INTERNATIONAL STANDARD

ISO 22477-2

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# Geotechnical investigation and testing — Testing of geotechnical structures —

## Part 2: Testing of piles: Static tension load testing

*Reconnaissance et essais géotechniques — Essais des structures géotechniques —*

*Partie 2: Essai de pieux: essais de chargement statique en traction*



Reference number
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# Foreword

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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).

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# Geotechnical investigation and testing — Testing of geotechnical structures —

# Part 2:
# Testing of piles: Static tension load testing

## 1 Scope

This document establishes the specifications for the execution of static pile load tests in which a single pile is subjected to an axial static load in tension in order to define its load-displacement behaviour.

This document is applicable to vertical piles as well as raking piles.

All types of piles are covered by this document. The tests considered in this document are limited to maintained load tests. Cyclic load tests are not covered by this document.

NOTE ISO 22477-2 is intended to be used in conjunction with EN 1997-1. Numerical values of partial factors for limit states and of correlation factors to derive characteristic values from static pile load tests to be taken into account in design are provided in EN 1997-1.

This document provides specifications for the execution of static axial pile load tests:

a) checking that a pile behaves as designed,

b) measuring the resistance of a pile.

## 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 7500-1, *Metallic materials — Calibration and verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Calibration and verification of the force-measuring system*

EN 1990, *Eurocode 0: Basis of structural design*

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

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



## 3 Terms, definitions and symbols

For the purposes of this document, the terms and definitions given in EN 1990, EN 1997-1, EN 1997-2 and the following 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, definitions

### 3.1.1
**pile load**
$F_t$
tension load applied to the head of the pile during the test

Note 1 to entry: For tests with embedded jack, the load is applied at another level (see ISO 22477-1).

### 3.1.2
**load increment**
increment of load added or removed during the test

### 3.1.3
**pile diameter**
**equivalent pile diameter**
$D$
diameter of the pile

Note 1 to entry: For non-circular pile with cross section A, the equivalent pile diameter equals $\sqrt{\frac{4A}{\pi}}$.

### 3.1.4
**working pile**
pile for the foundation of a structure

### 3.1.5
**test pile**
pile to which loads are applied to determine the resistance-displacement characteristics of the pile and the surrounding ground

### 3.1.6
**measured tensile resistance**
$R_{t,m}$
value of the measured tensile resistance at the ultimate limit state, in one or several pile load tests

Note 1 to entry: The recommended failure criterion may be defined in EN 1997-1 or its national annex.

### 3.1.7
**creep rate**
$\alpha$
ratio of the increase in pile head displacement to the decimal logarithm of time during a specified time interval



## 3.2 Symbols

| | |
|---|---|
| $A$ | pile cross section |
| $D$ | pile diameter/equivalent pile diameter |
| $F_t$ | load applied to the head of the pile during the test |
| $F_{t,cr}$ | critical creep load in tension |
| $F'_{t,cr}$ | intersection of the linear regression of the first and last part of the alpha versus load curve |
| $F_{t,k}$ | characteristic axial tensile load |
| $F_p$ | predefined maximum load applied during the test |

$N$ axial force

$q_s$ unit shaft friction

$q_{s,m}$ measured value of $q_s$

$q_{s,mob}$ mobilised shaft friction

$R_t$ tensile resistance of the ground against a pile, at the ultimate limit state

$R_{t,m}$ measured value of $R_t$ in one or several pile load tests

$s$ axial displacement of pile at any depth $z$

$s_1$ settlement at time $t_1$

$s_2$ settlement at time $t_2$

$s_h$ axial displacement of pile head

$t$ time

$t_1$ additional time reference for calculation of creep rate $\alpha$

$t_2$ additional time reference for calculation of creep rate $\alpha$

$z$ depth

$\alpha$ creep rate

# 4 Equipment

## 4.1 General

The selection of the equipment shall take into account the aim of the test, the ground conditions and the expected displacement of the pile under the maximum test load.

## 4.2 Reaction device

The reaction device for pile tested in tension can be:

— shallow foundations;

— compression piles.

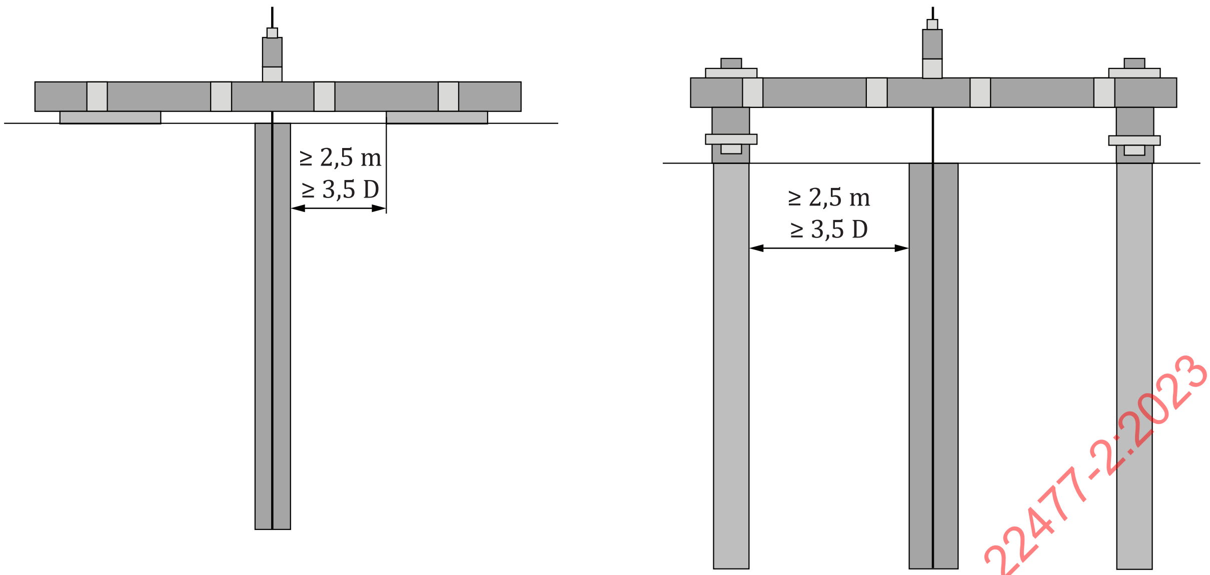
NOTE 1 The reaction device can be the test pile itself where the load is applied at depth by one or more hydraulic jacks which are cast into the pile for bi-directional pile loading (see ISO 22477-1).

