RR® and RD® piles

DESIGN AND INSTALLATION MANUAL

This manual deals with driven and jacked SSAB's RR and RRs piles, shaft grouted driven CSG-RR piles and drilled RD and RDs piles. It covers all SSAB's steel pile sizes. The manual is based on the piling instructions of the Finnish Piling Manual PO-2016 and the Eurocodes system. The manual describes the basics of the design and dimensioning of SSAB's steel piles and pile foundations according to Finnish application of Eurocodes, gives recommendations on the selection of pile type and size and provides advice on the handling and installation, quality control, measurements and documentation of piling. The manual includes pre-calculated dimensioning tables and design and implementation examples to facilitate the design and implementation of piling. When SSAB steel piles are used outside Finland, national requirements (implementation and national annexes of Eurocodes) shall be taken into account in design and execution of piles. SSAB's RR, RRs, RD and RDs piles have European Technical Assessment ETA 12/0526.

Applications:
- 1 and 2 family houses
- single- and multi-storey commercial, office, industrial and storage buildings
- multi-storey residential buildings
- sports arenas
- underpinning of foundations
- bridges
- pile slabs and other structures for transport infrastructure and municipal engineering
- noise barriers and fences
- ports
- wind turbines and other power plants

CE
ETA 12/0526

NOTE: This English manual follows the national regulations of Finland.

CONTENTS

1. GENERAL

This manual deals with driven and jacked SSAB's RR and RRs piles, shaft grouted driven CSG-RR piles and drilled RD and RDs piles. It covers all pile sizes from RR75 to RR/RD1200. This manual describes the basics of the design of SSAB's steel piles and provides advice on their handling and installation, quality control, measurements and documentation. This manual is supplemented by product brochures on RR and RRs piles and RD and RDs piles, which describe the applications, materials, structures and dimensions of steel piles on a general level.

This manual is based on the Finnish Piling Manual PO-2016 (RIL 254-2016). This manual is used when the site has been designed according to the Eurocodes system. If the piling of a site is designed using the maximum allowed pile loads method, the RR and RD Piling Instructions are followed in the design of steel piles. The installation, handling and end-of-driving instructions presented here can be used where applicable if the site has been designed based on maximum allowed pile loads.

This manual applies to both individual piles and pile groups. They can be applied to the design and implementation of support structures made of SSAB's steel piles, such as the RD pile wall, various Combi wall structures, and driven or drilled steel pipe piles used in other retaining walls.

2. SSAB'S STEEL PILES

2.1 General

SSAB has CE marking, based on European Technical Assessment (ETA 12/0526), which is the most comprehensive CE marking to be granted to pile structures made of structural steel. It covers the entire pile structure, manifests the requirements and conformity of the mechanical splices, and establishes that the product has been manufactured specifically for piling.

The approval is based on detailed load tests, especially on splices, continuous quality control during the various phases of production, and traceability of materials. Use of SSAB's CE marked piles in a construction project ensures the durability and performance of foundations. Tested products guarantee problem-free site installation.

SSAB's steel piles meet the requirements presented in Finnish Piling Manual PO-2016 (RIL 254-2016) for pile materials and accessories.

SSAB's steel piles have SP Technical Research Institute of Sweden quality certificate – P-mark (0656/94).

2.2 Steel grades and standards

The steel grades and chemical composition and mechanical properties of SSAB's steel piles are presented in Table 1.

The availability of steel grades by pile types and diameter and wall thickness are presented in Secs. 2.3.1 and 2.4.1. Against special order, the piles may also be delivered in X grades according to API5L standard.

The technical delivery terms of the piles comply with standard EN 10219-1. Dimensions and tolerances comply with standard EN 10219-2. SSAB's steel piles with mechanical splices are manufactured to tolerances stricter than those of standard EN 10219-2. A material certificate of type 3.1 specified in EN 10204 is provided for the pile material.

Table 1. Standard steel grades of SSAB's steel piles, against special order, the piles may also be delivered in X grades according to API5L standard.

Steel grade	**Carbon equivalent**	**Chemical composition, max.**				**Mechanical properties**				
									Impact strength	
	CEV max.	**C**	**Mn**	**P**	**S**	**f_y min**	**f_u**	**A_{5min}**	***T****	***KV* min**
	[%]	[%]	[%]	[%]	[%]	[MPa]	[MPa]	[%]	[°C]	[J]
S355J2H	0.45	0.22	1.6	0.03	0.03	355	470-630	20	-20	27
S440J2H	0.45	0.16	1.6	0.02	0.02	440	490-630	17	-20	27
S460MH	0.46	0.16	1.7	0.035	0.03	460	530-720	17	-30	27
S550J2H	0.47	0.12	1.9	0.02	0.02	550	605-760	14	-20	27

*) Testing temperature may also be -40 °C. Demanded impact energy remains the same.

2.3 Small diameter RR and RRs piles

2.3.1 Structure, steel grades and identification

The structure and members of RR and RRs piles are shown in Figure 1.

The basic steel grade of RR piles is S460MH and that of RRs piles S550J2H. Against special order, the piles may also be delivered in S420MH steel grade. RR270 to RR320 piles made of steel grade S355J2H are also available.

RR and RRs piles have mechanical friction splices and pile shoes up to pile size RR220/12.5. RR270 and RR320 piles are spliced, if necessary, by welding, and the pile shoe is attached by welding.

SSAB's RR small diameter piles are identified by a marking on the side of the pile. In addition, identification tape is attached to splices of RR pile elements or next to them. Pile bundles are delivered with product descriptions that indicate, besides pile manufacturer and dimensions, the steel grade of the RR piles.

2.3.2 Pile elements, pipes and splices

A pile element consists of a pile pipe and the attached external splice sleeve. The mill lengths of RR pile elements and pile pipes without external splice sleeves are presented in Table 2.

All pile sizes RR75 to RR220 made of steel grade S460MH can be spliced using external splice sleeves. RRs piles are manufactured in seven different sizes. All RRs pile sizes can be joined by external splice sleeves.

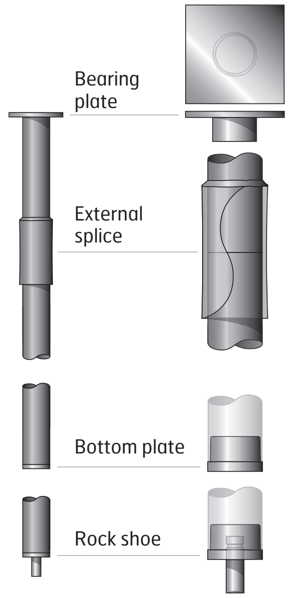


Figure 1. Structure and parts of RR piles, pile sizes RR75 to RR220.

The splices meet the requirements of PO-2016 for rigid splices and those of the national annex to standard EN 1993-5: Design of steel structures, Steel piles (Table 3). Since the splices meet the requirements, pile splices do not limit the structural capacity of the pile, and piles can be installed as straight as possible in all soil conditions.

Table 2. Mill dimensions of RR and RRs pile elements and pile pipes.

	Length of pile element (incl. splice)								Length of pile pipe (excl. splice)		
Pile type	**12 m**	**6 m**	**4 m**	**3 m**	**2 m**	**1.5 m**	**1.2 m**	**1.0 m**	**6 m**	**12 m**	**16 m**
RR75	-	X	O	O	O	O	O	O	X	O	-
RR90	-	X	O	O	O	O	O	O	X	O	-
RR115/6.3	O	X	O	O	O	O	O	O	X	O	-
RR115/8	O	X	O	O	O	O	O	O	O	X	O
RR140/8	X	X	O	O	O	O	O	O	O	X	O
RR140/10	X	X	O	O	O	O	O	O	O	X	O
RR170/10	X	X	O	O	O	O	O	O	O	X	O
RR170/12.5	X	O	O	O	O	O	O	O	O	X	O
RR220/10	X	O	O	O	-	-	-	-	O	X	O
RR220/12.5	X	O	O	O	-	-	-	-	O	X	O
RRs115/8	O	X	O	O	O	O	O	O	O	X	O
RRs125/6.3	X	X	O	O	-	-	-	-	O	X	-
RRs140/8	X	X	O	O	O	O	O	O	O	X	-
RRs140/10	X	O	O	O	O	O	O	O	O	X	O
RRs170/10	X	O	O	O	O	O	O	O	O	X	O
RRs220/10	X	O	O	O	-	-	-	-	O	X	O
RRs220/12.5	X	O	O	O	-	-	-	-	O	X	O

X = stock size O = project-specific size – = not in production

Table 3. Minimum strength and stiffness requirements of RR and RRs pile splices

Pile type	Tensile strength [kN]	Com-pression strength	Yield moment *M*	Flexural stiffness *EI* (0.3-0.8 M)
RR75	95	P_{pile}	M_{pile}	$0.75xEI_{pile}$
RR90	113			
RR115/6.3	147			
RR115/8	184			
RRs115/8	220			
RRs125/6.3	197			
RR140/8	228			
RRs140/8	273			
RR140/10	281			
RRs140/10	336			
RR170/10	343			
RRs170/10	410			
RR170/12.5	422			
RR220/10	453			
RRs220/10	542			
RR220/12.5	560			
RRs220/12.5	669			

2.3.3 Pile shoes

The mechanically attached pile shoes of RR and RRs piles, bottom plates and rock shoes, meet the requirements given in PO-2016. The rock shoe dowel is made of hardened special steel, which ensures good penetration into bedrock. Rock shoe is always the recommended shoe type for driven pile. Based on justification by the foundation designer, also other shoe types can be used (bottom plate, open ended pile, etc.). According to PO-2016 the justified reason can be for example soil layers with low stone content (GEO class d<60 mm) and piles resting in soil layer with no big stones (GEO class d<200 mm). Rock shoes make it possible for piles to penetrate compact or rocky soil layers better and remain straighter. SSAB's pile shoes are dimensioned to withstand the stresses from pile installation and use, provided that the instructions of Sec. 7.3 are observed in installation.

Jacked RR micropiles can be equipped with a special shoe through which post-grouting can be done after jacking to improve point, and to some extent, shaft resistance.

The shoes used with RR270 to RR320 piles are rock shoes with hardened rock dowels. Against special order, the pile tip can be protected by a bottom plate or a rock shoe different from the standard rock shoe. All shoes of RR270 to RR320 piles are attached to the pipe pile by welding. Pipe piles are delivered to site with welded-on rock shoes.

The design resistance values of standard rock shoes for RR270 to RR320 piles are presented in Table 4. The most

Figure 2. Large diameter RR pile

important dimensioning factor for rock shoes are the end blows and/or dynamic load test. Moreover addition, the installation instructions of Sec. 7.3 must be followed in installation, especially if the pile tip encounters a boulder or an inclined bedrock surface.

RR270 to RR320 rock shoes have the Finnish Transport Infrastructure Agency's permission for use (565/090/201, 4.10.2011).

With steel grade S460MH, the calculated resistance of the rock shoe limits the ultimate geotechnical resistance R_c of pile sizes RR270/12.5 and RR320/12.5 to that presented in Table 4 and with steel grade S550J2H and all pile dimensions RR270 to RR320 to the $R_{d,L}$ values presented in Table 4.

Table 4. Structural resistances of RR270 and RR320 standard rock shoes

Pile	$R_{d,L}$ [kN]
RR270	4073
RR320	4777

$R_{d,L}$ = design value of ultimate limit state of the structural resistance of a rock shoe for a centric vertical load at the installation stage (impact and PDA measurement)

2.4 Large diameter RR piles

2.4.1 Structure, dimensions and availability of steel grades

Large diameter RR piles are made of spirally welded steel pipes. It is possible to manufacture single-element piles up to 39 metres long. Piles are usually ordered in specific lengths. The standard stocked sizes are presented in Table 5.

