Elaboration of a European standard on Micropiles

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A. Introduction

During a period of 4 years the working group 8 of TC 288 gathered 11 times for the elaboration of a European standard on micropiles.

The working group consisted of national delegates of 14 countries, a technical editor and a convenor. For some meetings other experts have been invited.

The main points of discussion have been:
- the definition of a micropile
- the classification of micropiles and execution methods
- the definition of corrosion protection criteria
- the definition of injection criteria
- the definition of testing criteria.

Already in a very early stage it was proposed to maintain in the definition of a micropile a different diameter for piles installed by drilling and for piles installed by driving. As for piles installed by driving there was an overlapping with prEN on displacement piles it took a very long time before an agreement on the definition could be obtained. Finally to overcome the overlapping with pr EN a lower limit for the diameter of displacement piles has been introduced in pr EN. Finally a maximum outer diameter of 300mm has been adopted for micropiles installed by drilling and of 150mm for micropiles installed by driving.

As the standards for bored piles and displacement piles were already available due attention has been given to avoid discrepancies between this standards and the standard on micropiles. In some cases references are made directly to this standards.

After a few meetings it appeared clearly that it would be impossible to define a limited number of micropile types as has been done for instance in the French DTU standard. Therefore it has been decided to describe only execution methods and procedures and not micropile types.

For the corrosion protection the criteria introduced into the standard are a compromise of the actual normal practise in the different countries. For this item discrepancies with Chapter 5 of ENV 1993 on steel foundation piles had also to be avoided.

For the injection criteria only general principles are given in the standard. This is mainly due to the fact that on this moment very different techniques are used in the different countries. So it becomes impossible to define detailed criteria that are generally acceptable.

For the testing criteria rather precise information is given in the standard on the number of piles to be tested. Here also a compromise had to be found between the normal practise in the different countries.

As a closing remark it has to be stated that it was rather disenchanting to assess that during the meetings of the working group the discussions concerned mostly very specific and only exceptionally used items. This is probably due to the fact that for the execution of micropiles no techniques are available that are generally used.

B. Selection of important paragraphs:

1. Scope

1.1 This standard establishes general principles for the execution of piles:
- which have a small diameter (smaller than 300 mm outside diameter for bored piles and smaller than 150 mm for displacement piles).
- and which can be typically installed by means of small rigs

These piles are herein after referred as "micropiles".

1.2. Micropiles are structural members to transfer actions and may contain bearing elements to transfer loads and or to limit deformations. Their shaft and base resistance may be improved (mostly by grouting) and they may be constructed with: (see fig.1).

-uniform cross section (straight shaft)
-telescopically changing shaft dimensions or
-shaft enlargements and/or
-base enlargements

1.3 Other than practical considerations, there are no limitations regarding shaft or base enlargements, length , rake (definition of rake, see fig.2) or slenderness ratio.

1.4 The provisions of the Standard apply to (see fig.3)

-single micropiles
-micropile groups
-micropile walls
-reticulated micropiles

1.5 The piles which are the subject of this Standard can be installed into the ground using drilling, driving or a combination of these methods.

1.6 The material of micropiles covered by this Standard can be:

-steel, cast iron or other reinforcement materials
-grout, mortar or concrete
-a combination of above.

1.7 Mixed-in-place columns and timber piles are not included in this standard. Columns constructed by jet grouting are covered by prEN 12716. Ground anchors are covered by EN1537. Nails used in soil reinforcement are covered by prEN WG9/TC288.

1.8 Micropiles are often used for working under restricted access and/or head room conditions and for the underpinning of existing structures.

1.9 Micropiles may be used for:

-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,
-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.

2. Normative references

3. Definitions

3.1 micropile

fr : micropieu
de : Mikropfahl

Piles which have a small diameter (smaller than 300 mm outer diameter for bored piles and smaller than 150 mm for displacement piles) and can be installed with small rigs.

3.17 grout

fr : coulis
de : Verpressgut / Injektionsgut

A setting material, usually cement and water, which transfers load from the bearing element or the pile shaft to the ground and/or contributes to corrosion protection.

