BS EN 14199:2015

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Execution of special geotechnical works — Micropiles

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National foreword

This British Standard is the UK implementation of EN 14199:2015. It supersedes BS EN 14199:2005 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee B/526, Geotechnics.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Execution of special geotechnical works - Micropiles

Exécution des travaux géotechniques spéciaux - Micropieux

Ausführung von Arbeiten im Spezialtiefbau - Mikropfähle

This European Standard was approved by CEN on 12 March 2015.

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COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Contents

Page

Foreword

This document (EN 14199:2015) has been prepared by Technical Committee CEN/TC 288 “Execution of special geotechnical works”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by November 2015, and conflicting national standards shall be withdrawn at the latest by November 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 14199:2005.

The technical changes in comparison to EN 14199:2005 are:

— Driven piles are excluded from EN 14199 and transferred to EN 12699;

— sections describing concrete and testing have been minimised;

— EN 14199:2015 has been harmonized with EN 1536.

The general scope of CEN/TC 288 is the standardization of the execution procedures for geotechnical works, including testing and control methods, and the required material properties. WG 16 has been charged with the subject area of micropiles.

This document has been prepared to stand alongside EN 1997-1. Clause 7 of this Standard covers design aspects of micropiles.

According to the CEN/CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

1.1 This European Standard establishes general principles for the execution of micropiles.

They are for drilled piles constructed using a drilling tool with a diameter less than 300 mm.

NOTE 1 This European Standard is not applicable to driven piles, the execution of which is governed by EN 12699.

NOTE 2 For a definition of shaft diameter see 3.3.

1.2 Micropiles are structural members to transfer actions to the ground and can contain bearing elements to transfer directly or indirectly loads and or to limit deformations. For examples of micropiles see Figure 1, Figure 2 and Figure 3. Their shaft and base resistance can be improved (mostly by grouting) and they can be constructed with (see Figure 4):

— uniform cross section (straight shaft); or

— telescopically changing shaft dimensions;

— shaft enlargements; and/or

— base enlargement.

1.3 Other than practical considerations, there are no limitations regarding, length, inclination (definition of inclination, see Figure 5), slenderness ratio or shaft and base enlargements.

1.4 The provisions of this European Standard apply to (see Figure 6):

— single micropiles;

— micropile groups;

— reticulated micropiles;

— micropile walls.

1.5 The material of micropiles covered by this European Standard can be:

— steel or other reinforcement materials;

— grout, mortar or concrete;

— a combination of above.

1.6 Micropiles can be used for:

— working under restricted access and/or headroom conditions;

— foundations of new structures (particularly in very heterogeneous soil or rock formations);

— reinforcing or strengthening of existing structures to increase the capacity to transfer load to depth with acceptable load settlement characteristics, e.g. underpinning works;

— reducing settlements and/or displacements;

— forming a retaining wall;

— reinforcing of soil to form a bearing and/or retaining structure;

— improving slope stability;

— securing against uplift;

— other applications where micropile techniques are appropriate.

1.7 Deep mixing columns according to EN 14679 are not included in this European Standard. Columns constructed by jet grouting are covered by EN 12716. Ground anchors are covered by EN 1537.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 206:2013, *Concrete - Specification, performance, production and conformity*

EN 445, *Grout for prestressing tendons - Test methods*

EN 447:2007, *Grout for prestressing tendons - Basic requirements*

EN 934-2, *Admixtures for concrete, mortar and grout — Part 2: Concrete admixtures — Definitions, requirements, conformity, marking and labelling*

EN 1090-2, *Execution of steel structures and aluminium structures — Part 2: Technical requirements for steel structures*

EN 1536:2010, *Execution of special geotechnical work - Bored piles*

EN 1990, *Eurocode - Basis of structural design*

EN 1991 (all parts), *Eurocode 1: Actions on structures*

EN 1992-1-1, *Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings*

EN 1993 (all parts), *Eurocode 3: Design of steel structures*

EN 1994-1-1, *Eurocode 4: Design of composite steel and concrete structures — Part 1-1: General rules and rules for buildings*

EN 1997-1:2004, *Eurocode 7: Geotechnical design - Part 1: General rules*

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

EN 10025 (all parts), *Hot-rolled products of non-alloy structural steels*

EN 10080, *Steel for the reinforcement of concrete - Weldable reinforcing steel - General*

prEN 10138-4:2001, *Prestressing steels — Part 4: Bars*

EN 10210 (all parts), *Hot finished structural hollow sections of non-alloy and fine grain structural steels*

EN 10219 (all parts), *Cold formed welded structural hollow sections of non-alloy and fine grain steels*

EN 12390-3, *Testing hardened concrete - Part 3: Compressive strength of test specimens*

EN 16228 (all parts), *Drilling and foundation equipment — Safety*

EN ISO 2560, *Welding consumables - Covered electrodes for manual metal arc welding of non-alloy and fine grain steels - Classification (ISO 2560)*

EN ISO 4063, *Welding and allied processes - Nomenclature of processes and reference numbers (ISO 4063)*

EN ISO 5817, *Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) - Quality levels for imperfections (ISO 5817)*

EN ISO 9692-1, *Welding and allied processes - Types of joint preparation - Part 1: Manual metal arc welding, gas-shielded metal arc welding, gas welding, TIG welding and beam welding of steels (ISO 9692-1)*

EN ISO 9692-2, *Welding and allied processes - Joint preparation - Part 2: Submerged arc welding of steels (ISO 9692-2)*

EN ISO 11960, *Petroleum and natural gas industries - Steel pipes for use as casing or tubing for wells (ISO 11960)*

EN ISO 14341, *Welding consumables - Wire electrodes and weld deposits for gas shielded metal arc welding of non alloy and fine grain steels - Classification (ISO 14341)*

EN ISO 15630-3, *Steel for the reinforcement and prestressing of concrete - Test methods - Part 3: Prestressing steel (ISO 15630-3)*

EN ISO 15609-1, *Specification and qualification of welding procedures for metallic materials - Welding procedure specification - Part 1: Arc welding (ISO 15609-1)*

EN ISO 17632, *Welding consumables - Tubular cored electrodes for gas shielded and non-gas shielded metal arc welding of non-alloy and fine grain steels - Classification (ISO 17632)*

EN ISO 17660-1, *Welding - Welding of reinforcing steel - Part 1: Load-bearing welded joints (ISO 17660-1)*

EN ISO 18276, *Welding consumables - Tubular cored electrodes for gas-shielded and non-gas-shielded metal arc welding of high-strength steels - Classification (ISO 18276)*

prEN ISO 22477-1:2014, *Geotechnical investigation and testing — Testing of geotechnical structures — Part 1: Pile load test by static axially loaded compression (ISO/DIS 22477-1:2014)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
micropile
fr: micropieu
de: Mikropfahl
drilled piles which have a diameter smaller than 300 mm

3.2
enlarged base
fr: base élargie
de: Fußaufweitung
base of the micropile formed to have a cross section greater than that of its shaft

3.3
shaft diameter
fr: diamètre du fût
de: Pfahldurchmesser
diameter of the part of the micropile between the head and the base:

a) for micropiles constructed with casing: equal to the external diameter of the casing;

b) for micropiles constructed without casing: equal to the maximum diameter of the drilling tool

3.4
preliminary micropile
fr: micropieu préliminaire
de: Vorversuchs-Mikropfahl
micropile installed before the commencement of the main piling works or section of the works for the purpose of establishing the suitability of the chosen type of micropile and/or for confirming the design, dimensions and bearing capacity

3.5
trial micropile
fr: micropieu de faisabilité
de: Eignungsversuchs-Mikropfahl
micropile installed to assess the practicability and suitability of the construction method for a particular application

3.6
test micropile
fr: micropieu d'essai
de: Abnahmeversuchs-Mikropfahl
micropile to which a load is applied to determine the resistance and/or deformation characteristics of the micropile and/or the surrounding ground

3.7
working micropile
fr: micropieu de fondation
de: Bauwerksmikropfahl
micropile which is part of a structure

3.8
integrity test
fr: essai d' intégrité
de: Integritätsprüfung
test carried out on an installed micropile for the verification of soundness of micropile components

3.9
static load test
fr: essai de chargement statique
de: statische Probebelastung
loading test where a micropile is subjected to chosen axial and/or lateral forces for the analysis of its capacity and/or deformation characteristics

3.10
maintained load test (ML test)
fr:essai de chargement par palier
de: lastgesteuerte Probebelastung
static loading test in which a micropile has loads applied in incremental stages, each of which is held constant for a certain period or until micropile motion has virtually ceased or has reached a prescribed limit

3.11
constant rate of penetration test (CRP test)
fr:essai de chargement à vitesse d'enfoncement constante
de: weggesteuerte Probebelastung
static load test in which a micropile is forced into the ground at a constant rate and the force is measured

3.12
dynamic load test
fr: essai de chargement dynamique
de: dynamische Probebelastung
loading test where a dynamic force is applied on the micropile for analysis of micropile bearing capacity and deformation characteristics

3.13
grout
fr: coulis
de: Verpressmörtel
homogenous mixture of cement and water to which admixtures, additions, filler or sand can be added

3.14
mortar
fr: mortier
de: Zementmörtel/Feinkornbeton
concrete with an aggregate size of 4 mm or less

3.15
drilling / boring
fr: forage
de: Bohren
method of removing the soil or rock in an intermittent or continuous process

3.16
casing
fr: tubage
de: Verrohrung
tube used to support the micropile hole during the construction of a micropile

Note 1 to entry: The casing can be permanent or temporary. Permanent casing can act as a load bearing element and/or as a corrosion protection.

3.17
liner
fr: gaine, chemise
de: Hülse, Mantelrohr
tube, generally of thin steel sheet or plastic, forming at least part of the shaft of a micropile

EXAMPLE: used for the protection of micropile shafts in soft or aggressive grounds or to reduce negative skin friction

3.18
micropile joint
fr: assemblage, connexion de micropieu
de: Verbindung
means of joining lengths of bearing elements either by welding or by mechanical joints

3.19
coupler
fr: manchon
de: Koppelelement / Muffe
external device for joining lengths of bar or tube which comprise reinforcement or bearing element

3.20
nipple
fr: mamelon
de: Nippel
internal device for joining lengths of tubes which comprise reinforcement or bearing element

3.21
centraliser
fr: centreur
de: Zentrierer
device to locate reinforcement centrally in a borehole or casing

3.22
spacer
fr: écarteur
de: Abstandhalter
device to ensure the required grout, mortar or concrete cover or the internal spacing between reinforcing elements

3.23
load bearing element
fr: élément porteur
de: Tragglied
element of steel or other material that is capable of transmitting loads from the structure to the ground

3.24
drilling fluid/mud
fr: fluide de forage, boue de forage
de: Spülflüssigkeit, Bohrspülung
water or a suspension of bentonite, polymers or clay, in water with or without cement and other additions, for stabilization of borehole walls and/or for flushing

3.25
tube-à-manchettes
fr: tube à manchettes
de: Manschettenrohr
regularly slotted or perforated sleeved tube through which grout injections are possible using a packer device

3.26
piling platform level
fr: niveau de travail
de: Arbeitsebene
level of the platform on which the piling rig works

3.27
grouting
fr: injection sous pression
de: Verpressen
pumping of grout or mortar into the borehole with a pressure which is higher than the hydrostatic pressure

3.28
single-step grouting
fr: injection en une seule passe
de: Verpressen in einem Schritt
placement of grout or mortar in a single location, see Figures 11 and 12

3.29
multi-step grouting
fr: injection en plusieurs passes
de: Verpressen in mehreren Schritten
placement of grout or mortar in two or more locations, see Figure 13

3.30
multi-stage grouting
fr: injection sous pression répétée
de: Mehrfachverpressen
grouting at more than one occasion at different times such as initial grouting, second-stage grouting or post grouting

3.31
post grouting
fr: post-injection
de: Nachverpressen
high pressure grouting through one or more tube-à-manchettes, special valves or post-grouting tubes after the grout, mortar or concrete previously placed in the bore has set

3.32
filling
fr: remplissage
de: Verfüllen
placing under no applied fluid pressure other than the height of grout, mortar or concrete

3.33
execution specification
fr: specifications d'exécution
de: Ausführungsspezifikationen
set of documents covering all drawings, technical data and requirements necessary for the execution of a particular project

3.34
project specification
fr: dossier technique du projet
de: Projektspezifikation
project specific document describing the requirements applicable for the particular project

4 Information needed for the execution of the works

4.1 General

4.1.1 Prior to the execution of the work, all necessary information shall be available.

4.1.2 This information should include:

a) any legal or statutory restrictions;

b) the location of main grid lines for setting out;

c) the conditions of structures, roads, services, etc., adjacent to the work, including any necessary surveys;

d) a suitable quality management system, including supervision, monitoring and testing.