Table 5. Large diameter RR piles in stock (L=12 m)

Dimensions diameter x wall thickness [mm]	**Steel grade**
406 x 12.5	S440J2H (S355J2H)
508 x 12.5	S440J2H (S355J2H)
610 x 12.5	S355J2H
711 x 12.5	S355J2H
813 x 12.5	S355J2H

The main steel grades used for RR large diameter piles are S355J2H, S440J2H and S550J2H. Against special order, the piles may also be delivered in MH steel grades according to standard EN 10219 or X grades according to API5L. Standard dimensions and the availability of steel grades are presented in Table 6. The diameters primarily recommended for design are RR400, RR500, RR600, RR700, RR800, RR900, RR1000 and RR1200. In the case of end-bearing piles, the recommended minimum wall thickness to ensure easy installation is 10 mm for piles RR400 to RR800 and 12.5 mm for RR900 to RR1200.

Besides the standard dimensions presented in Table 6, RR piles can also be made with other diameters and customer-specific wall thicknesses selectable at 0.1 mm intervals. The selection of wall thicknesses and steel grades allows accurate optimisation of structures. Customer- or project-specific deviations from standard dimensions require a quite large project, and optimisation is particularly useful with combi wall or RD pile wall structures, but also in end-bearing pile projects.

RR large diameter piles are recognised from a marking on the side. Pile bundles are delivered with product descriptions that indicate, besides pile manufacturer and dimensions, the steel grade of the RR piles.

Table 6. Standard dimensions and availability of steel grades of large diameter steel pipe piles.

Pile	Diameter	Wall thickness [mm]									
	[mm]	8	10	12.5	14.2	16	18	20	21	22	23
RR400	406.4	●	●	●							
RR450	457.0	●	●	●							
RR500	508.0	●	●	●	●	■					
RR550	559.0	●	●	●	●	■					
RR600	610.0	●	●	●	●	●	◐				
RR650	660.0	●	●	●	●	●	◐				
RR700	711.0	●	●	●	●	●	●	◐			
RR750	762.0	●	●	●	●	●	●	◐			
RR800	813.0	●	●	●	●	●	●	◐	■	■	
RR900	914.0		●	●	●	●	●	◐	■	■	
RR1000	1016.0		●	●	●	●	●	◐	■	■	■
RR1200	1220.0		●	●	●	●	●	◐	■	■	■

● Steel grades S355J2H, S440J2H and S550J2H
◐ Steel grades S355J2H and S440J2H
■ Check availability from SSAB sales.

2.4.2 Pile shoes

In soil conditions typical of the Nordic countries, RR large diameter piles are usually equipped with RR rock shoes. SSAB's standard rock shoes were granted the Finnish Transport Agency's use permission (565/090/201, 4 October 2011) and the manufactured rock shoes are CE marked. Rock shoes are used to protect the lower end of the pile against installation stresses, to centre the stresses on the pile tip as evenly as possible across the pile pipe cross-section, and to prevent lateral sliding of the pile tip.

There are three types of RR rock shoes (Figure 3). The most common ones are rock shoes fitted with a structural steel dowel or a hardened rock dowel. SSAB also delivers rock shoes fitted with a hollow dowel, which allows drilling, for example, a dowel bar to be grouted to bedrock through the concrete filled hollow dowel of the rock shoe.

A rock shoe with a structural steel dowel is used in conditions where the target level of the piles is within coarse-grained or moraine soil layers, or in conditions where the bedrock surface is relatively even and there are supporting compact soil layers on top of the bedrock. A rock shoe with a structural steel dowel endures well penetration to the surface of the bedrock and into it.

A rock shoe with a hardened rock dowel is used in conditions where the bedrock surface is inclined or there are no compact coarse-grained or moraine soil layers on top of the bedrock – or the soil layers are thin and the pile tip is to be driven to the bedrock surface. Rock shoes with a hardened rock dowel can prevent lateral sliding of the pile tip in most conditions.

Rock shoes with a hollow dowel can be used in conditions where it is desired to ensure the staying in place of the pile tip by a grouted steel dowels drilled through the hollow dowel into bedrock. A typical application is a combi-wall structure used as a wharf where the penetration level of the piles is close to the bottom of the waterway and piles are subject to considerable horizontal loads. There, rock dowels drilled through the hollow dowel ensure the stability of the retaining structure. Rock shoes with a hollow dowel are also used at sites where piles are subject to tension forces. A pull anchor can be installed through the hole.

In conditions of no or few stones, where the pile tip is designed to bear on soil layers, the tip of the pile can be protected by a so-called reinforced bottom plate. The recommended solution for such conditions, however, is to use standard rock shoes with structural steel dowels.

Open ended piles are often equipped with a so-called reinforcement ring to protect the lower end. The reinforcement ring is usually a 150 to 500 mm wide steel band welded onto the lower end of the pile. The sheet thickness of the steel band is usually 10, 15 or 20 mm. Both reinforcement rings and reinforced bottom plates are manufactured to the client's project-specific designs.

Rock shoes are preheated before welding and assembly welding is carried out by robots. The rock shoes are numbered to ensure the traceability of the manufacture and raw-materials of the shoes.

The design resistance values of standard rock shoes for RR large diameter piles are presented in Table 7. The most important criterion for rock shoes are the end blows and/or the dynamic load test. Project specific rock shoes with different capacities are analyzed numerically by the requirements of Finnish Transport Infrastructure Agency. Moreover, the installation instructions of Sec. 7.3 must be followed in installation, especially if the pile tip encounters a boulder or an inclined rock surface.

At the design stage, however, the maximum impact resistance of each pile size should be limited to its/the $R_{d,L}$ value.

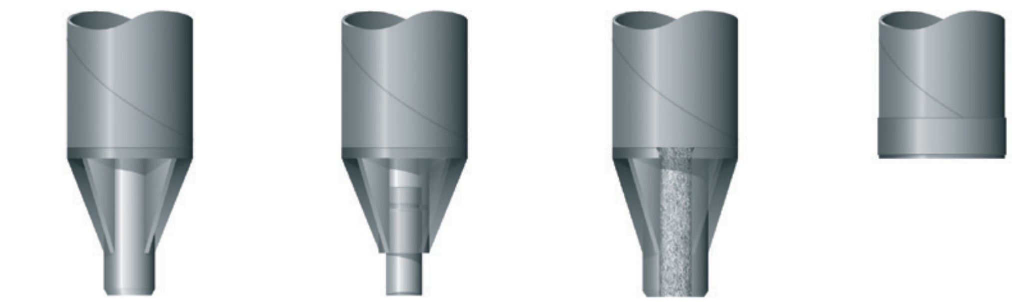


Figure 3. Shoe types of large diameter RR piles.

Table 7. Design values of ultimate limit state of the structural resistance of a rock shoes for a centric vertical load at the installation stage (impact and PDA measurement)

Pile	Structural steel dowel $R_{d,L}$ [kN]	Hardened steel dowel $R_{d,L}$ [kN]	Hollow dowel $R_{d,L}$ [kN]
RR400	5033	4982	
RR450	6057	6032	
RR500	7672	7545	
RR550	7994	7940	
RR600	9677	9681	9285
RR650	10084	10062	
RR700	11993	11605	11370
RR750	12387	12342	
RR800	12653	12610	12188
RR900	14910	14887	14512
RR1000	18751	15691	18371
RR1200	19317	19260	

2.5 RD and RDs piles

2.5.1 Structure, dimensions, steel grade selection and identification

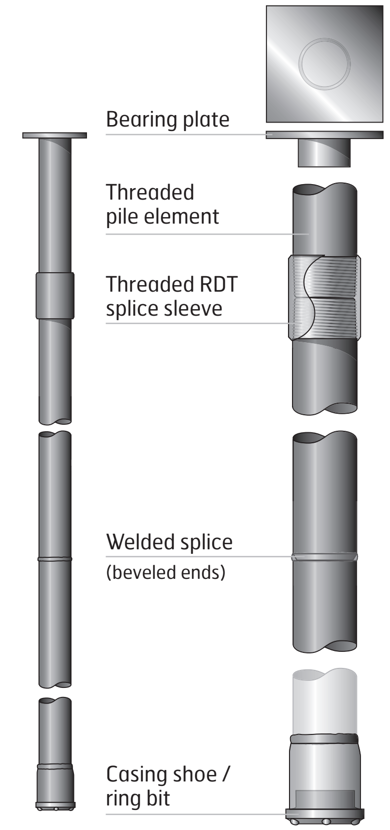


Figure 4. Structure of RD micropile.

The structure of the RD pile is shown in Figure 4. The standard steel grade of RD90 to RD220 piles is S460MH. The steel grade of RDs piles is S550J2H. Against special order, the piles may also be delivered in S420MH steel grade. RD270 to RD320 piles made of S355J2H steel grade are also available. All steel grades of SSAB's steel pile products can be used as steel grades of RD400 to RD1200 piles. The pile sizes and availability of steel grades of RD piles are presented in Table 8. Dimensions RD400, RD500, RD600, RD700, RD800, RD900, RD1000 and RD1200 are recommended for RD large diameter piles.

Table 8. Standard dimensions and availability of steel grades of RD piles.

Pile	Diameter [mm]	Wall thickness [mm] 6.3	8	10	12.5	14.2	16	18	20	21	22	23
RD90	88.9	S460MH										
RD115	114.3	S460MH	S440J2H/S550J2H									
RDs125	127.0	S550J2H										
RD140	139.7		S440J2H/S550J2H	S440J2H/S550J2H								
RD170	168.3			S440J2H/S550J2H	S440J2H/S550J2H							
RD220	219.1			S440J2H/S550J2H	S440J2H/S550J2H							
RD270	273.0			S355J2H/S460MH/S550J2H	S355J2H/S460MH/S550J2H							
RD320	323.9			S355J2H/S460MH/S550J2H	S355J2H/S460MH/S550J2H							
RD400	406.4		S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H							
RD450	457.0		S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H							
RD500	508.0		S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	Check availability					
RD550	559.0		S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	Check availability					
RD600	610.0		S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H				
RD650	660.0		S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H				
RD700	711.0		S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H			
RD750	762.0		S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H			
RD800	813.0		S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H	Check availability	Check availability	
RD900	914.0			S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H	Check availability	Check availability	
RD1000	1016.0			S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H	Check availability	Check availability	Check availability
RD1200	1220.0			S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H/S550J2H	S355J2H/S440J2H	Check availability	Check availability	Check availability

Steel grades S440J2H and S550J2H
Steel grade S550J2H
Steel grades S355J2H, S460MH and S550J2H
Steel grade S460MH
Steel grades S355J2H, S440J2H and S550J2H
Steel grades S355J2H and S440J2H
Check availability from SSAB sales.

The piles are delivered either as pile pipes or RDT pile elements with threaded ends. The lengths of pile pipes and elements are shown in Table 9. The inside burr of the longitudinal seam of RD90-RD320 piles can be removed in individual projects to order. With the most commonly used pilot bits the removal of the inside burr is usually not necessary, but the pilot bit should be selected considering the effect of the burr.

RD piles can be identified by the marking on their side. Pile bundles are delivered with product descriptions that indicate, besides pile manufacturer and dimensions, the steel grade of the RD piles. If these markings are missing, the pile pipe must not be used in RD piles.