The influence of the reaction system on the test pile shall be minimized.

The minimum clear distances between the test pile and the reaction system elements depend on the aim of the test (tensile resistance or stiffness).

For tests aiming at determining tensile resistance (ultimate limit state), minimum required distances are shown in Figure 1 a) and b). The maximum value shall be applied.

NOTE 2 If the minimum clear distance between reaction system and test pile is smaller than 5 $D$, the tensile resistance can be overestimated. The provided minimum distances limit the overestimation to approximately 5 %.




a) Shallow foundations

b) Compression piles

**Figure 1 — Minimum clear distances between test pile and reaction system**

For tests aiming at evaluating the axial displacement for the serviceability limit state design, the influence of reaction system is higher. In this case, a minimum 10 *D* clear distance should be implemented. This clear distance value may be reduced if a dedicated assessment is performed, taking into account the ground conditions. In any case, the clear distance shall not be lower than the values given in Figure 1 a) and b).

NOTE 3 This assessment can include a modification of the reaction system to reduce its influence on the tested pile. For example, reduction of the skin friction of the reaction piles or the use of embedded jack(s) can be considered.

For static pile load tests on piles with a diameter smaller than 300 mm, these distances may be reduced. However, the minimum clear distance shall be 1,5 m.

The reaction system shall be designed to resist the maximum test load $F_p$ in accordance with the relevant standards. The displacements of the reaction system shall be limited to ensure that the load is applied axially for the duration of the test.

Working piles may be used as reaction piles, provided that their structural resistance is sufficient and there is no detrimental effect on their ability to perform as part of the structure. The displacement of the working piles shall be monitored during the test.

Reaction systems should be arranged symmetrically around the test pile. In cases of non-symmetrical reaction systems, measures shall be taken to avoid detrimental rotation and/or translation of the reaction system.

## 4.3 Force Input

### 4.3.1 General

One or more hydraulic jacks should be used to apply the load on the test pile.

If several hydraulic jacks are used to apply the test load, they shall be arranged symmetrically, of the same model and be supplied by a common supply from one hydraulic unit. Each hydraulic jack shall be provided with a shut-off valve and an additional pressure gauge.

If a single jack is used, it shall be arranged centrally in order to ensure the pile is loaded axially.



### 4.3.2 Specifications of force input

The achievable force of the jack(s) shall exceed $F_p$. The stroke of the jack(s) shall exceed the expected deformations (pile head displacement and those of the reaction system under load).

It shall be possible to decrease or increase the load smoothly without any shocks or vibrations and to maintain the load at any required value.

To satisfy the required accuracies, an automatic and continuous electric or hydraulic control and regulation of the jack force may be used. Alternatively, a hand pump with accurate measurement of pressure or load and permanent regulation may be considered.

The accuracy of the force regulator shall be better than 0,5 % of $F_p$ or 10 kN, whichever is greater.

## 4.4 Measurement of pile head displacements

The displacements of the pile head shall be measured either by dial gauges or transducers, supported from reference beams.

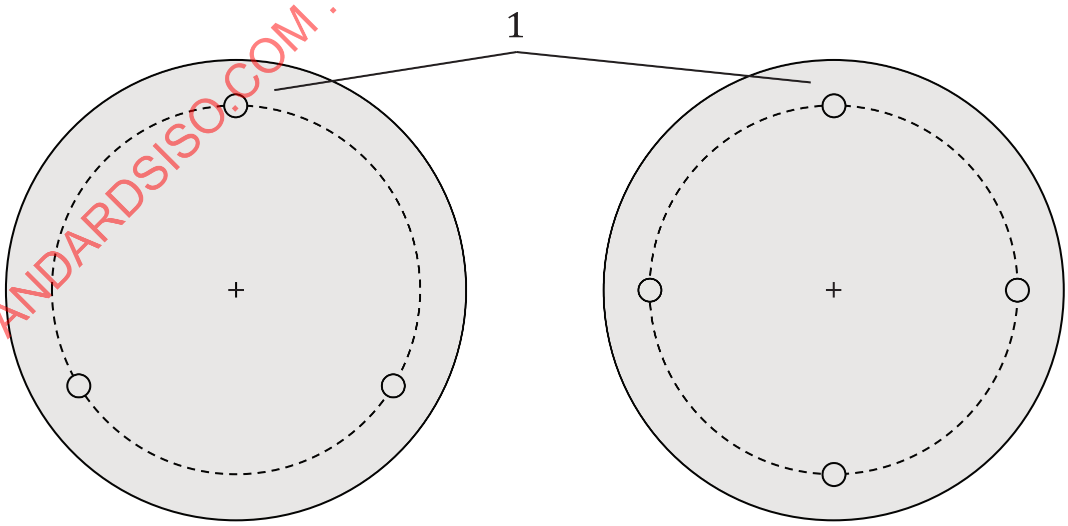
Reference beams shall be supported independently from the test pile.

