FINNISH ROAD ADMINISTRATION

Instructions for drilled piling

Design and execution guide

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Guidelines for design and implementation

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FOREWORD

Drilled piles and piling have been developed significantly in recent years which has increased their use. Yet, there have been no national guidelines for drilled piling in Finland. Consequently, builders have applied the information contained in the Driven piling instructions (LPO-87) and the High-capacity piling instructions (SPO-2001). These manuals do not, however, sufficiently cover the details of drilled piling.

These instructions for drilled piling are only provisional. It will be revised in 3-5 years, as soon as further experiences and research results from drilled piling have been collected. In connection with the revision, these instructions may be incorporated into revised instructions for piling.

The members of the steering group for these instructions have included: Juha Heinonen, LicTech, Oy VR-Rata Ab (chairman); Sami Eronen, LicTech, Rautaruukki Oyj/Metform; Jouko Lehtonen, LicTech, Rautaruukki Oyj/CRD; Esko Palmu, B.Sc. (Eng), Bridge Unit of the Road Administration; Pentti Salo, M.Sc. (Eng), Road and Traffic Engineering Unit of the Road Administration; Pekka Mantere, M.Sc. (Eng), Suomalainen Insinööritoimisto Oy and Professor Jorma Hartikainen and Pasi Korkeakoski, LicTech, the Laboratory of Foundation and Earth Structures at Tampere University of Technology.

The instructions were commissioned from the Laboratory of Foundation and Earth Structures at Tampere University of Technology (TUT). The funding comes from the Rail Administration, Rautaruukki Oyj and the Road Administration.

The R&D on drilled piling has been conducted primarily by the Geotechnical Laboratory at TUT, and the following master's and licentiate theses and publications have been used as source material for the instructions: Sami Eronen, Drilled Piles in Scandinavia (1997); Henning Muhra, Micropiles in Northern and Middle Europe (1997); Jouni Mali, Rautateiden sähköistyspylvään kaksoisputkiperustus (1999); Marko Öljymäki, Porapaalumenetelmän soveltaminen vaakakuormitetuissa rakenteissa (1997); Jyrki Kataja, Drilled Pile Execution by Dual Fluid Systems (2000) and Sami Eronen, Drilled Piles in Underpinning and Bridge Foundations (2001).

Table of contents

1 PILES COVERED BY INSTRUCTIONS AND REQUIREMENTS OF PILING SITE

1.1 Applicability of instructions

These instructions present the general principles of the design and execution of drilled piles. The cross-section of the piles in question is round. The instructions apply to individual piles and groups of piles.

The drilled-pile types covered by the instructions:

- steel core pile
- drilled steel pipe pile whose casing becomes part of the structure
- drilled steel pipe pile whose casing is withdrawn
- grouted drilled piles

The instructions do not deal with auger-bored cast-in-place piles.

The drilled-pile-types differ from each other, but are all suitable if:

- the construction site has layers that are difficult to penetrate
- the rock face is sharply inclined
- piles must reach a certain depth of penetration
- the surrounding structures are sensitive to vibration
- accurate positioning is a must.

In Finland, drilled piles are generally implemented as end-bearing piles bearing on rock which allows efficient utilisation of the strength of pile materials.

Vertically loaded drilled piles bearing on soil layers are used when the coarse-grained soil layer or moraine layer above the bedrock is thick.

Drilled piles that are primarily horizontally loaded are generally supported by soil layers.

Drilled piles are not used as cohesion piles.

1.2 Types of drilled piles

1.2.1 Steel core pile

Thin-walled pile casings are used for drilling traditional steel core piles. The casing is extended if necessary. When bedrock is reached, the pilot bit used to drill through the soil is extracted, and drilling is continued using a rock bit which does not sink the casing. After drilling is completed, the casing is flushed and filled with grout. Finally, a round bar equipped with a centralizer is installed in the casing (Figure 1 and 2). Drilling may be done either by a top hammer or a DTH hammer applying a concentric or an eccentric drilling method.

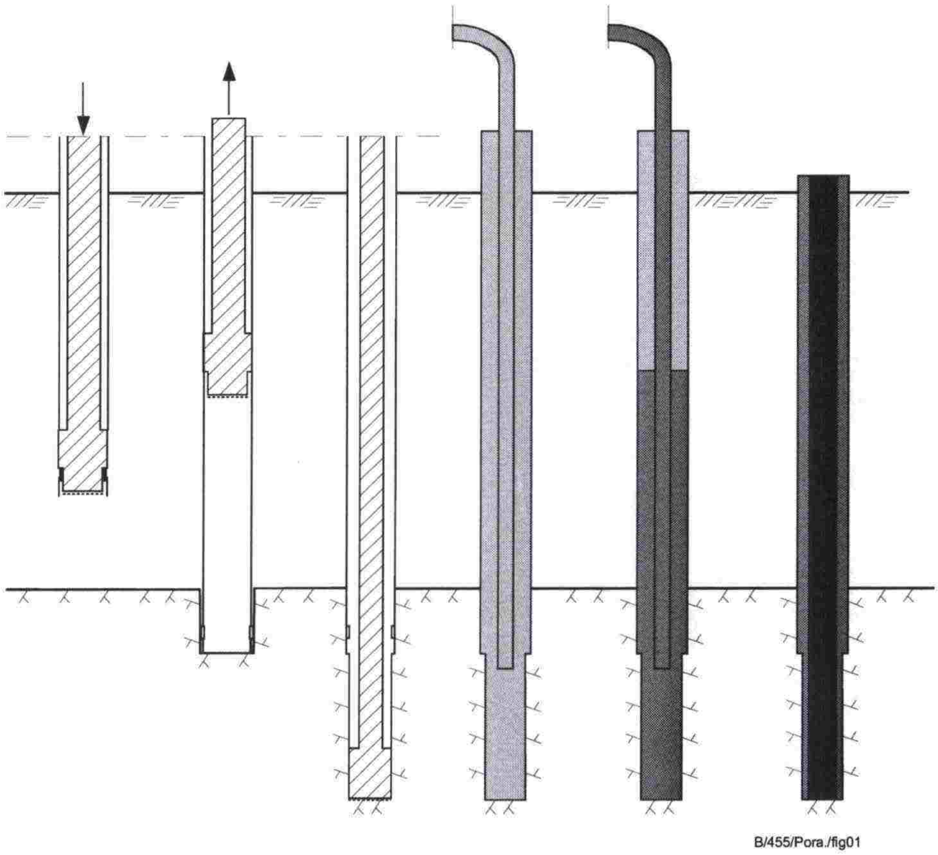

Fig. 1. Installation phases of a steel core pile.

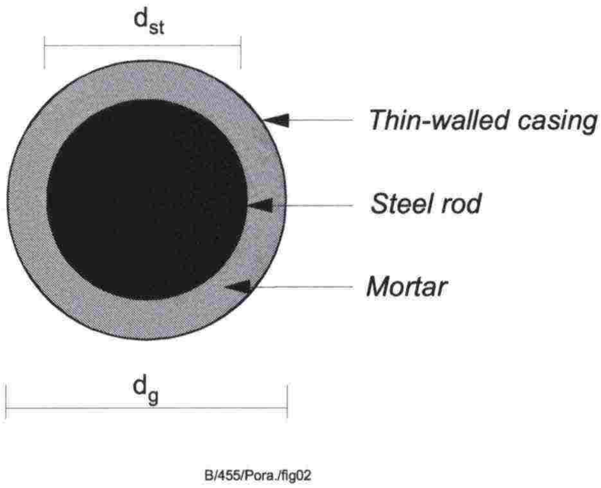

Fig. 2. Cross-section of steel core pile.

1.2.2 Drilled steel pipe pile whose casing becomes part of pile

The thick-walled steel pipe pile functions as a casing during drilling and as a bearing structure that takes part of the pile load of the finished drilled pile. The casing is extended if necessary. Rock drilling is implemented with the same equipment without separate work phases (Figure 4). The pipe is flushed after drilling. In case a reinforcement cage is used, it is installed in the casing prior to concreting. Drilling may be done as with steel core piles either with a top hammer or a DTH hammer applying a concentric or an eccentric drilling method.

Different types of reinforcements may also be used depending on pile loads and soil conditions (Figure 3).

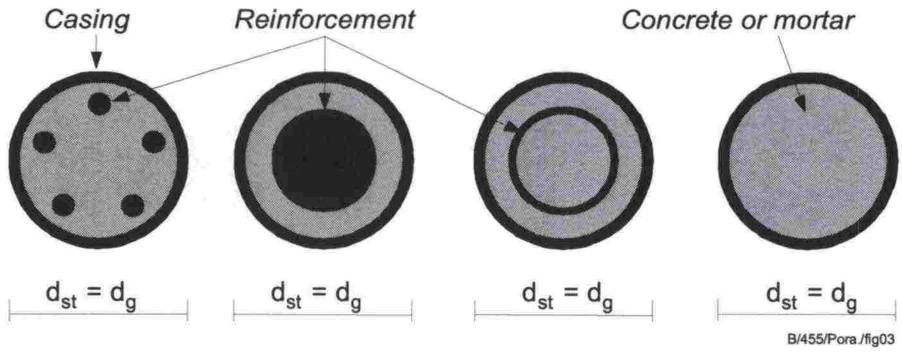

Fig. 3. *Reinforcement alternatives for drilled steel pipe piles when the casing becomes part of the pile.*

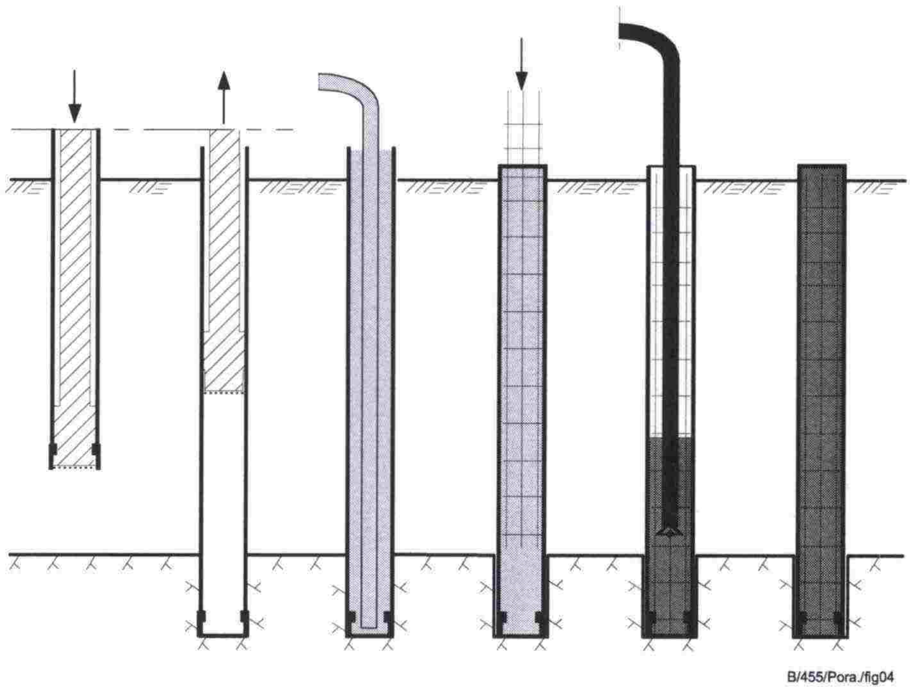

Fig. 4. *Installation phases of a drilled steel pipe pile whose casing becomes part of the pile.*

1.2.3 Drilled steel pipe pile whose casing is withdrawn

In the case of a drilled steel pipe pile whose casing is extracted, the steel pipe functions as a casing during drilling. The installation of a drilled steel core pile is described in Figure 6. Drilling may be done either by a top hammer or a DTH hammer as with the steel core pile.

A pile must always be reinforced. Different reinforcement types can be used with drilled piles depending on loads and soil conditions (Figure 5).

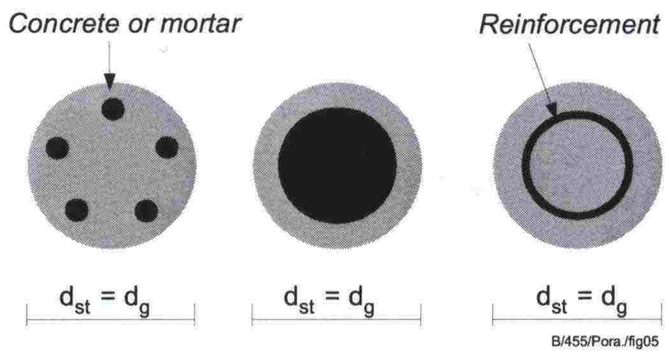

Fig. 5. Alternative reinforcements for drilled steel pipe piles when the casing is withdrawn.

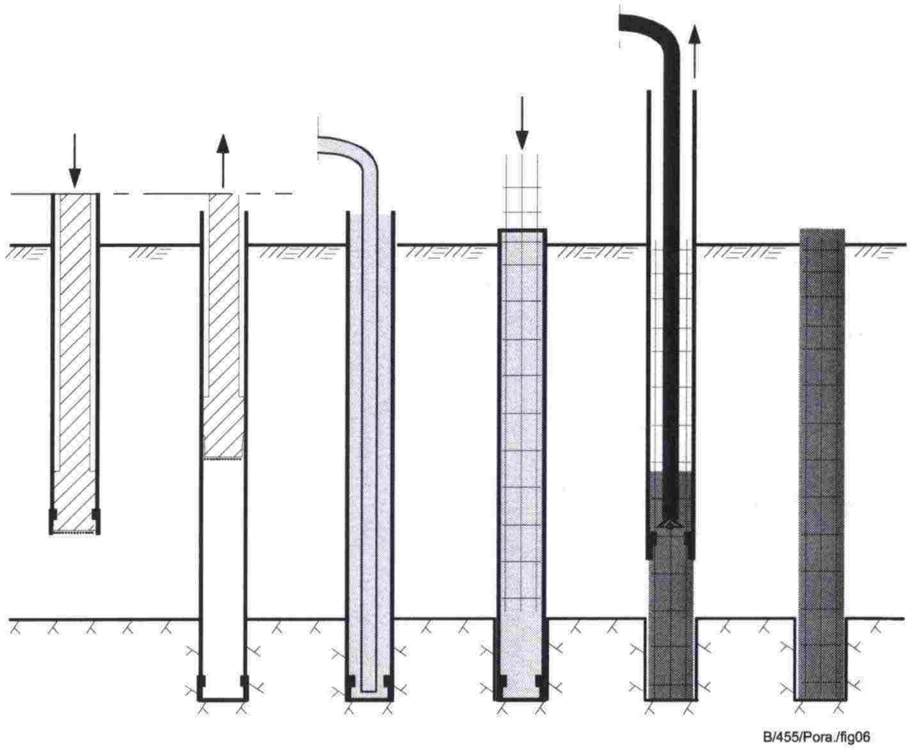

Fig. 6. Installation phases of a drilled steel pipe pile whose casing is withdrawn.