2.5.2 Splicing and steel grade selection of RD piles

RD-piles are spliced using external threaded RDT sleeves (up to pile size RD320) (Figure 6) or by welding. Mechanized welding is used specially in underpinning projects. When using a DTH hammer, the threads of the pile pipe and the sleeve are left-handed, but right-handed when a top hammer is used. Instructions for the handling and installation of splices, as well as the dimensions of threaded sleeves and recommended types and dimensions of ring bits are presented in Sec. 7.4.4 of these instructions. The sleeves meet the requirements for rigid splices of Piling Manual PO-2016 and the National Annex to Eurocode EN 1993-5, Design of steel structures, Steel piles (Table 10). The splice is guaranteed a tensile strength that is 50 % of the compressive strength of the pile when the handling and installation of the splice are done according to Secs. 7 and 8. All RD piles may also be spliced by welding.

Figure 6. Splice sleeve of RDT piles

Table 9 a. and table 9 b. Length range of RD and RDs piles

Pile type	Length of pile pipe without threads								
	1 m	1.2 m	1.5 m	2 m	3 m	4 m	6 m	12 m	12-16 m	16-34 m
RD90	0	0	0	0	0	0	X	-	-	-
RD115/6.3	0	0	0	0	0	0	X	0	-	-
RD115/8	0	0	0	0	0	0	0	X	0	-
RD140-RD320	0	0	0	0	0	0	0	X	0	-
RD400-RD1200	0	0	0	0	0	0	0	X	0	0
RDs115/8	0	0	0	0	0	0	0	X	0	-
RDs125/6.3	0	0	0	0	0	0	0	X	-	-
RDs140-RDs320	0	0	0	0	0	0	0	X	0	-

X = stock sizes
0 = project-specific size
- = not available

Pile type	Length of pile element with threaded ends							
	1 m	1.2 m	1.5 m	2 m	3 m	4 m	6 m	12 m
RDT90	0	0	0	0	0	0	0	-
RDT115/6.3	0	0	0	0	0	0	0	0
RDT115/8	0	0	0	0	X	0	X	0
RDT140/8	0	0	0	0	0	0	X	0
RDT140/10	0	0	0	0	0	0	X	0
RDT170/10	0	0	0	0	0	0	X	0
RDT170/12.5	0	0	0	0	0	0	X	0
RDT220/10	0	0	0	0	0	0	X	0
RDT220/12.5	0	0	0	0	0	0	X	0
RDT270/10	0	0	0	0	0	0	0	0
RDT270/12.5	0	0	0	0	0	0	0	0
RDT320/10	0	0	0	0	0	0	0	0
RDT320/12.5	0	0	0	0	0	0	0	0
RDTs115/8	0	0	0	0	0	0	0	0
RDTs140/8	0	0	0	0	0	0	X	0
RDTs140/10	0	0	0	0	0	0	0	0
RDTs170/10	0	0	0	0	0	0	X	0
RDTs170/12.5	0	0	0	0	0	0	X	0
RDTs220/10	0	0	0	0	0	0	X	0
RDTs220/12.5	0	0	0	0	0	0	X	0
RDTs270/10	0	0	0	0	0	0	0	0
RDTs270/12.5	0	0	0	0	0	0	0	0
RDTs320/10	0	0	0	0	0	0	0	0
RDTs320/12.5	0	0	0	0	0	0	0	0

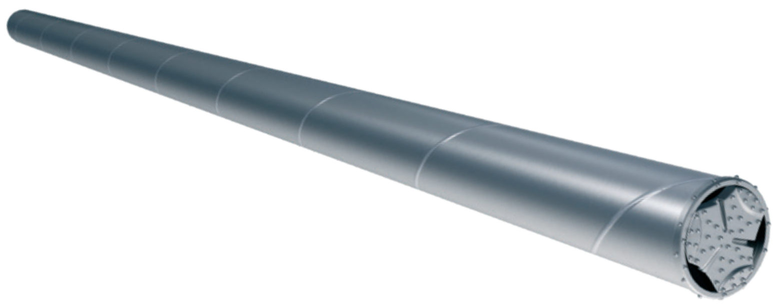


Figure 5. Structure of large diameter RD piles.

Table 10. Strengths of threaded RDT splices.

Pile	Tensile strength [kN]	Pile	Tensile strength [kN]	Compression strength	Bending strength	Flexural stiffness $EI_{(0.3-0.8\ M)}$"
RDT90*	380					
RDT115/6.3*	490					
RDT115/8	620	**RDTs115/8**	750			
RDT140/8	770	**RDTs140/8**	910			
RDT140/10	940	**RDTs140/10**	1120			
RDT170/10	1150	**RDTs170/10**	1370			
RDT170/12.5	1410	**RDTs170/12.5**	1680	P_{pile}	M_{pile}	$0.75 \times EI_{pile}$
RDT220/10	1520	**RDTs220/10**	1810			
RDT220/12.5	1870	**RDTs220/12.5**	2230			
RDT270/10	1900	**RDTs270/10**	2270			
RDT270/12.5	2350	**RDTs270/12.5**	2810			
RDT320/10	2270	**RDTs320/10**	2720			
RDT320/12.5	2820	**RDTs320/12.5**	3370			

**) With these pile sizes the maximum bending resistance of threaded RDT splice equals to the elastic bending resistance M_{el} of the pile pipe.*

2.6 Shaft grouted RR piles (CSG-RR piles)

Shaft grouted RR® piles are for the most part shaft-bearing micropiles where the geotechnical bearing capacity of the pile shaft is improved by Continuous Shaft Grouting using cement grout. Shaft grouted piles are suitable for use in friction soil layers where their high shaft resistance can be used to shorten pile length considerably.

Shaft grouted RR piles have all the mechanical components of RR micropiles as well as a so-called collar. The splice type is the external RR pile splice sleeve. The length of a pile element is usually 6 metres, but the other element lengths presented in Table 2 are also possible. The most common shaft grouted pile sizes are RR90 to RR140. The standard steel grade of shaft grouted RR piles is S460MH. RRs115/8, RRs125/6.3, RRs140/8, RRs140/10 and RRs170/10 pile elements of steel grade S550J2H may also be used. The pile structure is shown in Figure 7.

Shaft grouted driven RR piles are equipped either with a bottom plate or a rock shoe, usually a bottom plate. A rock shoe is used especially to ensure contact between the pile tip and bedrock or penetration of compact soil/fill layers in top soil. The lower end of a shaft grouted driven RR pile has a collar larger than the pile pipe. The purpose of the collar is to keep the grouting holes open during installation and to make a hole larger than the pile pipe in the ground. A guide device directs the tip of the pile and protects the collar from possible obstructions. The length of the guide device is usually 0.5 to 1.0 m. Table 11 shows the diameters of pre-dimensioned shoe collars. The collar of a pre-dimensioned shoe is detachable and installed in the shoe at the beginning of the installation stage. If necessary, the collars and shoes can be designed case by case. It is recommended that the outer diameter of the collar is at least 40 mm larger than the diameter of the pile pipe.

Table 11. Diameters of CSG-RR pile collars.

Pile size	Pile diameter *d* [mm]	Diameter of standard collar [mm]
CSG-RR75	76.1	127.0
CSG-RR90	88.9	139.7
CSG-RR115/6.3 and CSG-RR115/8	114.3	159
CSG-RRs125/6.3	127.0	168.3
CSG-RR140/8 and CSG-RR140/10	139.7	193.7
CSG-RR170/10 and CSG-RR170/12.5	168.3	219.1

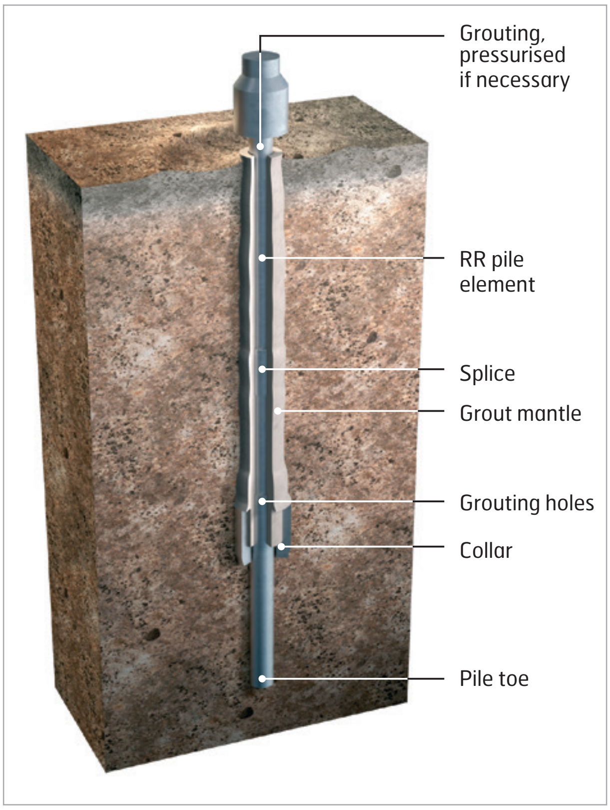


Figure 7. Grouted RR pile (CSG-RR pile)

2.7 Bearing plates

Usually a bearing plate is installed at the upper end of RR/RRs, RD/RDs and CSG-RR micropiles to transfer loads from the superstructure to the pile. Standard bearing plates are centralized on the pile shaft by an internal sleeve, which serves to keep the bearing plate in place during the construction phase. It is not designed to withstand possible horizontal loads of the pile. The plate of standard bearing plates is made of steel S355J2. The standard sizes of bearing plates are shown in Table 12.

Table 12 presents the suggested design strengths R_d of the bearing plates. It is recommended that the strength of the bearing plate be verified both as to the steel structure of the bearing plate and the compressive strength and punching shear capacity of the concrete on top of the bearing plate when the design value of load is about 90 to 100% of the design value of the strength of the bearing plate and when using concrete strengths C30/37 to C35/45.

Bearing plates may also be made based on specific site designs in dimensions and shapes different from standard bearing plates, for example, with a hole.

2.8 Pile dimensions and geometrical sectional properties

The dimensions and geometrical sectional properties of longitudinally welded RR and RD micropiles are presented in Table 13 and those of spirally welded large diameter RR and RD piles in Table 14.

Table 12. Dimensions of standard bearing plates, suggested design strengths of bearing plates.

Pile	Bearing plate dimensions [mm x mm x mm]	Suggested design resistance R_d [kN]
RR75**	150 x 150 x 15	380
RR/RD90**	150 x 150 x 15	450
RR/RD115/6.3**	200 x 200 x 20	780
RR/RD115/8**	250 x 250 x 25	910
RRs125/6.3	200 x 200 x 20 250 x 250 x 25	950 1080
RR/RD140/8 and RR/RD140/10**	250 x 250 x 25	1240
RR/RD170/10 and RR/RD170/12.5**	300 x 300 x 30	1810
RR/RD220/10**	300 x 300 x 30	2090
RR/RD220/12.5	300 x 300 x 30	2090
RRs/RDs220/12.5	350 x 350 x 35	2700
RR/RD270/10	350 x 350 x 35*	2700
RR/RD270/12.5	350 x 350 x 35*	2700
RR/RD320/10	400 x 400 x 30*	3480
RR/RD320/12.5	400 x 400 x 30*	3480
RR/RD270/10 S550J2H	400 x 400 x 30*	2950
RR/RD270/12.5 S550J2H	450 x 450 x 40*	3750
RR/RD320/10 S550J2H	450 x 450 x 40*	4050
RR/RD320/12.5 S550J2H	500 x 500 x 40*	4520

*) Product not in stock
**) Pile sizes RR75 to RR220/10 of steel grades S440J2H and S550J2H with same bearing plates

Table 13. Dimensions and geometrical sectional properties of RR® and RD® micropiles.