The clear distance between the supporting ends of the reference beams and the test pile and reaction piles or the nearest edge of the shallow foundations should be at least 2,5 m or 3,5 *D*, whichever is greater.

One end of each reference beam should be free to slide.

The position of the reference beams shall be checked by a secondary control measuring system, such as levelling methods or other measurement methods. The position of the pile head should be also checked by this secondary control system.

If the load is applied through several jacks or several bars, the axial pile head displacement shall be measured at least with three transducers or gauges. They shall be arranged symmetrically and parallel to the axis of the pile (see Figure 2). The friction between the pile head and the sensors should be minimized by using suitable devices such as glass plates fixed beneath the sensors.




**Key**

1 displacement transducers or dial gauges

**Figure 2 — Location of displacement transducers or dial gauges**

If the load is applied through a single jack and a single bar (or tube), the axial pile head displacement may be measured with one displacement transducer or dial gauge.



The overall accuracy of the measured pile head displacement shall be better than 0,1 mm or 0,2 % of the measured value, whichever is greater. Therefore, dial gauges or transducers shall enable readings to be made to a resolution of at least 0,01 mm and any optical system of 0,1 mm.

The dial gauges or transducers should also have a sufficient measuring range, in order to avoid readjustment during testing.

Unless otherwise agreed, the secondary control measuring system shall enable readings to an accuracy of at least 0,1 mm.

Any optical levelling measurements shall be controlled by reference to one or more fixed reference points.

For raking piles, either pile head transversal displacement or overall displacement of the reaction system shall be measured.

Relevant corner points of the reaction system should be included in the levelling checks.

## 4.5 Measurement of pile load

The load shall be measured at the head of the pile. Unless otherwise specified, load measurement shall be obtained from a load cell (load cells) or from the pressure of the jack or jack system, by means of suitable calibrated pressure gauges.

NOTE Additional guidance can be found in national standards.

The load measurement devices shall be calibrated against a suitable master device in accordance with ISO 7500-1, giving full traceability to national standards.

The accuracy of the load measurement should be 1 % of $F_t$.

When the load is measured using the jack pressure, the calibration shall be done within a period of six months before the test. Otherwise, a period of 12 months shall be applied.

In some circumstances, for example, shock or eccentric loading or deviations of electronic load cells, change of components or presumed damage, additional calibration should be performed.

## 4.6 Pile instrumentation

The pile instrumentation depends on the aim of the static pile load test:

— determine the overall tensile resistance;

— determine the distribution of the shaft friction along the length of the pile.

To determine only the overall tensile pile resistance, no pile instrumentation is needed.

The distribution of the shaft resistance can be determined by measurement of the strain at cross sections of the pile at various depths. This can be achieved for example by:

— built-in or removable extensometers;

— strain-measuring devices (such as vibrating wires strain gauges, optical fibre sensors, etc.) fixed to the reinforcement or embedded in the concrete of precast concrete piles or attached to the walls of steel piles.

The depth, the number of measuring levels, the number of devices at each level, shall take into account the ground conditions, the type and the size of the test pile and the aim of the test.

Removable extensometers shall be installed in diametrically opposed pairs for large diameter piles (shaft diameter > 0,6 m) and this for each depth to be measured. For smaller piles (shaft diameter



≤ 0,6 m), one removable extensometer can be installed in the centre, if this does not conflict with execution codes.

If instrumentation is installed before pile installation, like strain measuring devices, there should be at least four symmetrically arranged pieces for each depth to be measured to achieve redundancy.

Strain measurements using continuous fibre optics shall be arranged with at least two loops symmetrically arranged.

NOTE In case of special measurement device that does not require a full loop, two measurement lines can be sufficient.

To determine load from strain, the cross-section $A$ and the pile material equivalent Young's modulus shall be assessed. All the materials present in the pile shall be considered.

# 5 Test procedure

## 5.1 Test preparation

### 5.1.1 Protections

Throughout the test period, all necessary precautions shall be taken to prevent external conditions (such as weather, vibrations, etc.) to interfere with the test results.

Techniques to fulfil this requirement can include:

— covering the entire testing set-up by a tent or similar;

— protective covers;

— adequate choice of materials for reference beams and conception of these beams;

— use of temperature compensated measuring devices;

— reference beams painted white.

All components, cables and measuring devices embedded in or arranged outside the pile shall be protected against damage during all stages of construction and testing. This includes in particular adequate insulation of electric gauges and cables against water as well as mechanical protection against damage during the execution of the pile (e.g. concreting, trimming or driving), the preparation of the pile head and the setting up of the test installation and devices of the test.

Any other site activities that can influence the measurements, for example vibrations caused by ongoing construction activities, should be suspended for the duration of the test.

The air temperature shall be recorded regularly during the course of the test to identify any temperature effects on the test results.

### 5.1.2 Construction of a test pile

Test piles should be constructed in a similar manner as working piles (same installation method, machinery and materials).

Test piles should be of the same diameter as the working piles. Load tests on smaller diameter test piles may be considered following the specifications and restrictions specified in EN 1997-1.

Depending of the type of the pile, additional tension elements may be necessary to apply the load.

Test piles shall be designed to resist the maximum test load, so extra reinforcement is permitted. However, its possible influence on the pile's behaviour shall be considered.

The influence of pile instrumentation on the pile construction and integrity shall be minimized.

Particular care should be given to the supervision and the monitoring of the installation of the test piles and the production of piling records. Guidance on the various items to be monitored and recorded is given-in the respective piling execution standards.

#### 5.1.3 Test date

Between installation and testing of a pile, time periods given in Table 1 are recommended.

