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Geotechnical investigation and testing — Testing of geotechnical structures —

Part 10: Testing of piles: rapid load testing

Reconnaissance et essais géotechniques — Essais de structures géotechniques —

Partie 10: Essai des pieux: essai de charge rapide

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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 documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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ISO 22477-10 was prepared by the European Committee for Standardization (CEN) in collaboration with ISO Technical Committee TC 182, *Geotechnics*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

A list of all parts in the ISO 22477 series, published under the general title *Geotechnical investigation and testing — Testing of geotechnical structures*, can be found on the ISO website.

Introduction

This part of ISO 22477 outlines how a rapid load pile test is defined and specifies the equipment and testing procedures required. Informative, non-prescriptive guidance is included on the analysis of rapid load pile test results required to determine mobilised or ultimate compressive resistance of a pile.

Geotechnical investigation and testing — Testing of geotechnical structures —

Part 10: **Testing of piles: rapid load testing**

1 Scope

This part of ISO 22477 establishes the specifications for the execution of rapid load pile tests in which a single pile is subject to an axial load in compression to measure its load-displacement behaviour under rapid loading and to allow an assessment of its measured compressive resistance ($R_{c,m}$) and corresponding load-displacement behaviour.

This part of ISO 22477 is applicable to piles loaded axially in compression.

All pile types mentioned in EN 1536, EN 12699 and EN 14199 are covered by this part of ISO 22477.

The tests in this part of ISO 22477 are limited to rapid load pile tests only.

NOTE 1 This part of ISO 22477 can be used in conjunction with EN 1997–1. Numerical values of partial factors for limit states from pile load tests to be taken into account in design are provided in EN 1997–1. For design to EN 1997–1, the results from rapid load pile testing will be considered equivalent to the measured compressive resistance, $R_{c,m}$, after being subject to appropriate analysis.

NOTE 2 Guidance on analysis of the rapid load testing results to determine measured compressive resistance and corresponding load-displacement behaviour is given in Annex A.

This part of ISO 22477 provides specifications for the following:

a) investigation tests, whereby a sacrificial test pile is loaded up to ultimate limit state;

b) control tests, whereby the pile is loaded up to a specified load in excess of the serviceability limit state.

NOTE 3 Generally, an investigation test focuses on general knowledge of a pile type; a control test focuses on one specific application 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.

There are no normative references in this document.

3 Terms, definitions and symbols

3.1 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
trial pile
pile installed before the commencement of the main piling works or a specific part of the works for the purpose of investigating the suitability of the chosen type of pile and for confirming its design, dimensions and bearing resistance

Note 1 to entry: The trial pile might be sacrificed to achieve ultimate limit state.

3.1.2
working pile
pile that will form part of the foundation of the structure

3.1.3
test pile
pile to which loads are applied to determine the resistance deformation characteristics of the pile and the surrounding ground

Note 1 to entry: A test pile can be a *trial pile* (3.1.1), or a *working pile* (3.1.2).

3.1.4
pile load
axial compressive load (or force) applied to the head of the pile during the test

3.1.5
rapid load
force applied to the pile in a continuously increasing and then decreasing manner of a suitable duration (typically less than 1 s) relative to the natural period of the pile which causes the pile to compress over the full length and translate approximately as a unit during the full loading period

3.1.6
maximum compressive load
maximum axial compressive load (or force) applied to the pile during the test, generally defined prior to the test

3.1.7
rapid load test
pile loading test where a pile is subjected to chosen axial *rapid load* (3.1.5) at the pile head for the analysis of its capacity

3.1.8
ultimate measured compressive resistance of a pile
corresponding state in which the pile foundation displaces significantly with negligible increase of resistance

Note 1 to entry: Where it is difficult to define an ultimate limit state from a load settlement plot showing a continuous slight increase, a settlement of the pile top equal to 10 % of the pile base diameter should be adopted as the “failure” criterion.

Note 2 to entry: The maximum compressive resistance measured during a *rapid load test* (3.1.7) is not necessarily equal to the ultimate measured compressive resistance of a pile. The measured resistance obtained from rapid load testing must be analysed to remove the effects of inertia and soil dependent behaviour before it can be considered equivalent to the ultimate measured compressive resistance as outlined in Annex A.