A = Area of steel cross-section **A_u** = Pile surface area **A_b** = Area of pile toe						**Z** = Pile impedance **I** = Moment of inertia **W_{el}** = Elastic modulus				**Sectional properties incl. corrosion allowances of 1.2 mm and 2.0 mm**					
D [mm]	**t [mm]**	**M [kg/m]**	**A [mm²]**	**A_u [m²/m]**	**A_b [mm²]**	**W_{el} [cm³]**	**I [cm⁴]**	**EI [kNm²]**	**Z [kNs/m]**	**$A_{1,2}$ [mm²]**	**$A_{2,0}$ [cm⁴]**	**$I_{1,2}$ [cm⁴]**	**$I_{2,0}$ [cm⁴]**	**$EI_{1,2}$ [kNm²]**	**$EI_{2,0}$ [kNm²]**
76.1	**6.3**	10.8	1382	0.24	4548	22.3	84.8	178	56.1	1099	916	65.0	52.8	137	111
88.9	**6.3**	12.8	1635	0.28	6207	31.6	140.2	295	66.4	1304	1089	108.4	88.7	228	186
114.3	**6.3**	16.8	2138	0.36	10261	54.7	312.7	657	86.8	1711	1432	244.5	201.4	514	423
114.3	**8.0**	21.0	2672	0.36	10261	66.4	379.5	797	108.5	2245	1966	311.3	268.2	654	563
127.0	**6.3**	18.7	2389	0.40	12667	68.7	436.2	916	96.9	1914	1603	342.3	282.7	719	593
139.7	**8.0**	26.0	3310	0.44	15328	103.1	720.3	1513	134.4	2788	2445	595.1	515.2	1250	1082
139.7	**10.0**	32.0	4075	0.44	15328	123.4	861.9	1810	165.4	3553	3210	736.7	656.8	1547	1379
168.3	**10.0**	39.0	4973	0.53	22246	185.9	1564.0	3284	201.9	4343	3928	1344.1	1202.7	2823	2526
168.3	**12.5**	48.0	6118	0.53	22246	222.0	1868.4	3924	248.4	5488	5073	1648.5	1507.1	3462	3165
219.1	**10.0**	51.6	6569	0.69	37703	328.5	3598.4	7557	266.7	5748	5205	3110.9	2794.7	6533	5869
219.1	**12.5**	63.7	8113	0.69	37703	396.6	4344.6	9124	329.4	7292	6749	3857.0	3540.9	8100	7436
273.0	**10.0**	64.9	8262	0.86	58535	524.1	7154.1	15024	335.5	7238	6560	6207.9	5590.9	13037	11741
273.0	**12.5**	80.3	10230	0.86	58535	637.2	8697.4	18265	415.3	9205	8527	7751.2	7134.2	16278	14982
323.9	**10.0**	77.4	9861	1.02	82397	750.7	12158.3	25533	400.4	8645	7839	10574.7	9538.5	22207	20031
323.9	**12.5**	96.0	12229	1.02	82397	916.7	14846.5	31178	496.5	11012	10206	13262.9	12226.7	27852	25676

Table 14. Dimensions and geometrical sectional properties of RR® and RD® large diameter piles

A = Area of steel cross-section
A_u = Pile surface area
A_b = Area of pile toe
Z = Pile impedance
I = Moment of inertia
W_{el} = Elastic modulus

Sectional properties incl. corrosion allowances of 1.2 mm and 2.0 mm

D [mm]	t [mm]	M [kg/m]	A [mm²]	A_u [m²/m]	A_b [mm²]	W_{el} [cm³]	I [cm⁴]	EI [kNm²]	Z [kNs/m]	$A_{1,2}$ [mm²]	$A_{2,0}$ [cm⁴]	$I_{1,2}$ [cm⁴]	$I_{2,0}$ [cm⁴]	$EI_{1,2}$ [kNm²]	$EI_{2,0}$ [kNm²]
406.4	8.0	78.6	10013	1.28	129717	978.0	19873.9	41735	406.5	8485	7472	16738.8	14679.5	35151	30827
406.4	10.0	97.8	12453	1.28	129717	1204.5	24475.8	51399	505.6	10926	9912	21340.7	19281.4	44815	40491
406.4	12.5	121.4	15468	1.28	129717	1477.9	30030.7	63064	628.0	13941	12927	26895.6	24836.3	56481	52156
457.0	8.0	88.6	11285	1.44	164030	1244.9	28446.4	59737	458.2	9566	8426	23984.0	21048.1	50366	44201
457.0	10.0	110.2	14043	1.44	164030	1535.7	35091.3	73692	570.2	12325	11184	30628.9	27693.0	64321	58155
457.0	12.5	137.0	17455	1.44	164030	1888.2	43144.8	90604	708.7	15737	14597	38682.4	35746.5	81233	75068
508.0	8.0	98.6	12566	1.60	202683	1546.5	39280.0	82488	510.2	10656	9387	33145.8	29104.6	69606	61120
508.0	10.0	122.8	15645	1.60	202683	1910.2	48520.2	101893	635.2	13735	12466	42386.1	38344.9	89011	80524
508.0	12.5	152.7	19458	1.60	202683	2352.6	59755.4	125486	790.0	17548	16279	53621.3	49580.1	112605	104118
508.0	14.2	172.9	22029	1.60	202683	2645.6	67198.6	141117	894.4	20118	18849	61064.5	57023.3	128235	119749
508.0	16.0	194.1	24731	1.60	202683	2949.2	74909.0	157309	1004.1	22820	21551	68774.9	64733.7	144427	135941
559.0	8.0	108.7	13848	1.76	245422	1880.7	52564.9	110386	562.3	11745	10348	44386.4	38992.4	93211	81884
559.0	10.0	135.4	17247	1.76	245422	2325.6	65001.1	136502	700.3	15144	13748	56822.5	51428.6	119327	108000
559.0	12.5	168.5	21461	1.76	245422	2868.0	80161.8	168340	871.4	19358	17961	71983.2	66589.3	151165	139837
559.0	14.2	190.8	24304	1.76	245422	3228.3	90230.7	189485	986.8	22201	20804	82052.1	76658.2	172309	160982
559.0	16.0	214.3	27294	1.76	245422	3602.3	100683.0	211434	1108.2	25191	23794	92504.4	87110.5	194259	182932
610.0	8.0	118.8	15130	1.92	292247	2247.6	68551.4	143958	614.3	12835	11310	57918.1	50898.9	121628	106888
610.0	10.0	148.0	18850	1.92	292247	2781.9	84846.6	178178	765.3	16554	15029	74213.3	67194.1	155848	141108
610.0	12.5	184.2	23464	1.92	292247	3434.6	104754.7	219985	952.7	21169	19644	94121.5	87102.3	197655	182915
610.0	14.2	208.6	26579	1.92	292247	3869.0	118003.9	247808	1079.2	24284	22759	107370.6	100351.4	225478	210738
610.0	16.0	234.4	29858	1.92	292247	4320.7	131781.4	276741	1212.3	27563	26038	121148.2	114129.0	254411	239671
610.0	18.0	262.8	33477	1.92	292247	4812.8	146790.8	308261	1359.2	31182	29657	136157.5	129138.3	285931	271190
660.0	8.0	128.6	16387	2.07	342119	2639.0	87087.9	182885	665.3	13903	12252	73613.7	64712.5	154589	135896
660.0	10.0	160.3	20420	2.07	342119	3268.8	107870.5	226528	829.1	17937	16286	94396.3	85495.1	198232	179540
660.0	12.5	199.6	25427	2.07	342119	4039.6	133306.4	279943	1032.4	22944	21293	119832.2	110931.0	251648	232955
660.0	14.2	226.2	28810	2.07	342119	4553.4	150263.1	315552	1169.7	26326	24675	136788.9	127887.6	287257	268564
660.0	16.0	254.1	32371	2.07	342119	5088.5	167921.2	352634	1314.3	29887	28237	154447.0	145545.7	324339	305646
660.0	18.0	285.0	36304	2.07	342119	5672.4	187188.3	393095	1474.0	33821	32170	173714.1	164812.9	364800	346107
711.0	8.0	138.7	17668	2.23	397035	3070.7	109162.2	229241	717.4	14992	13214	92310.2	81170.3	193851	170458
711.0	10.0	172.9	22023	2.23	397035	3805.9	135301.4	284133	894.2	19347	17568	118449.4	107309.5	248744	225350
711.0	12.5	215.3	27430	2.23	397035	4707.3	167343.2	351421	1113.7	24754	22975	150491.3	139351.4	316032	292638
711.0	14.2	244.0	31085	2.23	397035	5309.0	188735.2	396344	1262.1	28409	26630	171883.3	160743.4	360955	337561
711.0	16.0	274.2	34935	2.23	397035	5936.4	211039.8	443184	1418.4	32259	30480	194187.9	183047.9	407794	384401
711.0	18.0	307.6	39188	2.23	397035	6621.9	235410.0	494361	1591.1	36512	34733	218558.1	207418.2	458972	435578
711.0	20.0	340.8	43417	2.23	397035	7295.4	259350.9	544637	1762.8	40741	38962	242498.9	231359.0	509248	485854
762.0	8.0	148.8	18950	2.39	456037	3535.0	134683.0	282834	769.4	16082	14175	113931.3	100205.7	239256	210432
762.0	10.0	185.5	23625	2.39	456037	4383.9	167028.4	350760	959.2	20757	18850	146276.7	132551.0	307181	278357
762.0	12.5	231.0	29433	2.39	456037	5426.0	206731.0	434135	1195.0	26565	24658	185979.3	172253.7	390557	361733
762.0	14.2	261.9	33360	2.39	456037	6122.6	233271.2	489870	1354.5	30492	28585	212519.5	198793.9	446291	417467
762.0	16.0	294.4	37498	2.39	456037	6849.7	260973.3	548044	1522.5	34630	32723	240221.6	226496.0	504465	475642
762.0	18.0	330.3	42072	2.39	456037	7645.1	291276.4	611680	1708.2	39204	37297	270524.7	256799.1	568102	539278
762.0	20.0	366.0	46621	2.39	456037	8427.4	321082.8	674274	1892.9	43753	41846	300331.1	286605.4	630695	601871
813.0	8.0	158.8	20232	2.55	519124	4032.0	163900.5	344191	821.4	17171	15136	138689.6	122006.2	291248	256213
813.0	10.0	198.0	25227	2.55	519124	5002.8	203363.9	427064	1024.3	22167	20131	178153.0	161469.6	374121	339086
813.0	12.5	246.8	31436	2.55	519124	6195.8	251860.3	528907	1276.3	28375	26340	226649.4	209966.0	475964	440929
813.0	14.2	279.7	35635	2.55	519124	6994.2	284314.9	597061	1446.8	32575	30539	259103.9	242420.6	544118	509083
813.0	16.0	314.5	40062	2.55	519124	7828.3	318221.7	668266	1626.6	37001	34966	293010.8	276327.4	615323	580288
813.0	18.0	352.9	44956	2.55	519124	8741.7	355350.0	746235	1825.3	41896	39861	330139.1	313455.7	693292	658257
813.0	20.0	391.1	49826	2.55	519124	9641.1	391909.3	823010	2023.0	46765	44730	366698.4	350015.0	770067	735032
813.0	23.0	448.1	57083	2.55	519124	10964.2	445694.2	935958	2317.7	54022	51987	420483.2	403799.9	883015	847980
914.0	10.0	222.9	28400	2.87	656118	6349.0	290147.2	609309	1153.1	24959	22670	254307.1	230570.4	534045	484198
914.0	12.5	277.9	35402	2.87	656118	7871.1	359708.4	755388	1437.4	31961	29672	323868.3	300131.7	680124	630277
914.0	14.2	315.1	40141	2.87	656118	8891.6	406344.5	853323	1629.8	36699	34410	370504.4	346767.8	778059	728212
914.0	16.0	354.3	45138	2.87	656118	9959.3	455141.8	955798	1832.7	41697	39408	419301.7	395565.1	880534	830687
914.0	18.0	397.7	50668	2.87	656118	11130.5	508664.8	1068196	2057.2	47226	44937	472824.7	449088.1	992932	943085
914.0	20.0	440.9	56172	2.87	656118	12285.8	561461.2	1179068	2280.7	52731	50441	525621.1	501884.5	1103804	1053957
914.0	23.0	505.4	64381	2.87	656118	13989.2	639308.0	1342547	2614.0	60939	58650	603467.9	579731.3	1267283	1217436
1016.0	10.0	248.1	31604	3.19	810732	7871.1	399849.7	839684	1283.2	27779	25233	350602.3	317964.5	736265	667725
1016.0	12.5	309.3	39407	3.19	810732	9766.2	496123.1	1041858	1600.0	35582	33036	446875.7	414237.9	938439	869899
1016.0	14.2	350.8	44691	3.19	810732	11038.6	560762.0	1177600	1814.5	40865	38320	511514.6	478876.8	1074181	1005641
1016.0	16.0	394.6	50265	3.19	810732	12371.6	628479.4	1319807	2040.9	46440	43894	579232.0	546594.2	1216387	1147848
1016.0	18.0	443.0	56436	3.19	810732	13835.7	702854.2	1475994	2291.4	52610	50064	653606.9	620969.0	1372574	1304035
1016.0	20.0	491.3	62581	3.19	810732	15282.0	776323.9	1630280	2540.9	58755	56209	727076.6	694438.7	1526861	1458321
1016.0	23.0	563.2	71751	3.19	810732	17418.3	884847.4	1858180	2913.2	67925	65380	835600.1	802962.2	1754760	1686221
1220.0	10.0	298.4	38013	3.83	1168987	11405.5	695737.9	1461050	1543.4	33419	30360	610420.2	553821.4	1281883	1163025
1220.0	12.5	372.2	47418	3.83	1168987	14169.3	864326.6	1815086	1925.3	42824	39765	779008.9	722410.0	1635919	1517061
1220.0	14.2	422.3	53791	3.83	1168987	16028.9	977764.6	2053306	2184.0	49197	46139	892446.9	835848.1	1874139	1755281
1220.0	16.0	475.1	60520	3.83	1168987	17980.7	1096821.7	2303325	2457.2	55925	52867	1011504.0	954905.2	2124158	2005301
1220.0	18.0	533.6	67971	3.83	1168987	20128.6	1227843.9	2578472	2759.8	63377	60319	1142526.3	1085927.4	2399305	2280448
1220.0	20.0	591.9	75398	3.83	1168987	22254.8	1357545.0	2850845	3061.3	70803	67745	1272227.4	1215628.5	2671677	2552820
1220.0	23.0	679.0	86491	3.83	1168987	25403.9	1549638.8	3254242	3511.7	81896	78838	1464321.2	1407722.3	3075074	2956217