**Table 1 — Recommended time periods between installation and testing of a pile**

| Soil type | Pile type | Minimum time (days) |
|---|---|---|
| Coarse soils | All | 7 |
| Fine soils | Bored | 21 |
| | Displacement | 28 |
| NOTE 1 Alternative time periods can be specified with appropriate justification. | | |
| NOTE 2 In sensitive soils, sometimes longer time periods are necessary. | | |

In rock, a site-specific time assessment shall be made and agreed.

Load testing on cast-in-place concrete piles and grouted micropiles shall only begin when the material and the interface between materials have reached the strength to accept the test load.

### 5.2 Loading procedure

#### 5.2.1 General

Unless otherwise specified, the load test should be executed following one single loading/unloading cycle. Alternatively, multiple loading/unloading cycles may be used.

NOTE Additional guidance can be found in national standards.

The loading procedure should start by a load of maximum 0,05 $F_p$, in order to check the loading and measurement equipment. If necessary, the pile is unloaded, and the equipment adjusted.

The loading should be increased or decreased smoothly, in order to avoid shocks and vibrations.

During a load step, the load shall be held constant.

During the pile load test, load-time and displacement-time data shall be available. The load-displacement graph should be manually or automatically plotted. The creep rate $\alpha$ should be calculated during the test.

#### 5.2.2 Load step sequence and duration of load steps for one cycle procedure

The pile load shall be increased in steps and each step shall be held constant over a certain specified duration. The maximum test load $F_p$ shall be reached in minimum eight load steps.

Load increments should generally be of equal magnitude.

Unloading of the pile should be performed in at least four load steps.

When approaching the failure load, the load step increment may be decreased in order to accurately determine the displacement behaviour approaching failure to refine the determination of the ultimate pile resistance.

Each loading and unloading step shall be maintained for a minimum duration, which should be the same for all loading steps and the same for all unloading steps respectively. A minimum duration of



60 min is recommended for the loading steps. A typical loading sequence is shown in Figure 3. The first three loading steps may have a shorter duration when the displacement rate of the pile is lower than 0,1 mm/20 min (during the last 20 min). For unloading steps, a minimum duration of 10 min and for the final unloading step a minimum duration of 30 min are recommended. Unless otherwise agreed, the loading duration should be extended on the basis of either the creep rate or the displacement rate. If the creep rate is to be used, the duration should be extended if it is still increasing. If the displacement rate is to be used, the duration should be extended if it is greater than 0,1 mm/10 min.

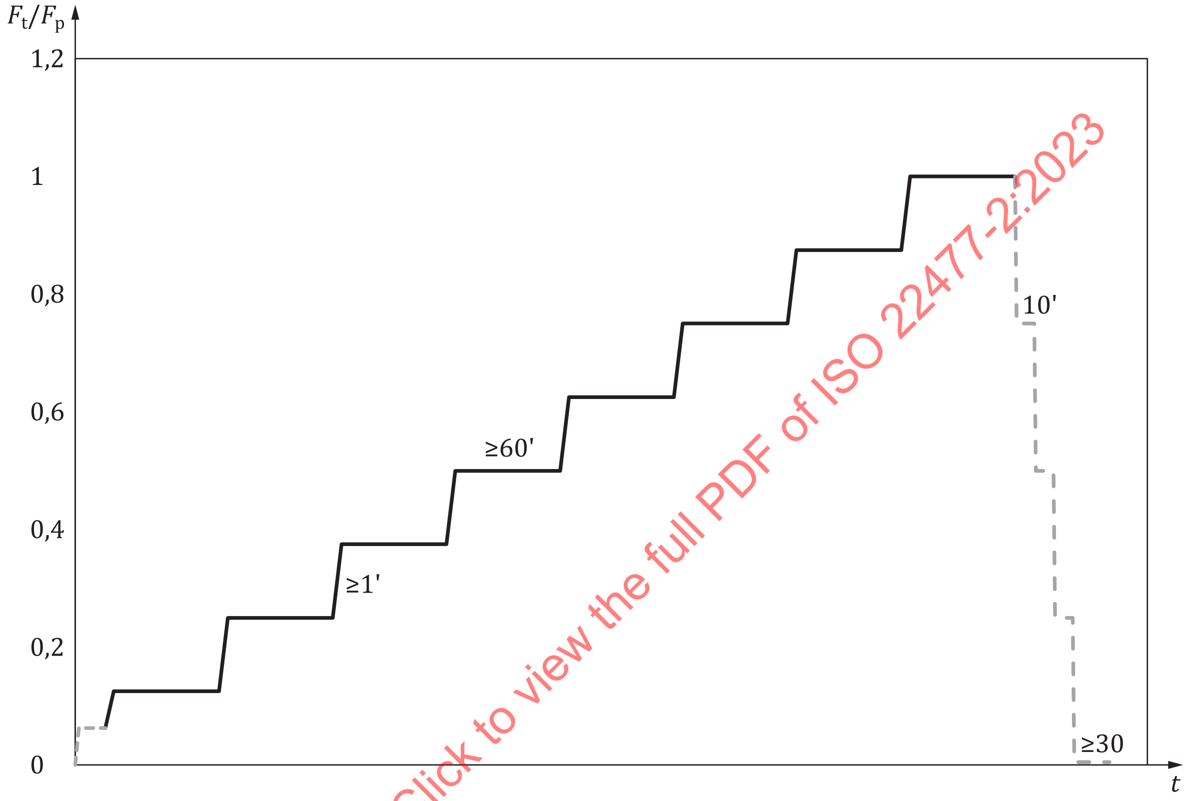



**Figure 3 — Load step sequence for one cycle procedure**



### 5.2.3 Load step sequence and duration of load steps for multiple cycle procedure

The pile load shall be increased in steps and each step shall be held constant over a certain specified duration. The maximum test load $F_p$ shall be reached in a minimum of two cycles. The maximum load during the first cycle shall be reached in a minimum of four load steps. During the second cycle, $F_p$ shall be reached in a minimum of eight load steps.

