction

Incrementally axially loading and unloading the cone and the friction sleeve calibrate the cone resistance and sleeve friction. The calibrations of cone resistance and sleeve friction can be carried out separately, but the other sensors should be checked individually to ensure that the applied load does not influence them. The calibration is carried out for various measuring ranges, with special emphasis on those ranges relevant for the forthcoming tests.

A new calibration should be carried out after a cone penetration test has been performed under difficult conditions if a significant zero shift has been recorded, for instance if the cone penetrometer has been loaded close to or over its maximum capacity.

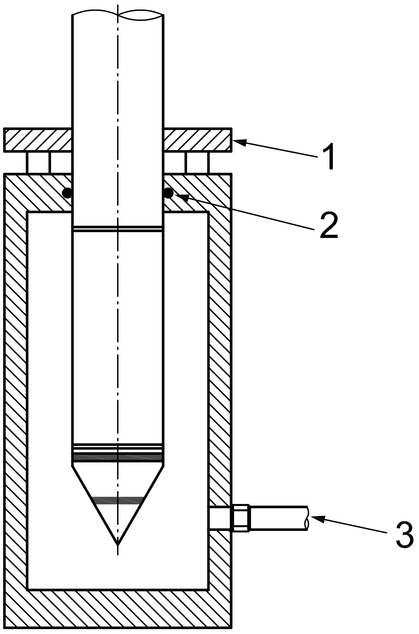
When loading the friction sleeve alone, a specially adapted calibration unit substitutes the cone. This unit is designed to transfer the axial forces to the lower end area of the friction sleeve.

When a new cone penetrometer is calibrated, the sensors should be subjected to 15 to 20 repeated loading cycles up to the maximum load, before the actual calibration is carried out.

NOTE The requirement for separate calibration procedures for cone and friction sleeve is usually not required for subtraction cone penetrometers.

A.2.3 Calibration of pore pressure and net area ratio

The calibration of the pore pressure measuring system, and determination of pore pressure effects on the cone resistance, sleeve friction and the net area ratio, a, should be carried out in a specially designed pressure chamber (e.g. Figure A.1). The pressure chamber should be constructed so that the lower part of the penetrometer can be mounted in the chamber and be sealed above the friction sleeve. The enclosed part of the cone penetrometer should then be subjected to an incrementally increasing chamber pressure, and cone resistance, sleeve friction and pore pressure are recorded. In this way a calibration curve for the pore pressure transducer is obtained and the net area ratio can be determined from the response curves for cone resistance and sleeve friction. The pressure chamber is also well suited to check the response of the pore pressure sensor to cyclic pressure variations.



Key

1 clamp

2 “O” ring seal

3 pressure line

Figure A.1 — Pressure chamber for determination of the net area ratio, a

A.2.4 Calibration of ambient temperature effects

The cone penetrometer shall be calibrated for ambient temperature effects at various temperature levels, for example by placing the cone penetrometer in water reservoirs at different temperatures. The sensor signals shall be recorded until the values stabilize. From these results a measure for changes in zero readings per °C is obtained and an impression is gained of the time needed for temperature stabilization in the field performance. This is important information for a proper preparation of the test equipment before the penetration test starts.The above applies to ambient temperatures only and not to transient temperatures.

A.2.5 Calibration of penetration length sensor

The depth sensor should be calibrated at least every sixth month and after repair.

A.2.6 Calibration of the inclinometer

The inclinometers in the cone penetrometer shall be calibrated over the measuring range with the vertical in two orthogonal directions. Calibration should be carried out every 1° for application classes 1 and 2 or 2° for application class 3. From these results an impression is gained of the linearity of the sensor.

Annex B
(normative)

Calculation of penetration depth

For application classes 1 and 2, the depth of cone penetration tests shall be corrected for inclination by the equation:

$$z = \int_0^l C_{\text{inc}} \, \mathrm{d}l \tag{B.1}$$

where

z is the penetration depth, in m;

l is the penetration length, in m;

C_{inc} is the correction factor for the effect of the inclination of the cone penetrometer relative to the vertical axis.

Equations for the calculation of the correction factor C_{inc} for the influence of the inclination of the cone penetrometer relative to the vertical axis, on the penetration depth:

a) for a non-directional inclinometer:

$$C_{\text{inc}} = \cos\alpha \tag{B.2}$$

where

α is the measured total angle between the vertical axis and the axis of the cone penetrometer, in degrees;

b) for a bi-axial inclinometer:

$$C_{\text{inc}} = \frac{1}{\sqrt{1 + \tan^2\beta_1 + \tan^2\beta_2}} \tag{B.3}$$

where

β_1 is the angle between the vertical axis and the projection of the axis of the cone penetrometer on a vertical plane, in degrees;

β_2 is the 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, in degrees.

Annex C
(informative)

Correction of sleeve friction for water pressure

The corrected sleeve friction can be determined from:

$$f_t = f_s - \frac{\left(u_2 \times A_{sb} - u_3 \times A_{st}\right)}{A_s} \qquad \text{(C.1)}$$

where

f_t is the corrected sleeve friction, in MPa;

f_s is the measured sleeve friction, in MPa;

A_s is the area of friction sleeve, in mm^2;

A_{sb} is the cross-sectional area of the bottom of the friction sleeve, in mm^2;

A_{st} is the cross-sectional area of the top of the friction sleeve, in mm^2;

u_2 is the pore pressure measured between the friction sleeve and the cone, in MPa;

u_3 is the pore pressure measured above the friction sleeve, in MPa.