The table shows the pile dimensions of standard products. Other dimensions than those defined in standard EN 10219-2 are also available against order.

3. DESIGN STANDARDS AND IMPLEMENTATION CONTROL

The Eurocode standards are followed in building construction projects according to the decrees of the Ministry of the Environment. In civil engineering projects, the Eurocode standards are applied according to the instructions of the Finnish Transport Infrastructure Agency. Instructions of other authorities (such as municipalities/cities) are observed where necessary.

The geotechnical class (GL1, GL2, GL3) of the site is selected according to PO-2016 and RIL 207 (Application Eurocode 7). The foundation engineer responsible for the site determines the geotechnical class.

GL1 sites do not normally require piling. Most soil conditions and sites belong to geotechnical class GL2. Owing to the good and versatile properties of steel piles, they have many applications at geotechnical class GL3 sites.
Piling class (PTL1, PTL2 or PTL3) is determined on the basis of consequence class (CC1 to CC3, cf. EN 1990 National Annex) and geotechnical class.

4. RECOMMENDATIONS FOR THE SELECTION AND DESIGN OF PILE TYPE, PILE SIZE AND PILING CLASS FOR DIFFERENT APPLICATIONS

Various applications and advantages of different SSAB's steel pile types are presented in brochures on RR and RRs piles, RD and RDs piles and RD pile walls.

The selection of a suitable pile type should be based primarily on soil conditions, but superstructures and ambient structures also play a major role. Some instructions and recommendations for the selection of pile type, pile size and piling class are given below.

Pile loads
SSAB's steel piles can be divided according to pile sizes and applications based on pile loads, for example, as follows:

RR75–RR/RD140/8	1 & 2 family houses and other structures subject to relatively light loads
RR/RD140/8–RR/RD270	multi-storey buildings of about 3 to 8 storeys
RR/RD220–RR/RD500	heavy multi-storey buildings (>5 storeys) or industrial building projects
RR/RD140–RR/RD270	pile slab projects
RR/RD220–RR/RD400	noise barrier piles (single pile foundations)
RR/RD500–RR/RD1200	bridge and harbour construction and buildings of more than 10 to 15 storeys

When selecting between RR and RD pile sizes, it should be noted that the design strength of RD piles bearing on solid bedrock is typically clearly higher (about 1.2 to 2.0 times) than that of an RR pile of corresponding size. Owing to the comprehensive pile size range, foundation structures can always be optimised by using several (typically two or three) pile sizes at a site.

Installability of piles
RD piles can be installed in all soil conditions. In very exacting conditions, such as those involving thick fill layers containing large boulders, the smallest RD piles (pile sizes around RD90 to RD140) may pose the risk of slightly higher pile bending in comparison to large diameter RD piles. If the bedrock surface is particularly inclined, close to ground level (<3 to 5 m), and in conditions where there are no supporting friction soil layers on top of the bedrock surface, an RD pile is a risk-free solution in terms of support for the lower end of the pile.

The penetrability of driven RR and RRs piles increases with increasing pile size. When the amount/size of stones and boulders in soil and fill layers – or the density or thickness of the soil layer – increases, the risk of deviations in the positions and verticality of driven piles increases. The risk that piles bend or fail to reach a load-bearing soil layer also increases. RR large diameter piles have successfully penetrated rock fills several metres thick, even ones over 20 metres thick. An RR170 or RR220 pile is often rigid enough to penetrate relatively thick layers of rocky fill and moraine all the way to a bearing basal formation, provided that the size and amount of stones and boulders is not exceptionally large. A rock shoe improves the penetrability of a pile. When building 1 & 2 family houses on thick moraine soils containing stones it is recommended to use at least pile size RR115/6.3.

Positional and verticality tolerances of piles
When a structure is set strict positional and verticality tolerances, like, for instance, railway bridges built using the bridge-moving technique, where a large diameter pile is attached to the deck and also acts as a column, the RD pile is the least risky alternative. It is also the most recommendable alternative for corresponding building construction projects where the pile also acts as a column. Strict tolerances may also be required in foundation underpinning or industrial building projects.

Environmental impacts of piling and nearby structures
The environmental impacts of piling and issues related to the selection of pile type are discussed in Sec. 6.7 of these instructions.

Selection of piling class
In most projects, the piling class can be either PTL2 or PTL3. In consequence class CC3 projects related to geotechnical classes GL2 and GL3, piling class PTL3 is always required.

Piling class PTL2 is recommended for 1 & 2 family house projects to ensure correct pile loads and geotechnical resistance. PTL3 may be applicable to these projects if the soil conditions are exceptional and/or the number of piles is large (a project involving several 1 & 2 family houses).

PTL3 should be considered with RR and RRs piles, when the number of piles is at least moderate and it is desired to minimise the environmental impacts of the piling. Then, the number of piles can be reduced due to the higher design value of pile strength by a maximum of 15 to 20% compared to PTL2. With large diameter piles, load-bearing capacity must always be ensured by dynamic load tests. In their case it is often recommendable to choose piling class PTL3 to optimise the structures.

With RD piles, the lowest piling class allowed by the consequence class and geotechnical class is recommended.

Considering installation equipment in design and selection of pile size

RR/RRs piles can be installed using light basic equipment (<20 to 25 t) up to a pile size of about RR170, and RD/ RDs piles up to about RD270 to RD320. Light basic equipment allows using essentially thinner piling platforms, especially in very soft subsoils, compared to heavy (>40 to 60 t) piling equipment. The environmental impacts of light installation equipment (mainly vibration) also remain low.

5. STRUCTURAL AND GEOTECHNICAL DESIGN OF PILES

5.1 Limit states of pile foundations to be considered

The limit states specified in PO-2016, Sec. 4.1, should be considered in the design of a pile foundation, considering the properties of the site.

5.2 Design process of a steel pile foundation

At conventional sites, where the piles are mainly subject to axial loading, the design of a steel pile foundation includes:

1) Selection of pile type suitable for the site:
   - soil conditions; pile drivability/installability and functioning of the pile foundation
   - loads from the superstructure and actions due to ground displacement
   - structures and conditions in the piling area and its surroundings

2) Selection of piling class PTL1 to 3 based on geotechnical class (GL1 to 3) and consequence class (CC1 to 3)

3) Determination of the geotechnical resistance of piles $R_{d,geo}$ according to Sec. 5.5
   - with RR75 to RR320 end-bearing piles, apply Table 22, end-of-driving instructions, and with PTL3 also dynamic load tests
   - with RD piles, geotechnical resistance is usually not a dimensioning factor
   - RR large diameter piles, dynamic load tests
   - stiffness of structure (non-stiff or stiff structure)

4) Determination of the design value $R_{d,str}$ of structural resistance of piles according to Sec. 5.7
   - determination of corrosion allowance
   - RR75 to RR320 and RD90 to RD320 normal cases, Tables 22 and 23
   - dimensioning program for RR and RD piles (www.ssab.com/infra)
   - end-of-driving instructions (Sec. 11) are observed with driven piles to ensure that impact stresses stay within allowed limits
   - the structural resistance of rock shoes for RR270 to RR1200 piles (Tables 4 and 7) may determine the maximum impact and structural resistance

5) Determining the design value for resistance to an action
   - the design value of resistance R_d is the smaller of geotechnical $R_{d,geo}$ and structural resistance $R_{d,str}$

6) Calculation of pile foundation displacements, if necessary (Sec. 5.8)
   - vertical displacement of an individual pile and displacements of pile groups

7) Assessment of and preparation for environmental impacts of piling
   - assessment of vibration, soil displacement, increase in pore water pressure and compaction of subsoil due to piling
   - preparation for environmental impacts
     - selection of pile type
     - piling sequence
     - monitoring measurements
     - special measures

8) Structural design of a pile foundation
- Pile foundations are always designed together with the structures to be supported on it, which allows selecting the most suitable shape, dimensions and stiffness for the entire structure. Things to be considered in the structural design of the pile foundation include
  - joints between piles and superstructure
  - determination of positional and verticality tolerances on the basis of pile type, soil conditions and superstructure
  - elevation of pile group foundation
  - centre-to-centre pile spacing
  - pile inclinations
  - distances of piles to nearby structures
  - distance from side of the foundation to side of the pile
  - other structural aspects to be considered

9) Foundation engineering print-outs
- Building specification (work schedule)
  - soil conditions
  - geotechnical works
    - Work stages prior to piling and measures affecting the work phases, piling platforms, excavations, etc.
    - Site-specific instructions related to piling, such as instructions for installation, piling sequence, quality control measurements, special measures
  - Foundation structures
- Pile foundation drawings
- Geotechnical and structural dimensioning calculations
  - normally dimensioning calculations for the structure of an axially loaded pile can be made and printed out easily using the pile dimensioning program for RR and RD piles
- As-built drawing

5.3 Actions and design situations

The design actions of loads must correspond to those specified in all parts of standard EN 1991 and the national annexes to them. They are included in publication RIL 201-1-2008 with their application instructions. Actions caused by subsoil displacement, such as downdrag (negative skin friction), are treated in dimensioning as permanent actions on the pile (for more details, see 5.9).