If $F_{t,k}$ is known, the maximum load during the first cycle shall correspond to the characteristic pile load $F_{t,k}$.

Load increments should be of equal magnitude (see Figure 4):

— between 0,05 $F_p$ and the maximum load of the first cycle;

— between the maximum load of the first cycle and $F_p$.

NOTE Magnitudes of increments between 0,05 $F_p$ and the maximum load of the first cycle and between the maximum load of the first cycle and $F_p$ are usually different.

When approaching the failure load, the load step increment may be decreased in order to accurately determine the displacement behaviour approaching failure to refine the determination of the pile resistance.

Unloading of the pile should be performed in at least two load steps after the first cycle and four load steps after the second cycle. After displacements ceased under 0,05 $F_p$, the pile should be completely unloaded.

Each loading and unloading step shall be maintained for a minimum duration. The minimum recommended duration for each load step is shown in Figure 4. The loading duration should be extended until the displacement rate of the pile is less than 0,1 mm/20 min for loads ≤ $F_{t,k}$ and 0,1 mm/5 min for the following load steps. Unless otherwise specified, the duration for loading steps reached for the first time shall be extended if the creep rate after the minimum recommended duration cannot be clearly determined or is increasing. The total unloading step should continue until the displacements have completely ceased.

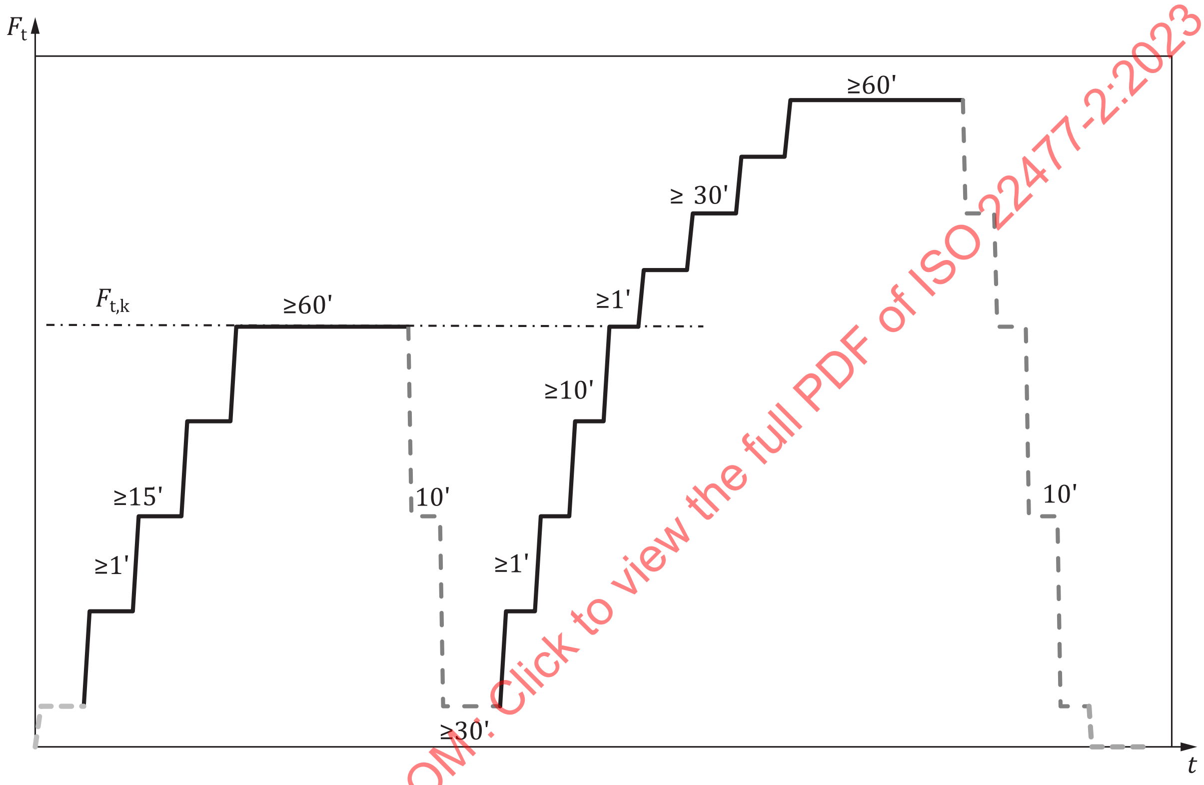





**Figure 4 — Load step sequence for multiple cycle procedure**

### 5.2.4 Maximum test load $F_p$

For all tests, the maximum test load $F_p$ shall be specified prior to the test.

If the pile load has been previously determined, the maximum test load shall be derived following EN 1997-1, depending of the aim of the test. If the pile load has not been previously determined, a value exceeding the estimated or expected pile tensile resistance $R_t$ should be used.

### 5.2.5 Measuring intervals

During each load step the axial displacements of the pile head, the load applied to the pile and, when installed, the measurements of the pile instrumentation shall be recorded.

Synchronization of clocks prior to the test shall be performed if multiple dataloggers are used.

The pile head displacements and the applied load shall at least be recorded at the following time intervals:

— loading steps: 0, 2, 5, 10, 15, 20, 25, 30, 40, 50 and 60 min and further on every 10 to 30 min;

— unloading steps: 0, 5 and 10 min (plus at 30 min for total unloading).

If automatic recording is used, a time interval of 30 s to 1 min is recommended.