3.18 mortar fr : mortier
de :Verpressmörtel

Concrete with very small aggregates (< 8 mm)

3.30 load bearing element fr: élément porteur
de:Tragglied

Element of steel , cast iron or other material that is capable of transmitting the load from the structure to the ground.

3.31 drilling fluid/ mud fr: fluide de forage, boue
de:

Water or a suspension of bentonite, polymers or clay, in water with or without cement and other additions, for stabilisation of borehole walls and for flushing.

4. Information needed to start the work on site.

4.1. Information needed for general foundation works

4.2. Additional needs for micropiles:

4.2.1. General

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

4.2.2. (RC) The following information should be considered before commencement of micropile works and made available where applicable:

- previous experience with micropiles or other foundations or underground works on or adjacent to the site.
- chemical aggressiveness of soil and/or groundwater
- potential instability of the soil
- presence of existing piles, anchors,and/or other artificial obstructions in the ground (as for example wood, steel, etc. ...)
- acceptable deformation of adjacent structures.

4.3. Additional needs for underpinning works.

4.3.1. (RC) The following information should be considered before commencement of underpinning works and made available where applicable:

- dimensions and composition of existing foundations, floors, drainage and groundwater lowering systems
- condition of structure to be underpinned
- acceptable deformation of the structures to be underpinned.

5. Site investigation

5.1. General

5.2. Specific aspects

5.2.1. (RQ) 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 function of the micropiles (end bearing and/or friction bearing).

5.2.2. (RQ) The site investigation shall demonstrate that, where end bearing is to be relied on, any competent founding stratum is not immediately underlain by a soft stratum where there is a possibility of a punching failure or unacceptable settlements.

5.2.3. (RQ) The following information, when relevant for the execution of micropiles, shall be given in the ground investigation report:

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 should be monitored separately and over a sufficient period of time to estimate the highest piezometric levels which may occur during the installation of the micropiles. Particular attention shall be paid to artesian conditions and rapid underground water flows (more than 30 meters a day).

b) presence of coarse highly permeable soils or cavities (natural or artificial) which may 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 may cause difficulties during execution or loading of piles (deformation or instability of the borehole, risk of buckling)

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

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

NOTE: In some cases it may also be 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.

6. Materials and products

6.1. General

6.2. Reinforcement and load bearing elements

6.2.2. Steel for load bearing elements:

6.2.2.1 (RQ) Steel bearing elements shall comply:

- with EN 10080 or prEN 10138 when bars are used
- with EN 10210 or EN 10129 when hollow sections (e.g. tubes) are used
- with EN 10025 or EN 10113 when hot rolled products (e.g. H-sections) are used

6.2.2.4 (RQ) Re-used and second choice steel bars, tubes and sections shall as a minimum comply with the requirements concerning type, size, tolerances, quality and steel grade specified in the design and be free from damage, deleterious matter and corrosion that would affect strength and durability.

6.2.3 Cast iron piles and castings.

6.2.3.1 (RQ) Cast iron for bearing elements and castings shall comply with the specifications of the manufacturer and the specifications of the design.

6.2.4 Other materials for reinforcement and load bearing elements:

6.2.4.1 (PM) Other materials may only be used if their suitability have been proven and they are approved by the Client's Technical Representative.

6.2.4.2 (RQ) Other materials shall meet the design specifications.

6.3. Materials for grout, mortar and concrete

6.4. Cement grout

6.4.1(RQ) Grout composition and the grouting technique and procedure shall be planned and carried out in a manner appropriate to the application (e.g. pile shaft grouting around precast elements, base or shaft grouting) and the ground conditions.

6.4.2 (PO) Sand and fillers can be used in cement grouts as bulking agent or as a means of varying the consistency of the grout, its resistance to wash out, or its mechanical strength or deformability.

NOTE: Unless otherwise specified cement grouts to which filler or sand (maximum grain size 2 mm) is added to a quantity by weight of less than 1.0 times the cement quantity are still considered as a cement grout. For more quantity of filler or sand, the mix shall be considered as a mortar.

6.4.3 (RC) Water/cement ratio should be appropriate to actual ground conditions and unless otherwere specified, not more than 0,55.