4.1.3 The information regarding the site conditions shall cover where relevant:

a) the geometry of the site (boundary conditions, topography, access, slopes);

b) the existing underground structures, underground and arial services, obstructions and known contaminations;

c) the environmental restrictions, including noise, vibration, pollution;

d) the future or ongoing construction activities such as dewatering, tunnelling, deep excavations.

4.2 Special features

4.2.1 The special features shall cover, where relevant:

— execution specifications (see 3.33);

— previous use of the site;

— adjacent foundations (types, loads and geometry);

— geotechnical information and data as specified in Clause 5;

— presence of obstructions in the ground (old masonry, anchors, etc.);

— presence of headroom restrictions;

— presence of archaeological remains;

— presence of natural and/or man made cavities (mines, etc.);

— presence of polluted ground;

— any specific requirements for the micropiling works, in particular those pertaining to tolerances, quality of materials;

— quality and bearing capacity of the working platform;

— where available, previous experience with micropiles or other foundations or underground works on or adjacent to the site;

— proposed or ongoing adjacent activities such as underpinning, pre-treatment of soil, dewatering.

4.2.2 Necessity, extent, procedure and content for any survey of the conditions of structures, roads, services, etc. adjacent to the works area shall be established.

4.2.3 The survey shall be carried out and be available prior to the commencement of the works and its conclusions shall be used to define the threshold values for any movement which can affect adjacent structures by the works area constructions.

4.2.4 Any additional or deviating requirements falling within the permissions given in this standard shall be established and agreed before the commencement of the works and the quality control system shall be suitably amended.

NOTE Such additional or deviating requirements can be:

— reduced or increased geometrical construction deviations;

— application of different or varying construction materials;

— special anchorage or doweling of micropiles to underlying rock;

— special reinforcement such as the use of steel tubes, steel cores or sections or of steel fibres;

— grouting of micropile shafts or bases.

4.3 List of activities

Design and execution should include the following activities:

NOTE The order shown does not necessarily represent a time sequence.

a) assessment of the design assumptions with respect to the site investigation data and construction feasibility;

b) execution of preliminary or trial micropiles and of the tests on these micropiles;

c) evaluation of the results obtained from preliminary and/or trial micropiles;

d) definition of the construction sequence of a micropile taking account of c);

e) directives regarding the construction sequence;

f) instruction to all parties involved of key items in the design criteria to which special attention should be directed;

g) specifications for monitoring the effects of micropile construction on underpinned and/or adjacent structures (type and accuracy of instruments, frequency of measurement) and for interpreting the results;

h) definition of tolerable limits regarding the influence of micropile installation works on underpinned and/or adjacent structures;

i) provision of construction drawings;

j) specifications for control tests during execution and for micropile tests.

5 Geotechnical investigation

5.1 General

5.1.1 The geotechnical investigation shall fulfil the requirements of EN 1997 (all parts).

5.1.2 The depth and the extent of the geotechnical investigation should be sufficient to identify all ground formations and layers affecting the construction, to determine the relevant properties of the ground and to recognize the ground conditions (e.g. where end bearing is to be relied on, it should demonstrate that any possible founding stratum is not immediately underlain by a weaker stratum where there is a possibility of a punching failure or excessive movements).

5.1.3 Relevant experience of the execution of comparable foundation works under similar conditions and/or in the vicinity of the site should be taken into account when determining the extent of site investigation

(reference to relevant experience is permitted if appropriate means of verification are taken, e.g. by penetration, pressuremeter or other tests).

5.1.4 The geotechnical investigation report shall be available in time, to allow for reliable design and execution of the special geotechnical works (micropiles).

5.1.5 The sufficiency of the geotechnical investigation shall be checked for the design and execution of the special geotechnical works (micropiles).

NOTE Guidance is given in EN 1997–2 on the depth and the contents of investigations.

5.2 Specific requirements

5.2.1 When determining the extent of geotechnical investigation, relevant experience which has been collected during the execution of comparable foundation works under similar conditions and/or at adjacent sites shall be taken into account.

NOTE Reference to relevant experience in this matter is acceptable if appropriate means of verification are taken (e.g. by penetration tests, pressuremeter or other tests).

5.2.2 The soil characteristics shall be determined by *in situ* tests and/or laboratory tests over the depth of the micropiles and to a depth beneath the base depending on the nature of the ground and on the type of the micropile (end bearing and/or friction bearing).

5.2.3 The geotechnical investigation shall demonstrate for end bearing micropiles that any competent foundation stratum is not immediately underlain by a soft stratum with a possibility of a punching failure or unacceptable settlements.

5.2.4 Particular attention shall be paid to the following aspects, which are relevant to the execution of micropiles, the requirements apply equally to made ground/fill as to natural soils and rock:

a) piezometric levels of all water-tables of the soil and rock layers. Where appropriate, the piezometric levels in the various water-tables existing on the site shall be monitored separately and over a sufficient period of time to estimate the highest piezometric levels which can occur during the installation of the micropiles. Particular attention shall be paid to artesian conditions and rapid underground water flows;

b) presence of coarse highly permeable soils or cavities (natural or artificial) which can cause sudden losses of drilling fluid and instability of the borehole, and thus may require special measures;

c) presence, strength and deformation characteristics of soft layers, such as very soft clay or peat, which can cause difficulties during execution or loading of micropiles (deformation or instability of the borehole, risk of buckling);

d) presence of cobbles and boulders or other underground obstructions which can cause difficulties for the installation and thus may require special methods or tools for penetration (passing through) or removal;

e) the level and the slope of rock surface, the thickness and extent of any existing weathered rock, the presence of fissures or cavities;

NOTE In some cases it is also necessary to determine the strength or hardness of the rock.

f) chemical aggressiveness of groundwater, soil or rock that can affect the properties of grout, mortar or concrete and steel;

g) presence, extent, thickness and nature of contaminated soil or waste that can influence the disposal of the spoil generated and that may require special measures for the protection and safety of the work force;

h) degradation of soil or rock properties when in contact with water;

i) site stability problems (slope stability for instance);

j) presence and characteristics of underground gases;

k) thickness and characteristics of bearing strata.

6 Materials and products

6.1 General

6.1.1 All material and products shall meet the requirements set in the respective European Standards, the provisions valid in the place of use and the provisions given in the project specification.

6.1.2 The sources of supply of all constituents shall be documented and shall not be changed without prior notification.

6.2 Reinforcement and load bearing elements

6.2.1 Steel for reinforcement

6.2.1.1 Steel bars for the reinforcement of micropiles shall comply with EN 10080 and EN 1992-1-1.

6.2.1.2 When selecting the type and grade of steel, attention shall be given to the assembly of reinforcement cages and the weldability requirements.

6.2.2 Steel for load bearing elements

6.2.2.1 The steel materials shall as a minimum comply with:

— EN 1993-1;

— EN 1993-5;

— EN 10080 or prEN 10138-4 when bars are used;

— EN 10210 or EN 10219 or EN ISO 11960 when hollow sections are used;

— EN 10025, when hot rolled products (e.g. H-sections or steel core piles) are used.

NOTE 1 Requirements on inspection documents can be found in EN 10204.

NOTE 2 For reused material see EN 1993–5:2007, 3.1.

6.2.2.2 If the steel properties are altered due to the manufacturing procedure e.g. cold forming of steel, these values shall be tested for the finished product and documentation of guaranteed technical data be provided by the supplier at delivery.

6.2.2.3 When selecting the type and grade of steel, attention shall be given to weldability requirements when relevant.

6.2.2.4 Connecting elements shall not compromise the required capacity of the bearing element.

6.2.3 Other materials or grades of steel

Other materials or grades for reinforcement and load bearing elements may only be used if their suitability has been proven.

6.3 Materials for grout, mortar and concrete

6.3.1 Cement

6.3.1.1 Cement for micropiles shall be in accordance with EN 206:2013, Annex D.

6.3.1.2 When selecting the type of cement, account shall be taken of the aggressiveness of the environment. The exposure class shall be defined in accordance with EN 206:2013.

6.3.1.3 In case of contact with prestressing steel CEM I according to EN 447:2007, 4.1 shall be used.

6.3.2 Aggregates

Aggregates shall comply with EN 206:2013, Annex D.

6.3.3 Water

Mixing water shall comply with EN 206:2013.

NOTE Potable water is acceptable for the preparation of grout, mortar or concrete.

6.3.4 Additions and admixtures

Additions and admixtures shall comply:

a) with EN 206:2013 and EN 934-2;

b) with the approval documents and the manufacturer's instructions.

6.4 Grout

6.4.1 Grout composition shall be planned and carried out in a manner appropriate to the application and the ground conditions.

6.4.2 Sand and fillers can be used in grouts as bulking agent or as a means of varying the consistency of the grout, its resistance to wash out or segregate.

NOTE Grouts to which filler or sand (maximum grain size 2 mm) is added to a quantity by weight of equal to or less than 1,0 times the cement quantity are still considered as a grout. For more quantity of filler or sand, the mix is considered as a mortar.

6.4.3 Water/cement ratio should be appropriate to actual ground conditions and, should not be more than 0,55.

6.4.4 Unless otherwise specified the minimum unconfined compressive strength shall be at least class C25/30 tested according to EN 12390-3.

6.4.5 Laboratory and field tests should be undertaken to verify mixture, mixture efficiency, setting time and performance of the grout.

6.4.6 Tests according to 6.4.5 should be undertaken in accordance with EN 445.

6.4.7 The allowable bleed after 2 h should be less than 3 %.

NOTE The limit of 3 % is not applicable in cases where the bleed water can be absorbed by the ground during grouting.

6.4.8 For grout used to encase a reinforcement within an encapsulation, the mix shall be designed to minimize bleeding and shrinkage according to EN 447.

6.4.9 Quality control

6.4.9.1 The quality of the grout shall be controlled during the works.

6.4.9.2 On site, the grouts should be subjected to the following routine tests:

— density at the mixer and, if applicable, at the inlet and at the outlet of the borehole;

— viscosity (Marsh value), where applicable;

— bleed.

6.4.9.3 Unless otherwise specified, for each site and for each period of maximum 7 working days, at least 2 sets of 3 samples (cylinders or cubes) shall be taken and tested for compressive strength.

6.4.9.4 The batching process shall be checked periodically and recorded.

6.5 Mortar and concrete

6.5.1 The mix composition shall be designed in accordance with EN 206:2013, Annex D, unless otherwise specified.

6.5.2 Mortar and concrete for micropiles shall:

a) have a high resistance against segregation;

b) be of high plasticity and good cohesiveness;

c) have good flow properties;

d) have the ability to self – compact;

e) be sufficiently workable for the duration of the placement procedure, including the removal of any temporary casing;

f) have a minimum unconfined compressive strength of at least class C25/30 at 28 days (or at the date of the first loading of the micropile if it is carried out before this date).

NOTE 1 For the properties a) to e) no objective testing procedures are established.

NOTE 2 Strength can be tested on either cylinder or cube samples.

6.5.3 For mortar, the size of the aggregates shall not exceed 4 mm, see EN 206:2013.

6.6 Spacers, centralisers and other components

6.6.1 Spacers or centralisers should be used to provide the grout, mortar or concrete cover specified in 7.6.

6.6.2 Spacers and centralisers shall be designed and manufactured using durable materials which will not lead:

— to corrosion of the reinforcement or bearing element;

— to spalling of the grout, mortar or concrete cover.

6.6.3 Materials for spacers, centralisers and other components shall be compatible with the materials of the micropile and shall not compromise the corrosion protection.

6.7 Coatings and corrosion protection compounds

6.7.1 Coatings and compounds for corrosion protection shall comply with the design specifications. The continuity of the protection, close to the connection elements shall comply with the specifications and the design.