The measurement of the pile instrumentation (e.g. strain gauges, extensometers) shall at least be recorded at the following time intervals:

— loading steps: 5 min and at the end of the load step;

— unloading steps: 5 and 10 min (plus at 30 min for total unloading).

The measurements from the secondary control measuring system should at least be recorded at the beginning and at the end of each loading step.

If transversal displacements of the pile head have to be measured, this shall be made at least at the beginning and at the end of the load step.

The air temperature shall be recorded at least at each load step.

# 6 Test report

## 6.1 General

The test report shall be presented in the form of a data report and an interpretative report.

## 6.2 General information

The data report shall include the following data:

a) a reference to this document, i.e. ISO 22477-2:2023 and all relevant standards;

b) general information concerning the test site and program:

   — the precise location;

   — the level of the working platform;

   — any items that can influence the test;

   — the test date;

   — reference of the organisation(s) which has(ve) carried out and supervised the test;

   — the purpose of the test;

   — the postulated maximum test load $F_p$;

c) information concerning the ground conditions:

   — reference to the site investigation report;

   — location and reference number of the relevant ground investigations;

   — a description of the ground conditions, in particular at the vicinity of the test pile;

d) specifications concerning the test pile:

   — reference of the organisation which build the pile;

   — the pile type, its reference number;

   — date of installation;

— description of the pile installation and of any observations related to the execution, likely to have an influence on the test results;

— pile data, such as geometry, top and base level, pile material and reinforcement;

— material specifications;

— driving and drilling logs, concreting or grouting reports;

e) specifications concerning the pile test setup:

— details of the reaction device;

— details of the loading and measuring apparatus;

— details of pile instrumentation;

— records of the calibration of the jacks or load cells and gauges;

— details of any additional tension elements;

— photographic documentation.



## 6.3 Data report

The data report shall include all measurements recorded during the test, including:

— the readings at the required time intervals of the loading measurement devices, expressed as a force (load cell) or as a pressure (hydraulic jack);

— the conversion into force of the pressure in the hydraulic jack, considering the calibration data of the device;

— the individual readings of the dial gauges or transducers and the mean displacement of the head of the pile;

— measurements from the secondary control measuring system;

— ambient temperature;

— any corrections applied to measured data.

For tests aiming to determine the distribution of the shaft resistance along the length of the pile, the following additional data shall be given:

— the readings of the pile instrumentation sensors in the pile shaft;

— for concrete piles, equivalent Young's Modulus taken into account and how it has been determined, if strain sensors are used.

The test data (including the calibration certificates) shall be transmitted in the form of tables and charts. If automatic recording is used, the measurements shall also be available electronically upon request.

For all tests, the following charts shall be given:

— the time-load curve ($t$-$F_t$ plot; see Figure 5);

— the load-displacement curve of the head of the pile [$F_t$-$s_h$ plot; see Figure 6 a) or b)], corresponding to the beginning and the end of each load step;

— the time–displacement curve for each load step, respectively plotted against time [$t$–$s_h$ plot; see Figure 7 a)] and in a semi-logarithmic timescale [$log(t)$-$s_h$ plot; see Figure 7 b)];

— the load-creep rate curve ($F_t$-$\alpha$ plot; see Figure 8).

The creep rate $\alpha$ is derived for each load step from the linear end of a logarithm of time–axial displacement plot, as:

$$\alpha = \frac{s_2 - s_1}{\log(t_2 / t_1)}$$

where

$s_1$ is the axial displacement at the time $t_1$;

$s_2$ is the axial displacement at the time $t_2$;

$t_1$ is the start of the respective time interval;

$t_2$ is the end of the respective time interval.

For tests aiming to determine the distribution of the shaft resistance along the length of the pile, the following additional plots shall be given:

— the axial force–depth curves ($N$-$z$ plot; see Figure 9);

— the unit shaft friction mobilisation curves ($q_{s,mob}$–$s$ plot; see Figure 10) for the different representative pile parts.

The elastic deformation of the pile can be deduced, for example, from the measured relative displacement of extensometers or calculated on basis of strain measurements in the pile shaft.

NOTE For concrete piles tested in tension, the uncertainty on the equivalent Young's Modulus determination can be significant, especially as cracking occurs during the test. So, axial force with depth and unit shaft friction are derived and not measured values.

For piles, the axial force should take into account the self-weight of the pile.

## 6.4 Interpretative report

For all tests, the following results shall be given:

— the value of the measured tensile pile resistance of the ground against a pile, at the ultimate limit state, $R_{t,m}$, or the maximum measured value of the pile tensile resistance, if the ultimate limit state is not reached during the test.

For tests aiming to determine the distribution of the shaft resistance along the length of the pile, the following additional results shall be given:

— the measured value of the unit shaft friction along the pile $q_{s,m}(z)$, or the maximum measured value of the shaft friction, if the ultimate limit state is not reached during the test.

If specified, more optional parameters or information can be required, as:

— the critical creep load $F_{t,cr}$ (see Annex A);

— further evaluation by mathematical models.

NOTE Additional guidance can be found in national standards.