6.4.4 (RC) Unless otherwise specified the minimum cylindric compressive strength should be at least 25 MPa at 28 days with test samples having height-diameter ratio equal to 2.

NOTE: When the compressive strength is determined on cubes or cylinders having a different height – diameter ratio, the transfer coefficients available for concrete can be used to deduce the cylindric compressive strength.

6.4.5 (RC) Laboratory and field tests should be undertaken to verify mixture,
mixture efficiency, setting time and performance. These tests should be undertaken in accordance with EN 445 where applicable.

6.4.6 (RC) Unless otherwise specified, the allowable bleed after 2 hours should be less than 3%.

6.4.7 (RC) For cement-grout used to encase a reinforcement within an encapsulation, the mix should be designed to prevent bleeding and shrinkage.

6.4.8 Quality control.

6.4.8.1 (RQ) The quality of the grout shall comply with the required characteristics and shall be checked during the works by control tests.

6.4.8.2 (RC) On site, the grouts should be subjected to the following routine tests:
- density at the inlet and the outlet of the borehole
- viscosity (Marsh value), where applicable
- setting time
- bleed

6.4.8.3. (RQ) 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.

6.4.8.4. (RQ) When mixing automatically, the batching process shall be checked periodically and when not mixing automatically, the batching process shall be recorded.

6.5. Mortar.

6.5.1 (RQ) The mix composition shall be in accordance with ENV 206

6.5.2 (RQ) Mortar for micropiles shall:
- have a high resistance against segregation;
- be of high plasticity and good cohesiveness;
- have good flowability;
- have the ability to self-compact and;
- be sufficiently workable for the duration of the placement procedure,including the removal of any temporary casings.

6.5.3 (RQ) Unless otherwise specified the design strength class of mortar used for micropiles shall be at least C 25/30, with water/cement ratio < 0,6

6.5.4 (RQ) The size of the aggregate shall not exceed the following grain size distribution:
d 85 <= 4 mm
d100 <= 8 mm

6.5.5 Quality control

6.5.5.1. (RQ) Control tests shall be performed in accordance with ENV 206.

6.6 Concrete

6.7 Spacers, centralisers and other components

6.8 Paints, coatings and other protection compounds

6.9 Drilling fluids

7. Design related considerations

7.1 Preliminaries

7.2. General

7.2.1 (RQ) The design of micropiles shall establish the type and size of micropiles and show that its installation is appopriate for the particular ground conditions and environmental constraint.

7.2.2 (RQ) If no comparable experience exists regarding the execution, one or more preliminary piles shall be installed at chosen locations before the main works commence.

NOTE: The installation of a preliminary pile offers the possibility of investigating execution procedures and equipment, and to assess the effect of the micropile installation on soil behaviour and the environment.

7.2.3 (RQ) The design shall take also into account
- the geometrical construction tolerances
- the specific execution restrictions.

7.3. Geometrical construction tolerances.

7.3.1 (RQ) The geometrical construction tolerances shall be given in the documentation.

NOTE: Guidance on construction tolerances are given in annex C.

7.3.2 (RQ) 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.

7.4 Installation

7.5. Reinforcement.

7.5.1(RQ) The reinforcement cage for cast in place micropiles shall be designed not only to have adequate strength in the final pile, but also adequate strength and stiffness during handling of the cage and construction of the pile. It shall also allow the fresh grout, mortar or concrete to flow easily around each of its components.

7.5.2 (RQ) Unless otherwise specified, cast in place concrete micropiles shall be reinforced over their full length.

NOTE: A cast in place 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 pile and, if
- the micropile is not located in a seismic area.

7.5.3 (RQ) Starter bars or dowel bars for connection to a superstructure shall be in accordance with ENV 1992-1-1.

7.5.4 (RQ) When steel reinforcement is considered as the bearing member of a micropile, the design shall be in accordance with ENV1993.

7.5.5 (RQ) When steel reinforcement and mortar or concrete are considered as bearing members of the pile, the design shall be in accordance with ENV1992 or ENV 1994.