This correction requires values of u_2 and u_3 and these parameters should both be measured if this correction is to be made.

NOTE u_3 can be estimated from u_2 using correlations given by SGI report 42 [7].

These corrections are most important in fine-grained soils where the excess pore pressure during penetration can be significant. Corrected values of the test results should be used for interpretation and classification purposes.

Annex D
(informative)

Preparation of the piezocone

D.1 Saturation

Usually, de-aired, distilled water is used when testing is carried out in saturated soils. When performing penetration tests in unsaturated soils, dry crust and dilative soils (like dense sands), the filter should be saturated with de-aired glycerine or a similar fluid, which makes it easier to maintain saturation throughout the test. When de-aired water is used, the filters should be boiled for at least 15 min. The filter should be cooled in the water, before being stored in a sealed container. A larger volume of de-aired water should also be prepared. This water is necessary when mounting before use. Boiling of filters might not be acceptable for some types of filters (like high density polyethylene). If glycerine is used, the dry filters are placed directly in the liquid and treated with vacuum for approximately 24 h. A larger volume of liquid should be treated similarly and stored in a sealed container. The transducer chamber is usually saturated with the same fluid as used for the filter. This can be done by direct injection of fluid into the chamber, or by treatment of the dismantled cone penetrometer in a vacuum chamber. The vacuum should be applied until no air bubbles escape from the cone penetrometer (approximately 15 min to 30 min). The final mounting of filter and seals should be carried out with the penetrometer submerged in the saturation fluid. After mounting, the fitting of the filter should be checked. The height of the filter should be sufficient so that the filter is not loose, but small enough so that the filter can be rotated by the fingertips. This prevents excessive stresses in the joint around the filter, and also reduces any influence on the measurements. After mounting the filter, it is good practice to cover the filter element with a rubber membrane, which will burst when the penetrometer comes into contact with the soil. Other alternatives are also possible.

NOTE During saturation and mounting of the rubber membrane, the penetrometer will be subjected to small stresses, so that the sensors can show values different from zero.

D.2 Slot filter

In this system, the pore pressure is measured by an open system with a 0,3 mm slot immediately behind the conical part. Hence the porous filter element between the soil and the pressure chamber becomes redundant. The slot communicates with the pressure chamber through several channels. De-aired water, antifreeze liquid or other liquid can be used to saturate the pressure chamber, whereas the channels are saturated with gelatine, or a similar liquid.

The use of a slot filter can reduce the time required for preparation of the cone penetrometer. In addition, this pore pressure system maintains its saturation better when passing through unsaturated zones in the soil. A pressure sensor, similar to conventional porous filter piezocones, records the pressure changes in the saturated system. As for other cone penetrometers, the requirements for sufficient saturation are the same, so that adequate pore pressure response is obtained during penetration.

Annex E
(informative)

Uncertainties in cone penetrometer testing

Sources of uncertainties in CPT/CPTU testing include but are not limited to:

- ambient and transient temperature effects;
- incorrect calibration parameters, e.g. loss of calibration due to bending or damage;
- lack of or poor saturation;
- improper transfer of loads due to dirt in gaps and seals;
- error in the data acquisition system;
- deviation of the geometry of the cone;
- zero shifts.

Even if the requirements of this part of ISO 22476 are met, uncertainties in the measurements can occur when conducting a CPT, mainly caused by temperature effects in the cone penetrometer during testing.

These temperature effects are:

- ambient temperature; condition when the temperature of the cone penetrometer is changed at a constant temperature without temperature gradients through the penetrometer body. For these circumstances, a compensation system can be applied;
- transient temperatures; temperature change of the cone penetrometer (like heating due to frictional forces on the cone penetrometer) with gradients through the penetrometer body that cannot be compensated.

Compensation of the cone penetrometer for ambient temperature effects can be achieved. The ambient temperature effects can also be avoided by adjusting the penetrometer body to the temperature in the ground. The transient temperature effects cannot be compensated for; special equipment and procedures can reduce these effects. These measures can consist in, for example, letting high temperatures in the cone penetrometer dissipate before penetrating from a dense sand layer into a soft clay layer.

In dense to very dense layers, temperature gradients in the cone penetrometer of approximately 1 °C per MPa cone resistance can occur, with uncertain gradients in the penetrometer body.

For special projects with CPTs in soft to very soft clays with special equipment, procedures and temperature measurement in the cone penetrometer (not necessary if all testing is in soft clay), application class 1 can be achieved.

For offshore operations with downhole equipment determination of zero load output of the cone penetrometer, the uncertainty can amount to 100 kPa to 200 kPa, depending on test depth and mud conditions in the drill string.

Metrological confirmation applicable to a cone penetration test should be according to ISO 10012.

A zero drift during the test can be an indication of not achieving the desired application class. If the zero drift exceeds the accuracy boundaries of the application class, the results will be assigned to a lower application class.

An uncertainty statement resulting from an uncertainty analysis can be presented. In this uncertainty analysis, uncertainties can be presented in accordance with WECC DOC. 19-1990 [5] and ISO 10012.

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