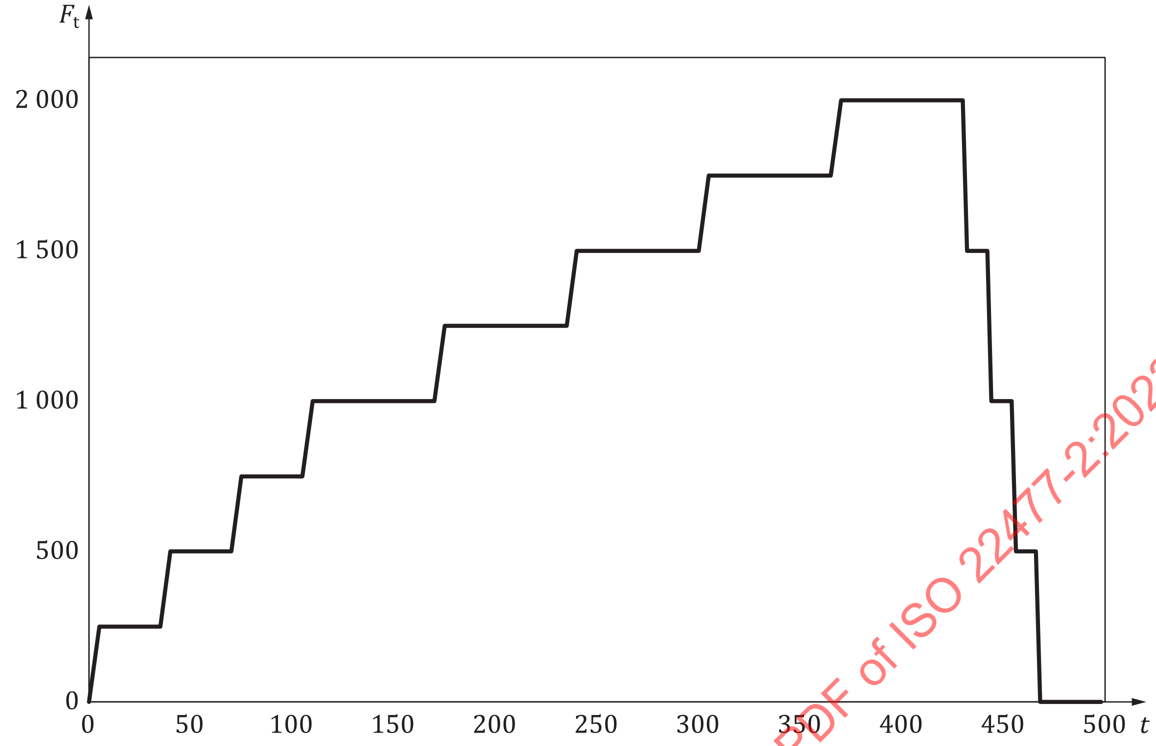
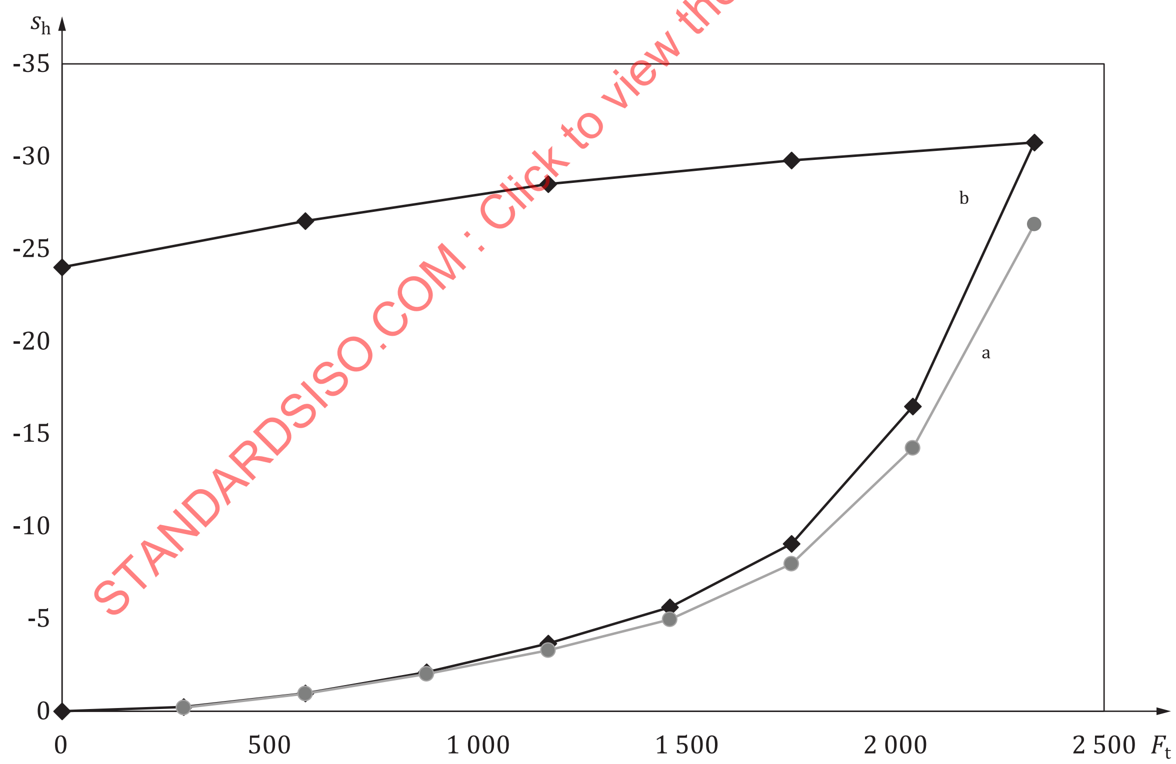
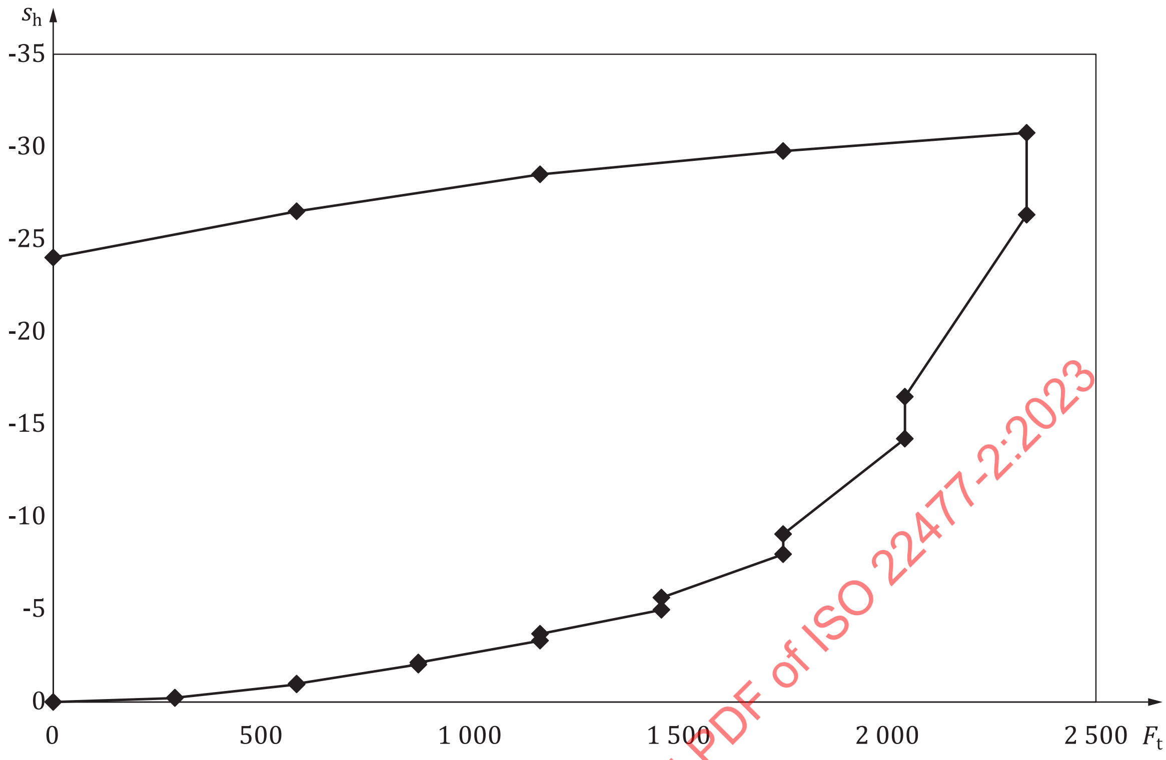