7.5.6 (RQ) The design value of bond strength between grout, mortar or concrete and the bearing elements of steel or cast iron in accordance with ENV 1994-1 (bars, tubes or sections) shall have been agreed before the commencement of the works.

7.5.7 (RQ) Unless otherwise specified the bond strength between grout mortar or concrete and the bearing element of steel or cast iron (bars, tubes or sections) shall be at least 400 kPa.

7.5.8 (RQ) The grout, mortar or concrete cover, shall be specified in the design documents according to 7.7.

7.6 Couplers and nipples

7.7 Corrosion protection of steel elements.

7.7.1 Steel components of low strength steel: (σ_e < 600 MPa):

7.7.1.1 (RQ) 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,..)
- the type of load (tension or compression) and
- the micropile type.

NOTE: A corrosion protection may consist of:

- a minimum cover of grout, mortar or concrete
- a loss of steel thickness
- specific precautions

7.7.1.2 (RQ) Unless otherwise specified for micropiles situated in a low aggressive environment (in accordance to ENV 206) no specific precautions against corrosion shall be taken when the minimum cover exceeds the values given in table 2.

Table 2

Minimum cover for reinforcement of low strength steel for cast in place micropiles in a low aggressive environment.

	Micropiles designed for working only	Micropiles designed for working in compression	Micropiles designed for working in tension and /or in bending
Grout		20 mm	30 mm
Mortar		35 mm	40 mm
Concrete		50 mm	50 mm

NOTE: Choise of class of environmental aggressiveness should be done with a specific care (e.g. Its evolution with time should be considered) and take into account the type of cover (grout, mortar or concrete).

7.7.1.3 (PM) For micropiles with a design life time of less than 2 years, the minimum cover may have 10 mm less than the value given in table 2.

7.7.1.4 (RQ) Values of the grout cover smaller than those given in Table 2 shall only be applied when the loss of steel thickness and possible debonding from the steel are considered in the design.

NOTE: Guidance on corrosion rates are given in annex D.

7.7.1.5 (RQ) : If corrosion is taken into account as corrosion allowance, only effective cross section shall be utilized in dimensioning.

7.7.1.6 (PO) In some cases par. 7.7.1.4 may be applied to couplers only and not to the reinforcing elements.

7.7.1.7 (PM) The grout, mortar or concrete cover of reinforcement given in table 2, installed inside a permanent casing may be reduced by 10 mm from the internal face of the casing if the thickness of the permanent casing is at least 4 mm.

7.7.1.8 (RQ) For micropiles in an aggressive environment (e.g. classes ... in accordance with ENV 206) specific precautions shall be taken by:

- using special cement type ...
- a greater thickness of grout cover or special mix design
- considering an extra loss of steel thickness
- special corrosion protection as described in ENV1537
- the use of an adequate chemical steel composition
- cathodic protection
- organic or inorganic coatings or treatment
- use of permanent casings or liners.

7.7.2. Steel components of high strength steel (σ_e > 600 MPa) and pre stressed steel:

7.7.2.1 (RQ) When steel components of high strength steel and pre stressed steel are used corrosion protection shall be in accordance with ENV 1537.

7.8 Spacers and centralisers

7.9 Micropile enlargement

7.10 Connections to the superstructure

7.11 Spacing of micropiles

7.12. Special requirements for micropiles installed through very soft and unstable soils.

7.12.1 (ST) In unstable soils it can be necessary to provide a sacrificial lining or permanent casing to contain the fresh grout, mortar or concrete.

7.12.2 (RC) For micropiles installed through soil layers with characteristic undrained shear strength of less than 15 kPa buckling should be considered taking into account the construction tolerances.

8. Execution

8.1 General

8.2 Site preparation

8.3 Sequence of installation

8.4 Drilling.

8.4.1. General

8.4.1.1 (ST) For the construction of micropiles the following drilling methods can be used by considering the actual soil and water conditions:

=> direct circulation drilling system
=> cased direct circulation drilling system
=> percussion drilling using top or down-the-hole hammer
=> cased percussion drilling with direct or reverse circulation
=> continuous flight auger drilling
=> grab, chisel and bailer borings
=> driving of a casing and excavation during driving or afterwards

NOTE : When constructing micropiles by drilling, continuous drilling with flushing for the removal of soil is the most common method.