6.7.2 Coatings used to reduce the shaft friction shall comply with the specification and the design.

7 Considerations related to design

7.1 General

7.1.1 The basic standards for the design of micropiles are:

— for basis of design: EN 1990;

— for actions on structures: EN 1991;

— for structural design of concrete elements: EN 1992-1-1;

— for structural design of steel elements: EN 1993;

— for structural design of composite elements: EN 1994-1-1;

— for design of prestressed elements: EN 1992-1-1 and EN ISO 15630-3;

— for bearing resistance: EN 1997-1.

7.1.2 The present document gives design rules related to execution which are not covered by the above standards and which can influence the design or details of the micropiles.

7.1.3 The design of micropiles shall establish the type and size of micropiles.

NOTE Micropiles can only be designed efficiently on the basis of sound knowledge of the construction project, of the structural requirements of the micropile system, of the geotechnical properties of the ground and of previous experience with micropiles in similar ground conditions.

7.1.4 If no comparable experience exists regarding the execution, one or more preliminary or trial micropiles shall be installed at chosen locations before the main works commence.

7.1.5 The design shall take also into account the specific execution restrictions.

7.1.6 Corrosion of concrete can affect the long term bearing capacity due to time induced reduction of skin friction.

7.2 Geometrical construction tolerances

7.2.1 Geometrical construction tolerances given in 8.2 shall be taken into account in the design.

7.2.2 If the specified geometrical construction tolerances are exceeded the extent of possible overloading of any structural part shall be taken into consideration and suitable measures shall be taken as necessary.

7.3 Installation

7.3.1 The limit values (such as displacement limit, vibration limits, ….) acceptable for adjacent structures and/or services should be defined in the project specifications.

7.3.2 When micropiles are to be socketed into a bearing stratum or into rock, the minimum depth and diameter of penetration shall be given in the project specifications.

7.3.3 Rock socket micropiles should be flushed out until all debris has been removed.

7.3.4 Wherever the starting point of the borehole is located below the water table or artesian head, special measures shall be taken into account in order to avoid piping through the boreholes or loosening of the ground.

7.3.5 Where ground conditions differ from those stipulated in the design, appropriate action shall be taken to modify the design.

7.3.6 If micropiles encounter an impenetrable obstruction prior to reaching their designed founding depth, the design shall be reviewed in the light of any available knowledge about the obstruction and in view of consequences on the bearing behaviour of the foundation.

7.3.7 In order to protect fresh grout, mortar or concrete against detrimental effects of groundwater flow, permanent casings or other measures should be considered.

7.3.8 The installation of a permanent casing or lining shall be taken into account for the design of the load transfer length in the soil.

7.4 Reinforcement and load bearing elements

7.4.1 The reinforcement and load bearing elements in micropiles shall be designed not only to have adequate strength in the final micropile, but also adequate strength and stiffness during its handling and during the construction of the micropile. It shall also allow the fresh grout, mortar or concrete to flow easily around each of its components.

7.4.2 Micropiles should be reinforced over their full length.

7.4.3 A micropile may be designed as a partially unreinforced element:

— if the design actions and/or actions caused by the construction and/or actions resulting from the ground, produce only a compressive stress in the micropile

or

— when a permanent casing is used.

7.4.4 Starter bars or dowel bars for connection to a superstructure shall be in accordance with EN 1992-1-1.

7.4.5 When steel reinforcement is considered as the load bearing element of a micropile, the design shall be in accordance with EN 1993-1-1.

7.4.6 When steel reinforcement and mortar or concrete are considered as bearing members of the micropile, the design shall be in accordance with EN 1992-1-1.

7.4.7 The grout, mortar or concrete cover shall be specified according to 7.6 in the project specifications.

7.5 Connecting elements

7.5.1 Connecting elements shall be designed for service loads and all actions which can occur during handling, transportation and installation.

7.5.2 For couplers and nipples, the cross section of which is reduced by a thread shall be calculated in accordance with EN 1993-5.

7.5.3 Joints between load bearing elements shall satisfy the required capacity in compression, tension and bending.

7.5.4 When reinforcement is installed within a permanent casing, filled afterwards with grout, mortar or concrete, normal overlapping may be used in accordance with EN 1992-1-1.

7.6 Corrosion protection of steel elements

7.6.1 The protection against corrosion of steel elements placed in a micropile shall take into account:

— the aggressiveness of the environment (groundwater, soil, stray electric currents, etc.);

— the micropile type;

— the type of load (tension or compression);

— the type of steel; and

— required design working life.

7.6.2 A corrosion protection shall consist of:

— an efficient cover of appropriate grout, mortar or concrete and/or;

— a sacrificial thickness of steel for the corrosion and/or;

— specific precautions.

NOTE 1 Guidance on the loss of steel thickness to consider is given in EN 1993–5:2007, Table 4–1.

NOTE 2 Specific precautions for protection against corrosion can be specified and consist of:

— use of special cement;

— use of an adequate steel type;

— use of permanent casings or linings;

— surface coating.

7.6.3 The nominal cover c_{nom} to all reinforcement in cast *in situ* micropiles shall be not less than:

— 50 mm for micropiles with temporary casing;

— 75 mm when the reinforcement is installed after concreting;

— 25 mm to the internal face of a permanent casing or lining.

The nominal distance between the inside of the casing and the reinforcement for micropiles with a temporary casing is not to be less than 1,5 times the largest grain size in the used concrete.

NOTE Guidance on the minimum cover of appropriate grout or mortar to load bearing elements is given in Annex B.

7.6.4 The minimum cover for grout to an internal face of a permanent casing or lining in cast *in situ* micropiles can be reduced to 10 mm.

7.6.5 The selection of grout, mortar and concrete composition and properties shall take into account the environment exposure class given in EN 206:2013.

NOTE Guidance on the concrete composition and properties to consider is given in EN 206:2013, Annex D.

7.6.6 The class of exposure of the environment should be chosen with special care and the time dependent development of the aggressiveness should be taken into account.

7.6.7 Specific precautions shall not reduce other properties.

7.6.8 The corrosion protection of high strength steel and pre-stressing steel shall take into account the tensile stresses and corresponding crack widths.

NOTE 1 The corrosion protection of a tension element embedded in concrete does not depend on, whether this element is identified as an anchor or a micropile, but solely on the magnitude of the tension stresses in the tension element. I.e. utilization of high strength steel can imply the need for special corrosion protection depending on the induced crack widths in the concrete.

NOTE 2 The steel is classified as high-strength steel if it has f_{yk} > 500 MPa (limit as recommended in EN 1993–5).

7.6.9 For connecting elements the same rules of corrosion protection shall be applied as for the other steel elements.

7.6.10 Particular care shall be given to the continuity of the corrosion protection at connecting elements.

7.6.11 When permanent casings are used as primary bearing elements and are not filled with grout or mortar internal corrosion of tube shall be taken into account in design.

7.7 Spacers and centralisers

7.7.1 The design of spacers and centralisers shall take into account the size of the hole, the weight of the reinforcement, the grout, mortar or concrete cover and the possible disturbance of soil during the insertion of the reinforcement.

7.7.2 Spacers and centralisers shall not impede grout, mortar or concrete flow.

7.8 Micropile enlargement

7.8.1 Enlargements of a micropile base or shaft shall be designed only when the intended shape can be constructed in a controllable way and checked by suitable methods. Typical examples of enlargements are shown in Figure 7.

7.8.2 In case of enlargements on micropiles the method used to form the micropile and the nominal value of base and shaft perimeter to be used in the design shall be agreed before commencement of the work.

NOTE 1 If the enlarged base is installed by hammering inside the tube (bottom hammering) using semi dry concrete instead of the basic perimeter the base volume can be specified.

NOTE 2 If the enlarged base is installed by top driving with wet concrete instead of the basic perimeter the base volume can be specified.

7.9 Connections to the superstructure

7.9.1 Unless otherwise specified the connection between the micropile and the superstructure shall be designed for the micropile capacity.

7.9.2 For micropiles of reinforced mortar or concrete the connection shall be designed in accordance with EN 1992-1-1.

7.9.3 For micropiles with bearing elements the selected method of load transfer between the bearing element and the superstructure shall be designed in detail and/or proven by tests.

7.10 Spacing of micropiles

7.10.1 The spacing of micropiles shall be considered in relation to micropile type, micropile diameter, length of micropile, the ground conditions, and their group performance.

7.10.2 The possible interference of one micropile with another during installation should be considered when determining micropile spacing, orientation and installation sequence.

7.11 Special requirements for micropiles

7.11.1 It can be necessary to provide a sacrificial lining or permanent casing to contain the fresh grout, mortar or concrete.

7.11.2 The design of micropiles shall take into account the geometrical construction tolerances, curvature and the soil support.

8 Execution

8.1 General

8.1.1 All works shall be planned, carried out and documented in a manner appropriate to the application.

8.1.2 Micropiles shall be executed and supervised by trained personnel experienced in the type of work.

8.1.3 A method statement should be provided before starting the execution of micropiles. This method statement should contain (but is not limited to) the following information:

— identification, objective and scope of the micropiles;

— soil description; (possibly by reference to geotechnical investigation report);

— environmental issues;

— technical requirements;

— equipment and working procedure for:

  — drilling;

  — installation of reinforcement or bearing element;

- filling, grouting or concreting;

— measures to ensure the boring accuracy;

— grouting parameters;

— site installation and working areas;

— spoil management;

— quality control procedures.

8.1.4 Special care shall be taken for the execution of contiguous or secant micropiles for the formation of walls (spacing, deviation, sequence of drilling, constitutive material).

8.1.5 Where possible the preliminary, trial or test micropiles should be installed close to positions of soil investigation.

8.1.6 Where the ground conditions differ from those stipulated, the design specification shall be reviewed.

NOTE Further measures can be required before continuing the work.

8.1.7 Any major deviation of the ground conditions shall be reported and considered in the design of micropiles as indicated in 7.3.5.

8.1.8 A drilling log should be established using simple practical identification data which can easily be recognized by the operator, e.g. class of ground, colour of flushing returns or loss of drilling fluid.

8.2 Construction tolerances

8.2.1 Unless otherwise specified, micropiles shall be installed within the following geometrical deviations:

— plan location of vertical and inclined micropiles measured at the working level: ≤ 0,10 m;

— deviation from the theoretical axis:

- for vertical micropiles: max 2 % of the length;
- for inclined micropiles: $n \geq 4$, max 4 % of the length (see Figure 5);
- for inclined micropiles: $n < 4$, max 6 % of the length (see Figure 5);

— max angle deviation in a micropile joint = 1/150 radian.

8.2.2 Where geometrical deviations other than those stated in 8.2.1 are required or allowed they shall be agreed before the commencement of the work.

NOTE This might be the case in regard to constructional demands, ground conditions, available drilling equipment or low cut-off level.

8.3 Site preparation

8.3.1 The piling platform, necessary for the installation of the micropiles, shall be prepared and maintained in such a way that all operations can be carried out safely and not detrimental to the quality of the micropiles.

8.3.2 Services and existing underground installations should be recognized and removed if necessary.

8.4 Sequence of installation

8.4.1 The sequence of installation of micropiles shall be planned.

8.4.2 This sequence shall take into account if relevant:

— detrimental effects of settlements on structures to be underpinned or on adjacent structures;

— detrimental effects on the bearing resistance of previously installed micropiles.

8.5 Drilling

8.5.1 General

8.5.1.1 The drilling method shall ensure a full length stable bore of at least the design cross section.

8.5.1.2 The drilling methods which can be used for micropiles are given in Annex A.

8.5.1.3 Micropiles shall be drilled until they reach:

— the specified embedment in the bearing stratum; or

— the anticipated founding level; or

— the prescribed length.

8.5.1.4 Boreholes shall be checked for position and length on completion of drilling.

8.5.1.5 Boreholes shall be checked for inclination and orientation when specified on completion of drilling.

8.5.1.6 Loose and remoulded drilling deposit shall be removed from the borehole.

8.5.1.7 The drilling method used for preliminary or trial micropiles on which the design is based shall be used.

8.5.1.8 When uncontrolled inflow of water and/or soil into the borehole can occur or when there is a risk of collapse, special measures, such as excess pressure of flushing or stabilizing fluids, shall be taken to maintain the stability of the borehole.