5.4 Geotechnical investigations

Geotechnical investigations for the design of steel piles are generally regulated by the Finnish Building Code and standards EN 1997-1 and EN 1997-2. PO-2016 presents the general requirements for geotechnical investigations in building construction, requirements and recommendations for different geotechnical classes and foundation underpinning sites, as well as requirements and instructions for the presentation of geotechnical information. Valid guidelines of the Finnish Transport Infrastructure Agency are observed in infrastructure construction. Geotechnical investigations must be complemented with sufficiently extensive investigations of nearby structures (ducts, pipes, cables, underground structures, etc.), their location and condition, foundation methods, as well as sensitivity to displacement and vibration.

Geotechnical information and its assessment are presented in the ground investigation report according to PO-2016, Ch 1, Sec. 3.3. The ground investigation report should indicate the following points most essential for the design and dimensioning of steel piles:
- the characteristic value of the undrained shear strength of soil used in dimensioning – by soil layers, if necessary, and/or with the site divided into different zones if the site is large and/or the undrained shear strength of soil varies considerably
- corrosion allowance used in dimensioning
- estimated pile length and basis of estimate
- estimate of subsoil properties affecting piling, such as the quality, stoniness and thickness of fills, dense/stony intermediate layers, density and stoniness of moraine, inclination of bedrock surface
- shoe type of driven pile used at site
- estimate of the occurrence of downdrag (negative skin friction) and determination of the design value of downdrag for different pile dimensions and different areas of the site, if necessary

Depending on the site, the following may also be needed:
- axial spring constant of pile for service state displacement analysis (see Sec. 5.8), is in principle always required in PTL3 but also in PTL2 in the case of long piles
- geotechnical parameters of soil layers to determine extreme values of modulus of subgrade reaction and lateral resistance, when piles are subject to a horizontal load and/or moment.

5.5 Dimensioning methods and analyses of geotechnical resistance

5.5.1 Selection of geotechnical dimensioning method for steel piles

The geotechnical compressive strength of steel piles can be determined according to PO-2016 in several ways, whose applicability is shown in Table 15.

5.5.2 Stiffness of a piled structure

The stiffness of a piled structure is taken into account in building construction projects according to the instructions of PO-2016 and in civil engineering projects according to those of NCCI7. The correlation coefficients presented in these instructions and the design values based on them assume that the structures are not so-called rigid structures.

Table 15. Suitability of geotechnical dimensioning methods for different steel pile types.

Pile	static load test	dynamic load test	based on ground test results	end-of-driving criterias/ measurements based on pile driving formulas	end-of-driving instructions based on stress wave analysis	based on the behaviour of a corresponding foundation
RR small diameter piles/end-bearing piles PTL1–2	X	XX	X	XX	XXX	X
RR small diameter piles/end-bearing piles PTL3	X	XXX	X	XX	XX	X
RR large diameter piles/end-bearing piles	-	XXX	X	XX	XX	X
RR small diameter piles/friction piles	XX	XXX	XX	XX	XX	X
RR large diameter piles/friction piles	-	XXX	XX	XX	XX	X
CSG-RR piles/friction piles	XXX	-	XX	-	X	XX
Jacked RR-piles	XXX	X	XX	-	-	XX
RD piles	X	X	XXX*	X	X	X
Tension piles	xxx	x	xx	–	x	x

XXX = preferred method
XX = applicable
X = possible, applicability to be assessed case by case
- = technically infeasible or uneconomical
XXX* = RD piles feasible assuming that the bedrock surface has been reliably established or that the bearing capacity of RD piles based on skin friction is determined by calculations

5.5.3 Resistances determined by stress wave analysis

Determining end-of-driving criterias by stress wave analysis is the preferred method for driven RR75 to RR320 piles in piling classes PTL1 and PTL2.

Sec. 11 of these instructions and Appendix 3 present end-of-driving criterias for different pile driving equipments, piles and pile lengths (5, 10, 20 and 30 m) based on the one-dimensional stress wave theory using the GRLWEAP program. Correlation factor ξ_5 is 1.47 (1.40 x 1.05) according to PO-2016 Part 1 Sections 4.5.2.4 and 4.5.2.6. The end-of-driving tables present the targeted geotechnical ultimate resistance R_c at different piling class, design values of geotechnical resistance R_d corresponding to the ultimate resistance, and end-of-driving criterias for each pile driving equipment/pile combination. The design value R_d is obtained as follows:

$$R_d = R_c/(\xi_5 \times \gamma_t) = R_c/(1.47 \times 1.20) = R_c/1.764 \quad (1)$$

The R_d values presented in the end-of-driving conditions and Table 22 can be used directly in design for piling class PTL1 and PTL2, and the geotechnical resistance of the pile is ensured when the end-of-driving criterias are met.

In Table 22 the design values of geotechnical resistance for PTL3 are calculated according to Formula (1). The design values can be used as input values for design, and geotechnical resistance must be ensured by dynamic load tests.

5.5.4 Resistances determined by dynamic load tests

Resistances determined by dynamic load tests are suitable for friction and end-bearing piles at pile sizes RR75 to RR1200 in all piling classes. Dynamic load tests must always be used at building construction sites where driven piles are used and the piling class is PTL3. In the case of large diameter piles, dynamic load tests are always recommended even with PTL2.

Correlation coefficients and related model coefficients are presented in PO-2016, Part 1, chapter 4.5.2.4. The dimensioning program RRPileCalc calculates correlation coefficients as well as required minimum and mean results for load tests automatically on the basis of input data.

Dimensioning based on dynamic load tests can in principle be performed in two different ways.

1) The design value of geotechnical resistance R_d is selected on the basis of piling class from Table 22, and is used to calculate the minimum and average targets for dynamic load tests.

2) The ultimate geotechnical resistance of the pile type in question reliably achievable in the soil conditions of the site is assessed considering the highest allowable impact resistance of the piling class (Appendix 1), and the design value of geotechnical compressive resistance is calculated on the basis of this assessment and dynamic load tests.

5.5.5 Resistances determined by pile driving formulas

Pile driving formulas can be used in piling class PTL1 or PTL2, for example, in situations where, according to the end-of-driving table, the used pile driver is not able to mobilise sufficient ultimate geotechnical resistance and geotechnical resistance is ensured by a separate test loading hammer without a dynamic load test. The pile driving formulas are used according to PO-2016, Ch. 1, Sec. 4.5.2.5.

5.5.6 Resistances determined on the basis of ground test results

Geotechnical resistance is determined on the basis of ground test results according to PO-2016, Ch. 1, Sec. 4.5.2.3. It is recommended that the so-called alternative method is used in design, where a model factor of ≥1.6 is used for end-bearing and friction piles and ≥1.95 for cohesion piles in long-term loading and ≥1.40 in short-term loading.

As concerns steel piles, the capacity of both smooth and grouted friction piles can be determined on the basis of ground investigation results, but it is recommended that the capacity is also determined by static or dynamic load tests. This method is highly suitable for calculating the geotechnical compressive strength of foundation piles of lightweight noise barriers.

The point and shaft resistance of piles can be estimated either on the basis of the angle of friction or cohesion of soil or directly based on sounding resistance according to PO-2016.

5.5.6.1 Special features of the geotechnical resistance of open ended steel pipe piles

In preliminary analyses of open ended steel piles with point reinforcement ring (a steel collar over the shaft), external shaft resistance can be estimated to decrease by 50 % in a dense coarse-grained soil layer or moraine layer, and 25 % in a loose layer compared to the table values presented in PO-2016 or static capacity formulas. Point resistance increases with increasing pile-point area.

If no plugging occurs in the pile, internal shaft resistance can be assumed to be half of external shaft resistance in preliminary analyses. However, the capacity consisting of internal shaft resistance and point resistance of the area of the steel cross-section of the pile must not exceed the capacity of a plugged pile of corresponding size due to point resistance.

5.5.6.2 Geotechnical resistance of grouted CSG-RR piles bearing on a soil layer

The dimensioning geotechnical diameter of shaft grouted piles (d_d) may be larger than the diameter of the collar (d_0) used with the pile. The increase in diameter is caused by the pressurising effect of grout with this installation method, which makes the grout both displace and mix with the soil layers surrounding the pile.

The dimensioning geotechnical diameter can be determined, for example, by measurements on a test pile or by using information on shaft grouted micropiles in corresponding soil conditions. The magnitude of the dimensioning diameter can be evaluated using Formula 2.

$$d_d = a \cdot d_0 \qquad (2)$$

where d_d is the dimensioning geotechnical diameter;
a is the coefficient that depends on soil type, grout pressure, etc. and
d_0 is the diameter of the collar used with the pile in question

The coefficient can vary with different soil types as follows:

clay	a = 1.0
silt	a = 1.0 to 1.1
sand, gravel	a = 1.1 to 1.2
moraine	a = 1.0 to 1.2

With shaft grouted CSG-RR piles the shaft resistance factors of Table 16 can be used as shaft resistance factor $K_s tan\varphi_a$, and the dimensioning of point resistance is the same as with non-grouted piles. Values based on sounding resistance may also be used to evaluate shaft and point resistance, see PO-2016, Ch. 1, Tables 4.6 and 4.8.

5.5.6.3 Geotechnical resistance of RD piles drilled into bedrock

The point resistance of a pile bearing on solid Finnish bedrock is usually not a dimensioning factor, but resistance is determined on the basis of the structural resistance of the pile.

The tip of the pile is assumed to bear on bedrock when both drilling observations and geotechnical investigations confirm it.

Table 16. Shaft resistance factor $K_s tan\varphi_a$ for grouted piles in coarse-grained soil types.

	Internal angle of friction of soil [°]							
	28	**30**	**32**	**34**	**36**	**38**	**40**	**42**
$K_s tan\varphi_a$	1.2	1.3	1.5	1.7	2.1	2.5	2.9	3.4

The quality of the rock contact of RD piles is ensured by drilling the pile at least 3·*d* deep, but no less than 0.5 m, in solid bedrock. With larger drilled piles, over 300 mm in diameter, 3·*d* can be considered a safe drilling depth into bedrock, but drilling the pile more than 1.5 m into bedrock is usually not practical in Finland. In bridge projects of the Finnish Transport Infrastructure Agency, the dimensioning and implementation instructions of the publication "Sillan geotekninen suunnittelu" (Geotechnical design of a bridge) for joint stiffness and drilling depth of RD piles into bedrock are followed.

Drilling piles more than 1.5 m into solid bedrock may be appropriate, for instance, when excavation or blasting takes place after installation of piles in their immediate vicinity. Three metres below the excavation level can be considered a safe target level for piles in bedrock in the case of conventional blasting. If the target level is 3 metres higher than above, the properties of the rock and its breaking during blasting must be considered carefully in the planning and execution of the work.