1.2.4 Drilled piles grouted through the bearing element

In the case of drilled piles grouted through the bearing element the drill rod remains in the ground and the shaft is grouted with mortar during drilling. Piles are drilled using top hammer equipment. Drill rods are generally extended using threaded sleeves. In principle, pile installation involves only a single work phase: simultaneous drilling and grouting (Figure 7). Flushing is effected through the hole in the middle of the drill rod using mortar. When the drill bit is larger in diameter than the drill rod, the pile gets a shell of grout equal to the diameter of the drill bit depending on the soil, flushing pressure and extent and drilling speed. The wall of the drill hole receives a mortar layer that supports the hole. Depending on the soil, a zone of mixed mortar and soil may form outside the cement layer. In structural dimensioning, only the capacity of the drill rod can be taken into account. In buckling dimensioning, the width of the soil layer supporting the pile can be considered equal to the diameter of the drill bit. In geotechnical dimensioning, a grouted shaft equal to the diameter of the drill bit may be taken into account. The consideration of the zone of mixed cement slurry and soil in geotechnical dimensioning requires procedural tests and loading tests at the piling site or, at least, in comparable soil conditions near the site (Figure 8).

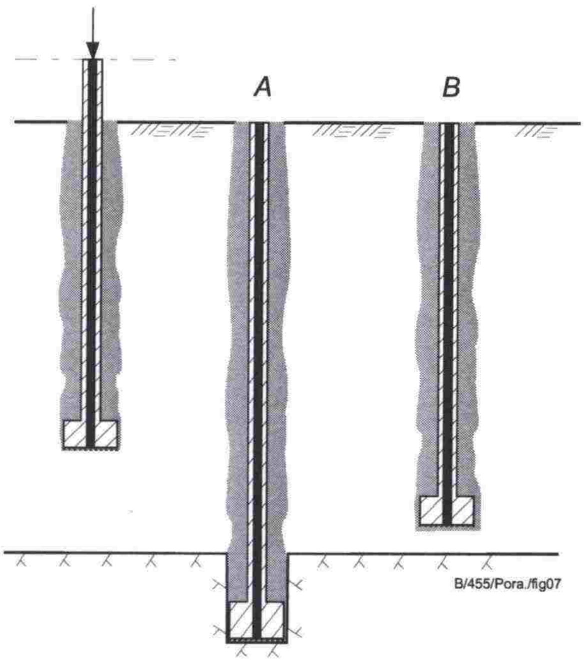

Fig. 7. *Installation phases of a drilled pile grouted through the bearing element. Pile bearing on rock (A) and pile bearing on ground (B).*

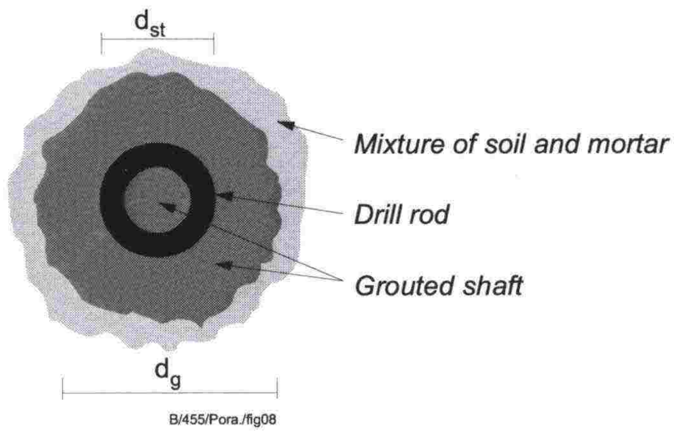

Fig. 8. Cross-section of a drilled pile grouted through the bearing element.

1.3 Requirements of piling site

Based on the Foundation engineering instructions of 1988, piling sites can be divided into three categories: easy, demanding and very demanding.

The requirements of a site are determined on the basis of the superstructure, soil conditions and degree and direction of loading.

The requirements of the superstructure are defined as follows:

Easy projects
- Light, basic structures: buildings for non-continuous habitation such as lightly built free-time housing, warehouses and sheds, noise barriers, fence and other lightly loaded piers.

Demanding projects
- Basic buildings and structures, lighting and traffic control posts and portals.

Very demanding projects
- Complicated structures and buildings
- Bridges, hydraulic constructions, industrial constructions and similar engineering structures.
- Columns and masts for electrification, power transmission and data transmission networks.
- Structures subject to dynamic or otherwise exceptional loads, such as significant horizontal loads, bending or high vertical loads, or ones subject to special requirements.

2 STATUS OF INSTRUCTIONS

2.1 General

These instructions are based on the laws, ordinances and regulations of the Finnish Building Code (RakMK), decisions of the Ministry of the Environment concerning Eurocodes and use of their national application documents as an alternative design system, and established European Standards (SFS-EN).

The instructions for drilled piling are transitional and deal with the design, execution and quality control of drilled piles.

An effort has been made to build the instructions on European Standards while taking into account Finnish soil conditions and piling practice.

The user of these instructions must be aware of the current status of national guidelines and European Standards. Due to the incompleteness of the CEN Standards available at the time these instructions were prepared, there may be inconsistencies between said standards and the instructions. In case of any contradictions, Draft Standard CEN/TC 288 N213E Execution of special geotechnical work. Micropiles (April 2000) takes precedence.

2.2 Rules, regulations and standards for design

The alternative design systems consist of a system based o the Finnish Building Code and the Foundation Engineering Instructions (RIL-121, 1988) and a system based on Eurocodes and their national application documents (NADs). So far, the use of Eurocodes in bridge design has not been approved.

The following is a list of Eurocode-based standards published by the Finnish Standards Association and the corresponding application documents published by the Ministry of the Environment

SFS-ENV 1991-1:1995
Eurocode 1: Basis of design and actions on structures
Part 1: Basis of design

National application document for Prestandard SFS-ENV 1991-1:1995
Eurocode 1: Basis of design and actions on structures.
Part 1: Basis of design

SFS-ENV 1992-1-1
Eurocode 2: Design of concrete structures
Part 1: General rules and rules for buildings

National application document for Prestandard SFS-ENV 1992-1:1991
Eurocode 2: Design of concrete structures
Part 1: General rules and rules for buildings

SFS-ENV 1993-1-1:1992
Eurocode 3: Design of steel structures
Part 1: General rules and rules for buildings

National application document for Prestandard SFS-ENV 1993-1-1:1992
Eurocode 3: Design of steel structures
Part 1-1: General rules and rules for buildings

SFS-ENV 1993-5:1997
Eurocode 3: Design of steel structures
Part 5: Piling

SFS- ENV 1994-1-1:1992
Eurocode 4: Design of composite steel and concrete structures
Part 1: General rules and rules for buildings

National application document for Prestandard SFS-ENV 1994-1-1:1992(NAD)
Eurocode 4: Design of composite steel and concrete structures.
Part 1-1: General rules and rules for buildings

SFS-ENV 1997-1
Eurocode 7: Geotechnical design. Part 1: General rules

National application document for Prestandard SFS-ENV 1997-1
Eurocode 7: Geotechnical design.
Part 1: General rules

SFS-ENV 1997-2
Eurocode 7: Geotechnical design. Part 2: Laboratory testing

SFS-ENV 1997-3
Eurocode 7: Geotechnical design. Part 3: Field testing

2.3 Standards

This section lists all national (SFS) and European (SFS-EN) standards which are to be taken into account in the design and execution of piles. The rules and regulations of the effective version of a standard are to be followed. Listed are also prestandards and proposals for standards (SFS-ENV, ENVC and prEN)

SFS-EN 996:1996
Piling equipment. Safety requirements

SFS-EN 791:1996
Drill rigs – Safety

SFS-EN 1536:1999
Execution of special geotechnical work. Bored piles

SFS-EN 1537:2000
Execution of special geotechnical work. Ground anchors

SFS-EN 1538:2000
Execution of special geotechnical works. Diaphragm walls

SFS 3165:1993
Cement. Composition, specification and conformity criteria. Part 1: Common cement

SFS-EN 12063:1999
Execution of special geotechnical work. Sheet-pile walls

SFS 1215:1996-08-26
Reinforcing steels. Weldable hot rolled ribbed steel bars A500HW

SFS 1257:1996-08-26
Reinforcing steels. Cold worked ribbed steel bars B500K

SFS-EN 10025:1990
Hot rolled products of non-alloy structural steels. Technical delivery conditions

SFS-EN 10219-1:1998 ja SFS-EN 10219-2-1998
Cold formed welded structural hollow sections of non-alloy and fine grain steels.
Part 1 Technical delivery requirements.
Part 2 Tolerances, dimensions and sectional properties.

SFS-EN 287-1:1997
Approval testing of welders. Fusion welding. Part 1: Steels

SFS-EN 25817:1993
Arc-welded joints in steel. Guidance on quality levels for imperfections (ISO 5817:1992)

SFS-EN 449:1995
Welding consumables. Covered electrodes for manual metal arc welding of non alloy and fine grain steels. Classification.

SFS-EN 29692:1994
Metal-arc welding with covered electrode, gas-shielded metal-arc welding and gas welding. Joint preparations for steel (ISO9692:1992)

SFS-EN 288-1:1997, SFS-EN 288-2:1997, SFS-EN 288-3:1998
Specification and qualification for welding procedures for metallic materials;
Part 1: General rules for fusion welding.
Part 2: Welding procedure specification for arc welding.
Part 3: Welding procedure tests for the arc welding of steels.

Here follows a list of European Prestandards (SFS-ENV or ENV) and European Draft Standards (prEN) under preparation:

SFS-ENV 206
Concrete. Performance, production, placing and compliance criteria.

SFS-ENV 197-1
Cement – Composition, specifications and conformity criteria. Part 1: common cements

ENV 10080
Steel for reinforcement of concrete, weldable ribbed reinforcing steel B500 – Technical delivery conditions for bars, coils and welded fabric.

EN 12699:2000
Execution of special geotechnical work. Displacement piles

EN 12715:2000
Execution of special geotechnical work. Grouting

prEN 1008:1997
Mixing water for cement – Specifications for sampling, testing and assessing the suitability of water, including wash water from recycling installations in the concrete industry as mixing water for concrete

prEN 1260:1996
Aggregates for concrete including those for use in roads and pavements

CEN/TC 288 N213E Execution of special geotechnical work. Micropiles (April 2000) (under preparation)

2.4 National standards and regulations

In this section are listed all national standards to be taken into account in the design and execution of the piles referred to in the instructions.

Finnish Building Code (RakMK)
B3 Foundation structures
B4 Concrete structures
B7 Steel structures

The instructions are complemented, for instance, by the effective sections of the following publications which deal with piling issues.

Instructions on the programming and execution of ground investigation:

- Ground investigation instructions for building construction (SGY, TPO-83, 1983)
- Instructions for geotechnical laboratory work (SGY, GLO-85, 1985)
- Sounding manuals (SGY) –
- Sounding manual I—weight sounding and dynamic probing (1980)
- Sounding manual II—vane test (1999)
- Sounding manual III—sampling (1984)
- Sounding manual IV—monitoring of groundwater level (1990)
- Sounding manual V—drilling (1986)

Rock investigation instructions for construction (SGY, RKO-79, 1979)

Instructions for the design and construction of foundation structures:

- Foundation engineering instructions 1988 (RIL 121-181)
- Structural loading instructions (RIL 144-1987)
- High-capacity piling instructions SPO-2001 (SGY, RIL-212-2001)
- Building excavation instructions (RIL 181-1989)
- Tasks of geotechnical design GEO 95 (SKOL 1995)
- General building specifications (RYL-90, 1989)
- Talo 90 (Building 90) nomenclature (The Finnish Building Centre Ltd)

Instructions concerning design of composite piles

- Composite structures, design instructions (TRY, BY 26, 1988)
- Application instructions for composite structures (TRY, BY 36, 1991)

Instructions for supervision:

- Instructions for the supervision of foundation engineering works (SGY PRP-84, 1984)

Abbreviations:
BY, Suomen Betoniyhdistys ry. (Concrete Association of Finland)
RIL, Suomen Rakennusinsinöörien Liitto ry.(Association of Finnish Civil Engineers)
SGY, Suomen Geoteknillinen yhdistys ry. (Finnish Geotechnical Society)
TRY, Suomen Teräsrakenneyhdistys ry. (Finnish Constructional Steelwork Association)
VTT, Valtion teknillinen tutkimuskeskus (Technical Research Centre of Finland)

3 DEFINITIONS

Centralizer
Spacers attached to reinforcement which centre reinforcement cage and prevent it from pressing against the casing.

Cohesion pile
Pile that transmits the load to soil layers via adhesion acting on pile shaft.

Compression pile
Pile that takes compression forces parallel to its longitudinal axis.

Concreting pipe
Metal pipe for concreting with a funnel and a chute.

Cut-off level
Level of pile head after removal of excess length

Deviation in pile inclination
Difference between intended and actual inclination of pile at cut-off level.

Deviation in pile position
Difference between intended and actual position of pile at cut-off level.

Drill rod
A hollow rod that transmits the blows of a top hammer and the power that rotates the bit, and conveys the medium that operates the DTH hammer and the flushing agent for the drill bit. The hollow drill rod sits inside the casing. Some top hammer hammers may also use a solid drill rod.

End-bearing pile
A pile which transfers most of the load via the tip to the rock or soil layer.

Foundation pile
Pile that functions as a foundation or a foundation component.

Friction pile
A pile that transmits most of the load to soil layers via the friction on pile shaft.

Geotechnical capacity
Capacity of soil or rock to bear loads transmitted through pile.

Geotechnical diameter, d_g
Pile diameter used in geotechnical dimensioning of pile and width of soil layer supporting pile in dimensioning of buckling.

Grout
Mixture of cement or different chemicals and water that is forced into pores of surrounding soil or cracks in rock under pressure.

Head of pile
Upper end of pile.

Horizontally loaded pile
Pile subject to significant horizontal loads.

Inclined pile
A pile installed off the vertical.

Lightweight sound
A device intended for inspections inside the casing made of closed, lightweight pipes. Its weight corresponds approximately to the buoyancy exerted on it.

Loading test at constant speed
A static loading test where a pile is compressed into the soil at constant speed while constantly monitoring the compressive force.

Mortar
Concrete of extremely small aggregate size which can form a composite structure with a steel pipe but does not penetrate into soil.

Negative shaft resistance
Load on pile created by the friction and adhesion forces between pile shaft and the surrounding soil layer, when the soil settles more than the pile.

Pile
Slender structural component which transmits loads to rock of a bearing soil layers and prevents displacement of structures.

Pile base
Bottom of drill hole.

Pile casing
A drill pipe that can be left in the ground or withdrawn; it may function as a bearing structure of the pile by itself or as part of a composite structure. If left in the ground, it can ensure successful concreting.

Pile section
A pile shaft, or part of one, made prior to drilling or installing a pile.

Pile shaft
Bearing structure of pile, part between head and tip of pile.

Preliminary pile
Pile made prior to piling proper intended to ensure suitability of chosen pile type for the site.

Reinforcement cage
The reinforcement cage consists of main bars parallel with the pile shaft tied together with spiral stirrups.

Rock contact
Contact between pile base and rock.