NOTE 1 An inflow of water and/or soil could cause for instance:

— a disturbance to or instability of the bearing stratum or the surrounding ground;

— loss of support by the removal of soil from beneath underpinned or adjacent foundations;

— damage to the unset grout, mortar or concrete in the micropile or micropiles recently installed nearby;

— defaults in the shaft;

— washing out of cement.

NOTE 2 There are increased risks in:

— loose granular soil;

— soft cohesive soil;

— ground which is variable;

— when using air as drilling fluid with direct circulation under the groundwater table.

8.5.2 Use of flushing

8.5.2.1 Drilling can be performed with water, air and drilling fluids.

8.5.2.2 When drilling methods with air as flushing medium are used close to existing structures, special care should be taken to avoid disturbance or fracturing of the ground.

8.5.2.3 The drilling fluid shall not impede the success of any subsequent filling or grouting operation.

8.5.2.4 Special care shall be taken when drilling through ground under artesian water pressure at the piling platform.

8.5.2.5 Techniques to counteract the water pressure and to prevent any blow-out, hole collapse and erosion during drilling, installation and filling or grouting operations shall be identified in advance and implemented as and when required.

NOTE For ground water levels which are higher than the working platform it can be appropriate to perform the drilling from a higher working level or to use heavy drilling fluids.

8.5.3 Boreholes supported by casings

Casings shall be used when the borehole is unstable or there is a significant fluid loss.

8.5.4 Drilling with segmental hollow stem augers

No special limitations exist concerning the inclination provided the direction of excavation is controlled and the installation of the reinforcement can be achieved correctly.

8.6 Enlargements

8.6.1 Micropile enlargements can be formed:

— by excavation;

— by driving compacted quantities of concrete below the bottom of the casing;

— by installing an expanded body;

— by mixing concrete in place around the micropile tip and/or shaft;

— by pressure grouting.

8.6.2 The proper formation of an enlargement executed by excavation requires a stable excavation and complete filling with grout, mortar or concrete.

8.6.3 The excavation of enlargements should be done using mechanical tools which allow the control of their operation from the surface.

8.6.4 The proper formation of an enlargement constructed by driving out of concrete requires:

— special measures to prevent the segregation or washing out of the concrete of the base enlargement;

— the construction of the base enlargement without significant interruptions;

— the use of an appropriate hammer.

8.6.5 The concrete or mortar consumption as well as driving energy for the base enlargement fabrication shall be measured and recorded.

8.6.6 For micropiles which are subjected to tensile forces, particular care shall be taken to provide sufficient anchoring of the reinforcement cage and/or other bearing elements in the enlarged base.

8.7 Reinforcement and load bearing elements

8.7.1 Handling and storing

8.7.1.1 Reinforcement shall be constructed in such a way that they can be handled and lowered into the borehole or casing without damage or permanent distortion.

8.7.1.2 Steel reinforcement shall be stored under controlled conditions and shall be clean and free from loose rust and loose mill scale at the time of installation and filling, grouting or concreting.

8.7.1.3 Welding of reinforcing steel shall be in accordance with EN ISO 17660-1.

8.7.2 Joints

8.7.2.1 Joints in reinforcement bars shall be made so that there is no detrimental displacement of the reinforcement during the installation and the withdrawal of the casing.

8.7.2.2 Joints shall be fastened properly and checked before lowering into the ground.

8.7.2.3 For structural steel the welding process, the joint preparation, the welding procedure, the testing and inspection shall comply with EN 1090-2 and the execution specification.

NOTE For guidance on minimum criteria see Table 1.

Table 1 — Guidance on welding testing and inspection, minimum criteria for micropiles and micropile details in structural steels

Welding*						**Testing and inspection of welds**		
Type of joint	**Type of weld**	**Joint preparation**	**Welding consumables**	**Welding process according to** EN ISO 4063	**Description of welding procedure**	**Acceptance class for defects** EN ISO 5817	**Type of testing**	**Extent of testing**
butt joint / lap joint a	EN ISO 9692-1, EN ISO 9692-2	EN ISO 9692-1, EN ISO 9692-2	EN ISO 2560 EN ISO 18275 EN ISO 14341 EN ISO 17632 EN ISO 18276	111 114 12 131 135 136	EN ISO 15609-1	C	Visual	100 %
							NDT	See EN 1090–2 ***
butt joint / lap joint b	EN ISO 9692-1, EN ISO 9692-2	EN ISO 9692-1, EN ISO 9692-2			EN ISO 15609-1	D	Visual	100 %

[a] for structural welds**

[b] for non - structural welds**

*When welding is executed in a workshop, all welding procedures suitable for carbon steels are acceptable.

**Structural weld is a weld when a steel member is a bearing element e.g. a steel pipe, beam; non-structural weld is a weld for non-bearing element as a temporary or permanent casing or lining or a driving tube.

***Extent of NDT in accordance with execution specification and EN 1090–2.

8.7.2.4 When bearing elements of a micropile are welded on site the welding shall be carried out in appropriate controlled conditions.

8.7.2.5 Welding of galvanized or coated reinforcement bars or bearing elements shall only be done when a procedure for repair of the corrosion protection is agreed before the commencement of the work.

8.7.3 Spacers and centralisers

8.7.3.1 The concentric position of the reinforcement in the borehole and the necessary grout, mortar or concrete cover shall be maintained by spacers and centralisers unless the position and cover are otherwise provided.

8.7.3.2 Spacers and centralisers shall be provided at intervals of not more than 3 m and at least for every element.

8.7.3.3 For inclined micropiles the intervals shall be chosen in such a way that the required cover is provided after placing taking into account the weight and stiffness of the reinforcement and bearing elements.

8.7.4 Installation

8.7.4.1 Reinforcement or load bearing elements shall be suspended or supported so as to maintain their correct position and level.

8.7.4.2 The sequence of reinforcement or load bearing element installation and the borehole filling shall take into account:

— the execution method;

— the filling material (grout, mortar or concrete);

— the type of reinforcement (cage, tube, bar);

— the condition of filling (dry or submerged condition).

8.7.4.3 The installation of the reinforcement or bearing element shall provide for the specified alignment with the micropile axis.

8.7.4.4 When reinforcements or load bearing elements have to be installed in raking micropiles, suitable means of support shall be employed for the installation and the direction control of the reinforcement or load bearing element.

8.7.4.5 The temperature of the reinforcement or bearing element shall be high enough to avoid formation of ice on the surface when installed.

8.7.4.6 The reinforcement may be placed either before or after the temporary casing is extracted.

8.8 Filling and grouting

8.8.1 General

8.8.1.1 The method of grout placement shall be determined by the ground conditions, the required shaft and end bearing capacity, the type of grout and equipment used and shall be specified in the project specifications.

8.8.1.2 For shaft bearing micropiles, high pressure second stage grouting may be used to increase the friction resistance by introducing further grout into the ground and raising the normal stresses at the ground/grout interface. This may be carried out before or after installation of the reinforcement.

8.8.2 Grout preparation

8.8.2.1 The grout preparation and the filling or grouting procedure shall be carried out in such a way that the required design strength of the material is ensured.

8.8.2.2 Contamination of the grout and its constituents shall be avoided during storage, handling and delivery.

8.8.2.3 The proportioning of grout components shall be carried out with calibrated measuring devices and respecting the tolerances given by the suppliers of the measuring devices.

8.8.2.4 Batching and/or mixing processes shall be controlled in accordance with 6.4.9.

8.8.2.5 Mixers shall be selected to ensure the homogeneity of the grout.

8.8.2.6 An intermediate holding tank should be located between the mixing tank and the pump(s). The mix in the holding tank should be agitated to prevent segregation and/or premature setting.

8.8.2.7 Pumps and grouting systems shall be compatible with the selected filling or grouting method.

8.8.2.8 The grouting pressure should be measured as close to the point of placement as it is practicable.

8.8.3 Borehole testing and pregrouting

For micropiles installed into weathered or strongly fissured rock, borehole testing and pregrouting can be necessary to avoid uncontrolled loss of grout into the surrounding rock mass and to guarantee the required grout cover of the reinforcement or load bearing element.

NOTE General information on borehole testing and pregrouting is given in informative Annex C.

8.8.4 Filling the borehole

8.8.4.1 The interval between the completion of the borehole drilling and the filling up of the borehole shall be kept short to avoid detrimental damage to the micropile.

8.8.4.2 Measures shall be taken to ensure that the micropile length is completely filled.

8.8.4.3 When filling the borehole with a tremie pipe or through the drill rods or tubular bearing elements, the end of the tremie pipe or drill rods shall start at the base and remain submerged in the grout, mortar or concrete. Filling shall continue until the emerging grout, mortar or concrete on top is almost the same as the initial grout, mortar or concrete.

8.8.4.4 The final grout, mortar or concrete level should be checked until it has stabilized.

8.8.4.5 When filling the borehole, air and drilling fluid shall be able to escape to permit complete grout or filling.

8.8.4.6 For drilled and flushed boreholes the remaining cuttings shall be able to escape when filling the borehole.

8.8.5 Filling or grouting through a temporary casing

8.8.5.1 During extraction of the temporary casing the grout level within the casing shall be filled to above ground level before the next length of casing is removed, Figure 10 shows filling in progress.

8.8.5.2 Grouting may also be done under pressure during withdrawing of the casing (Figure 11). The grouting pressure should be applied at least every 2 m during the extraction of the casing through the founding strata.

8.8.6 Filling or grouting through a load bearing element

8.8.6.1 When tubes are used as bearing element, filling can be applied through the bearing element (Figure 9).

8.8.6.2 After filling a single step grouting can be carried out.

8.8.6.3 When the specified grouting pressure cannot be applied, re-grouting shall be performed after a certain waiting period, but before setting, until the specified grouting pressure can be applied.

8.8.7 Grouting during drilling

8.8.7.1 When grouting is applied during drilling, the bearing elements are fitted with a drill bit and they are drilled into the ground.

8.8.7.2 For grouting during drilling, the grout pressure and flow rate should be adjusted to maintain grout flush at the ground surface at all times.

NOTE The required grout pressure is depending on the grout susceptibility to penetrate the ground loosened by the drilling process and contained within the annulus around the reinforcing element.

8.8.7.3 When grouting during drilling, grout flushing should be carried out at a constant rate and the flush should be re-established each time a new section of bearing element is added prior to advancing the drill bit.

8.8.8 Multi-stage grouting

8.8.8.1 Multi-stage grouting can be executed by single step grouting through tube-à-manchettes (Figure 12) or by multiple step grouting through tube-à-manchettes or special valves (Figure 13) or by single step grouting through several post-grouting tubes staggered in length (Figure 14).

8.8.8.2 The multi-stage grouting phase(s) shall take place only after the grout placed into the borehole according to 8.8.4, 8.8.5 or 8.8.6 has set.

8.8.8.3 The grouting shall be carried out either in single or multiple step(s) and in single or multiple stage(s), according to the project specifications.

8.8.8.4 When the specified grouting pressure cannot be applied additional step(s) of grouting shall be performed after a certain waiting period until the specified grouting pressure can be applied.

8.8.8.5 The grouting tubes shall be flushed with water after each grouting step and filled with grout at the end of the whole grouting process.

8.9 Concreting

8.9.1 Concreting in submerged conditions

Concreting in submerged conditions shall be in accordance with EN 1536:2010, 8.4.3.

8.9.2 Concreting through a segmental hollow stem augers

8.9.2.1 Concreting of micropiles excavated with segmental hollow stem augers shall be carried out by placing concrete through the hollow central stem of the auger, the stem being closed at its base, to avoid entry of water or soil until concrete placing commences.

8.9.2.2 Once boring has reached the final depth, concrete shall be placed through the stem to fill the micropile as the auger is withdrawn.

8.9.2.3 If concrete flow cannot be initiated, it is necessary to completely remove the auger by backscrewing it from the ground, backfilling the bore hole so that no voids or collapses occur.

8.9.2.4 The pile may then be rebored at the same location to at least the original depth.

8.9.2.5 During withdrawal and concrete placement, the auger shall not be rotated in the opposite direction as for excavation.

NOTE Rotation can sometimes be used in the direction as for excavation at low speed.

8.9.2.6 During continuing placement, the concrete at the tip of the auger shall be kept under a pressure exceeding the external pressure, so that the volume vacated by the auger's extraction is concurrent and completely filled.