3.1.9
design compressive static resistance of a pile
ultimate compressive static resistance of a pile that shall be determined prior to load testing to allow specification of appropriate magnitude *rapid load test* (3.1.7) cycles

3.1.10
equivalent diameter
diameter of an equivalent circle of which the area equals the area of the relevant pile section

Note 1 to entry: The equivalent diameter for a circular pile is the outer diameter of the pile, for a square pile the diameter which gives the same area as the square pile (as long as the longest side is smaller than 1,5 times the shortest side) is the equivalent diameter.

3.1.11
minimum reference separation distance
distance which separates a stationary reference point from a point that will be significantly displaced by the testing method

Note 1 to entry: Only stationary points can be used for reference of *displacement* (3.1.12) measurement devices. Displacement measuring systems can be placed on the soil outside the reference distance without isolating (displacement compensating) measures.

3.1.12
displacement
axial displacement of the pile head measured during testing

3.2 Symbols

a pile acceleration

c_p velocity of the stress wave in the test pile

c_s velocity of the shear wave in the ground

D diameter or equivalent diameter of the test pile

F_c pile load in compression

$F_{c,max}$ maximum compressive load

g acceleration due to gravity

L total length of the test pile

$R_{c,m}$ measured ultimate resistance of the ground in the test, or measured geotechnical resistance of the pile

r_{ref} minimum reference separation distance

t time

t_f duration of the rapid load application

t_g duration of the falling of the mass for a falling mass equipment

w pile displacement

4 Testing equipment

4.1 General

The equipment should generate a rapid load at the pile head where the duration of the load fulfils Formula (1):

$$10 < \frac{\left(t_\mathrm{f} \times c_\mathrm{p}\right)}{L} \leq 1\,000 \qquad (1)$$

If information on the ultimate compressive resistance of the pile is one of the aims of the test, the equipment shall have enough capacity to reach the ultimate compressive resistance under rapid loading.

The force applied to the pile head during a rapid load test for measuring the ultimate compressive resistance might exceed the design compressive static resistance of a pile by a factor of two to three due to soil specific rate effects. The need to apply such high loads shall be considered when specifying equipment and pile materials.

If for a rapid load test one or more of the requirements mentioned in this part of ISO 22477 is not met, it should be proven that this shortcoming has no influence on the achievement of the objectives of the test, before the results can be interpreted as a rapid load test.

For long piles where the criteria in Formula (1) is exceeded or where rock sockets result in non-uniform strains within the pile, embedded pile instrumentation and specialized analysis will be required. Additional instrumentation should conform to 4.3.

Rapid load testing systems rely on a mass to apply load to a pile. This is either through launching a mass upwards, referred to as a launched mass system, or by dropping a mass, referred to as a drop mass system. In both cases, the upward or the downward movement of the mass is controlled to produce the required load duration in 4.1. To avoid eccentric loading of piles and additional safety considerations, the movement of the mass should be guided during launched mass testing and drop mass testing.

4.2 Loading

The selection of the loading equipment shall take into account the following:

— aim of the test;

— ground conditions;

— maximum pile load ($F_{c,\mathrm{max}}$);

— strength of the pile (material);

— execution of the test;

— safety considerations.

The loading equipment shall generate a force which fulfils the requirements in 4.1 and is able to apply the required maximum compressive force to mobilize a specified compressive resistance or the ultimate compressive resistance of a pile.

If a test pile is tested by several cycles beginning with a low magnitude force cycle, the maximum force of each proceeding cycle should be larger than the maximum force of the preceding cycle. Where cycles of loading are applied, this should be undertaken in a manner that removes the potential for uncontrolled reloading of the pile. This will require the device to have a mass catching mechanism.

The equipment shall load the pile accurately along the direction of the pile axis. The eccentricity of the load shall be less than 10 % of the equivalent diameter. The deviation or eccentricity of the alignment of the force to the axis of the pile shall be less than 20 mm/m. Eccentric loading of the pile is allowed where this has been specifically allowed for during pile design and it has been verified that this will not unduly effect the performance of the testing equipment.

The stress in the pile under the maximum applied load shall not exceed the permissible stress of the pile material.

4.3 Measurements

Prior to a rapid load test, two variables shall be directly measured where the reaction mass comes into contact with the pile head prior to testing (not required for all equipment types):

— the force applied to the pile head;

— the displacement of the pile head;

During a rapid load test, a minimum of three variables shall be directly measured relative to time (t):

— the force applied to the pile head (F_c);

— the displacement of the pile head (w);

— the acceleration of the pile head (a).