8.4.1.2 (RQ) When compressed air and/or water flushing is used during the drilling sequence, the influence of the compressed air and/or the water flushing effect on the already installed micropiles as well as excessive disturbance of underlying soil layers shall be considered.

8.4.1.3 (RQ) Pile bores shall be drilled until they reach:
-the specified embedment in the bearing stratum or
-the anticipated founding level or
-the prescribed length.

8.4.1.4. (RQ) Boreholes shall be checked for position and length.

8.4.1.5 (RQ) Boreholes shall be checked for inclination and orientation when specified.

8.4.1.6 (RQ) For end bearing micropiles, methods to counteract the deposit of remolded or loose disturbed materials and the negative effects of these deposits on the end bearing capacity shall be identified in advance and implemented as and when required.

8.4.1.7 (RQ) Where the ground conditions differ from those stipulated in the design or where unexpected underground obstructions are encountered, appropriate action shall be taken in agreement with the designer.

8.4.2. Choice of drilling method

8.4.2.1 (RQ) The drilling method to be used shall be decided by taking care of all requirements of soil and foundation conditions, and in such a way that the designed length can be reached and that a stable borehole of the intended geometrical cross section is created over the entire length .

8.4.2.2. (RQ) The type of drilling shall:
- be appropriate to the given soil, rock, groundwater or other environmental conditions
- be selected with a view to preventing loosening of material outside the pile bore and below the base

8.4.2.3 (RQ) When uncontrolled inflow of water and soil into the borehole occurs or when there is a risk of collapse, special measures shall be taken to maintain the stability and thereby prevent the uncontrolled entry of soil and water.

NOTE : 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 or concrete in the pile or piles recently installed nearby
- voids in the shaft during grouting or concreting
- washing out of cement.

NOTE : There are increased risks in:

- loose granular ground:
- soft cohesive ground or;
- ground which is variable.
- when using a DTH hammer with direct circulation under the groundwater table.

8.4.2.4. (RC) If necessary the method or tool employed should be changed in order to prevent uncontrolled inflow of water and soil into the borehole.

8.4.3. Drilling methods with flushing for soil removal.

8.4.3.1 (ST) Drilling can be performed with water, air and drilling fluids according to par.6.10.

8.4.3.2 (RC) For underpinning works drilling methods with air as flushing medium should be used with care to avoid disturbance or fracturing of the soil.

8.4.3.3 (RQ) For shaft bearing piles, the drilling method shall be chosen with due regard to the ground conditions so as to cause either minimum ground modification or the modification most benificial to the shaft bearing capacity to be mobilised.

8.4.3.4 (RQ) The drilling fluid (flushing medium) shall not impede the success of any subsequent grouting operation.

8.4.3.5 (RQ) Special care shall be taken when drilling through ground under artesian conditions at the working platform.

8.4.3.6 (RQ) Techniques to conteract the water pressure and to prevent any blow-out, hole collapse and erosion during drilling, installation and grouting operations shall be identified in advance and implemented as and when required.

NOTE: In high water table situations it may be appropriate to perform the drilling from a higher working level or to use heavy drilling fluids.

8.4. 4. Boreholes supported by casings.

8.4.4.1 (RC) Casings should be used when the borehole is unstable or there is a significant fluid loss or when grouting under pressure is performed through the casing.

NOTE: When forming a micropile the casing is installed generally during the drilling with continuous drilling method using fluid for the removal of the soil.

8.4.5 Boring with continuous flight augers:

8.4.5.1 (RQ) Boring with continuous flight augers shall be done in accordance with par. 8.1.5 of prEN 1536.

8.4.5.2. (ST) No special limitations exist concerning the inclination on the basis that the direction of excavation is controlled and the installation of the reinforcement can be achieved correctly.

NOTE: Normally grout or mortar is used for the realisation of micropiles with continuous flight augers

8.5 Driving

8.5.1 General:

8.5.1.1 (RQ) Driving shall be performed in accordance with pr EN 12699

8.5.1.2 (RQ) When impact or vibrating driving methods are applied for underpinnig works, their feasibility shall be proven (e.g. with comparable experience taking into account the soil type and the condition of the structures to be underpinned)

8.5.1.3 (RQ) The driving method to be used has to be decided by taking care of all requirements of soil, foundation conditions and site environment.