The rock contact of the tip of RD piles installed by the concentric drilling method remains after rock penetration. When the RD pile is filled completely or partly with grouting mortar or concrete, loads from the pile to the bedrock are transmitted across the entire area of the pile bottom.

In fragmented bedrock piles are drilled deeper all the way to solid bedrock, or the rock is grouted or geotechnical resistance is evaluated case by case. Geotechnical resistance can be determined by calculations if the strength properties of the fragmented rock can be estimated or determined reliably enough.

The contact of RD piles with rock after the end of drilling is ensured by applying "final or control blows" by a drill hammer to the top of each pile.

The shaft resistance of a pile in bedrock can be made use of in geotechnical dimensioning of RD piles. It can be used, for example, if the pile bears on a weakness zone in bedrock or is subject to tensile loads. With vertically loaded RD piles dimensioned to be shaft-bearing, the distance between the hole in the rock and the reinforcement must be at least 15 mm. The shaft resistance of RD piles in bedrock can be utilised, for example, by drilling the RD pile first to the surface of bedrock, and then continuing to drill with a smaller drill bit deeper into bedrock. The drill hole is flushed clean, filled with concrete, grouting mortar or injection grout, and then a steel pipe equipped with centralisers, at least 30 mm smaller in outer diameter than the diameter of the hole in the bedrock, is installed in the hole. The bond stress values between steel and grouting mortar and grouting mortar and rock are presented in PO2016, Ch. 1, Table 4.9.

5.5.7 Resistances determined by static load tests

Static load tests are used mainly in the geotechnical dimensioning of shaft grouted CSG-RR piles, jacked RR-piles and tension piles. In rapid load tests, the correlation coefficients of PO-2016, Ch. 1, Tables 4.1 and 4.2 are multiplied by 1.2. Even in rapid loading, the displacement during the load step of the highest load must be monitored for at least 5 minutes. The rate of settlement during the last 5 minutes of the monitoring period must be less than half of that of the first 5 minutes.

5.6 Geotechnical dimensioning of tension piles

The geotechnical dimensioning of tension piles is carried out according to PO-2016, Sec. 4.5.3.

If mechanical splices are used in pile splicing, the design value of tensile strength must be limited to that of the splice, which in the case of driven RR piles is 15% of compressive strength and with RD piles 50% of compressive strength.

In the case of RD piles with conventional casing shoes and ring bits, the grouting mortar or concrete possibly penetrating between the hole in the bedrock and the pile pipe after concreting cannot be taken into account in dimensioning without a closer analysis.

If anchors are used with the piles, the entire tensile force on the pile must be taken by the anchor.

5.7 Structural resistance

5.7.1 Resistance of RR piles during installation

The structural resistance of driven piles in different piling classes must be limited according to PO-2016 as follows:

Table 17. Maximum characteristic value of geotechnical resistance for driven piles and maximum centric impact force.

Maximum allowed centric impact force causing compression stress during installation* $N_{impact\,(-)}$	Maximum characteristic value of resistance $R_{c;max}$
$\leq 0.9 \times f_{yk} \times A_s$	PTL3: $R_{c;max} \leq N_{impact(-)}$
	PTL2: $R_{c;max} \leq 0.8 \times N_{impact(-)}$
	PTL1: $R_{c;max} \leq 0.6 \times N_{impact(-)}$

*when stresses/impact force are measured during driving, the above stress level cannot be exceeded by more than 20 % (impact stress ≤ 1.08 x f_y) (EN 12699).

Appendix 1 presents the maximum resistance $R_{c;max}$ values during driving for all RR piles in various piling classes.

5.7.2 Structural resistance during service

The structural resistance of a pile is verified in terms of both pile structure and soil failure according to Piling Manual PO-2016.

The compressive resistance of piles against buckling is determined in conditions where piles may buckle due to the lack of sufficient lateral support. The lateral support of soil is usually not utilised if the shear strength of the organic soil layer around the pile is less than 5 kN/m^2. Then, the pile is dimensioned as a column and the unbraced length is determined on the basis of soil conditions and the structural joint between the upper and lower ends of the pile.

The ultimate buckling resistance of an axially loaded pile is calculated by the method presented in PO-2016, Sec. 4.7.5, where the pile is assumed to be surrounded by a fine-grained soil layer over its entire unbraced length. A constant spring value is used for subsoil along the entire unbraced length in dimensioning. In a coarse-grained soil layer, the above calculation method can be utilised by estimating the unbraced length and using, for example, a conservative spring value for frictional soil along the entire unbraced length.

Initial deflection after installation prior to loading is taken into account in buckling analyses of axially loaded piles. At the design stage, values $L_{cr}/200$ to $L_{cr}/800$ of the table can be used as the value of the geometric initial deflection of a pile. The values of the greater divisor of the table, that is, the larger radius of curvature, can be used when the installation conditions are expected to be easy, and the smaller radius of curvature values when the installation conditions are expected to be difficult. The value recommended for a spliced pile is used only if the splice is located along the unbraced length L_{cr} in a soft soil layer.

Table 18. Initial deflection values used with SSAB's steel piles in design.

	Unspliced pile	**Spliced pile**
Initial deflection δ_g [m], RR and RRs piles and CSG-RR piles	$L_{cr}/300$–$L_{cr}/600$	$L_{cr}/200$–$L_{cr}/400$
Initial deflection δ_g [m], RD and RDs piles	$L_{cr}/500$–$L_{cr}/800$	$L_{cr}/300$–$L_{cr}/600$

If the straightness of the pile is measured, for example, with a torch or an inclinometer, the radius of curvature determined on the basis of the measurements can be used in design. The dimensioning program for RR and RD piles can be used for easy calculation of the radius of curvature used in the dimensioning of a pile. The calculated radius of curvature depends on the critical unbraced length, which, in turn, depends on the stiffness of the pile, the modulus of subgrade reaction and effective width of the pile.

According to PO-2016 and in the dimensioning program for RR and RD piles, the partial safety factor for strength of soil is applied to the ultimate stress limit of lateral resistance at the end of the calculation.

Steel cross-section classes are taken into account according to standards EN 1993-1-1 and EN 1994-1-1 in the calculation of the ultimate bending moment capacity of the pile structure.

With CSG-RR piles, the effective width of the pile is based on the width of the collar. An external grout mantle is not taken into account in determining the ultimate bending moment capacity of the structure.

If a pile is loaded by an external bending moment and/or a torque and/or a shear force, besides a normal force, the pile or the part of it subject to the stress in question must be dimensioned for the combined stresses.

Secs. 5.12 and 5.13 of these instructions present pre-calculated dimensioning values for structural resistance at corrosion allowances of 1.2 mm and 2.0 mm.

5.7.3 Corrosion

The average corrosion rate of unprotected steel piles in normal conditions underground can be assumed to be at least 1.2 mm in a hundred years in the case of the external surfaces susceptible to corrosion. Corrosion of the inner surfaces of steel pipe piles with a closed lower end or ones filled with concrete can be ignored.

Corrosion rate depends on ambient conditions.
Table 19 presents some indicative values for average surface corrosion of steel piles in some conditions. The recommendations of the table were originally presented in standard EN 1993-5.

Alternatively, the corrosion rate of piles not filled with concrete can in certain normal conditions be estimated on the basis of the values presented in Table 20. The table is based on statistical processing of corrosion observations, where the risk related to conditions is taken into account by using the so-called pit corrosion factor and possible internal corrosion by theoretical calculations.

If soil conditions prove unusual, Table 19 can be applied where applicable.

Table 19. Average surface corrosion [mm] of unprotected steel piles in soil above and below ground water level (EN 1993-5).

Target service life	5 years	25 years	50 years	75 years	100 years
Normal conditions					
Undisturbed natural soils (sand, silt, clay, ...)	0.00	0.30	0.60	0.90	1.20
Non-compacted, non-aggressive mineral soil fills (clay, sand, silt, ...)	0.18	0.70	1.20	1.70	2.20
Exceptional or aggressive conditions					
Contaminated natural soils and soils in industrial areas	0.15	0.75	1.50	2.25	3.00
Aggressive natural soils (swamp, marsh, peat, ...)	0.20	1.00	1.75	2.50	3.25
Non-compacted aggressive fills (ash, slag, ...)	0.50	2.00	3.25	4.50	5.75

Note: Corrosion rates are lower in compacted than in non-compacted fills. In the case of compacted fills, the values for non-compacted fills can be divided by two.
The values are indicative. Local conditions must be taken into account.
The values for a service life of 5 and 25 years are based on measurements, other values have been extrapolated.
Corrosion in air in one hundred years: 1 mm in normal climate and 2 mm near the sea.

*Table 20. Dimensioning corrosion of unconcreted micropiles in 100 years in different conditions.**

Conditions	Corrosion in 100 years [mm]
Homogeneous natural soil conditions above and below ground water level	1.2
Compacted mineral soil fills above and below ground water level	1.5
Non-compacted mineral soil fills above and below ground water level	2.0

* Jouko Törnqvist: Corrosion steel pipe piles. Dimensioning based on empirical material VTT Technical Research Centre of Finland (2005).
• Espoo (2005)

Table 21. Recommended values for thickness reduction of bearing piles and sheet piling installed in fresh or sea water due to corrosion [mm] (EN 1993-5).

Design life required in designs	5 years	25 years	50 years	75 years	100 years
Normal fresh water (river, navigable channel, ...) in a high stress (water line)	0.15	0.55	0.90	1.15	1.40
Badly polluted fresh water (sewage, industrial waste water...) in a high stress area (water line)	0.30	1.30	2.30	3.30	4.30
Sea water in temperate climate in high stress area (shallow water and splash zones)	0.55	1.90	3.75	5.60	7.50
Sea water in temperate climate in areas permanently under water and tidal zones.	0.25	0.90	1.75	2.60	3.50

Note:
1) Corrosion rate is usually highest in a splash or tidal zone at low tide level. In most cases, however, the highest flexural stresses occur in areas permanently under water.
2) Values for 5 and 25 years are based on measurements, while others have been extrapolated.

In uncertain cases it is advisable to overdimension excessively or use corrosion protection.

The usualness of conditions is established on the basis of geotechnical investigations and historical data on the area when there is no reason to assume the soil to be contaminated. Special investigations can be carried out in uncertain situations to ascertain that the separately determined limit values for aggressive conditions are not exceeded. The instructions of the publication ”Sillan geotekniset suunnitteluperusteet” (Geotechnical design criteria for bridges) are followed in corrosion dimensioning and corrosion investigations in bridge projects commissioned by the Finnish Transport Infrastructure Agency.

Use of filter fabric or plastic sheeting or pipes is recommended around unprotected steel piles to prevent direct contact between granules and steel in lightweight aggregate fills.

The corrosion of piles installed in water can be estimated on the basis of the values presented in Table 21. Higher corrosion values must be used in unusual conditions including sites where pile surfaces are subject to mechanical stress caused, for example, by propeller slipstreams of ships. The recommendations of the Table were originally presented in standard EN 1993-5.

When cement-based injection grout, grouting mortar or concrete is used as corrosion protection of steel piles, corrosion dimensioning and determination of the correct protective coating thickness can be based on Tables 4.25 ja 4.26 of PO-2016, Ch. 1.

External coatings can be used as corrosion protection on steel piles, although overdimensioning of wall thickness is generally the recommended method. Possible external coatings are protective paint or 3-layer HDPE coating. The selected coating must be able to withstand stresses during installation. Protective painting is highly suitable for piles that are installed in water where the purpose of the protective painting is to prolong service life, for instance, in the most aggressive splash zone areas. The service life of protective painting can be assessed in the case of the protective paint systems specified in standard EN 12944-5. There is always the risk of damage to the coating of piles driven into soil unless special measures are taken. In the case of drilled piles, when there are no stones or boulders in the soil, it may be possible to use the strong 3-layer HDPE coatings specified in DIN 30670 without the coatings being damaged. Even then, the use of a coating should be considered case by case and the durability of the coating ensured, for example, by test installations.