Shaft diameter, d
Maximum pile diameter between head and tip of pile.
a) external diameter of casing with piles drilled using a casing

b) diameter of drill bit with piles drilled without a casing

Shaft resistance
Friction and/or adhesion acting on skin of shaft.

Skin of pile
Contact surface between pile shaft and soil.

Stabilizing fluid
A mixture of water and bentonite or other suitable materials. Used sometimes in Finland to prevent hydraulic failure of bottom of drill hole.

Static loading test
A loading test where a pile is subjected to an axial and/or lateral load in order to determine its load/displacement correlation and/or failure and/or yield capacity.

Stepped loading test
A static loading test where loading of a pile is increased in steps holding each load constant for a certain time. Loading is, however, maintained at least long enough to reach a pile penetration rate smaller than the set limit.

Structural capacity
Capacity of pile shaft to transmit received loads to the ground or rock.

Structural diameter, d_{st}
Pile diameter used for structural dimensioning of pile.

Suspension bars
Steel bars from which the reinforcement cage in the casing or the drill hole is suspended.

Target level
Level to which tip must be drilled in order that the pile obtains sufficient geotechnical capacity. It must be sufficiently below the planned excavation or cutting level.

Tension pile
A pile that takes tensile loads parallel to its longitudinal axis.

Test pile
Pile loaded to determine bearing capacity of pile and dependence of settlement on loading in the examined soil layers.

Tip of pile
Lower end of pile.

Tremie for underwater concreting
Concreting pipe equipped with watertight joints and a watertight plug, which opens when underwater concreting is started. During concreting the lower end of the tremie pipe is submerged in the fresh concrete.

Trial pile
Pile made before piling intended to ensure the applicability of the piling method to a certain site.

4 REQUIRED PILING DOCUMENTATION

4.1 Documentation required for regular piling

This chapter deals with the documentation required for regular piling work based on the European Prestandard CEN/TC 288 N213E Execution of special geotechnical work. Micropiles (April 2000) which is under preparation.

All information essential to drilled piling must be included in the construction documents.

The following information essential for piling must be available for use on site in written form prior to the launching of works in demanding and very demanding projects:

- Construction documents: contract specifications, work specification or quality requirements and related ground investigations, foundation engineering and structural drawings. The requirements concerning ground investigation are presented in Chapter 5.
- Work schedule and quality plan which describe the piling method in detail, the piling sequence and quality control measurements, inspections and testing.
- Site conditions such as its boundaries, inclination of ground surface, access to area, factors restricting work, etc.
- Location and condition of nearby buildings, roads, railways, equipment, lines and cables, underground structures, foundations, piles, anchors and other obstacles in the ground, archaeological relics and structures that hamper work such as power lines and electrical and lighting systems.
- Data on soil contamination and factors that induce corrosion and other similar drawbacks which may impact the selection of pile type or work safety.
- Threshold values for environmental nuisances such as noise, vibration and emissions as well as other statutory constraints such as time limits for construction works.
- Information on piling, other substructure construction or underground works done on the site or nearby earlier.
- Simultaneously ongoing activities which may have an impact on the work such as a nearby excavation or lowering of the groundwater level.
- Location of bench marks.
- Allowable deformations in adjacent buildings and structures.
- Required control measurement system and inspections.
- Dimensions of usable traffic routes and working areas.

4.2 Further documentation required for foundation strengthening

The following data is also necessary for foundation strengthening:

- Allowable deformations in buildings to be strengthened and adjacent buildings
- Condition of buildings to be strengthened and adjacent buildings as well of their foundations
- Dimensions and materials of existing foundation structures, floors, drains, drainage and groundwater control systems
- Dimensions of usable spaces.

5 GROUND INVESTIGATIONS

5.1 Requirements

The conduct of ground investigations is regulated on the general level by national codes (RakMK B3 Pohjarakennus) and effective national guidelines and European Standards (ENV 1997-1, ENV 1997-2, ENV 1997-3).

Ground investigation techniques, spacing of test points and sounding depth are chosen on the basis of the requirements of the piling project and the pile-bearing layer. A target level, pile diameter and piling equipment are determined on the basis of the ground investigation. That is why a ground investigation is essential also in small piling projects.

Table 1 shows the used ground investigation techniques according to the requirements of the piling project and type of pile support. The following chapters describe in more detail the carrying out of ground investigations and the numbers of sounding and sampling points done.

Table 1 Ground investigation methods according to requirements of piling project and type of pile support.

	percussion drilling	weight sounding	cone penetration test	dynamic probing	vane test	sampling and laboratory tests	monitoring of groundwater level
EASY SITES							
Piles bearing on rock	(X)						
Piles bearing on ground		(X)					
Horizontally loaded piles		(X)					
DEMANDING SITES							
Piles bearing on rock	X			(X)	X	(X)	
Piles bearing on ground				X	X	(X)	
Horizontally loaded piles		X	X		(X)	X	
VERY DEMANDING SITES			X				
Piles bearing on rock	X			X	(X)	(X)	
Piles bearing on ground		X		X	(X)	X	
Horizontally loaded piles				(X)	(X)	X	X

x required
(x) when necessary

5.2 Easy sites

5.2.1 Piles bearing on rock

Percussion drilling should be performed to aid the design of drilled pilling (Kairausopas V 1986) at each corner of the planned building or at individual structures or at every fourth noise barrier or fence pier or at maximum intervals of 20 m.

In exceptional cases drilled piling may be equated with ground investigation. Then, pile drilling must be documented in the same manner as percussion drilling (Kairausopas V 1986). The technique may be used to estimate pile length.

5.2.2 Piles bearing on ground

Ground investigations for the design of drilled piling may be performed as weight soundings which should be done at least at each corner of the planned building or at individual structures or at every fourth noise barrier of fence pier or at maximum intervals of 20 m.

5.2.3. Horizontally loaded piles

It is recommendable to perform weight soundings for pile dimensioning at least at each individual structure or at every fourth noise barrier or fence pier or at maximum intervals of 20 m.

5.3 Demanding sites

5.3.1 Piles bearing on rock

At least percussion drillings must be done for the design of drilled piling. Dynamic probings should also be implemented in order to determine the drillability of soil layers.

Drillings must be performed at least at the corners of a planned structure. Depending on the extent of the variations in the rock surface and soil conditions, the drilling points should be spaced at maximum intervals of 5-15 m. Percussion drillings must extend 3 m into the rock and 2 m below the target level for the pile tip.

The definition of the parameters needed in calculating the buckling load of a pile requires performing vane tests in soft organic or fine-grained soil layers.

Moreover, disturbed samples should be taken from every fourth drilled point in order to determine soil-layer boundaries.

5.3.2 Piles bearing on ground

Dynamic probings must be performed at least at the corners of the designed structure. Depending on the extent of the variations in the rock surface and soil conditions, the test points should be spaced at 5-15 m intervals (max). When the piles are supported by soil layers, drillings should extend at least 3 m below the target level for piles.

The definition of the parameters needed in calculating the buckling load of a pile requires performing vane tests in soft organic or fine-grained soil layers.

Moreover, disturbed samples should be taken from every fourth boring point in order to determine soil-layer boundaries.

5.3.3 Horizontally loaded piles

Horizontally loaded drilled piles require a weight sounding or a cone penetration test at least at every other barrier or fence pier, or at each individual pier, or at least at 15 m intervals. In order to determine soil-layer boundaries, disturbed samples must be taken at every other sounding point.

To secure horizontal capacity, vane tests must be performed at every fourth pile in organic and fine-grained soil layers.

5.4 Very demanding sites

5.4.1 General

At very demanding sites a ground investigation must be made at each foundation and at each corner of a large foundation such as pile group foundations of bridges.

Moreover, the requirements of the client must also be met in the programming and implementation of ground investigations in case they are stricter than the ones presented here.

5.4.2 Piles bearing on rock

The position of the rock face is always determined by percussion drillings. The position and forms of the rock face must always be determined when the piles are to penetrate into the rock. In the case of large-diameter drilled piles (d > 300 mm), a percussion drilling is required at each pile. The drilling must penetrate 3 m into solid rock and at least 2 m below the target level for pile tips.

The properties of all soil layers above the rock must be determined. Soil-layer boundaries are determined by taking a sufficient number of disturbed soil samples.

The strength of coarse-grained and moraine layers can be determined indirectly on the basis of soil type and sounding resistance. The drillability of soil layers can be predicted by dynamic probings.

The definition of the parameters needed in dimensioning the buckling load of a pile requires vane tests in soft organic or fine-grained soil layers.

In the case of fine-grained and organic soil layers, soil samples should be taken in order to determine compressibility and/or strength by an oedometer and/or triaxial tests.

5.4.3 Piles bearing on ground

Ground investigations are conducted by dynamic probings. The soundings must extend at least 3 m below the target level for piles.

The properties of all soil layers above the rock must be determined. Soil-layer boundaries are determined by taking a sufficient number of disturbed soil samples.

The stability of coarse-grained and moraine layers can be determined indirectly on the basis of soil type and sounding resistance. The drillability of soil layers can be evaluated by dynamic probings.

The definition of the parameters needed in dimensioning the buckling load of a pile requires performing vane tests in soft organic or fine-grained soil layers.

In the case of fine-grained and organic soil layers, soil samples should be taken in order to determine compressibility and/or strength by an oedometer and/or triaxial tests.

5.4.4 Horizontally loaded piles

When making use of the lateral capacity of a pile, for instance, with horizontally loaded or bending stressed piles, especially the strength and deformation characteristics of the soil layers supporting the top part of the pile must be determined.

Strength values of fine-grained soil layers can be determined by vane tests. Strength of coarse-grained and moraine layers can be determined indirectly on the basis of soil type and sounding resistance. If horizontal loads and moment stresses are heavy, soil samples need to be taken in order to determine compressibility and/or strength by an oedometer and/or triaxial tests.

The groundwater level is monitored and the range of variation is estimated.

5.5 Presentation of ground investigations

The issues raised in the Foundation engineering instructions (RIL 121-1988) as well as the client's requirements must be considered in the presentation of ground investigations.

Ground investigation drawings, maps and printouts as well as the description of soil conditions must show all soil layers and factors essential to drilled piling, including:
a) Ground level at all examined points based on some known elevation-measurement system.
b) Locations and properties of soil layers that are soft, loose or easily disturbed by piling, unstable, or tend to compact.
c) Thickness, ingredients and other properties of fill layers.
d) Rocks, boulders and built underground obstacles which impact piling or require special measures or tools to penetrate or remove.
e) Properties of soft layers beneath coarse-grained layer which affect performance of pile foundation.
f) Levels of perched groundwater and actual groundwater including range of variation as well as data on artesian water.
g) Depth and inclination of rock face.
h) An account of the aggressiveness of soil or groundwater which may affect the durability of pile materials in contaminated or otherwise high-risk land areas.

It is recommendable to present the ground investigation as part of the work specification, so that the description of soil conditions which deals with geotechnical soil layers and their properties by layers from the surface to the rock, and which makes reference to the ground investigation drawings and laboratory test results constitutes the first chapter of the work specification.

6 PILE MATERIALS AND REINFORCEMENTS

6.1 General

All materials and reinforcements used to make drilled piles must meet the requirements of the Finnish Building Code (RakMK) and SFS-EN Standards.

The supplier of a material cannot be changed without prior approval.

Any rejected material must be removed immediately from the site.

6.2 Ingredients of concrete, mortar and grouts

6.2.1 Cement and substitute additives

Concrete must be made with construction cements that conform to Standard SFS 3165. Other cement types may also be used if their composition has been analyzed in detail and their behaviour under similar conditions has been established.

Aluminate cement must not be used in making concrete.

Other additives may be used instead of cement as a binder on the condition that it can be shown that they have a beneficial impact on the workability of concrete, heat generation during the curing of concrete as well as the attainment of concrete qualities corresponding to the ambient conditions.

When using as binder substances from which no experience has been gathered under similar conditions, workability must be ensured through preliminary tests.

If substitute binders are used, concrete quality is to be assessed based on the water-binder ratio instead of the water-cement ratio.

When making frost resistant concrete using an air-entraining agent, fly ash may be added to the concrete only when using Portland cement. Then, the fly ash must be of grade A and its maximum content 25 percent of the amount of Portland cement (RakMK B4).

6.2.2 Aggregate

Used aggregates must comply with the requirements of Betonin kiviainesohjeet By 43 (1996).

The material extraction site and grade and particle-size distribution of the aggregate must be approved prior to launching the work.

Rounded aggregate is recommended when using a concreting pipe

Aggregates are to be clean and must not contain organic or otherwise detrimental substances.

The maximum size of aggregate is 32 mm or 1/4 of the clear distance between main rebars or 1/6 of the inside diameter of the concreting pipe, whichever is smaller.

Aggregates of different types and particle size must be stored separately.

Frozen aggregate must be heated so that it contains no ice or frost.

6.2.3 Water

If the water for making the concrete is not drawn from a water distribution network, the quality of the water must be examined and be approved by the client.

6.2.4 Admixtures

Admixtures must meet the requirements of the Finnish Building Code (RakMK B4) and certified product declarations must be available.

The following admixtures which impact concreting may be used:
- plasticizers that reduce the amount of water needed and increase plasticity
- retardants
- air-entraining agents

Admixtures must not contain harmful ingredients which degrade the durability of concrete or cause rebars to corrode. If several admixtures are used, their combined effect must be determined. Use of chloride-laden admixtures is forbidden.

Admixtures may be used for the following purposes to ensure the strength, durability and placement properties of concrete:
- to improve workability of fresh concrete
- to reduce water-content of concrete, and to render the mix more plastic in order to prevent separation and honeycombing after placement
- to retard hardening of concrete during placement and possible interruptions in placement
- to improve durability of concrete.

The concrete may become defective if unsuitable admixtures are used.

The mixing ratios of admixtures must be approved by the client prior to concrete placement.

The admixtures may be mixed into the concrete during the making of concrete or prior to placement.

Air-entraining agents may be added to the concrete mix used for the top sections of piles exposed to frost.

6.3 Concrete

6.3.1 General

The proportioning of concrete used for large-diameter piles must be designed in accordance with the Finnish Building Code (RakMK B4) taking into account the requirements of Table 2.

The design strength of concrete used for drilled piles must be at least K30, and maximum strength values of K50 may be used in dimensioning. The amount of binder in the concrete, considering the durability properties of the plan, must be in accordance with Table 2. Plasticity must be in line with Table 3.

The concrete mix used for a pile must:

- have high durability against separation
- have high plasticity and cohesion
- have good pourability
- be self-compacting
- be sufficiently workable during pouring until the casing is withdrawn.

Table 2. Mix proportions of concrete

Amount of binder - dry placement - underwater placement	 ≥ 325 kg/m³ ≥ 375 kg/m³
Water-cement ratio (W/C)	< 0.6
Fines content (d < 0.125 mm) including binder - aggregate d > 8 mm - aggregate d ≤ 8 mm	 ≥ 400 kg/m³ ≥ 450 kg/m³

Table 3. Consistency grading of concrete mix

Spread test; range of concrete cake diameter (ϕ) [mm]	Slump test; range of settlement (H) [mm]	Concreting conditions
460-530	130-180	Dry concreting
530-600	≥ 160	Underwater concreting or concreting by pumping
570-630	≥ 180	Underwater concreting with stabilizing fluid using a tremie.
Measured diameter or settlement is rounded to nearest 10 mm.		