8.5.1.4 (RQ) The driving shall be done with equipment which allows penetration to the prescribed depth or to attain the required resistance without damage and limiting environmental disturbance.

8.6 Reinforcement and load bearing element

8.7 Grout preparation

8.8 Grouting

8.8.1 General

8.8.1.1 (ST) The following grouting methods can be employed (see fig.6):

- filling up the borehole with grout
- grouting under pressure:
  - single step through a temporary casing
  - single step through a bearing element
  - single step through tube-à-manchettes
  - multiple step through tube-à-manchettes
- grouting during driving

NOTE: Grouting meets one or more of the following functions:

- to create or improve the bond between the pile shaft and the surrounding ground to allow the design shaft bearing capacity to be mobilised.
- to protect the reinforcement against corrosion
- to improve the structural capacity of the micropile
- to strengthen the ground immediately adjacent to the micropile in order to enhance the ground pile capacity.
- to seal the ground immediately.

8.8.1.2. (RQ) The method of grout placement shall be determined by the ground conditions, the job specifications (shaft and end bearing capacity) the type of grout and equipment used.

8.8.1.3 (PM) For friction bearing micropiles, high pressure multistage 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.

8.8.3. Filling up the hole with grout.

8.8.3.1 (RQ) The interval between the completion of the hole and the filling up of the hole with grout shall be kept as short as possible.

8.8.3.2. (RQ) During grouting of the micropile measures shall be taken to ensure that the pile length is fully grouted.

8.8.3.3. (RQ) When filling up the hole with the tremie method or through the drill rods or reinforcement, the end of the tremie pipe or drill rods shall remain submerged in the grout and grouting shall continue until the consistency of the grout emerging is almost the same as that of the injected grout.

8.8.3.4 (RQ) When filling up the hole, air and drilling fluids shall be able to escape to permit complete grout filling.

8.8.3.5 (RQ) For drilled holes the remained cuttings shall be able to escape when filling the hole.

8.8.4. Grouting under pressure.

8.8.4.1 General

8.8.4.1.1 (RQ) The grouting pressure shall be specified in the project documentation or defined in the method statement.

8.8.4.1.2 (RC) Grouting under pressure should be stopped when a sudden drop down of the injection pressure is observed.

8.8.4.2 Single step grouting trough a temporary casing

8.8.4.2.1 (RQ) The reinforcement shall be placed before the temporary casing is extracted.

8.8.4.2.1 (RQ) During extraction of the temporary casing the grout level within the casing shall be brought back up to ground level before the next length of casing is removed.

8.8.4.2.2 (RC) The injection pressure should be applied at least every 2 m during the extraction of the casing.

8.8.4.3 Single step grouting through a bearing element.

8.8.4.3.1 (ST) When tubes are used as bearing element single step grouting can be applied at the bottom of the bearing element.

8.8.4.3.2 (RQ) When the specified grouting pressure cannot be applied, reinjection shall be performed after a certain waiting period until the specified grouting pressure can be applied.

8.8.4.4 Single and multiple step grouting through tube – à – manchettes.

8.8.4.4.1 (RQ) The intermediate distance between the injection points shall not be larger than 1 m over the length where load transfer into the ground takes place.

8.8.4.4.2 (RQ) Immeditately after the completion of the borehole, the borehole shall be filled up with grout according to par. 8.8.3 and the tube- à - manchettes shall be introduced immediately afterwards.

8.8.4.4.3 (PM) In some cases the grout may be installed after introducing the tube-à-manchettes

8.8.4.4.4 (RQ) The grouting phase shall take place only after the filling grout has set

8.8.4.4.5 (RQ) The grouting shall be carried out either in single or multiple step and according to the design and technical specification requirements.

8.8.4.4.6 (RQ) When the specified grouting pressure cannot be applied reinjection shall be performed after a certain waiting period until the specified grouting pressure can be applied.