The transducers and signal processing shall satisfy the requirements from Table 1, Table 2, Table 3 and Table 4. Sampling shall commence a minimum of 50 ms before loading commences and continue for a minimum duration of 500 ms. Where duration of the loading event means that the duration of sampling exceeds 500 ms, the duration of sampling shall be increased to capture the entire event and allow for the required post event sampling. All transducer sampling shall be synchronised. The transducers shall have sufficient measuring range, in order to avoid re-adjustment during testing. All instrumentation must be able to withstand pile installation and testing procedures.

Table 1 — Rapid load test transducer and signal processing general requirements

Parameter	Requirement
Sampling rate	≥4 000 samples per second
Duration of pre-event sampling	≥50 ms
Duration of post-event sampling	≥300 ms
Cut off frequency low pass filter	≥1 kHz

Table 2 — Rapid load test load transducer and signal processing load requirements

Parameter	Requirement
Maximum load	>maximum test load
Linearity	<2 % of maximum value reached
Hysteresis	<2 % of maximum value reached
Response time	<0,1 ms

Table 3 — Rapid load test acceleration transducer and signal processing requirements

Parameter	Requirement
number of transducers	≥1
resonant frequency	>5 kHz
linearity	up to 50 g

Table 4 — Rapid load test transducer and signal processing displacement requirements

Parameter	Requirement
Range	>50 mm or D/10, whichever is greater
Accuracy	±0,25 mm
Response time	<0,1 ms

Before and after each load cycle, the level of the pile head shall be determined relative to a point outside of the minimum reference separation distance by optical levelling. The optical levelling measurements shall be controlled by reference to one or more fixed reference points and should be undertaken to an accuracy of ±1 mm.

The base of a test displacement measuring system (where this is placed on the ground surface) should not be placed closer than the minimum reference separation distance from the pile. This shall be verified at the test site. If the minimum reference separation distance for a test displacement measuring system cannot be reached or vibration-free measurement cannot be undertaken, the test displacement measuring system should be placed on or fixed to a vibration-free surface such as an adjacent pile.

The minimum reference separation distance shall be measured from

— the pile, when the test is undertaken with a launched mass, or

— supporting component of the equipment which is nearest the pile, when the test is undertaken with a falling mass.

The value of the minimum reference separation distance should be a minimum of 15 m and

— equal to or greater than the distance which the shear waves in the soil travel during the duration of the loading (t_f), when the test is undertaken with a launched mass, thus $r_{ref} = c_s \times t_f$, or

— equal to or greater than the distance which the shear waves in the soil travel during the duration of the falling of the mass (t_g) and the subsequent loading (t_f), when the test is undertaken with a falling mass, thus $r_{ref} = c_s \times (t_g + t_f)$.

The load applied to the pile shall be determined directly by a purpose built calibrated load cell which does not form part of the pile. The use of pile mounted strain gauges to derive externally applied loads for steel or precast concrete piles shall only be considered in special circumstances where a load cell is unavailable and the stiffness of the pile material is known from manufacturer's certification or has been verified directly through material element testing for the piles under test. For cast insitu concrete piles, a purpose built calibrated load cell should be used or where pile mounted strain gauges to derive externally applied loads are used, these should be calibrated against load cell readings for the specific piles under test.

Surface mounted strain gauges should be mounted in diametrically opposed pairs. Where embedded strain gauges are used to compliment test results or where the criteria exceeds in Formula (1), strain gauges or strain gauge devices should be fixed to the reinforcement bars or embedded in the concrete of concrete piles or attached to the walls of steel piles at least in diametrically opposed pairs at each depth to be considered. Where strain gauge devices are cast in concrete, it is advised that a minimum of three devices should be used at each depth to be considered. To determine load from strain, the cross section and the pile material modulus of elasticity shall be assessed. All the materials present in the pile shall be considered in this determination.

NOTE 1 Strain-transducers based upon vibrating wire technology are generally not suitable for rapid load test monitoring and strain gauge based instruments are preferred.

All loading and settlement (as a result of loading larger than 1 % of the expected static bearing capacity of the pile) after installation of the pile shall be measured. This includes all types of static preloading of the pile. In addition, any additional equipment or component parts of the loading system connected to or in contact with the pile during the application of load that can to contribute the inertial resistance