If the amount of binder from Table 2 and the consistency of Table 3 do not produce proper compaction of the mix, the amount of binder and consistency grade may be altered on approval of the client.

Sufficient protection against the effects of soil and/or groundwater must be ensured either through proportioning or by leaving the casing in the ground.

In aggressive groundwater or soil conditions sufficient protection is not necessarily attained by mere proportioning.

Contaminated soil or water can degrade the quality of the concrete mix. Heavy metals may retard the hardening of concrete or change its pore structure.

Unhardened concrete may be protected against groundwater flow by a permanent casing or a permanent lining.

6.3.2 Mixing of ingredients

The general requirements set for mixing and ingredients must conform to the rules of the Finnish Building Code (RakMK B4) and the figures presented in the design documents.

Ready-mixed concrete is to be used to concrete drilled piles.

Unless the designs indicate otherwise, three separate batches of concrete must be made as a preliminary test.

Six (6) test cubes or cylinders are to be made of each test batch of concrete. Two (2) are to be compressed of 7-day old concrete, two (2) of 28-day old concrete and another two (2) are to be stored away for possible further examination.

Water must not be added to the concrete mix immediately before placement until proper mixing of the admixtures has been secured. The water-cement ratio indicated in the designs must be maintained.

6.3.3 Compliance verification of concrete

The compliance of concrete must be verified in accordance with Section B4 of the Finnish Building Code (RakMK) for constructions where the load-bearing structure is of concrete.

When concrete is delivered by a ready-mixed plant with non-certified quality control, the following conditions must also be met:

The making of test pieces from fresh concrete for compressive strength tests on site must carried out as follows:

- a test piece is to be made for the first three piles, and
- a test piece for every subsequent five piles, and if the concrete volume of an individual pile < 4 m^3, one test piece for every subsequent fifteen (15) piles
- two extra test pieces after long interruptions in placement (over 7 days)
- a sample for every 75 m^3 of concrete placed in a single day
- at least one test piece for each pile if the concrete strength requirement is over K45.

A complete record must be kept of the results of the compliance tests of concrete. The results of the tests must also be entered in the concreting record.

6.4 Mortars

The size of mortar aggregate must not exceed the following values:

$d_{85} \leq 4$ mm
$d_{100} \leq 8$ mm

Mortar strength must be at least K25. If mortar is used as a bearing structure, the value must be at least K30. The maximum strength value that can be considered in dimensioning is K60.

The maximum allowed water-cement ratio is 0.6.

The guidelines of Chapter 6.3.3 and Section 6.3.8 of the Finnish Building Code (RakMK B4) are to be followed in verifying compliance.

6.5. Grouts

6.5.1 General

Cement-based grouts are to comply with the instructions of this chapter. The properties of other grout types are dealt with in more detail in Draft Standard CEN/TC 288 N213E Execution of special geotechnical work. Micropiles (April 2000).

Grouts must be cement grouts or other substances that conform to the design.

Cement-based grouting mortars are mixtures of cement and water. If the maximum size of aggregate is 2 mm and its portion by weight is less than that of cement, the substance is considered a grout otherwise it is regarded as a mortar.

The water-cement ratio must be suited to the actual soil conditions. Yet, it must not exceed 0.55.

The strength of a grout must be at least K25. A grout cannot be used as a bearing structure.

Separation after two hours must be less than 3 percent.

When using a grout as protection against corrosion, its separation and shrinkage must be taken into account in proportioning.

6.5.2 Determination of compliance

At least two series of three test pieces must be made at each site at seven day intervals for testing compressive strength.

In automatic mixing, batching is to be checked regularly. If using non-automatic mixing, the mixing ratios must be recorded.

6.6 Other substances used in drilling

Liquids used to stabilize drill holes:
- bentonite slurry
- polymers
- other liquids.

The required properties of liquids reinforcing a drill hole are dealt with in Standard SFS-EN 1536, section 6.5.

The liquids and admixtures used in drilling must not have detrimental effects on steel, mortar or the properties of the surrounding soil, the environment or groundwater.

6.7 Steels

6.7.1 General

The reinforcement steels, steel pipes or steel sections used as pile reinforcement must meet the conditions set in national product standards, e.g. SFS 1215 (A500HW) and SFS 1257 (B500K), as well as European product standards, e.g. SFS-EN 10025 and SFS-EN 10219.

Centralizers must be installed on pile reinforcement at intervals not exceeding 2 metres.

6.7.2 Reinforcement steels

In the selection of steel grade attention must be paid to the assembly and weldability of cage reinforcement.

Reinforcement steel joints must be such that they do not decrease reinforcement capacity, and they must conform to the Finnish Building Code, B4 Concrete structures.

6.7.3 Structural sections

Whenever piles are reinforced with steel pipes or sections, the reinforcement must be designed in accordance with ENV 1994-1-1.

Weldability must be considered in the selection of steel grade where necessary.

6.8 Joints

6.8.1 General

Direction of pile may change at a joint by a maximum of 1:100 in the easy category, 1:150 in the demanding category, and 1:200 in the very demanding category.

If piles are jointed so that the joints withstand at least the same tensile, compressive and bending action as the pile section, pile capacity need not be decreased due to joints. If the properties of the joint are inferior to those of the pile section, it must be considered in the dimensioning of the pile. The strength and deformation properties given by the pile-joint manufacturer may generally be used in dimensioning. Joints must be protected against corrosion just like the actual pile element.

Piles may be extended by welding or using mechanical joints. The material of the joints must be composed of materials that do not essentially increase the risk of corrosion.

Grouted pile sections are generally extended using external threaded sleeves.

6.8.2 Extension of piles by welding

The details of welded joints must be shown in site plans. Welding of joints is explained in the work and quality plan for the site.

The details of the inspection procedure for welded joints during piling are agreed separately in each case.

When using solid-bar reinforcement, the joint surfaces must be machined in a mechanical workshop. The planarity of the joint surfaces must be < 0.1 mm.

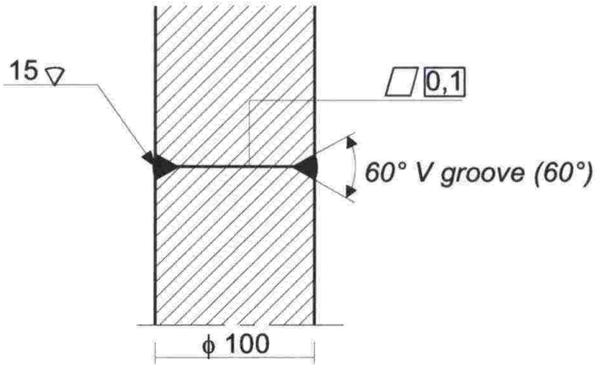

Fig. 9. Example of welding design for solid bar.

Weld quality requirements for joints are presented in Table 4.

Table 4. Weld quality requirements for bearing steel components of drilled piles for different requirement categories. SFS-EN 25817

Requirement category of site	Weld quality class	Weld-quality requirement
very demanding	B	demanding
demanding	C	good
easy	D	satisfactory

In the easy category joints are inspected visually to determine weld dimensions, misalignments, undercuts and possible welding defects extending to the surface. Ultrasonic examination (NDT) of welds is done only after they have passed visual inspection.

In the case of the demanding category, the welder is to do a so-called production weld test prior to welding. All seams are also to be inspected visually. The production weld test involves welding two pile pipes together in accordance with the welding program under conditions comparable to the installation conditions. Welding length is about a quarter of the entire weld. A piece about 100 mm square, which contains a weld, is cut from a spot that appears critical in visual inspection. One cross-sectional surface is ground and inspected visually. It must meet the requirements of the applicable weld class as to detectable defects. Special attention must be paid to complete penetration. The execution of a production weld test is recorded in the documents of the site in question. The test is valid for a maximum of 2 months when the test has been conducted under similar conditions using similar pile materials and types.

At very demanding sites, at least 10 percent of the seams are inspected ultrasonically in addition to performing the production weld test and visual inspection. In ultrasonic examination an entire weld is inspected, that is, one weld out of ten is examined entirely unless otherwise agreed. However, at least 30 percent of the seams of solid rods must be inspected ultrasonically. Inspections are documented by seams in the inspection record. Inspection must always start with the first weld involving, for instance, examination of internal weld defects such as incomplete fusion, pores and slag inclusions as well as defects of the root of the weld such as incomplete penetration and too large root ridge. Defects in excess of the limits of the weld category are repaired. Repaired welds as well as two other welds are reexamined. An NDT examination may be conducted only by a qualified inspector.

A related inspection record is always prepared.

7 DESIGN

7.1 General

The design of drilled piles must apply an engineering system based on the provisions of the Finnish Building Code and Foundation Engineering Instructions (RIL 121, 1988) or on Eurocodes and their National Application Documents (NAD). The instructions to be observed in design and dimensioning are listed under 2.2. and 2.3.

The design must be based on
- special requirements for the project, presented in Chapter 4
- ground investigations, presented in Chapter 5
- requirements for pile material presented in Chapter 6

Permissible deviations in positions and inclination of piles, and requirements for the piling work must be taken into account in the design, as shown in Chapters 7.6 and 8.

7.2 Tasks included in the design

The following tasks are included in the design:
- collection and assessment of basic data
- programming of ground investigation
- geotechnical and structural dimensioning of piles
- effect of drilling on surrounding soil and, through it, on surrounding structures
- design and supervision of test piling, and evaluation of results, where needed
- piling design, which contains
  - work specification or quality requirements containing instructions or requirements for drilling, cleaning of drill hole, reinforcement and concreting
  - measurements to monitor the effects of the piling work on adjoining buildings and/or the building to be strengthened, with permissible limits
  - quality control tests for piling
  - requirements for the piling records
  - requirements for the as-built drawings
- piling drawing that includes
  - pile loads and numbering of piles
  - target level of piles, which must be at least 3 metres below the future excavation or cutting level
  - permissible deviations of dimensions and locations
  - piling sequence

7.3 Limit states and dimensioning mechanisms to be considered

The compression and lateral capacity of piles, and tensile capacity, where applicable, must be checked in both service and ultimate limit states.

Limit states possibly caused by the displacement of piles in the foundation structures or structures supported by them must be checked both in service and ultimate limit state.

Loads on piles in the ultimate limit state must be multiplied by the partial safety factors of the load corresponding to the loading situation, and the pile capacity must be divided by the partial safety factor of capacity.

Pile analyses in serviceability limit state must be based on the characteristic values of loads on the piles, thus pile capacities are to be calculated according to the characteristic values of capacity.
At least the following dimensioning mechanisms must be taken into account in the dimensioning of the pile foundation:

- settlement
- heave
- lateral movement
- differential settlements and distortions
- soil-structure interaction
- capacity of foundation and/or single pile against compression, tension, bending and lateral load
- overall stability
- dynamic stiffness, where applicable
- stability of drill hole during concreting, and need of casing

Dimensioning situations must be inspected in all limit states on the basis of determining loads and load combinations.

7.4 Geotechnical design of piles

7.4.1 General

The transmittance of vertical load to rock or ground, or the ratio of shaft resistance to point resistance, depends on the piling method, pile dimensions and materials, and soil conditions as well as the resistance-deformation behaviour of soil and the loading time.

Lateral loads on the pile foundation can be transmitted to soil layers by the lateral resistance of soil and/or by inclined piles.

This document presents the principles of geotechnical and structural design of piles bearing on rock. Geotechnical dimensioning of piles bearing on ground and the dimensioning of the lateral resistance of the pile are to be carried out according to the High-capacity piling instructions (SPO-2001). However, this document contains some additions to the High-capacity piling instructions.

Dimensioning of the geotechnical compression, horizontal and tensile capacity of piles should be based on the safety level defined in ENV 1997-1 and the related national application document (NAD), with regard to the additions presented here and the partial safety factors of load combination C defined in ENV 1991-1.

7.4.2 Calculation of geotechnical bearing capacity

In the dimensioning of the base and shaft resistance of piles, the drilled pile is usually treated as a replacement pile. Pressure grouting may cause soil displacement, which can be taken into account in the geotechnical dimensioning of piles and based on data derived from load tests under similar conditions.

The geotechnical bearing capacity of the pile should be determined by dimensioning separately the contribution of the base and the shaft to the geotechnical bearing capacity.

It is not always necessary to take the shaft resistance into account; this is particularly true of piles bearing on rock.

Rock faults and cracks should be taken into account in dimensioning, where applicable.

Geotechnical dimensioning of drilled piles should be verified primarily with the following methods:

- earlier static loading tests under similar conditions with a corresponding pile type
- static loading tests

7.4.3 Base resistance of piles bearing on rock

The pile tip can be presumed to be bearing on rock, if observations during drilling and the ground investigations indicate that the tip of the pile has reached solid rock.

The base resistance of a drilled pile bearing on solid rock can be dimensioned for service state loads based on yield strength of the pile, if rock contact is verified by percussion drilling and observations during drilling. The uniaxial compressive strength of hard and solid Finnish intrusive rock is generally in the range of 200-300 MPa.

Piles are to be drilled at least 3 d deep but not less than 0.5 m and not more than 1.5 m into solid rock. However, piles must always be drilled at least 3 m below the future excavation or cutting level. This ensures sufficient bearing capacity of the pile tip in relation to the structural bearing capacity of a steel or composite pile, and slipping of the pile tip on the rock is prevented. If the levels of the tips of adjacent piles differ considerably, shorter piles must go deeper. If the rock face is very steep, additional drillings around the piles may be necessary. In rock with faults, piles can be drilled deeper or shaft-grouted piles used.

7.4.4 Shaft resistance of piles bearing on rock

Where piles are supported on the plane of weakness of rock or are under tensile stress, it may be necessary to factor shaft resistance of the pile in rock into dimensioning.

If the shaft resistance of a pile bearing on rock is used, the casing is drilled to the surface of the rock, after which drilling is continued in rock. If the drilling method allows grouting of the casing simultaneously with the drilling of the pile section, rock drilling is not needed.

The dimensioning strength of the adhesion between the concrete and the drill hole is usually presumed to be constant throughout the adhesion length. Then, the dimensioning value of the adhesion capacity is obtained from the formula:

$$R_{sd} = \pi d L_i \tau_{bd} \qquad (1)$$

d is the outer diameter of drill bit
L_i is adhesion length
τ_{bd} is the dimensioning strength of adhesion, obtained from Table 5

Table 5. Dimensioning strength of adhesion between concrete and rock in solid rock.

Concrete	t_{bd} [Mpa]
K30	0.75
K35	0.85
K40	0.95
K45	1.05
K50	1.10
K60	1.15

Adhesion between concrete or mortar and anchor steel is calculated in the same way as the adhesion capacity between concrete and the drill hole. The value of the adhesion strength between concrete and steel can be calculated according to RakMk B4 with the formula:

$$\tau_{bd} = k_b f_{ctd} \qquad (2)$$

k_b is 2,4 for ribbed bars and 1.0 for round bars
f_{ctd} is dimensioning value of the tensile strength of concrete or mortar

The adhesion between grouts, mortar and the drill rod of grouted drilled piles varies considerably depending on the pile profile. Where mortar or grout is used, the strength properties of the materials must be taken into account.