8.9.2.7 To control continuity, monitoring of micropile construction shall comprise:

— the control of concrete supply;

— the concreting pressure;

— the rate of extraction; and

— the record of rotation of the auger.

NOTE If one of the above monitoring systems fails during the micropile concreting, alternative manual control can be required.

8.9.2.8 Other than in special conditions, an adequate concrete supply shall be maintained to fill the micropile section until the tip of the auger has reached the piling platform level.

NOTE It is generally necessary to bring concrete to piling platform level in order to insert the reinforcement cage.

8.9.3 Concreting in dry conditions

8.9.3.1 The concreting in dry conditions shall be done by one of the following three methods:

1) using high workability concrete that is discharged in sufficient quantity into the drive tube before and during extraction of the tube;

2) by pumping concrete of high workability into the borehole/casing;

3) by using semi-dry concrete that is added in small charges in the casing, each charge being expelled and compacted by internal tamping during the incremental withdrawal of the tube.

NOTE The first and third methods can be combined e.g. fabrication of the micropile base (eventual enlarged) with semi-dry concrete, and of the micropile shaft with high workability concrete.

8.9.3.2 The concrete shall be directed vertically into the centre of the tube by means of a funnel and an attached length of pipe so that the concrete does not:

— hit the reinforcement, or the walls of the tube; and

— fall freely into the tube, segregate or become contaminated.

NOTE Usually, the maximum outside diameter of the concreting pipe including its joints is not more than 0,6 times the inner width of the reinforcement cage.

8.9.3.3 The concreting pipe shall be smooth to allow free flow of concrete and its internal diameter shall be not less than eight times the maximum size of the aggregate.

8.9.3.4 The concreting pipe shall be cleaned of all encrusted concrete or mortar prior to its use.

8.9.3.5 Fresh concrete shall always be poured into concrete which retains its full workability.

8.9.3.6 When determining the workability time of the concrete allowance should be made for potential interruptions in the supply and the time required for the placement process.

8.9.3.7 The concrete shall be placed in sufficient quantity and with sufficient workability and coherence in order:

— to ensure that no significant quantities of air are entrapped;

— to avoid lifting of the concrete during withdrawal of the casing;

— to prevent segregation of the concrete;

— to prevent inflow of soil or water.

8.9.3.8 External vibrating or light tamping of the casing may be used during tube extraction to improve the concrete outflow and the concrete compaction.

8.9.3.9 An adequate head of concrete shall be maintained above the toe of the casing during extraction.

8.9.3.10 The level of concrete within the casing should be maintained at or above working level during the extraction operation.

8.9.3.11 The micropile should be cast to piling platform level unless relevant experience has proven that this is not necessary to ensure integrity and geometry.

8.9.3.12 If a semi-dry concrete mix is used, the method of casing extraction shall ensure that the semi-dry concrete does not lift and is adequately compacted and tamped.

8.9.3.13 During concreting the volume placed and the level of concrete inside the tube should be checked and recorded.

8.9.3.14 The method and the sequence of checking the concrete level should suit dimensions, type of micropile and soil conditions and should be agreed prior to the beginning of the work.

8.9.3.15 In cold weather with ambient air temperature less than 3 °C and falling, the heads of newly cast micropiles shall be protected against frost.

8.10 Trimming of micropiles

8.10.1 The trimming operation:

— shall be carried out only when the grout, mortar or concrete has obtained sufficient strength;

— shall remove all grout, mortar or concrete which is contaminated or of lower quality than required.

8.10.2 Cutting off and stripping of the micropile head shall be done carefully to avoid shattering and damage of the rest of the micropile.

9 Supervision, monitoring and testing

9.1 Supervision

9.1.1 The execution of any type of micropile shall require careful supervision and monitoring of the work.

NOTE 1 This includes the supervision and the specified monitoring for the surrounding constructions.

NOTE 2 The aim of the supervision and inspection of the work is to check that the construction is completed in accordance with the execution specification and inspection refers to verifying conformity of the properties of products and materials to be used as well as inspection of the execution of the works.

NOTE 3 Clause 9 of this standard gives the additional provisions to take into account for the establishment of the execution specification for the supervision, control and testing of micropiles.

9.1.2 Control of the execution shall be in accordance with the project specifications and comply with EN 1997-1 and this standard.

9.1.3 The following items shall be supervised and controlled during the various phases of construction:

a) preliminary work prior to the construction phase:

   1) location of micropiles;

   2) materials;

   3) bearing elements and reinforcement cages (dimensions, assembly to be inserted);

b) micropile construction:

   1) installation method (tools and equipment), dimensions and depth;

   2) Installation execution (where applicable: installation of casings, construction of micropile sockets and of enlargements, etc.);

   3) where applicable; cleaning the bore;

   4) filling, grouting, concreting;

   5) placing (depth, position) the bearing element or reinforcement cage.

NOTE 1 Not all items are applicable to each type of micropile.

NOTE 2 Other items can be applicable (e.g. ground conditions and groundwater levels, obstructions, special events).

NOTE 3 The controls include the duration of the various phases of construction.

9.1.4 Material testing shall comply with the execution specification, EN 206:2013 and this standard (see e.g. Clause 6 and 9.1.3).

9.1.5 During execution the ground behaviour shall be observed and any unforeseen change or feature relevant to the performance of the micropile shall be notified as specified in the project specification.

9.2 Monitoring of micropile construction

9.2.1 The specific procedures for verification, control and acceptance shall be established before the commencement of the works.

9.2.2 The micropile construction process shall be monitored and all relevant data according to Tables 2 to 4 shall be recorded.

NOTE Rig instrumentation is an acceptable and preferable alternative to hand produced records.

9.2.3 The duration of the respective operations should also be recorded.

9.2.4 All non conformances shall be notified.

9.2.5 During installation, the ground behaviour shall be observed and any unforeseen change or feature that might be important for micropile quality shall be considered and where relevant appropriate measures shall be taken.

9.2.6 After construction of the micropiles, an “as built” record shall be drawn up showing positions and dimensions of micropiles together with their head and founding levels.

9.2.7 The record plan, the micropile monitoring records and any other construction documentation shall be kept to the files as required by the contract and/or the statutory requirements.

9.3 Micropile testing

9.3.1 General

9.3.1.1 Tests on micropiles can be performed on preliminary micropiles and/or working micropiles.

9.3.1.2 The principal requirements for micropile load testing are contained in EN 1997-1.

9.3.1.3 Testing shall be in accordance with prEN ISO 22477-1:2014.

As long as a European Standard concerning static axially loaded tension test on pile is not available, the national standards can be used as reference for the requirements on this test.

9.3.1.4 Micropiles shall be allowed to gain sufficient strength after installation and before testing.

9.3.1.5 In the project specifications it shall be specified if static load tests have to be performed on micropiles.

9.3.2 Static load tests

9.3.2.1 General

Static load tests on micropiles can consist of:

a) maintained load tests;

b) constant rate of penetration/pull out tests.

9.3.2.2 Static load tests on preliminary micropiles

9.3.2.2.1 Static load tests on preliminary micropiles shall be performed when:

a) new techniques are used for the execution of the micropiles;

b) micropiles have to be installed in ground conditions for which previous tests are not available;

c) higher working loads are applied than those already adopted in similar ground conditions;

d) when the results of static load tests are used to determine the design load.

9.3.2.2.2 When static load tests are performed on preliminary micropiles at least two micropiles should be tested.

9.3.2.2.3 When choosing the location of preliminary micropiles, due consideration shall be given to ground conditions.

9.3.2.3 Static load tests on working micropiles

9.3.2.3.1 Unless otherwise specified, static load tests on at least two micropiles should be performed for the first 100 micropiles and 1 for every subsequent 100 micropiles.

9.3.2.3.2 Unless otherwise specified for tension micropiles static load test on at least two micropiles should be performed for the first 50 micropiles and 1 for every subsequent 50 micropiles.

9.3.2.4 Loading procedure

9.3.2.4.1 The loading procedure should be in accordance with EN 1997-1:2004, 7.5.2.1.

9.3.2.4.2 For static load tests on working micropiles the maximum proof load shall not jeopardize its serviceability.

9.3.2.4.3 The transverse displacements of the micropile head should also be measured during the test.

9.3.2.4.4 Testing should be carried out and evaluated in such a manner that the test represents the working load conditions. If, for example, a micropile is subjected to repeated loading and unloading, the test shall be carried out in a corresponding manner.

9.3.3 Dynamic load tests

9.3.3.1 The use of dynamic load tests should be limited to cases where experience or comparison with static load tests has demonstrated that the results can be interpreted in a confident way.

9.3.3.2 Dynamic tests shall be carried out using equipment built and approved for the purpose and are required to be interpreted by persons competent in this area who should also have a sufficient knowledge and experience of the techniques of piling and experience of the specific ground conditions.

9.3.3.3 The apparatus shall be used in accordance with the manufacturer’s instructions and the micropile shall be prepared for the purpose of testing in an appropriate manner.

9.3.3.4 The number of dynamic tests shall be defined in the project specification.

9.3.4 Low strain integrity tests

9.3.4.1 The use of integrity tests should be limited to cases where experience has demonstrated that the results can be interpreted in a confident way.

9.3.4.2 **I**ntegrity tests shall be carried out using equipment built and approved for the purpose and are required to be interpreted by persons competent in this area who should also have a sufficient knowledge and experience of the techniques of piling and experience of the specific ground conditions.

9.3.4.3 The number of integrity tests shall be defined in the project specification.

10 Records

10.1 General

Details of recording and the format of the site records shall be agreed before the commencement of the works.

10.2 Records for the execution of construction micropiles

10.2.1 The site records shall consist of two parts:

The first making reference to general information on the contract and to site conditions, including:

a) the micropile (type, dimensions, etc.);

b) the reinforcement and grout, mortar or concrete specification;

c) the construction method.

The second part shall contain particular information related to the construction of each micropile.

10.2.2 The general information part should be similar for the different types of micropiles and construction methods and should contain the details listed in Table 2 and Table 3.

10.2.3 The part of particular as-built information for each micropile should contain the details listed in Table 4.

10.2.4 As appropriate, the information can be provided in the form of:

— individual records;

— summary records for groups of micropiles of the same type, installed with the same construction method.

Table 2 — General information concerning the site

No.	Information	Necessity
1	Micropile contractor	X
2	Site name, location	X
3	Client/employer	(X)
4	Contract identification	X
5	Main contractor	(X)
6	Working drawing n°	X
7	Micropile works: quantity	X
8	Reference level of site	X
9	Level of piling platform	X
10	Ground water level	(X)

X Necessary information.

(X) Information as applicable.

Table 3 — General information concerning the micropile construction

No.	Information	Necessity
1	Micropile type	X
2	Micropile diameter	X
3	Reinforcement details	X
4	Spacers	(X)
5	Grout, mortar or concrete specifications	X
6	Grout, mortar or concrete placement	X
7	Drilling method	X
8	Drilling equipment	X
9	Drilling fluid	(X)
10	Groundwater / soil pollution	(X)
11	Top end of bearing element	(X)

X Necessary-information.

(X) Information as applicable.

Table 4 — Schedule of as-built information to be provided as applicable

No.	Information	Necessity
1	Micropile reference number	X
2	Date of execution	X
3	Installation time	X
4	Interruptions of installation	(X)
5	Obstructions	(X)
6	Depth of micropile	X
7	Plan position	X
8	Inclination	(X)
9	Depth of casing	(X)
10	Length of reinforcement	X
11	Level of top of reinforcement	X
12	Number and location of joints or welds	(X)
13	Number and distance of spacers	(X)
14	Data on borehole testing and pregrouting	(X)
15	Grout, mortar or concrete placement volume	X
16	Grout, mortar or concrete placement pressure	X
17	Grout, mortar or concrete site tests	(X)
18	Volume or diameter of base enlargement	(X)
19	Multi-stage grouting procedure	(X)
20	Construction deviations: position	X
21	Construction deviations: inclination	(X)
X Necessary information. (X) Information as applicable.		

10.2.5 Guidelines for the preparation of records are provided in Annex D.

10.3 Records for micropile tests

10.3.1 Recording requirements for static load tests and the format of the load test report shall be in accordance with EN 1997-1.

10.3.2 Records of dynamic load tests and integrity tests shall provide:

a) the reasons of the testing;

b) the test records;

c) the conclusions of the tests.

