
**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

ISO 22477-2:2023

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Foreword

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

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A list of all parts in the ISO 22477 series can be found on the ISO website.

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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

α
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 α
t_2	additional time reference for calculation of creep rate α
z	depth
α	creep rate

4 Equipment

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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 %.

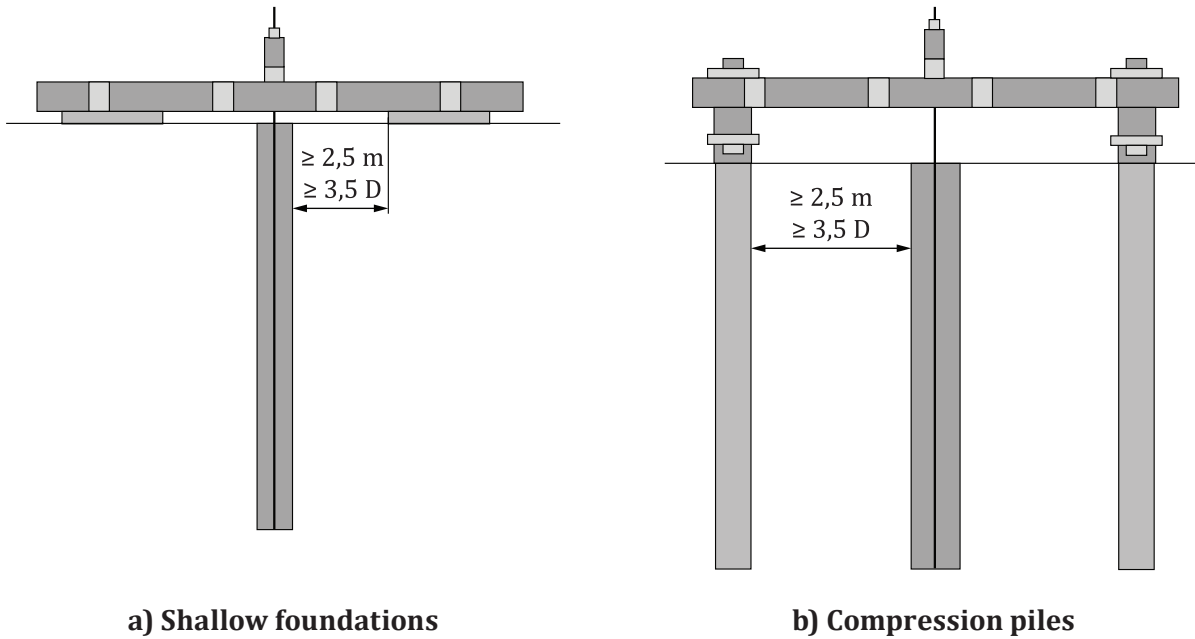


Figure 1 — Minimum clear distances between test pile and reaction system

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.

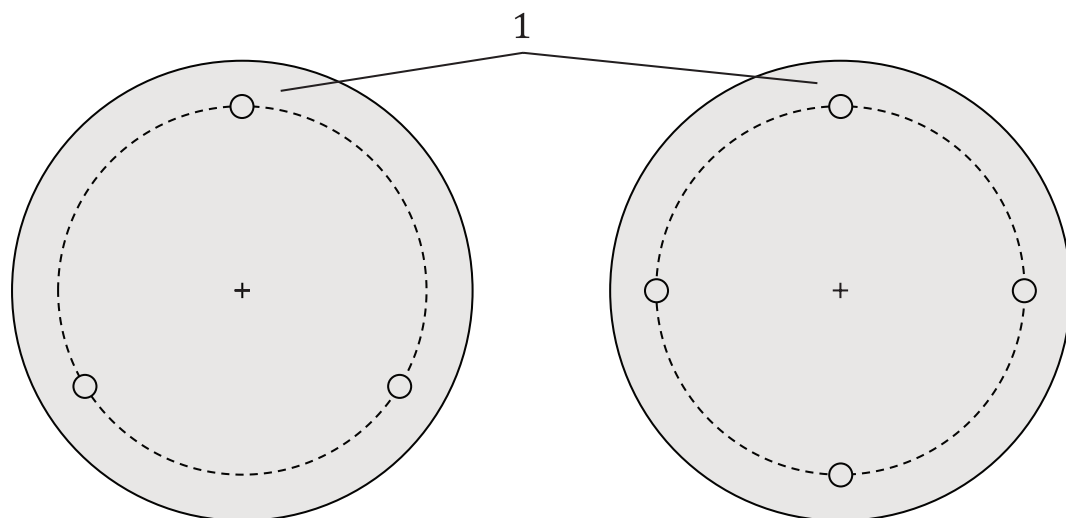
Reference beams shall be supported independently from the test pile.

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.