7.4.5 Bearing capacity of pile bearing on ground

The load-bearing capacity of a pile bearing on ground is calculated according to the High-capacity piling instructions (SPO-2001).

The effect of soil displacement caused by pressure grouting can be taken into account by a shaft resistance factor between the factors of a displacement and a non-displacement pile.

7.4.6 Tensile capacity of pile

If a pile is subjected to permanent tensile stress, it acts as an anchor and must be designed according to the instructions on anchoring.

The geotechnical tensile capacity of a pile is the sum of pile weight and the effective shaft resistance in tension.

In the case of fine-grained soil layers shaft resistance cannot be exploited in long-term tension.

The stress state around a tension pile differs from that around a compression pile, which means that the shaft resistance of a tension pile in soil is lower than that of a compression pile. An approximation for the characteristic value of the shaft resistance of a tension pile can be derived from the characteristic value of the shaft resistance of a compression pile as follows:

- short-term loading $$R = \frac{R_{sk}}{1.6} \qquad (3)$$

• long-term loading $R = \frac{R_{sk}}{2.0}$ (4)

The tensile capacity of a pile in rock is the sum of pile weight and the shaft resistance of the casing grouted into the rock.

The minimum anchoring length in rock of a pile under tension can be calculated according to the principle presented in Figure 10 using the formula:

$$L_{min} = \sqrt[3]{\frac{3R_{td}}{(\gamma_d - 10)\pi \tan\phi}} \quad (5)$$

R_{td} is the dimensioning value of tensile stress

γ_d is the dimensioning unit weight of rock, generally 26.5 kN/m^3

ϕ is generally 45°

If the cracking of the rock has not been determined reliably, a minimum anchoring length of 3 m should always be used for tension piles.

When dimensioning the tensile capacity of several adjacent piles, the effective weight of the rock cone on which the tension of the pile group is concentrated should be taken into account according to the principle shown in Figure 10.

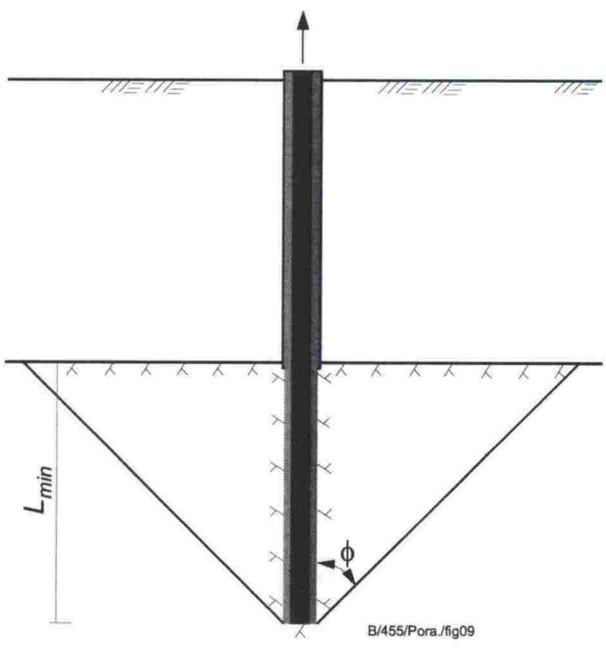

Figure 10. Minimum anchoring length of a tension pile in rock.

On the basis of tensile loading tests, the characteristic value of the shaft resistance of a pile is determined according to ENV 1997-1 and its national application document (NAD) complemented with the additions presented in Chapter 7.3.21.

In the demanding category, the tension capacities of piles can be dimensioned on the basis of ground investigation results.

In the very demanding category, where tensile loads are frequently repeated or cyclical, tensile resistance should be assessed by loading tests corresponding to the actual loading of the tension pile.

7.4.7 Lateral capacity of pile

The lateral capacity of a pile should be dimensioned according to the instructions given in the High-capacity piling instructions (SPO-2001).

The dimensioning of lateral capacity in the very demanding category should be based on numerical methods whose validity has been proven by loading tests simulating the actual loading of the pile or by results of measurements or loading tests conducted under corresponding conditions.

Loading tests simulating the actual loading of piles must be performed when dimensioning a pile foundation in the very demanding category where no previous loading test results or practical experiences from a corresponding structure are available.

When calculating lateral capacities of piles, soil strength parametres must be divided by the partial safety factors, and in the calculation of lateral loading they must be multiplied by the partial safety factors.

7.4.8 Dimensioning for a cyclic load

Drilled piles should be dimensioned for cyclic loads according to the instructions given in the High-capacity piling instructions (SPO-2001).

7.4.9. Determining geotechnical bearing capacity of pile by static loading tests

In case of piles bearing on ground the geotechnical load-bearing capacity can be determined by static loading tests according to the High-capacity piling instructions (SPO-2001).

If pile diameter is (d<200 mm) a test pile with the same diameter should be used. If pile diameter is greater than 200 mm, the diameter of the test pile should be at least 50% of the pile diameter but not less than 200 mm.

To verify the bearing capacity of piles bearing on rock, it is usually sufficient to establish on the basis of percussion drillings and observations during pile drilling that the pile stands on solid rock.

7.5. Structural design

7.5.1. General

The dimensioning of the structural strength of piles should be based either on the safety factors presented in the national instructions (RakMK) or, if applying an alternative dimensioning system, on the partial safety factors of materials presented in European standards ENV 1992-1-1, ENV 1993-1-1, and ENV 1994-1-1, together with the partial safety factors of load combination B presented in ENV 1991-1.

Piles bearing on rock can be dimensioned as piers, in which case the specific instructions pertaining to pile material or structural performance should be taken into account, such as the regulations presented in RakMk B7 for steel piles and the regulations presented in Liittorakenteet BY 26 and Liittorakenteiden sovellutusohjeet B 36 for composite piles.

The interaction between the pile and soil may also be considered in the structural dimensioning of piles. In structural dimensioning, only the structural diameter can be taken into account. In buckling dimensioning, the geotechnical diameter can be used as the width of the soil layer supporting the pile.

Stresses during the transport, handling and installation of piles should also be taken into account in the structural dimensioning of piles.

A drilled pile should be designed in the same way as
- a steel structure, or
- a steel/concrete composite structure

The structural class of concrete used in drilled piles and possible requirements for its durability must be presented in the designs, and they must meet at least the requirements presented in RakMk B4 or ENV 1992-1-1 and its national application document (NAD).

7.5.2. Corrosion of shaft-grouted piles

When using external corrosion protection, the thickness of the protective layer must be at least equal to that presented in Table 6. In piles subjected to tensile or bending stresses, crack width in the service state must not exceed:
- 0.3 mm under non-aggressive conditions
- 0.15 mm under aggressive conditions

The profile of the reinforcement should be taken into account in calculating crack width.

Table 6. Minimum thickness of external corrosion protection layer in a non-aggressive environment.

	Minimum thickness of protective layer [mm]	
	Piles under compressive action	Piles under tensile or bending action
Grout	20	30
Mortar	35	40
Concrete	50	50

If the thickness of the protective layer used is smaller than that indicated in Table 6, corrosion is to be taken into account as a corrosion allowance for the steel cross-section, as shown in Table 7 in Chapter 7.5.3.

In the case of drilled piles with a design service life of less than 20 years, it is possible to use a protective layer that is 10 mm thinner than that indicated in Table 6.

If necessary, the thickness of the protective layer of grout, mortar or concrete inside a permanent casing can be reduced by 10 mm, provided that the wall thickness of the casing is greater than 4 mm.

In an aggressive environment, corrosion protection should be provided by
- a greater protective layer thickness than that indicated in Table 6
- a higher corrosion allowance for the steel cross-section
- organic or inorganic coatings
- a permanent casing
- cathodic protection

7.5.3 Corrosion allowance of steel-surfaced drilled piles

Surrounding conditions are to be taken into account in the corrosion protection of drilled piles. Corrosion is usually taken into account in the form of the so-called corrosion allowance. Corrosion allowance depends on the designed service life of the structure and estimated corrosion rate.

In clean soil corrosion is generally so low that the protection of piles can be achieved by increasing wall thickness. Table 7 presents the corrosion allowances recommended in Eurocode 3, Part 5: Piling. Because of the higher safety requirements of bridges, the Finnish Road Administration uses the values given in Table 8. If piles are exposed to anti-icing salt, corrosion protection or corrosion allowance must be determined separately.

Under difficult corrosion conditions, such as in contaminated soil or air, corrosion protection can be achieved, for instance, by a concrete structure. Separate protection can also be attained by painting or using epoxy or polyethylene coatings or cathodic protection. If these protection methods are used, their strength during installation must be taken into account. If piles are installed into rocky or otherwise "scratching" soil, coatings may be damaged. The rate of the resulting spotty corrosion is markedly higher than the rate of even corrosion. If cathodic protection is used, its service life should be taken into account.

Table 7. Oversizing of steel parts for corrosion [mm] SFS-ENV 1993-5:1997According to Eurocode 3:- 5 Piling.

Soil conditions	Service life (years)				
	5	25	50	75	100
Undisturbed natural soil (sand, silt, clay...)	0.00	0.30	0.60	0.90	1.20
Contaminated natural soil and industrial areas	0.15	0.75	1.50	2.25	3.00
Aggressive natural soil (marsh, bog, peat...)	0.20	1.00	1.75	2.50	3.25
Non-compacted non-aggressive fill (sand, clay, silt...)	0.18	0.70	1.20	1.70	2.20
Non-compacted aggressive fill (ash, slag...)	0.50	2.00	3.25	4.50	5.70
- Compacted fill has a slower corrosion rate than non-compacted fill. With compacted fill the corrosion allowance of non-compacted fill can be divided by two. - The values are recommendations. Local conditions must always be taken into account. - The values for a service life of 5 or 25 years are based on measurements. Other values were obtained by linear extrapolation and are therefore on the safe side.					

Furthermore, Appendix F. Bearing Piles, section 2 mentions that corrosion in air in 100 years is
- 1mm in a normal climate
- 2 mm near the sea

Table 8. Oversizing of steel parts for corrosion by the Finnish Road Administration.

Waterway			Land area	
Zone	Oversizing [mm]		Zone	Oversizing [mm]
	Sea	Inland		
>HW + 1.5	4	3	Ground level +1.0	3*
HW +1.5...NW -1.5	10	6	Ground level +1.0...HW +1.0	4*
NW-1.5...Bottom -1.5	4	3	HW +1.0...NW -1.0	4
<Bottom -1.5	2	2	<NW -1.0	2

*If piles are exposed to de-icing salt, the corrosion allowance must be determined separately

7.5.4 Structural dimensioning

7.5.4.1 General

The factors to be considered in the structural dimensioning of piles are: structural failure of pile due to compression, tensile stress, bending stress or shearing stress, and buckling.
If no external corrosion protection has been used, structural dimensioning uses cross-sectional dimensions of the steel or composite structure minus the corrosion allowance corresponding to the soil conditions and service life. The corrosion allowance is discussed in Chapters 7.5.2 and 7.5.3.

7.5.4.2 Buckling capacity

Pile buckling may be caused by the lack of sufficient lateral support.

A pile is considered to be inadequately supported against buckling if the pile is partly surrounded by air or water or the shear strength of the surrounding soil is low.

In dimensioning piles against buckling, the piles are assumed to be curved. The curvature of radius depends on soil conditions, pile cross-section, number of joints and the drilling method.

If part of or the entire pile length is unsupported, the pile should be considered in buckling dimensioning a curved steel or composite pier.

In determining the buckling load the pile is assumed to be surrounded by a fully elastic medium. When the pile bends, an equivalent horizontal deformation is caused in the surrounding soil. The supporting action of the soil can be determined on the basis of the deformation modulus of the soil in terms of springs, as indicated in the High-capacity piling instructions (SPO-2001).

The initial curvature of the pile after installation and before loading must be taken into account in the structural dimensioning of all piles. In the supervision of piling work, it should be ensured that the assumed curvature of the piles is not exceeded. The minimum radius at bend of piles is determined on the basis of production tolerances and permissible direction change at joint.

The capacity limit of the pile is reached when the structural capacity of the most loaded pile cross-section is exceeded or the lateral pressure caused by the bending of pile exceeds the lateral resistance of the surrounding soil.

7.5.4.3 Lateral pressure caused by buckling

The load caused by an axially loaded pile in soil is discussed in the following. If a pile is also subjected to a horizontal or bending load, it should also be taken into account. Buckling dimensioning is discussed in more depth, for example, in Sami Eronen's licentiate thesis: Drilled Piles in Underpinning and Bridge Foundations, Tampere 2001.

When the capacity of surrounding soil is exceeded, pile load P can be calculated from the formula:

$$P = \frac{P_{cr}}{1 + \frac{k_s \delta_0}{p_{ma}}} \qquad (6)$$

P_{ma} is the contribution of axial loading to the ultimate stress limit of soil
δ_0 is initial bend
P_{cr} is buckling load of straight pile
k_s is module of subgrade reaction

Since the degree of fixing of the pile heads does not affect the buckling loads of the middle sections of long piles, the buckling theory for piles articulated at both ends can be used. Then, the buckling load P_{cr} of a straight pile can be calculated as follows:

$$P_{cr} = 2\sqrt{k_s dEI} \qquad (7)$$

d is pile diameter
EI is bending stiffness of pile
k_s is the module of subgrade reaction

Critical buckling length L_{cr} in the weakest soil layer is calculated from the formula:

$$L_{cr} = \sqrt[4]{\frac{EI}{k_s d}} \times \pi \qquad (8)$$

If the thickness of the weakest soil layer is less than the buckling length, the effective module of subgrade reaction is determined by more accurate calculations.

If pile length is shorter than the critical buckling length L_{cr}, the critical buckling load of the pile is calculated according to the following formula:

$$P_{cr} = n^2 \frac{\pi^2 EI}{L_n^2} + \frac{k_s d L_n^2}{n^2 \pi^2} \qquad (9)$$

n is the number of half-waves that determines the minimum value of the buckling load
L_n is the Eulerian buckling length that takes the fixing of pile heads into account

The relation between defection, δ_0, and the radius of curvature, R, can be expressed by the formula:

$$R = \frac{L_{cr}^2}{8\delta_0} \tag{10}$$

The value of the defection of a loaded pile can be calculated from the correlation:

$$\delta_0 + y_0 = \frac{P_{cr}}{P_{cr} - P}\delta_0 = a\delta_0 \tag{11}$$

y_0 is the increase of defection due to loading

Determining the module of subgrade reaction k_s

The buckling resistance of pile for permanent loads is determined using the long-term module of subgrade reaction. For simultaneous permanent and temporary loads the short-term module of subgrade reaction is used.