11 Special requirements

11.1 Regarding:

a) safety on the site;

b) safety of the working practices;

c) operational safety of micropiling and auxiliary equipment and tools,

the relevant European Standards shall be followed, or where these are not available or incomplete, respective national standards, specifications or statutory requirements regarding execution of micropiling works shall be observed.

11.2 Equipment shall be in accordance with EN 16228.

11.3 Particular attention shall be drawn to all processes requiring personnel operating alongside heavy equipment and heavy tools.

11.4 The extent of nuisance and/or environmental damage that can be caused by piling work shall comply with local regulations and European standards.

11.5 Such nuisance and/or environmental damage can be caused by:

— noise;

— ground vibration;

— ground pollution;

— surface water pollution;

— groundwater pollution; and

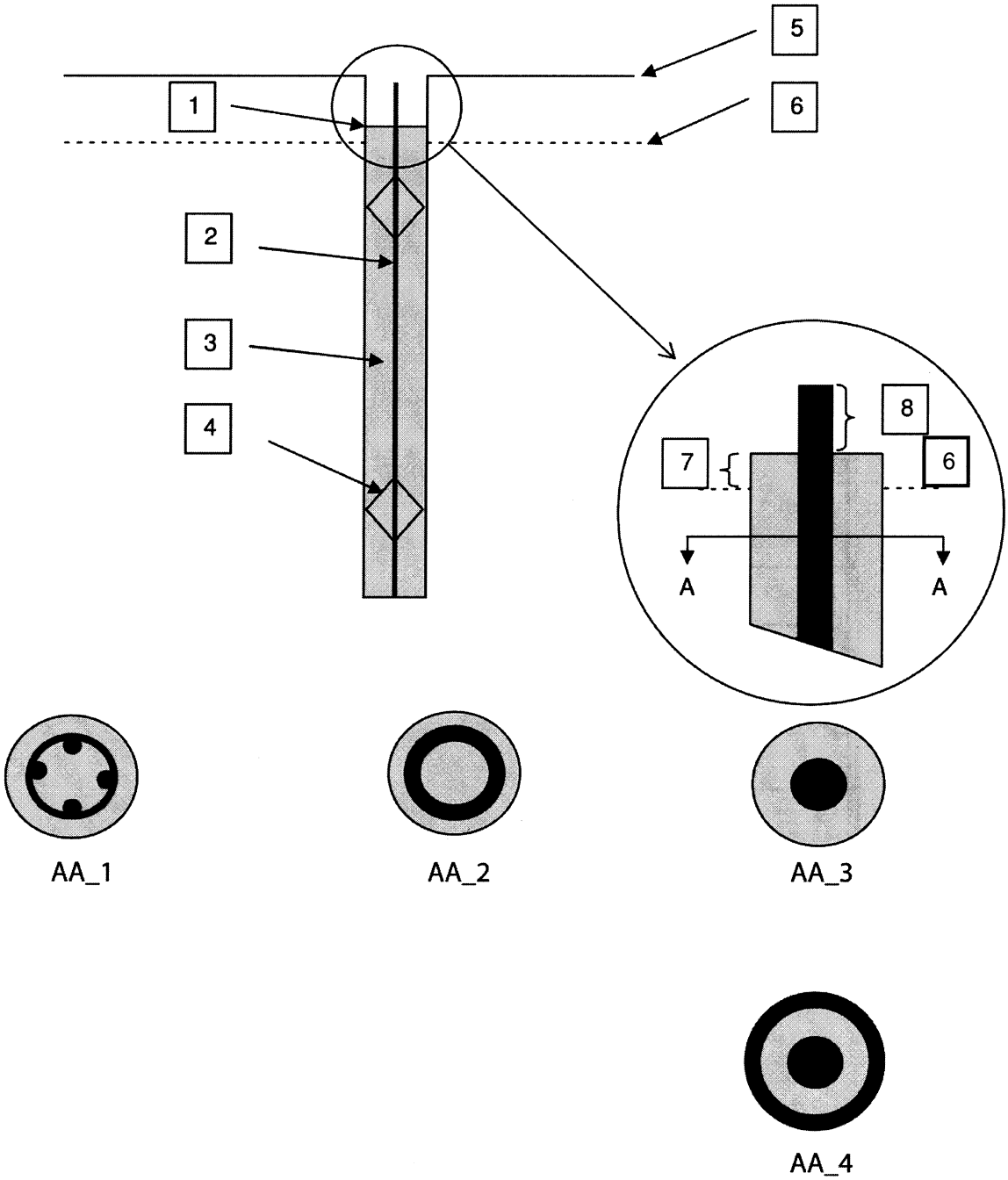
— air pollution.

NOTE The type and extent of possible nuisance or environmental impact depends on the location, the working method, the actual processes and the soil conditions.

11.6 Impact on adjacent structures and slopes

11.6.1 When specified in the project specification the condition of adjacent structures and slopes shall be carefully observed and documented prior and during the execution of the micropile works.

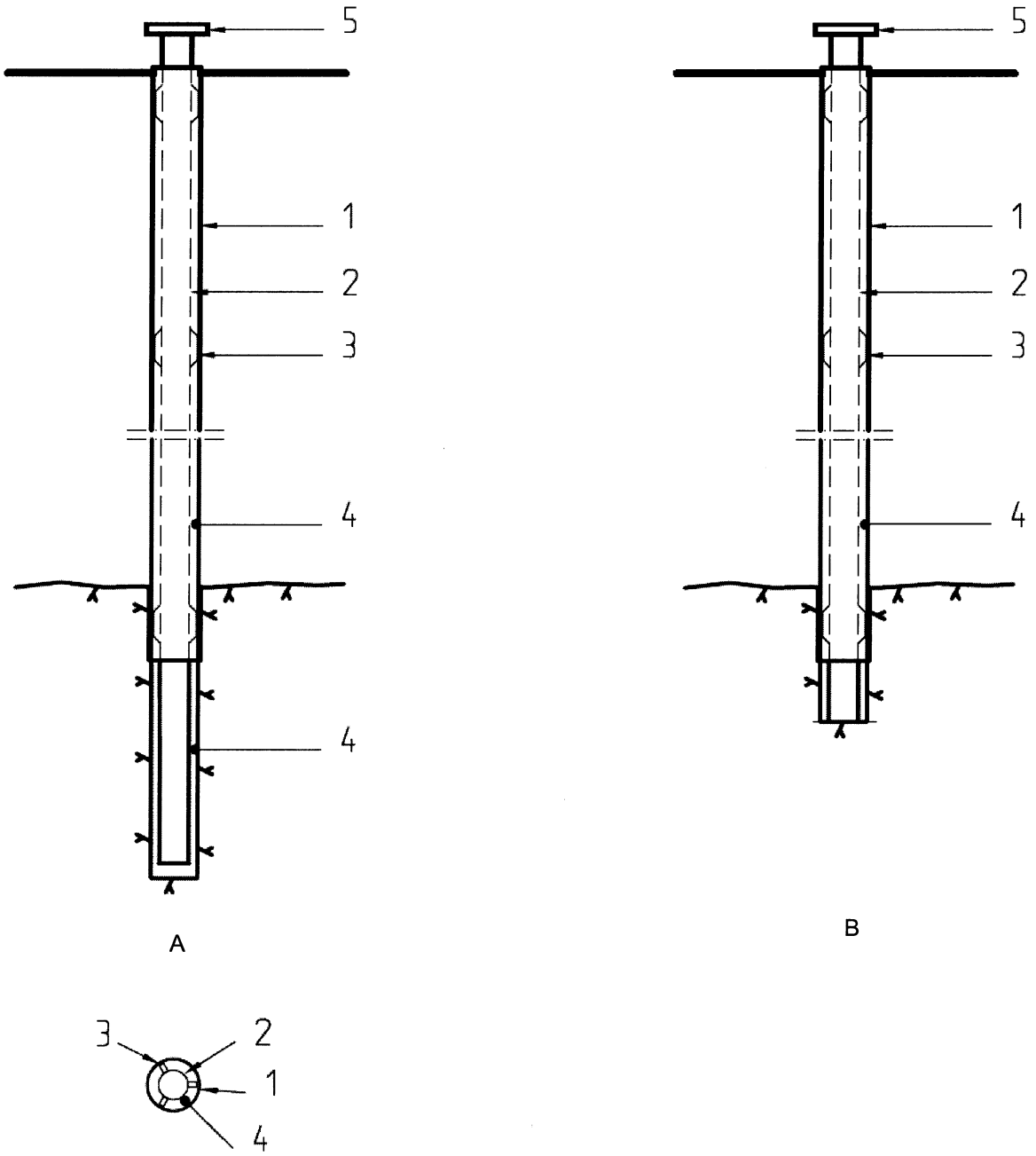
11.6.2 When specified in the project specification, surrounding structures and slopes shall be adequately monitored by repeated levelling and alarm systems shall be employed where appropriate.



Key

1	cut-off level	Section AA_1	alternative showing cage
2	bearing element	Section AA_2	alternative showing tube
3	grout, mortar or concrete	Section AA_3	single bar bearing element
4	centraliser	Section AA_4	optional external casing with single bar bearing element
5	piling platform		
6	formation/excavation level		
7	pile projection into foundation cap		
8	bearing element projection (overlength)		

Figure 1 — Typical components of micropiles



Key

A shaft bearing steel core pile (in the bedrock, below the permanent casing)

B end bearing steel core pile

1 permanent casing

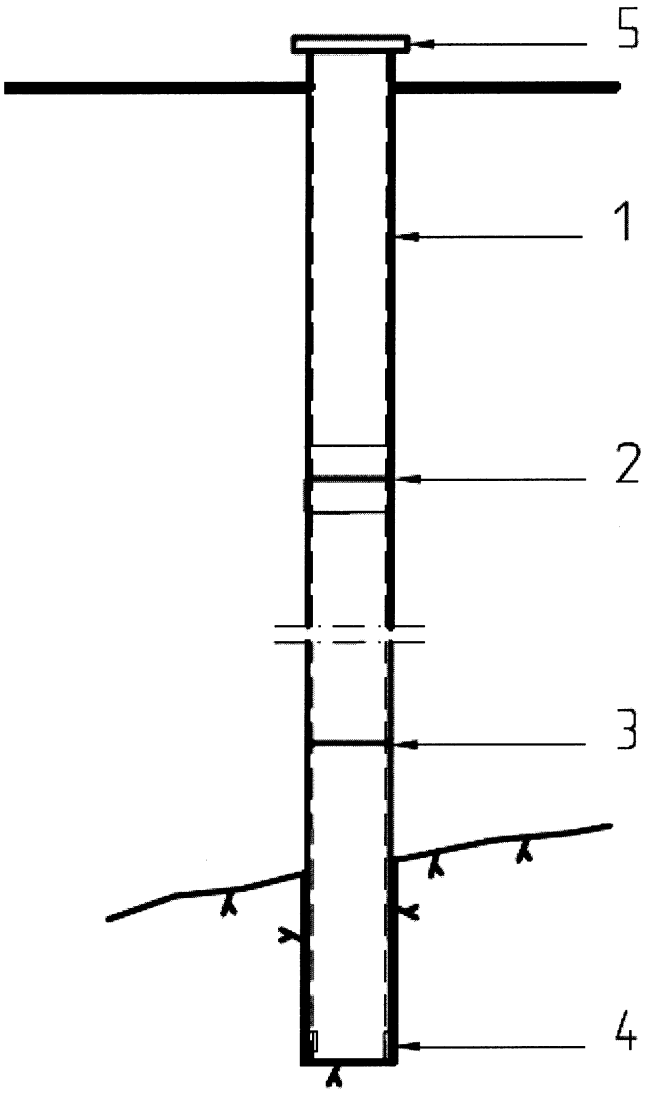
2 bearing element, steel core

3 centraliser

4 grout

5 bearing plate

Figure 2 — Example of steel core pile



Key

1 bearing element, steel pipe

2 mechanical joint or

3 welded joint

4 casing shoe and/or ringbit (depending on drilling system)