8.8.4.4.7 (RQ) The grouting tubes shall be flushed with water after each grouting stage and filled with grout at the end of the whole grouting process.

8.9 Concreting

8.10 Trimming of micropiles

9. Supervision, testing and monitoring.

9.1 Supervision

9.2 Monitoring of micropile construction

9.3. Pile testing

9.3.2. Static load tests

9.3.2.2 Static load tests on preliminary micropiles.

9.3.2.2.1 (RQ) Static load tests on preliminary micropiles shall be performed when:
- new techniques are used for the execution of the micropiles;
- micropiles have to be installed in ground conditions for which previous tests are not available;
- higher working loads are applied than those already adopted in similar ground conditions
- when the results of static load tests are used to determine the design load.

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

9.3.2.2.3 (RQ) 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 (RQ) In the documents it shall be specified if static load tests have to be performed on working micropiles.

9.3.2.3.2 (RC) Unless otherwise specified, for micropiles working in compression at least one static load test should be performed for the first 100 micropiles and 1 for each next 100 micropiles.

9.3.2.3.3 (RC) Unless otherwise specified for micropiles working in tension at least one static load test should be performed for the first 25 micropiles and 1 for each next 25 micropiles.

9.3.2.4.10 (RC) The supports or anchorages of a reaction system should observe the following minimum clear distances to the test pile:
a) supports of kentledge: a > 1,0 m.
b) tension pile or vertical anchorages: a > 1,5 m.
c) top of the bond length of inclined anchorages: a > 1,5 m.

9.3.3. Dynamic load tests and integrity tests

NOTE: The use of dynamic load tests and integrity tests can not be generalised for micropiles because the interpretation of the results concerning the bearing capacity and integrity may be difficult due to the small diameter and/or shape of the micropile and the presence of a bearing element. So the use of dynamic load tests and integrity tests has to be limited to cases where experience or comparison with static load tests has demonstrated that the results can be interpretated in a confident way.

9.3.3.1 (RQ) For dynamic load tests the micropile shall be allowed to gain sufficient strength after installation and before testing.

9.3.3.2 (RQ) Dynamic and integrity 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 shall also have a knowledge of the techniques of piling and experience of the specific ground conditions.

9.3.3.3. (RQ) The apparatus shall be used in accordance with the manifacturer's instructions and the micropile shall be prepared for the purpose of testing in an appropriate manner.

10 Records

11 Safety and environmental requirements

ANNEX A (Informative)= EXECUTION METHODS OF MICROPILES:

A1) Bored piles				
DRILLING METHOD	REINFORCEMENT TYPE	GROUTING METHOD	GROUT TYPE	OPTIONS
Rotary drilling Percussion drilling Grab,chisel or bailer boring	Reinforcement cage	Gravity grouting,concreting	Grout,mortar or concrete	Casing
		Single step grouting through temporary casing	Grout or mortar	
	Bearing element	Gravity grouting	Grout or mortar	Casing
		Single step grouting through - temporary casing - bearing element - tube à manchettes	Grout or mortar	
		Multiple step grouting through tube à manchettes	Grout	
	Permanent casing (with or without reinforcement cage)	Gravity grouting or concreting	Grout, mortar or concrete	Enlarged base
Continuous flight auger drilling	Reinforcement cage	Concreting through the hollow stem of the auger	Grout, mortar or concrete	

A2) Displacement piles			
DRIVING METHOD	MATERIAL (CASING)	CROSSSECTION/ REINFORCEMENT	OPTIONS/GROUTING
2.1Prefabricated	Reinforced concrete Steel or cast iron	Solid	Shaft grouting
		Open end tube	Shaft grouting
		Closed end tube	Filling with grout, mortar or Concrete, with or without shaft grouting
		Profiles	Shaft grouting
2.2 Cast in place	Temporary casing	Reinforcement cage	Gravity grouting Single step grouting through casing
		Bearing element	Gravity grouting, concreting Single step grouting through casing Single step grouting through TAM Multiple step grouting through TAM
	Permanent casing	Reinforcement cage	Concreting in dry conditions, with or without base enlargements

Annex C: (= informative) = Guidance on construction tolerances.