In static loading the subgrade reaction of friction soil can be determined as follows:

$$k_s = n_h \frac{z}{d} \tag{12}$$

The factor for the module of subgrade reaction n_h is derived from the compression modulus M or the module of elasticity in drained state, E_d, which can be determined by oedometer or triaxial tests.

$$n_h = \alpha\beta\frac{M}{z} = \frac{E_d}{z} \tag{13}$$

α 0.74 (according to Terzaghi)
α 1.0 (according to Poulos)
β 0.83…0.95 for sand with corresponding variation of the Poisson constant of 0.25…0.15

In coarse-grained soil pile displacement can be determined according to the lateral pressure-pile displacement correlation presented in Figure 11, where p_m is the maximum value of the lateral pressure and y_m is the corresponding displacement.

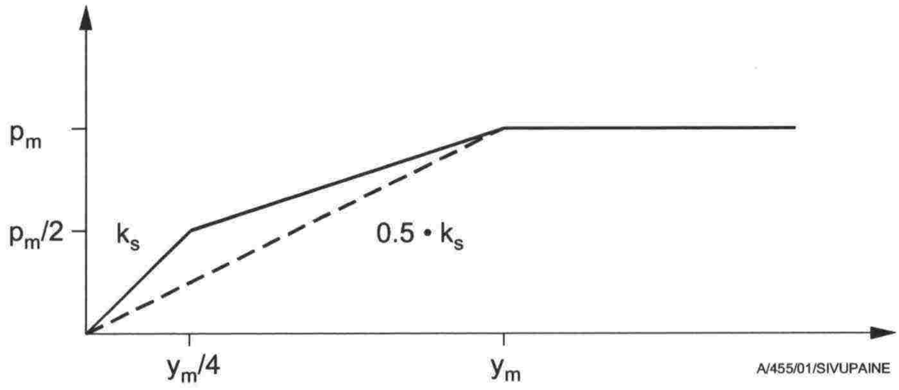

Figure 11. Lateral pressure-pile displacement relation in coarse-grained soil.

In fine-grained soil the horizontal module of subgrade reaction depends not only on pile diameter but also on loading time.

In long-term loading the module of subgrade reaction for fine-grained soil is assumed to be:

$$k_s = 20..50\frac{c_u}{d} \qquad (14)$$

c_u is undrained shear strength

In long-term loading the module of subgrade reaction for fine-grained soil can also be determined by the compression modulus M, in which case the module of subgrade reaction k_s is

$$k_s = \beta\frac{M}{d} \qquad (15)$$

β 0.46…0.76 for clay with corresponding variation of the Poisson constant of 0.4…0.3
β 0.62…0.83 for silt with corresponding variation of the Poisson constant of 0.35…0.25

and in short-term loading the module of subgrade reaction is assumed to be:

$$k_s = 50..150\frac{c_u}{d} \qquad (16)$$

In short-term loading the module of subgrade reaction of fine-grained soil can be determined based on the module of elasticity in undrained state, E_u, using, for example, an undrained triaxial test.

In fine-grained soil the lateral pressure-pile displacement relation can be presented in the case of short-term loading as shown in Figure 12 a and in the case of long-term loading as shown in Figure 12 b.

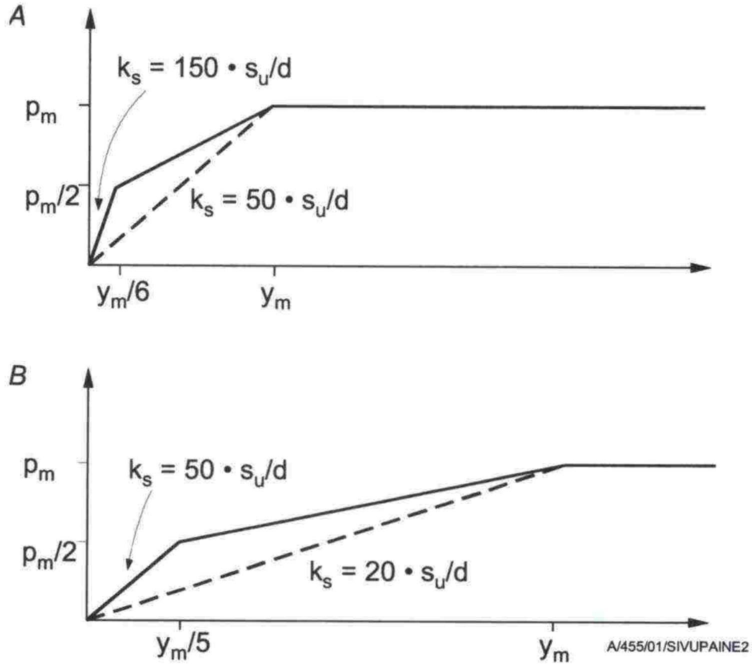

Figure 12. Lateral pressure-pile displacement relation in fine-grained soil: a) short-term loading, b) long-term loading.

7.5.4.4 Structural capacity

The structural capacity of a pile is calculated according to RakMK B7 if the pile is dimensioned as a steel structure, or according to Liittorakenteet By 26 and Liittorakenteiden sovellusohjeet By 36 if the pile is dimensioned as a composite structure. Correspondingly, if the pile is dimensioned as a steel structure, the SFS-ENV 1993-1-1:1992 Part 1 and its national application document as well as SFSENV 1993-5:1997 are to be applied, but if the pile is dimensioned as a composite structure, the applicable documents are SFSENV 1994-1-1:1992 and its national application document. Buckling length can be based on the critical buckling length L_{cr}.

A more accurate method for dimensioning the structural capacity of piles is the element method and the element-spring model defined in the High-capacity piling instructions (SPO-2001).

7.5.5 Vertical pile displacements

Vertical pile displacements are calculated according to the High-capacity piling instructions (SPO-2001).

The elastic compression of the rock below the pile tip is small compared to the elastic compression of the pile shaft and can usually be ignored. Thus the overall settlement of a pile bearing on rock is practically equal to the elastic compression of the pile shaft.

In simple cases, the elastic compression of the pile shaft can be estimated with sufficient accuracy on the basis of Hooke's law. However, the distribution of shaft resistance in long piles must be taken into account. The settlement of piles bearing on ground is calculated according to the High-capacity piling instructions (SPO-2001).

7.6 Position of piles

7.6.1 Permissible deviations in pile positioning

An advantage of drilled piles is that usually no deviations in pile positioning occur in the installation. This advantage can be utilized in the design.
Piles must be executed within the limits of the following permissible deviations in pile positioning, see Figure 13.

a) Positioning measurement ± 5mm

b) vertical and inclined piles and their horizontal position measured from the working level
- e = 50 mm, in the easy category
- e = 25 mm, in the demanding category
- e = 15 mm, in the very demanding category

c) vertical or inclined piles with an inclination of less than 15:1
- tangent of the designed and actualized angle of the centre line of pile
  - $i \leq 0.03$ (≤ 30 mm/m), in the easy category
  - $i \leq 0.02$ (≤ 20 mm/m), in the demanding category
  - $i \leq 0.01$ (≤ 10 mm/m), in the very demanding category

d) inclined piles with an inclination in the range of 4:1 ... 15:1
- tangent of the designed and actualized angle of the centre line of pile
  - $i \leq 0.05$ (≤ 50 mm/m), in the easy category
  - $i \leq 0.035$ (≤ 35 mm/m), in the demanding category
  - $i \leq 0.02$ (≤ 20 mm/m), in the very demanding category

If deviations in pile positioning different from the above are set, the following factors must be considered
- structural demands
- soil conditions
- available drilling equipment

Permissible deviations in pile location must be agreed on before starting the work.

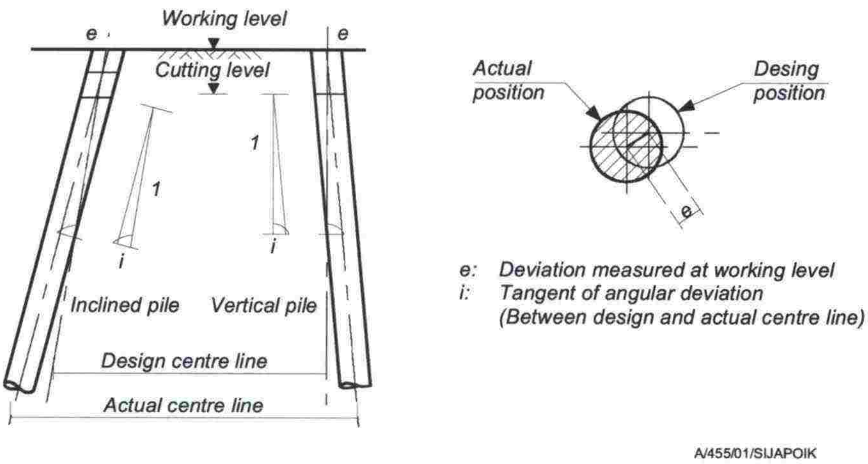

Figure 13 Permissible deviations in positions of drilled piles

7.6.2 Pile positions

7.6.2.1 Distance between piles

The positions of piles must be indicated in the design documents.

Distances between piles must be chosen so that adjacent piles will not reduce the load-bearing capacity of each other.

In a group of piles the intersection of intersecting piles should be designed as close to ground level as possible.

Permissible deviations in pile positions should be taken into account In the design of the minimum distance between both parallel and intersecting piles.

The distance between tension piles bearing on ground should be 5 D or at least 1,5 m.

In determining the distances between tension piles anchored on rock from each other, the minimum anchoring length L_{min} (Chapter 7.4.6) should be determined so that the weight of the rock cone formed around the group of piles is able to take the tensile load of the piles (cf. Figure 10).

7.6.2.2 Distances between piles and other structures

The minimum distances between piles and other structures should be designed separately for each case considering the special requirements and limitations posed by the piling, soil conditions and surrounding structures.

Pile type, area of pile cross-section, and vibration caused by piling should also be considered in choosing the distance between piles and adjacent structures.

If piles are to reach below the foundation level of adjacent or previously completed structures, the settlement and displacements caused by piling and their influence on surrounding structures must be evaluated.

7.7 Drilling of piles

If piles are drilled to the bearing layer or rock, the drilling method and minimum drilling depth and possible grouting method are to be specified in the design.

During drilling the ground and its behaviour must be observed. If soil conditions differ from those specified in the design, the designer of the foundation and the supervisor of the foundation work must be contacted.

7.8 Reinforcement

7.8.1.1 General

The starter bars and dowels installed in fresh or hardened concrete that attach the pile to the superstructure must conform to ENV 1992-1-1.

Where steel pipes or profiles are used, the dimensioning of the pile reinforcement must conform to ENV 1994-1-1.

Corrosion allowance must be considered in dimensioning if a steel pipe or permanent casing is used as a structural part, unless reliable contiguous corrosion protection is achieved by concrete, mortar or other corrosion protection agent.

The length of the reinforcement and the number and diameter of steels must be specified in dimensioning.

The work plan should specify measures to ensure the rigidity of the reinforcement cage.

7.8.1.2 Main rebars

The distance between the main rebars should be sufficient to ensure adequate flow of concrete between the rebars. Reinforcement cages cannot be used if the inner diameter of the pile casing is less than 200 mm.

When using underwater concreting, the clear distance between steel bars of the reinforcement cage must be at least 100 mm.

The clear distance between steel bars or bundles of bars in one layer can be set to 64 mm when the maximum grain size of the used mineral aggregate is 16 mm.

The minimum distance between the steel bars of different reinforcement layers (distance between circles) must be 2 times the diameter of the steel bar or 1.5 times the maximum grain size of mineral aggregate. The higher of the above values must be used.

Bar spacing can be reduced at the bar joint.

If bars are not distributed evenly, special methods must be used to ensure the positioning of bars during installation and concreting.

7.8.1.3 Stirrups

The diameters of stirrups should correspond to those presented in Table 9 (SFS-EN 1536/7.6.3.2).

Table 9 Recommended diameters or widths of stirrups.

Type of stirrup	Recommended diameter
Rings, bands or threaded hooks	The higher of the following values: 6 mm or one fourth of the maximum diameter of main rebars
Welded steel net	5 mm

Stirrups must be fixed to the main rebars.

7.8.1.4 Special reinforcements

Special reinforcements should be designed and installed according to the preliminary standard ENV 1994-1-1 and the documents Liittorakenteet By 26 and Liittorakenteiden sovellusohjeet By 36.

The thickness of the concrete cover must be indicated in the design (SFS-EN 1536/7.6.5.2).

Where necessary, adhesion strength can be established by means of field or laboratory tests.

Special reinforcement must be installed parallel to the pile axis. In installation the designed thickness of concrete cover around the special reinforcements must be ensured.

8 PILING WORK

8.1 Work and quality plan

Before starting the piling work the implementer of the piling work must prepare a site-specific work and quality plan for the piling. The work plan should detail the working methods and drilling equipment to be used to attain the requirements for the foundation design. The work plan should consider the actual conditions on the site during piling. The quality plan should indicate how the attainment of required quality is verified, measured and recorded.

The work and quality plan for piling must be presented in the form of a written document and drawings, and it must be submitted for approval to the client two weeks before the launching of the piling work.

Before the piling work it may be necessary to carry out additional ground investigations to establish the depth of the rock face, the suitability of alternative pile types and the target levels of piles.

The foundation design can be complemented while planning the work in the following ways:

- reviewing the production method and sequence of piling
- preparing designs for possible working platforms or scaffolding
- preparing a plan for the cleaning of pile bottom and casing
- preparing a plan for lifting, handling and centring the reinforcement cage
- preparing a concreting plan
- agreeing on inspection and survey procedures such as inspection of pile base, establishment of contact to rock, inspection of the cleanness of pile, inspection of the straightness of pile, need of loading tests
- defining treatment procedure for pile base and planning possible for rock contact
- revising pile drilling instructions
- assessing the effect of limitations set by environment on working performance
    - assessing the risk of slope failures
    - assessing vibration caused by blasting and piling
    - displacement and vibration measurements for surrounding structures
    - establishing the groundwater level
    - protection of waterways
    - reduction of noise

Details of the work plan that were left to be complemented during the piling work on the basis of more accurate knowledge of the boundaries and properties of soil layers should be filled in at the starting phase of the piling work.

In addition, the work plan should also contain, at least, the following information:

- selection and location of machinery, and the performance and direction of auxiliary functions such as hoisting
- design of positioning measurements and setting of necessary couplings
- transportation, storage and handling of piles
- pile joints and welding plan
- attachment of piles to superstructures
- design of quality assurance measures for piles
- design of labour protection measures and inspections

8.2 Requirements for the implementers of the piling work

8.2.1 Piling supervisor

A piling work supervisor must be appointed to supervise piling work on site.

In demanding and very demanding projects the piling work supervisor must have such training and experience of piling work that he can be accepted by the authorities as a responsible supervisor or manager of demanding construction work.

The piling work supervisor should generally have a few years of practical experience from drilling and piling work and adequate theoretical knowledge.

A person can be considered to have adequate theoretical knowledge if he or she has taken a degree in civil engineering in an institute of technology or a polytechnic or who has acquired the necessary basic knowledge for piling work by receiving relevant practical training elsewhere.

The piling work supervisor should be sufficiently familiar with the pile type used. He should supervise and manage all tasks related to the piling work and carry out necessary inspections. The qualification requirements for the person who supervises concreting work are defined in RakMK B4.