5 bearing plate

Figure 3 — Example of drilled end-bearing steel pipe micropile

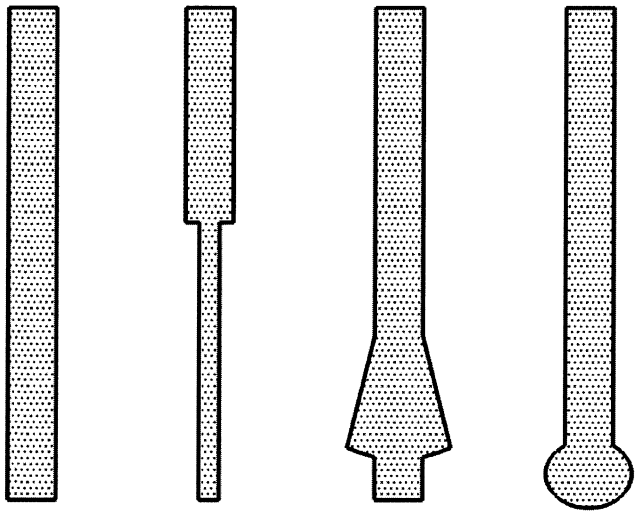


Figure 4 — Examples of micropile shafts and bases

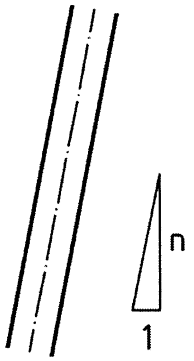
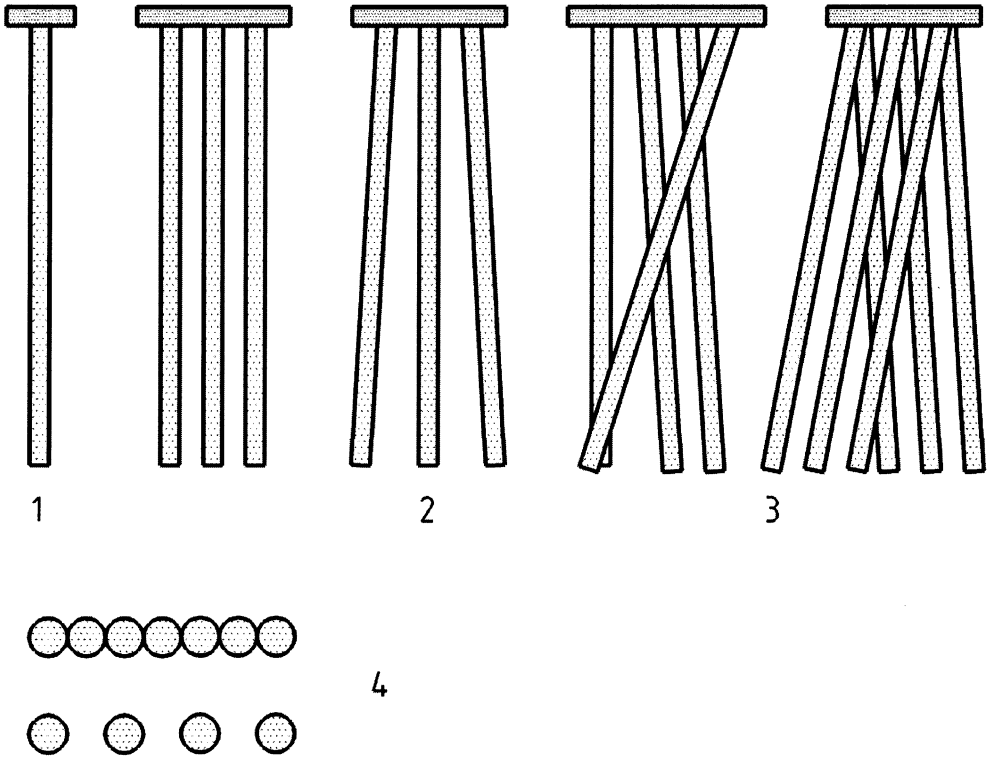


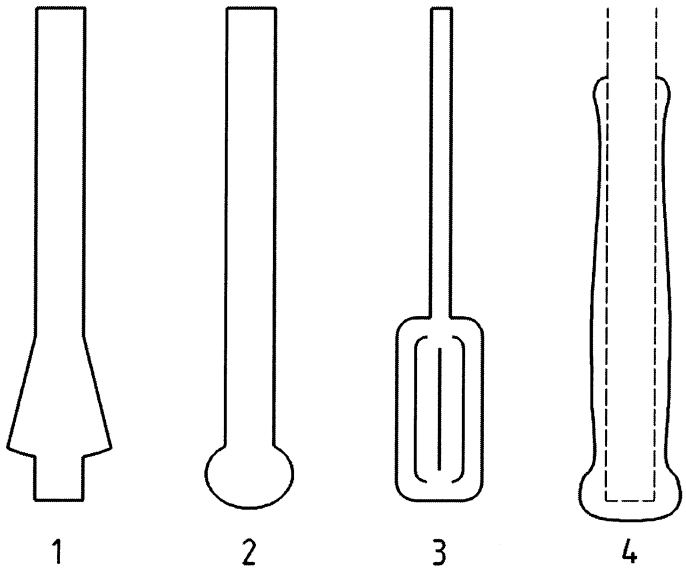
Figure 5 — Definition of inclination



Key

1 single micropile
2 micropile groups
3 reticulated micropiles
4 micropile walls

Figure 6 — Examples of micropile structures



Key

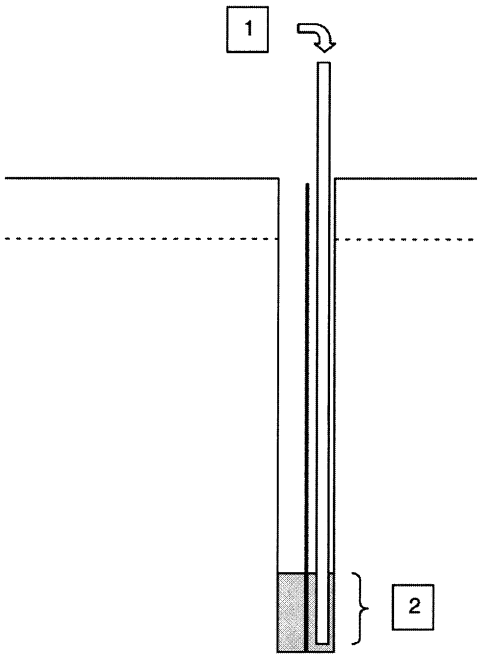
1 drilled micropile with base enlargement

2 cast-in-place cased micropile with base enlargement

3 micropile with base of expanded body

4 micropile with enlargement by grouting

Figure 7 — Examples of base and shaft enlargements

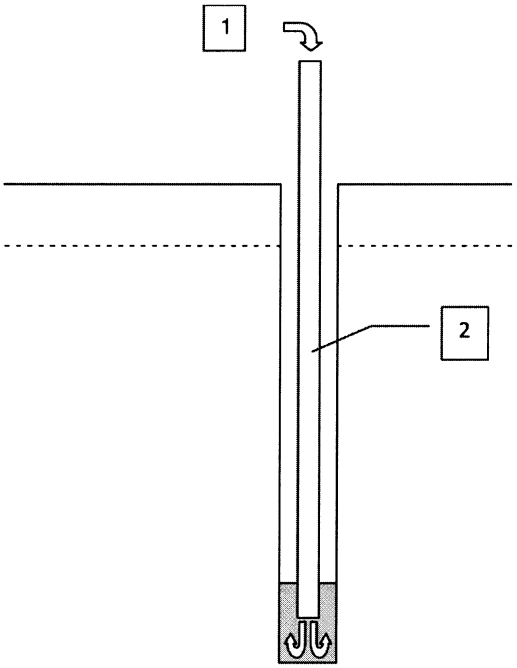


Key

1 grout, mortar or concrete is pumped via a tremie tube

2 tremie pipe always below the level of fill material

Figure 8 — Filling borehole through tremie pipe (bearing element in place first)

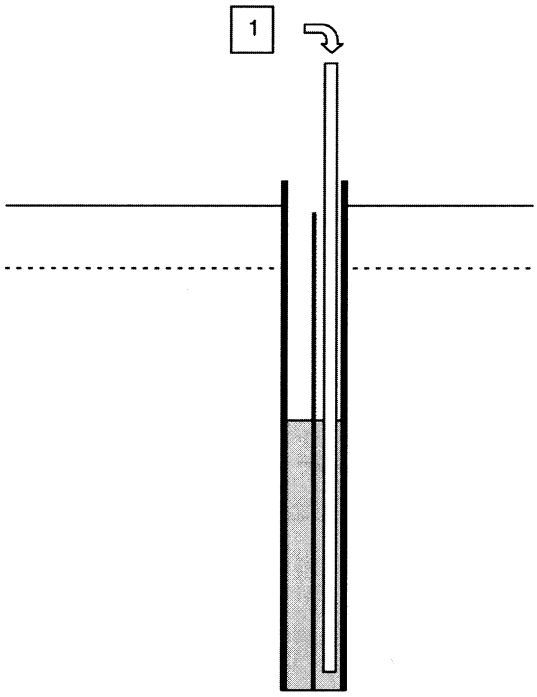


Key

1 grout, mortar or concrete is pumped via drill rods or bearing element

2 bearing element can be drill rod or hollow tube

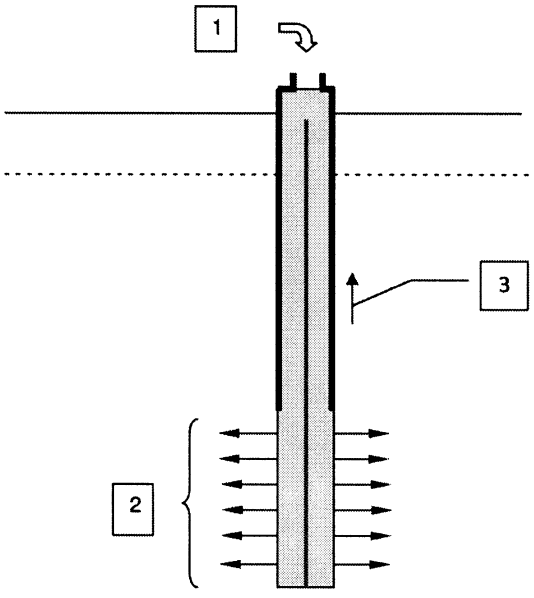
Figure 9 — Filling borehole through drill rods or bearing element



Key

1 grout, mortar or concrete is pumped via a tremie tube

Figure 10 — Filling borehole with temporary casing (no pressure)



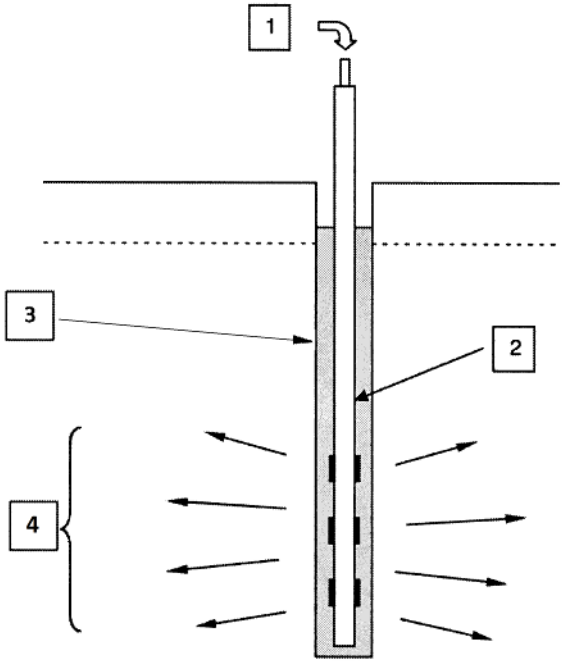
Key

1 grout, mortar or concrete is pumped via temporary casing under pressure

2 pressure is applied to soil through fluid grout at the time of filling

3 casing is progressively withdrawn as filling takes place

Figure 11 — Grouting borehole with temporary casing with applied pressure



Key

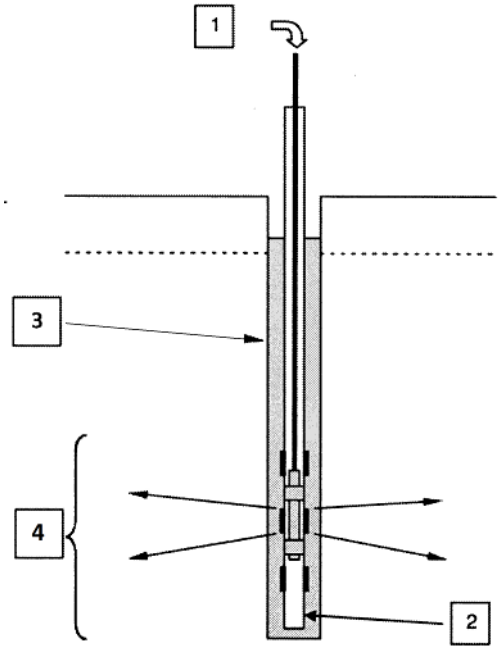
1 grout injected through tube-à-manchettes

2 tube-à-manchettes

3 grout placed in the borehole by filling which has set before grout is applied under pressure

4 all manchettes grouted at the same time with or without a packer in the tube. (Packer not shown).