The following construction tolerances can be considered as normal values for common applications:

- plan location of vertical and raking piles (measured at the working level) = 0,05m
- deviation from the axis:
  - max. 2% of the length for vertical piles
  - max. 4% of the length for subvertical piles (n > 4)
  - max. 6% of the length for inclined piles (n< 4)
- radius of cuvature > = 200m depending on buckling conditions
- max. angle deviation in a pile joint = 1/150

Annex D (informative) Guidance on corrosion rates.

D.1 General

(1) This annex gives guidance on the loss of thickness of steel bearing piles and steel sheet piling due to corrosion.

D.2 Bearing piles

(1) Unless otherwise specified, for both serviceability and ultimate limit states the loss of thickness (in mm) die to corrosion of piles on the side in contact with soil, with or without groundwater, should be taken from table D.1 and for piles in water should be taken from table D.2, depending on the required design working life of the construction.

(2) The loss of thickness due to atmospheric corrosion may be taken as [0.01] mm per year in normal atmospheres and as [0.02] mm per year in locations close to the sea.

D.3 Sheet piling

(1) Unless otherwise specified, the loss of thickness for parts of sheet pile walls in contact with soil, with or without groundwater, should be taken from table D.1, depending on the required design working life of the construction. Where sheet piles are in contact with soil on both sides, the corrosion rates apply to each side.

(2) Unless otherwise specified, for both serviceability and ultimate limit states the loss of thickness for unprotected parts of sheet pile walls in contact with river or sea water should be taken from table D.2, depending on the required design working life of the construction.

(3) The loss of thickness due to atmospheric corrosion may be taken as [0.01] mm per year in normal atmospheres and as [0.02] mm per year in locations close to the sea.

NOTE: The following effects have a major influence on the corrosion rates given in tables D.1 and D.2:

- whether the structure is above or below the groundwater table
- the variation of the level of the groundwater table
- the presence of oxygen.

Table D.1: Loss of thickness [mm] due to corrosion for piles and sheet piles in Soils, with or without groundwater .

Required design working life	5 years	25 years	50 years	75 years	100 years
Undisturbed natural soils (sand, silt, clay, schist, ...)	0,00	0,30	0,60	0,90	1,20
Polluted natural soils and industrial grounds	0,15	0,75	1,50	2,25	3,00
Aggressive natural soils (swamp, marsh, peat, ...)	0,20	1,00	1,75	2,50	3,25
Non-compacted and non-aggressive fills (clay; schist, sand, silt, ...)	0,18	0,70	1,20	1,70	2,20
Non-compacted and aggressive fills (ashes, slag, ...)	0,18	0,70	1,20	1,70	2,20

Notes:

1. Corrosion rates in compacted fills are lower than those in non-compacted ones. In compacted fills the figures in the table should be divided by two.

2. The values given are only for guidance. Local conditions should be considered because they might affect the actual corrosion rate, which can be lower or higher than the average value given in the table.

3. The values given for 5 and 25 years are based on measurements, whereas the other values are extrapolated.

Table D.2: Loss of thickness [mm] due to corrosion for piles and sheet piles in fresh water or in sea water.

Required design working life	5 years	25 years	50 years	75 years	100 years
Common fresh water (river, ship canal, ...) in the zone of high attack (water line)	0,15	0,55	0,90	1,15	1,40
Very polluted fresh water (sewage, industrial effluent, ...) in the zone of high attack (water line)	0,30	1,30	2,30	3,30	4,30
Sea water in temperate climate in the zone of high attack (low water and splash zones)	0,55	1,90	3,75	5,60	7,50
Sea water in temperate climate in the zone of permanent immersion or in the interidal zone	0,25	0,90	1,75	2,60	3,50

Notes:

1. The highest corrosion rate is usually found at the splash zone or at the low water level in tidal waters. However, in most cases, the highest stresses are in the permanent immersion zone.
2. The values given are only for guidance. Local conditions should be considered because they might affect the actual corrosion rate, which can be lower or higher than the average value given in the table.
3. The values given for 5 and 25 years are based on measurements, whereas the other values are extrapolated.