8.2.2 Tasks of the piling work supervisor

It is the task of the piling work supervisor to ensure that

1) the personnel have the necessary skills and the machinery are suited for the work
2) the piling work and quality plan have been prepared and approved
3) piles have been measured for correct positions and couplings exist
4) piling records containing position measurements are made and inspected using the proper procedure
5) contact with the supervisors, authorities and designers is maintained
6) the drilling work proceeds as planned and the environment and soil layers are monitored
7) measurements of pile position and inclination are made during the drilling work
8) the cleanness of the base and the cleanness and straightness of piles are checked
9) the production and centring of the reinforcement are controlled
10) the concreting plan is made
11) the concreting work is supervised
12) pile quality assurance measures are taken
13) supplied pile components meet the quality requirements and pile parts are attached as designed
14) the pile is positioned in the measured location vertically or at the designed angle supported according to the piling work plan
15) pile joints and their inspections are carried out as planned.
16) designed test piles and loading tests are performed and revised drilling instructions are obtained from the geotechnical designer

8.3 Piling work

Piling work is to be performed according to these instructions, unless otherwise stated in the foundation design.

The used piling method must be such that the work can be carried out as planned and it will not damage adjacent structures.

8.4 Different installation methods

The performer of piling work needs equipment suitable for each pile type to ensure that the end result will meet the requirements specified in the foundation design and these instructions.

In Finland, pile drilling is generally effected by percussion drilling methods. Percussion drilling methods are based on four main components:

- Feed force
- Rotation
- Percussion
- Flushing

The drilling equipment consist either of a top hammer (drifter) or a DTH (down-the-hole) hammer. The drilling equipment is discussed in more detail in Chapter 8.4.1.

There are two different methods for pile drilling: concentric and eccentric. Drilling methods are discussed in more detail in Chapter 8.4.2.

8.4.1 Drilling equipment

8.4.1.1 General

The drilling equipment may be either DTH, as shown in Figure 14a, or top hammer equipment, Figure 14b. Both types of equipment may use either the concentric or the eccentric drilling method. Drilling methods are discussed in more detail in Chapter 8.4.2.

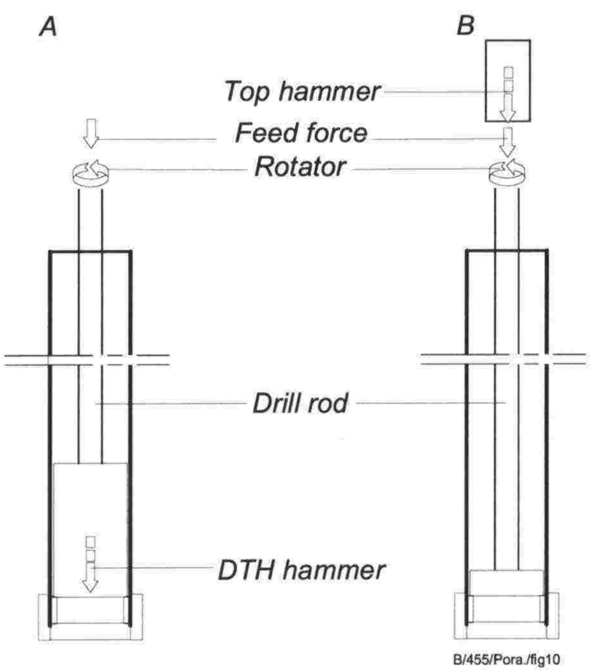

Figure 14 Principles of drilling equipment a) DTH equipment b) top hammer equipment

8.4.1.2 Top hammer equipment

Top hammer equipment may have either a pneumatic or a hydraulic hammer. The percussion frequency of pneumatic hammers ranges from 1600 to 3400 percussions per minute while hydraulic hammers achieve 2000 to 4000 percussions per minute.

Top hammer equipment can be used up to a casing diameter of about 200 mm.

With top hammer equipment, the drilling power decreases with increasing pile length and the number of joints. Top hammer equipment is normally not used for piles over 30 m long. In deep soft soil, however, top driving equipment has been used for drilling piles over 50 m long.

Grouted drilled piles are always drilled using top hammer equipment.

Some types of top hammer equipment also allow upward percussion. This is useful for lifting the casing if it is not intended to remain as a permanent pile.

8.4.1.3 DTH equipment

DTH equipment is usually pneumatic, although some water-driven DTH equipment exist but are not yet very widely used. The high operating pressure and water consumption of water-driven hammers may disturb the soil.

The percussion hammer is located right on top of the drill bit and follows the bit into the drilled hole. The main advantage of DTH equipment is its better efficiency, because the impact energy is used more efficiently than with top hammer equipment. The penetration rate is also more constant, irrespective of the depth of the drilled hole. Normally DTH equipment also produce straighter piles.

DTH equipment can be used up to casing diameters of 800-1000 mm.

In the case of DTH equipment the pile length has virtually no effect on drilling power.

8.4.2 Drilling method

8.4.2.1 The eccentric drilling method

The equipment used in the eccentric drilling method consist of a pilot bit and an eccentric reamer. The eccentric drilling method may use either top hammer or DTH drilling equipment.

The eccentric drilling method is described in Figure 15. As the drilling proceeds, the eccentric reamer reams the hole drilled by the pilot bit slightly bigger than the casing diameter. At the same time, the drill bit pulls the casing into the ground. The flushing agent blows part of the removed soil through the casing up above the ground. When the target depth has been reached, the drill rods are rotated in the reverse direction, which causes the reamer to close and the drilling equipment can be extracted from the casing. Drilling may then be continued by a standard rock bit.

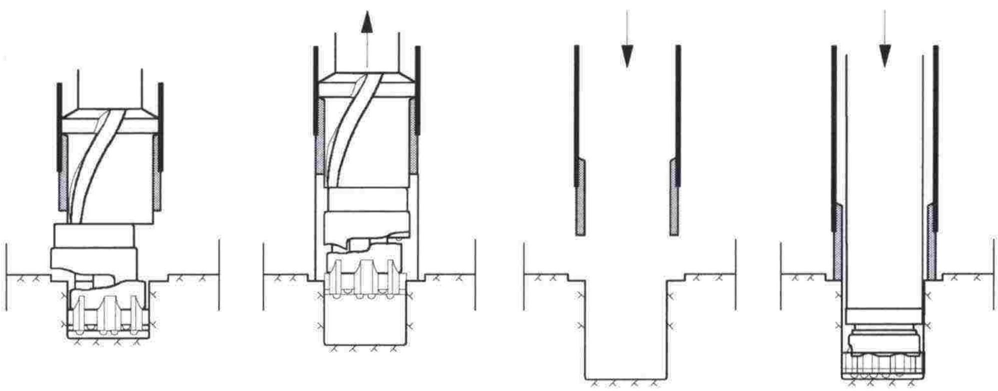

Figure 15 The eccentric drilling method

In the eccentric drilling method, the casing always remains on a rock shelf caused by the method. The dimensions of the rock shelf depend on the equipment used. This must be taken into account in the design of the piling.

8.4.2.2 The concentric drilling method

The equipment used in concentric drilling methods consist of a pilot bit and a concentric reamer (ring bit). The concentric drilling method may use either top hammer or DTH drilling equipment. At present, there are two different concentric drilling methods. In the older OD method, the casing is rotated from behind and the reamer is attached to the head of the casing. The drawback of this method is that it requires high torque, which makes it unsuitable for large-diameter drilled piles.

In the newer concentric drilling method, the casing is no longer rotated. A reamer is locked to the pilot bit, and they rotate together and drill a hole slightly bigger than the casing. The unrotating casing is pulled down by the pilot bit. When the target depth has been reached, the pilot bit is unlocked from the reamer and lifted up. If necessary, drilling may then be continued by a standard rock bit (Figure 16).The new concentric drilling method requires low torque resulting in faster penetration and straighter holes. The method is also well suited for drill large-diameter piles. Grouted piles are always drilled by the concentric drilling method.

8.5 Drilling of a pile

During drilling, the pressure caused by the feed force under the drill bit must be lower that the flushing pressure to ensure that the flushing holes stay open throughout the drilling.

If the flushing holes are blocked, an attempt can be made to open them by using maximum flushing pressure and by varying the rotating power and feed force. If the flushing holes cannot be opened, the pilot bit should be extracted from the casing and the holes cleaned, after which drilling can continue.

If the pile meets a stone or a rock, the feed force must be kept low and the speed of rotation must be increased to avoid lateral shift, curving or inclination of the pile.

Some drill bits provided with special carbide inserts can penetrate wood and possibly steel. Drilling through wood is considerably slower than drilling through soil or rock. Drilling through steel involves a high risk of breaking the drill bit.

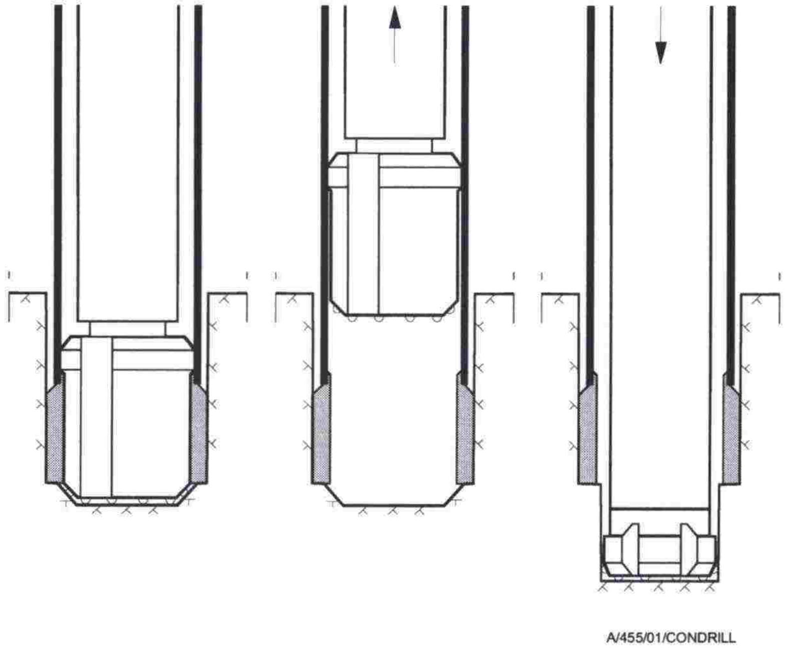

Figure 16. The concentric drilling method

If the casing breaks during drilling, the entire casing has to be lifted up. If this is not possible, the pile must be rejected.

Pile drilling must not be interrupted for a longer period of time.

Drilling into coarse-grained soil layers may cause loosening of dense layers or compaction of loose layers.

The ground bearing the pile loosens if the volume of the soil removed from the ground during drilling exceeds the volume of the casing.

A high grouting pressure can be used to achieve slight compaction of the coarse-grained soil supporting the pile.

Pile drilling may disturb fine-grained soil layers and increase the pore water pressure, decreasing the strength of the soil layers. Strength returns rather slowly, and in case of over-consolidated soil layers, only partly.

Disturbance and increase of pore water pressure can be eliminated by:
- selecting a drilling method that is suited to the soil conditions
- limiting the used flushing or grouting pressure
- intermittent drilling or slowing down piling speed

When the drilling has reached the target level, it must be ensured that the casing, which acts as a load-bearing structure, is supported tightly on the rock. This is particularly important with the eccentric drilling method.

The casing may be lifted off the rock when the drilling equipment is extracted from the casing. In the eccentric drilling method, the casing always remains at a distance from the rock equal to the distance between the pilot bit and the reamer. If the casing acts as a load-bearing structure, it must definitely rest on the rock.

The casing may usually be hammered against the rock by hitting on the head of the casing with the drill hammer.

8.6 Flushing during drilling

The flushing agent used in drilling may be air, water, bentonite, polymers or slurry.

The flushing agent must not remove more soil from the ground than the volume of the casing. Likewise, the flushing must not remove more water than what was fed into the ground during drilling.

Drilling must be interrupted if the air used in flushing does not escape from the soil through the pile casing.

Water and/or soil extracted by flushing may cause:
- disturbance of soil layers around the pile
- loss of bearing capacity of the soil layers under the foundation of adjacent structures or the structure to be supported by the pile
- damage to the unhardened grout or concrete grouted through adjacent recently installed piles
- flushing of cement

The risk of soil and/or water escaping from the ground increases:
- in loose uniformly grained soil layers
- in soft fine-grained soil layers
- in changing soil layers
- when using DTH equipment with direct flushing below the level of groundwater

If water is used as the flushing agent with top hammer equipment, the flushing water pressure must generally exceed 20 bar and the water supply rate must be at least 20 l/min to avoid blocking of the flushing holes in the drill bit.

8.7 Joints

Welded joints must be made by the metal arc welding or the powder or gas shielded arc welding method.

The requirements for welded joints are discussed in Chapter 6.8

When using welded joints, drilling must not be continued until the welded area has cooled sufficiently. This is particularly important if water flushing is used or the level of water is close to the drilling level.

A detailed welding plan must be prepared for welding work to be carried out in a mechanical workshop and on site.

If threaded joints are used, the cleanness of the thread must be ensured before extension. Threads must be tightened carefully applying sufficient torque. A threaded joint can be secured during drilling, for instance, by light welding.

8.8 Grouting

8.8.1 General

The grouting of piles is discussed in detail in the draft standard CEN/TC 288 N213E Execution of special geotechnical work. Micropiles (April 2000).

The preparations for grouting and the actual grouting must be performed in such a way that design material strengths are attained.

Ingredients must be dosed using calibrated equipment with a minimum measurement accuracy of 5 %.

In automatic mixing the batching of ingredients is to be checked regularly. If using non-automatic mixing, the mixing ratios must be recorded.

Grouting pressure must be measured as close to the grouting point as possible.

The following methods can be used in grouting:

- gravity grouting
- pressure grouting
  - single-phase grouting through a casing
  - single-phase grouting through a grouting pipe
  - multi-phase grouting through a grouting pipe
- grouting during drilling

The grouting method is selected on the basis of the soil conditions, grout, and available equipment.

The time between the drilling and grouting of grouted piles must be kept as short as possible.

If a sudden drop of grouting pressure is detected, pressure grouting must be stopped.

8.8.2 Grouting in soil layers

8.8.2.1 General

Grouting parameters, pressure, amount, flow and velocity of flow should be chosen with a view to preventing harmful deformation or displacement in soil layers. This is particularly important close to sensitive structures.

When grouting under such soil conditions where the flow of groundwater is possible, dilution of the grout may occur or the grout may even be flushed away. Depending on the soil conditions, the above effects may be reduced using the following procedures:

- use of rapidly hardening grout
- use of high-viscosity grouts and/or mortar with a high dry matter content
- use of additives to prevent the dilution of the grout

If the grout tends to pass the plug, especially in multi-phase grouting, a flushing system for removing the grout that passed the plug should be installed in the pile.

8.8.2.2 Shaft grouting

Multi-phase high-pressure grouting can be used to improve the bearing capacity of shaft bearing piles. This can be done before or after the installation of reinforcement.

If the entire pile shaft is grouted, grouting is continued until the consistency of the grout rising up the shaft is almost similar to the grout prior to grouting.