Figure 12 — Single step grouting through tube-à-manchettes



Key

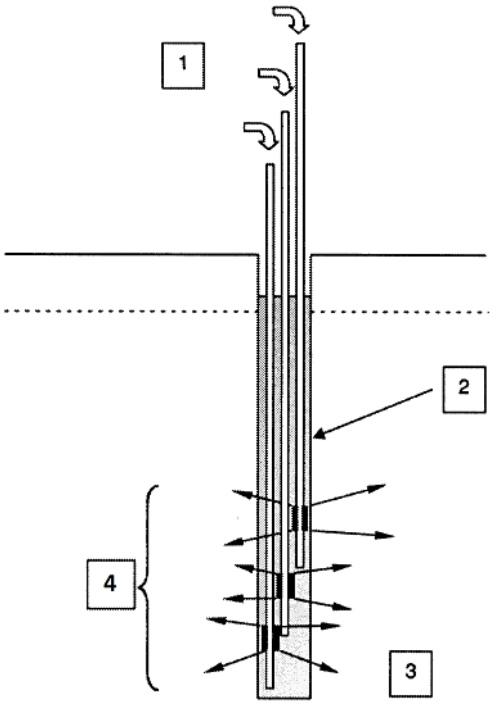
1 grout injected through grout pipe with packer

2 tube-à-manchettes

3 grout placed in the borehole by filling which has set before grout is applied under pressure

4 all manchettes grouted individually (shown with a packer in the tube)

Figure 13 — Multi step grouting through tube-à-manchettes



Key

1 grout injected through single tube-à-manchettes in succession

2 tube-à-manchettes

3 bearing element not shown

4 all manchettes grouted individually with or without packer (shown without packer)

Figure 14 — Single step grouting through tube-à-manchettes in succession

Annex A
(informative)

Execution methods of micropiles

Table A.1

Installation method	Reinforcement type	Filling/Grouting method	Grout type	Options
Rotary / flush drilling Percussion drilling Grab, chisel or bailer boring	Reinforcement cage	Filling, concreting	Grout mortar or concrete	Casing
		Single step grouting through temporary casing	Grout or mortar	
	Bearing element — solid bars — hollow bars — tubes — profiles	Filling, concreting	Grout, mortar or concrete	Casing
		Single step grouting through: — temporary casing; — bearing element; — tube-à-manchettes.	Grout	
		Multi-step grouting through: — tube-à-manchettes — special valves — post-grouting tubes	Grout	Enlarged shaft
		Grouting during drilling	Grout	Multi-stage grouting through bearing element
	Permanent casing (with or without reinforcement cage)	Filling or concreting	Grout, mortar or concrete	Enlarged base
Hollow stem sectional flight auger drilling	Reinforcement cage Bearing element	Grouting/Concreting through the hollow stem of the auger	Grout mortar or concrete	

Annex B
(informative)

Guidance on minimum cover (in mm) for bearing element of low strength steel for cast *in situ* micropiles

Table B.1

Exposure class[a]	Chemical aggressiveness	Bearing element with grout cover		Bearing element with mortar	
		Compression	Tension	Compression	Tension
X0	with permanent casing	10	10	25	25
X0, XC1 - XC4	Not existing	20[b]	20[b]	35	40
XD1, XD2	Chloride except salt water	20	20	35	40
XS1	Chloride from salt water	20	20	35	40

[a] For other Exposure classes in EN 206 minimum cover are given in EN 1992–1-1:2004, Clause 4, and the valid National Annex.

[b] For service life of maximum 5 years minimum grout cover may be reduced to 10 mm.

Annex C
(informative)

Borehole testing and pregrouting

For micropiles installed in weathered and strongly fissured rock borehole testing and pregrouting can be necessary to avoid uncontrolled loss of grout and to guarantee the required grout cover of the bearing element.

The likelihood of cement grout loss can be assessed from an analysis of a water injection test. Routinely a falling head test is applied to the borehole or part of the borehole length via a packer. Pregrouting is not usually required if leakage or water loss in the bore hole or part of the borehole is less than 5 l/min at an excess head of 0,1 MPa measured over a period of 10 min.

Pregrouting is carried out by filling the borehole with a cement based grout. Sand/cement grout is commonly employed in rock with partially filled or open fissures to reduce grout consumption.

On completion of pregrouting the borehole should be retested and if necessary, the grouting process should be repeated after redrilling.

Annex D
(informative)

Guideline for a record for micropiles

Table D.1

Micropile contractor Responsible at site			Sheet No. **Date:**			
Site, location Client Contract			**Micropile:** type, borehole diameter Reinforcement: type, grade, dia., spacers Grout: cement quality, w/c-ratio Mortar: class, max. grain, consistency Concrete: class, max. grain, consistency Placing method: casing, grout tube, tremie Drilling method: equipment, drilling fluid Specials:			
Drawing No. Total quantity of micropiles Pile length above/below platform Level of: site platform ground water						
Micropile number:						
	Date of construction					
	Start of drilling, time (hr)					
	Interruptions (hrs)					
	Obstructions at depth (m)					
	Depth of micropile (m)					
	Depth of casing (m)					
	Length of reinforcement (m)					
	Length above/below ground (m)					
	No. and location of joints/welds					
	Spacers at distance (m), quantity					
	Borehole testing (at depth/ bar)					
	Pregrouting (ltr or kg / bar)					
	Grout/Mortar/concrete volume (ltr or kg)					
	Max. pressure (bar)					
	Site tests of grout/concrete (type)					
	Base/shaft enlargement (ltr/dia.)					
	Post grouting (ltr or kg / bar)					
	Deviation of position (mm): x,y					
	Deviation of inclination (°)					

Annex E
(informative)

Degree of obligation of the provisions

The provisions are marked corresponding to their degree of obligation:

— RQ: requirement

— RC: recommendation

— PE: permission

— PO: possibility and eventuality

— ST: statement

Clause 1	ST
Clause 2	ST
Clause 3	ST
4.1.1	RQ
4.1.2	RC
4.1.3	RQ
4.2	RQ
4.3	RC
5.1.1	RQ
5.1.2	RC
5.1.3	RC
5.1.4	RQ
5.1.5	RQ
5.2	RQ
6.1	RQ
6.2.1	RQ
6.2.2	RQ
6.2.3	PE
6.3	RQ
6.4.1	RQ
6.4.2	PO
6.4.3	RC
6.4.4	RQ
6.4.5	RC
6.4.6	RC

6.4.7	RC
6.4.8	RQ
6.4.9.1	RQ
6.4.9.2	RC
6.4.9.3	RQ
6.4.9.4	RQ
6.5	RQ
6.6.1	PE
6.6.2	RQ
6.6.3	RQ
6.7	RQ
7.1.1	ST
7.1.2	ST
7.1.3	RQ
7.1.4	RQ
7.1.5	RQ
7.1.6	PO
7.2	RQ
7.3.1	RC
7.3.2	RQ
7.3.3	RC
7.3.4	RQ
7.3.5	RQ
7.3.6	RQ
7.3.7	RC
7.3.8	RQ
7.4.1	RQ
7.4.2	RC
7.4.3	PE
7.4.4	RQ
7.4.5	RQ
7.4.6	RQ
7.4.7	RQ
7.5.1	RQ
7.5.2	RQ
7.5.3	RQ
7.5.4	PE
7.6.1	RQ
7.6.2	RQ

7.6.3	RQ
7.6.4	PO
7.6.5	RQ
7.6.6	RC
7.6.7	RQ
7.6.8	RQ
7.6.9	RQ
7.6.10	RQ
7.6.11	RQ
7.7	RQ
7.8	RQ
7.9	RQ
7.10.1	RQ
7.10.2	RC
7.11.1	PO
7.11.2	RQ
8.1.1	RQ
8.1.2	RQ
8.1.3	RC
8.1.4	RQ
8.1.5	RC
8.1.6	RQ
8.1.7	RQ
8.1.8	RC
8.2	RQ
8.3.1	RQ
8.3.2	RC
8.4	RQ
8.5.1.1	RQ
8.5.1.2	PO
8.5.1.3	RQ
8.5.1.4	RQ
8.5.1.5	RQ
8.5.1.6	RQ
8.5.1.7	RQ
8.5.1.8	RQ
8.5.2.1	PO
8.5.2.2	RC
8.5.2.3	RQ

8.5.2.4	RQ
8.5.2.5	RQ
8.5.3	RQ
8.5.4	PO
8.6.1	PO
8.6.2	RQ
8.6.3	RC
8.6.4	RQ
8.6.5	RQ
8.6.6	RQ
8.7.1	RQ
8.7.2	RQ
8.7.3	RQ
8.7.4.1	RQ
8.7.4.2	RQ
8.7.4.3	RQ
8.7.4.4	RQ
8.7.4.5	RQ
8.7.4.6	PE
8.8.1.1	RQ
8.8.1.2	PE
8.8.2.1	RQ
8.8.2.2	RQ
8.8.2.3	RQ
8.8.2.4	RQ
8.8.2.5	RQ
8.8.2.6	RC
8.8.2.7	RQ
8.8.2.8	RC
8.8.3	PO
8.8.4.1	RQ
8.8.4.2	RQ
8.8.4.3	RQ
8.8.4.4	RC
8.8.4.5	RQ
8.8.4.6	RQ
8.8.5.1	PQ
8.8.5.2	PE
8.8.6.1	PO

8.8.6.2	PO
8.8.6.3	RQ
8.8.7.1	ST
8.8.7.2	RC
8.8.7.3	RC
8.8.8.1	PO
8.8.8.2	RQ
8.8.8.3	RQ
8.8.8.4	RQ
8.8.8.5	RQ
8.9.1	RQ
8.9.2.1	RQ
8.9.2.2	RQ
8.9.2.3	RQ
8.9.2.4	PE
8.9.2.5	RQ
8.9.2.6	RQ
8.9.2.7	RQ
8.9.2.8	RQ
8.9.3.1	RQ
8.9.3.2	RQ
8.9.3.3	RQ
8.9.3.4	RQ
8.9.3.5	RQ
8.9.3.6	RC
8.9.3.7	RQ
8.9.3.8	PE
8.9.3.9	RQ
8.9.3.10	RC
8.9.3.11	RC
8.9.3.12	RQ
8.9.3.13	RC
8.9.3.14	RC
8.9.3.15	RQ
8.10	RQ
9.1	RQ
9.2.1	RQ
9.2.2	RQ
9.2.3	RC

9.2.4	RQ
9.2.5	RQ
9.2.6	RQ
9.2.7	RQ
9.3.1.1	PO
9.3.1.2	ST
9.3.1.3	RQ
9.3.1.4	RQ
9.3.1.5	RQ
9.3.2.1	PO
9.3.2.2.1	RQ
9.3.2.2.2	RC
9.3.2.2.3	RQ
9.3.2.3	RC
9.3.2.4.1	RC
9.3.2.4.2	RQ
9.3.2.4.3	RC
9.3.2.4.4	RC
9.3.3.1	RC
9.3.3.2	RQ
9.3.3.3	RQ
9.3.3.4	RQ
9.3.4.1	RC
9.3.4.2	RQ
9.3.4.3	RQ
10.1	RQ
10.2.1	RQ
10.2.2	RC
10.2.3	RC
10.2.4	PO
10.2.5	ST
10.3	RQ
11.1	RQ
11.2	RQ
11.3	RQ
11.4	RQ
11.5	PO
11.6	RQ
Annex A	informative

Annex B	informative
Annex C	informative
Annex D	informative
Annex E	informative

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