**Figure 5 — Time-load ($t$-$F_t$) plot**




**a) Load-displacement of the head of the pile ($F_t$-$s_h$) plot, different curves for beginning and end of each load step**

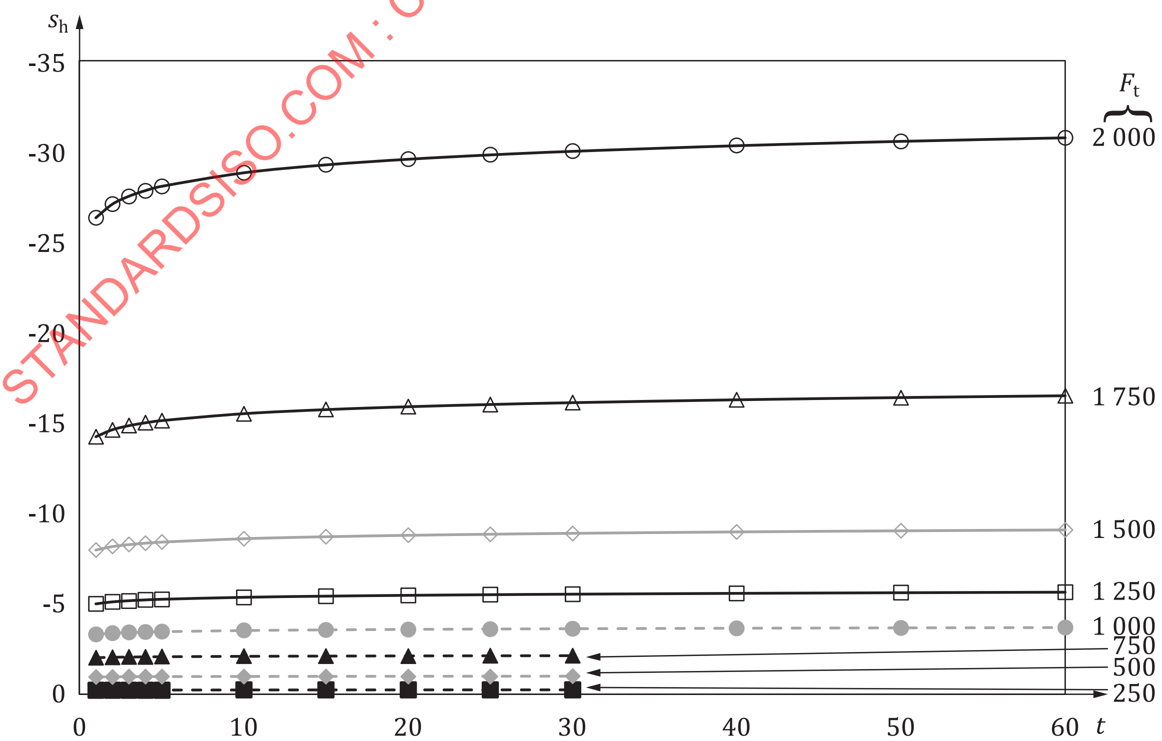



**b) Load-displacement of the head of the pile ($F_t$-$s_h$) plot, one single curve**

a Beginning of each load step.

b End of each load step.

**Figure 6 — Load-displacement of the head of the pile ($F_t$-$s_h$) plot**




**a) ($t$–$s_h$) plot**