8.8.2.3 Base grouting

If only the pile base is grouted, grouting plugs should be used to prevent the grouting of the pile shaft. Grouting plugs are either passive, mechanical or pneumatic.

Grouting plugs should be long enough to minimize the grouting of pile shaft through soil.

8.8.3 Grouting in rock

If there is loose material between the tip of a pile bearing on rock and the rock that impairs the bearing capacity of the pile, the contact of the pile tip with the rock can be improved by grouting the pile base.

If only the rock section of the pile shaft is to be grouted, a grouting plug can be used.

If necessary, the base of the pile can be grouted to prevent water from entering the pile. After this the pile can be grouted by dry placement.

8.9 Closing of pile heads and cutting of piles

Pile heads must be closed after pile installation to prevent the entry of foreign matter into the pile. In addition, low open pile casings can also pose a risk to the safety of people.

Piles are cut at the cutting height specified in the piling plan perpendicular to the pile axis. The deviation of the cutting angle from the perpendicular must not exceed 1/50, unless otherwise stated in the design. Pile heads must be closed after cutting.

8.10 Cleaning

The cleanness of the casing must be checked before concreting of the casing.

Possible impurities must be removed from the casing.

In composite piles where the adhesion between the casing and concrete is exploited, special attention should be paid to the cleanness of the casing.

8.11 Reinforcement

Piles are reinforced according to the instructions given in the High-capacity piling instructions (SPO-2001).

8.12 Concreting of piles

Before concreting the cleanness of the casing must be verified, and the casing cleaned, if necessary.

Whenever possible, concreting should be carried out as dry placement. If necessary, the casing should be emptied by a pump.

If a lot of water leaks into the pile, concreting must be carried out as underwater concreting according to the High-capacity piling instructions (SPO-2001).

Piles with an inner diameter greater than 200 mm can be concreted using concrete while mortar is used for other piles.

The concreting of composite piles is discussed in more detail in the High-capacity piling instructions (SPO-2001).

9 QUALITY CONTROL AND MEASUREMENTS

9.1 Quality control

The piling work supervisor must be a qualified and experienced person (Chapter 8.2), and he is responsible for maintaining quality by ensuring that

- the work is performed according to the project-specific quality requirements or specification, other instructions and good building practice
- the work and quality plan of piling and other required designs are prepared and inspected by the proper procedure
- the piling record is written in connection with piling and is submitted for inspection to the controller and designer without delay
- monitoring measurements are made and necessary documents written
- a representative of the client and/or designer are informed of exceptional situations and conditions on the site and other things affecting the progress of the work
- skilled workers (e.g. welders) have passed a qualification examination

9.2 Piling work monitoring

Piling must be monitored by measurements and all relevant information recorded in a piling record that contains the following information:

A) Piling site and piles
  - piling site, contractor, pile types, measures and depths as well as steel types and types of pile tips

B) Information on soil
  - types of soil, soil layer boundaries
  - layers that are difficult to penetrate

C) Pile drilling
  - drilling equipment
  - drilling method
  - pile joints

D) Straightness measurement
  - if necessary, the straightness of pile is measured with an inclinometer or other similar measuring device

E) Measurement of load-bearing capacity
  - where necessary, but always for piles bearing on ground in very demanding projects

All exceptional situations and conditions affecting the end result of the work must be reported to the supervisor.

The monitoring measurement records must be prepared without delay. The records or their copies must be kept on site until the work is completed. The records must be prepared as the piling work proceeds.

The piling records must be submitted to the client's supervisor and/or designer as agreed. The documentation of piling is discussed in Chapter 10.

After piling an as-built drawing must be made, indicating pile positions, pile sizes, pile tip and cutting levels, and accessories used in the piles.

The measurement plan, measurement results and other piling documents must be stored in accordance with the contract schedule, work specification, quality requirements, or instructions and regulations on building.

9.3 Testing of piles

9.3.1 General requirements

The general principles of pile testing are included in ENV 1997.

In very demanding projects, the geotechnical load-bearing capacity of piles bearing on ground must be verified by loading tests. For each pile type, loading tests amounting to 5% of the number of piles must be performed, but not less than two load tests.

Drilled piles bearing on rock do not need to be test-loaded if they rest on solid rock. The quality of the rock must be examined by percussion drillings. In rock drilling the quality of the rock should be verified by monitoring the feeding and rotation pressures of the drilling.

Loading tests are done as static loading tests.

Loading tests on piles can be used for dimensioning and inspecting working methods and/or quality:

- by establishing the correlation between base resistance and shaft resistance and settlement
- by establishing the integrity of the pile
- by examining the long-term behaviour of the pile

The loading test plan should be prepared or at least approved by the foundation designer and the structural designer.

9.3.2 Special requirements

Static loading test should include at least six loading steps. Settlement rate must be measured by at least three indicators and it must be less than 0.25 mm/h before the next loading step is started.

In constant-speed loading the speed must be kept constant at about 0.1 mm/min through the test.

The accuracy of the settlement indicator must be at least 0.1 mm.

All scales and pressure gauges must be calibrated at least once a year.

After completion of loading tests, the client should immediately get a report containing a detailed description of each test-loaded pile, information on pile positions, and a ground investigation report. The results are to presented in graphical and numerical form.

10 DOCUMENTATION OF THE PILING WORK

The piling record has two parts. The first contains information on:

- pile type
- piling method
- quality requirements concerning reinforcement and concreting

The second part contains detailed information on the piling work, that is, the piling records.

The contents of the general section of the piling record must be the same for different pile types and methods, and must include the information listed in Table 10.

Table 10 Contents of the general section of the piling record

Project	X
Contract documents	X
Superstructure	X
Main contractor	(X)
Piling contractor	X
Client	(X)
Designer	X
Pile diameter/size	X
Steel grade, joints, pile tip, pile diameter	X
Piling method	X
Cleaning method	(X)
Reinforcement details	(X)
Quality requirements for concrete	(X)
Used grout	(X)
Concrete placement	(X)

X always required (X) indicated if necessary

The details and form of the piling record must be agreed before starting the piling work.

The inspection record for each pile presents:

- the reason of inspection
- testing method and its implementation
- test results
- conclusions

All records must be signed by the piling work supervisor and the client's supervisor.

The pile-specific section of the piling record presents the data on one pile.

Contents of the pile-specific section of the record:

Pile drilling

- duration of drilling
- drilling speed m/min
- amount of mortar grouted during drilling

- grouting pressure during drilling
- interruptions
- penetration of obstacles
- pile length
- soil layers

Pile position

- position
- inclination (to be recorded if the pile has exceeded permissible deviation)
- curvature (to be recorded if the pile has exceeded permissible curvature)

Where applicable, the pile-specific section must also contain:

- inspection of pile for cleanness and absence of water in pile
- pile cleaning and time of cleaning

Reinforcement

- used reinforcement
- installation, before or after placement
- position
- length
- suspension

Concreting and grouting

- concrete/mortar and its properties
- admixtures
- dry/underwater placement
- interruptions
- consumption
- strength tests

Appendix 1 shows a model of the piling record. The contents of the piling record are to be agreed for each project. The model record does not contain all of the above-mentioned points, therefore the piling record model to be used should be agreed on before starting the piling work.

11 LABOUR PROTECTION AND ENVIRONMENTAL CONTROL

11.1 Labour protection

Piling work must be performed observing laws and statutes and other regulations and instructions concerning:

- safety of the work site
- safety of the working method
- operational reliability of the piling machine and other tools and equipment used in the piling work

Special attention must be paid to:

- all work stages where heavy machinery and tools are used
- covering the open head of pile casings securely

11.2 Environmental impacts of piling

11.2.1 General

The piling work should cause as little disturbance and environmental nuisance as possible.

Possible disturbance and environmental nuisance may arise from:

- soil removed in drilling, and flushing agents
- compaction of loose soil layers caused by the drilling
- vibration
- noise
- contamination of soil, water and air

The type and extent of possible disturbances and environmental impacts depend on:

- soil and groundwater conditions of the piling site
- pile type and piling method
- work stage

11.2.2 Vibration

The level of vibration caused by drilled piling is usually rather low. If vibration-sensitive structures exist close to the piling site, actual vibration values must always be measured on site.

11.2.3 Noise

No calculation methods suitable for determining the noise level caused by piling are available. The maximum permissible noise level L_{Aeq} may not exceed 80 dB in spaces primarily occupied by persons not involved in the piling work

11.2.4 Discharges

When working in or close to catchment or groundwater areas protective measures must be taken on the site and, if necessary, in the vicinity to prevent discharges of hazardous grouts and flushing agents from entering waterways. Special attention should also be paid to the recovery of oil, flushing agent or grout leaking due to breakage of the piling machine or other reason to ensure that they cannot enter waterways.

In catchment areas and their immediate vicinity, it is recommended to use rapeseed oil in the transmission system of hydraulic machines because it is biodegradable.

Flue gas emissions can be reduced by using modern and efficient hydraulic machinery.

APPENDICES

DRILLED PILE INSTALLATION RECORD, GENERAL INFORMATION

Page 1/1

Contractor ______________________

Work site ______________________

____

Pile type ______________________

Drilling method ______________________

Work drawing no. ______________________

1. PILE INFORMATION

1.1 Pile/rock contact
Load-bearing tip
Load-bearing shaft

1.2 Pile shaft
Casing left in the ground
Casing withdrawn from the ground

2. DRILLING EQUIPMENT

2.1 Drilling machine

2.2 Drill

2.3 Drilling principle
DTH
Top hammer
Other

2.4 Drilling method
Concentric
Eccentric
Reamer bit OD mm
Pilot bit OD mm

3 PILE CASING

3.1 Outer diameter mm

3.2 Wall thickness mm

3.3 Steel type

3.4 Section length

3.5 Joints
Welding
Thread

4 Reinforcement

4.1 Type of reinforcement
Bar __________ ø = _________ mm
Pipe d=__________ t = _________ mm

4.2 Steel type __________

4.3 Section length _____________mm

4.3 Joints
Welded
Threaded
Sleeve ______/________ mm

4.4 Installation of reinforcement
Before concreting
After concreting

4.6 Centralizers, type
pcs/longitudinal spacing ____/____ m

5 CONCRETE/MORTAR

5.2 Nominal strength K

5.3 Consistency _____________ sVB

5.4 Premixed concrete/mortar
Concrete/mortar mixed on site

5.5 Cement type

5.6 Amount of cement ____________ kg/m^3

5.7 Aggregate (max. grain size) #_____ mm

5.8 Water/cement ratio w/c=
w=weight of water, c=weight of cement

5.9 Concrete admixtures
% of the weight of cement

5.10 Inhibitor
workability period

5.11 Underwater concreting
Dry concreting

5.12 Concrete placement method
Tremie pipe for underwater concreting ø = ___ mm
Pump hose ø = ___ mm
Other placement method

5.13 Measures to prevent the mixing of water and concrete at the beginning of concreting

5.13 NOTES/OBSERVATIONS

DRILLED PILE INSTALLATION RECORD, PILE-SPECIFIC INFORMATION **Page 1/1**

Pile number ____________________

Contractor ____________________ **Pile type** ____________________
Work site ____________________ **Drilling method** ____________________
____________________ **Work drawing no.** ____________________

Drilling
Started Date________ At________ Starting level + ________ Pile head level +________
Ended Date________ At________ Ending level + ________ Pile base level +________
Observed level of rock face +________ Drilling depth ________ Pile length ________

DRILLING DEPTH (m)	DRILLING RESISTANCE (s/0.1 m)	SOIL CONDITIONS	DRILLING OBSERVATIONS (groundwater, interruptions)	DRILLING METHOD & EQUIPMENT	NOTES

Drilling resistance [s/0.1 m] to be indicated at least for rock drilling section

Actual deviations (deviations in pile positioning on pile head cutting level)
Δx= ________ cm Inclination ________ °
Δy= ________ cm Radius of curvature $R_{0,min}$ ________ m On level + ________

Bottom cleaning Date ______ Time ________

Concreting
Concreting started Date________ Time ________
Concreting ended Date________ Time ________
Level of water in hole at start of concreting ________ m Below pile head cutting level
Concrete consumption Theoretical: ________ m^3 Actual ________ m^3
Special observations during concreting ____________________

____

Notes/observations: ____________________

Signatures: Piling work supervisor ____________________
Controller ____________________

INSTALLATION RECORD FOR GROUTED PILES | **Page**
GENERAL INFORMATION | **1/1**

Contractor ____________________ **Pile type** ____________________
Work site ____________________ **Drilling method** ____________________
____________________ **Work drawing no.** ____________________

3. PILE INFORMATION

1.1 Load-bearing capacity of pile
Load-bearing tip
Load-bearing shaft

1.2 Pile shaft
Casing left in the ground
Casing withdrawn from the ground

2. DRILLING EQUIPMENT

2.1 Drilling machine

2.2 Drill

2.3 Drilling principle
DTH equipment
Top hammer equipment
Other

2.4 Drill bit
Model ______________ mm
Size ø ______________ mm

3 DRILL ROD

3.1 Outer diameter mm

3.2 Wall thickness mm

3.3 Steel type

3.4 Section length

3.5 Joints
Welded
Threaded
Sleeve

3.6 Centralizers, type ___________
pcs/longitudinal spacing ______/____ m

4 PILE CASING

4.1 Outer diameter ___________ **mm**

4.2 Wall thickness ___________ **mm**

4.3 Steel type

4.4 Section length

4.5 Joints
Welded
Threaded
Sleeve

6 GROUTING

6.2 Maximum grouting pressure

7 MORTAR

7.2 Nominal strength K ______________

7.3 Consistency ______________ **sVB**

7.4 Premixed concrete/mortar
Concrete/mortar mixed on site

7.5 Cement type

7.6 Amount of cement _____________ **kg/m^3**

7.7 Aggregate (max. grain size) #________ **mm**

7.8 Water/cement ratio w/c=
w=weight of water, c=weight of cement

7.9 Concrete admixtures
% of the weight of cement

5.13 NOTES/OBSERVATIONS

INSTALLATION RECORD FOR GROUTED PILES,
PILE-SPECIFIC INFORMATION
Pile number ______________________

Page
1/1

Contractor ______________________ **Pile type** ______________________
Work site ______________________ **Drilling method** ______________________
______________________ **Work drawing no.** ______________________

Drilling
Started Date________ At_______ Starting level + ________ Pile head level +_______
Ended Date________ At_______ Ending level + ________ Pile bottom level +_______
Observed level of rock face +________ Drilling depth ________ Pile length _______________

DRILLING DEPTH (m)	DRILLING RESISTANCE (s/0.1 m)	SOIL CONDITIONS	MORTAR CONSUMPTION	GROUTING PRESSURE	DRILLING OBSERVATIONS (groundwater, interruptions)	NOTES

Actual deviations (deviations in pile positioning on pile head cutting level)
Δx= _______ cm Inclination ________ °
Δy= _______ cm Radius of curvature $R_{0,min}$ ________ m On level + _________

Mortar consumption: Theoretical: ________ m^3 Actual: _________ m^3
Special observations during grouting: ____

____

Notes/observations: ____

____

Signatures: Piling work supervisor ______________________
Controller ______________________