In the case of electric protection methods, the electric current required by the system and the replaceability/service life of galvanic anodes must be taken into account.

5.8 Vertical displacements of pile foundation

If necessary, vertical displacements of pile foundations are analysed according to PO-2016, Sec. 4.5.4. An analysis of settlements is generally not needed with steel piles bearing on dense moraine or bedrock, if ultimate limit state analyses of the piles have been conducted. However, for example, at foundation underpinning sites, especially with long piles, the elastic compression of piles may become a dimensioning factor, which is why the piles are often prestressed.

The assessment of vertical displacements must cover both the settlement of individual piles and settlement due to group effect as well as structural rotations and changes in inclination possibly caused by uneven settlement.

In the case of tension piles, upward displacements should be assessed on the basis of the same principles. If very strict criteria have been set for the service limit state, a separate analysis of upward displacements is needed.

5.9 Considering downdrag (negative skin friction) in dimensioning

Negative skin friction is taken into account according to PO-2016, Ch. 4.2.2.2 as a downward acting load.

In building construction projects, the design value of downdrag load is obtained by multiplying the characteristic value of negative skin friction by a factor of 1.2. When the design value of short-term loads exceeds the design load of downdrag, downdrag load is not taken into account in ultimate limit state analysis.

In infrastructure projects, the characteristic value is multiplied by the partial safety factors of dead load (Load Combination 6.10a). Downdrag load does not affect the pile simultaneously with compressive stresses from traffic loads.

Small diameter steel pipe piles have dimensioning advantages over conventional pile types in terms of negative skin friction, since the skin area is small and the downdrag load on the piles is often smaller than short-term loads. On the other hand, due to their low soil displacement, driven small diameter piles, even large RD piles when installed carefully, do not cause soil heave and subsequent settlement in normally consolidated clay. Thus, installation of piles does not cause significant displacement of soil or lead to a situation where negative skin friction should be taken into account according to PO-2016.

Accurate determination of the negative skin friction on an individual pile requires calculating the settlements of both the pile and soil layers. Normally it can be simply assumed that negative skin friction occurs across the entire compressed layer and that its magnitude [of skin friction] can be estimated on the basis of undrained shear strength and the adhesion coefficient.

5.10 Transversely loaded steel piles

Laterally loaded piles are dimensioned according to the principles of PO-2016, Ch. 1, Sec. 4.6. Usually a dimensioning program is used, which can take into account the stiffness of the pile, attachment of the upper and lower ends of the pile, and the properties of soil layers. Flexural stiffnesses (*EI*) of steel piles, either unconcreted or concreted and reinforced, can be easily calculated by the dimensioning program for RR and RD piles.

5.11 Short piles

It must be borne in mind in design that the shortest allowable lengths of driven RR piles in soil are:

RR75 to RR220:	1.5 m
RR270 to RR320:	2.0 m
RR400 to RR600:	2.5 m
RR650 to RR1200:	3.0 m

If the penetration depth of an RR pile is less than 5 metres, it must be estimated whether the soil provides sufficient lateral support for the pile. Lateral support can often be improved by using rock shoes to attach the pile tip to bedrock. If the soil does not provide sufficient lateral support, the sufficiency of lateral support vs. allowed deviations in inclination (lateral component acting on inclined pile vs. lateral resistance) is checked. In consequence class CC1, and with caution also at CC2 sites, it is also possible to reduce the design value of the compressive resistance of piles by a factor of 0.6 to 1.0 (pile length 3 to 5 m) in lieu of more accurate calculations. Piles shorter than 3 metres are usually attached rigidly to the superstructure according to Sec. 6.1.

RD piles have no minimum penetration depth, but pile length is determined according to site properties and the portion to be drilled into bedrock according to Sec. 5.5.6.3. When short RD pile (pile length less than 3 m) is drilled at least $4 \cdot d$ into the bedrock, the rigid connection with superstructure is not needed.

5.12 Dimensioning tables for RR and RRs piles, pile sizes RR75 to RR320/12.5

The design values of the geotechnical resistance of RR and RRs piles have been determined according to Sec. 5.5.4 to correspond to the end-of-driving criteria based on stress wave analysis. In piling class PTL3 geotechnical resistance must be ensured by dynamic test loadings according to Sec. 5.5.5.

Coefficient of modulus of subgrade reaction used to calculate the spring constant of soil is 50 ($k_s = 50 \times c_{u,k}/d_{eff}$) and that used to calculate the extreme value of lateral resistance is 9 ($p_m = (9 \times c_{u,k}) / \gamma_{R,e}$).

The buckling analysis of piles has been performed by a structural model where the partial safety factor of soil resistance is applied to the characteristic values of the resistances of the springs representing the soil. The springs themselves have been calculated on the basis of characteristic soil values. The partial safety factor of soil resistance has been set to the default value of $\gamma_{R,e} = 1.5$ (RIL 207-2009). The partial safety factor of steel has been set to $\gamma_{si} = 1.0$ according to EN 1993-1-1. The structure of the pile has been dimensioned as a steel structure. Calculation method of dimensioning the structural resistance of pile's cross-section is presented in detail in the RRPileCalc program manual.

If the input values differ from the above or those presented in Table 22, the axial structural resistance of piles can be easily determined with RRPileCalc program.

The design values of the geotechnical resistance of piles are independent of the used corrosion allowance. If driven RR or RRs piles are concreted and dimensioned as a composite structure, the design values of RD piles (Sec. 5.13) can be used as design values of the pile structure, or they can be determined by the dimensioning program for RR and RD piles.

5.13 Dimensioning tables for RD and RDs piles, RD/RDs90 to RD320/12.5

Coefficient of modulus of subgrade reaction used in calculating the spring constant of soil is 50 ($k_s = 50 \times c_{u,k}/d_{eff}$) and that used in the calculation of the extreme value of lateral resistance is 9 ($p_m = (9 \times c_{u,k}) / \gamma_{R,e}$).

Buckling analysis of piles has been performed by a structural model where the partial safety factor for soil resistance is applied to the characteristic values of the resistances of the springs representing soil. The springs themselves have been calculated on the basis of characteristic values of soil. The partial safety factor for soil resistance has been set to the default value of $\gamma_{R,e} = 1.5$ (RIL 207-2009). The partial safety factor of steel has been set to $\gamma_{si} = 1.0$ in both steel structure dimensioning according to EN 1993-1-1 and composite structure dimensioning according to EN 1994-1-1. The partial safety factor for the strength of concrete/grouting mortar is $\gamma_{ci} = 1.5$ according to EN 1992-1-1. Concrete strength has been C30/37. Calculation method of dimensioning the structural resistance of pile's cross-section is presented in detail in the RRPileCalc program manual.

Concrete creep and the share of dead load of the overall load is considered in determining the effective elastic modulus of concrete/grouting mortar ($E_{c,eff}$) according to standard EN 1992-1-1. The creep factor used in the calculations is $\varphi_t = 1.5$ and the default value of dead load share is 0.5.

If the input values change, the structural axial resistance of piles can be easily determined with RRPileCalc program.

Table 22. Design values for structural compressive resistances of RR and RRs piles and geotechnical resistances in different piling work classes. The compressive strength of the structure is dimensioned for a steel structure.

Corrosion allowance 1.2 mm											
Pile	Steel grade	Initial deflection	Design value of structural compression resistance R_d [kN] undrained shear strength c_{uk} [kPa]						Design values of geotechnical resistance R_d [kN]		
		δ_g	5	7	10	15	20	30	PTL1	PTL2	PTL3
RR75	S460MH	L_{cr}/400	210	257	318	359	377	398	195	259	324
		L_{cr}/600	245	298	346	377	395	415			
RR90	S460MH	L_{cr}/400	274	336	406	439	458	481	230	307	384
		L_{cr}/600	320	389	427	460	479	501			
RR115/6.3	S460MH	L_{cr}/400	421	516	562	600	622	648	301	401	502
		L_{cr}/600	489	550	590	628	649	672			
RR115/8	S460MH	L_{cr}/400	464	568	694	751	786	826	376	502	627
		L_{cr}/600	541	657	730	788	822	860			
RRs115/8	S550J2H	L_{cr}/400	464	568	703	854	903	961	450	600	749
		L_{cr}/600	541	657	807	896	946	1002			
RRs125/6.3	S550J2H	L_{cr}/400	504	616	729	787	821	859	402	536	670
		L_{cr}/600	582	704	766	823	856	892			
RR140/8	S460MH	L_{cr}/400	653	799	901	965	1004	1048	466	621	777
		L_{cr}/600	758	877	947	1011	1047	1088			
RRs140/8	S550J2H	L_{cr}/400	653	799	988	1107	1162	1225	557	743	929
		L_{cr}/600	758	921	1066	1160	1214	1275			
RR140/10	S460MH	L_{cr}/400	710	870	1078	1177	1233	1299	574	765	956
		L_{cr}/600	829	1007	1140	1236	1291	1353			
RRs140/10	S550J2H	L_{cr}/400	710	870	1078	1334	1414	1509	686	915	1143
		L_{cr}/600	829	1007	1237	1401	1482	1577			
RR170/10	S460MH	L_{cr}/400	975	1194	1384	1488	1549	1621	700	934	1167
		L_{cr}/600	1134	1343	1455	1559	1618	1684			
RRs170/10	S550J2H	L_{cr}/400	975	1194	1477	1700	1789	1893	837	1116	1396
		L_{cr}/600	1134	1377	1632	1784	1872	1971			
RR170/12.5	S460MH	L_{cr}/400	1057	1295	1604	1797	1887	1992	862	1149	1436
		L_{cr}/600	1234	1501	1736	1887	1976	2076			
RR220/10	S460MH	L_{cr}/400	1519	1802	1929	2048	2118	2199	925	1233	1542
		L_{cr}/600	1751	1895	2023	2139	2204	2277			
RRs220/10	S550J2H	L_{cr}/400	1519	1858	2193	2365	2466	2582	1106	1475	1843
		L_{cr}/600	1756	2117	2302	2474	2572	2679			
RR220/12.5	S460MH	L_{cr}/400	1654	2026	2331	2505	2607	2726	1142	1523	1904
		L_{cr}/600	1922	2265	2451	2624	2722	2832			
RRs220/12.5	S550J2H	L_{cr}/400	1654	2026	2506	2865	3013	3185	1366	1821	2277
		L_{cr}/600	1922	2336	2752	3004	3151	3315			
RR270/10	S460MH	L_{cr}/400	2188	2674	2518	2651	2728	2817	1163	1551	1939
		L_{cr}/600	2332	2494	2635	2760	2831	2910			
	S550J2H	L_{cr}/400	2188	2396	2540	2671	2748	2835	1391	1855	2319
		L_{cr}/600	2351	2514	2655	2779	2848	2926			
RR270/12.5	S460MH	L_{cr}/400	2391	2867	3074	3268	3382	3513	1441	1921	2401
		L_{cr}/600	2767	3016	3225	3414	3520	3639			
	S550J2H	L_{cr}/400	2391	2926	3491	3770	3934	4123	1722	2296	2871
		L_{cr}/600	2767	3359	3665	3945	4104	4280			
RR320/10	S460MH	L_{cr}/400	2432	2555	2663	2763	2821	2889	1389	1852	2314
		L_{cr}/600	2553	2672	2773	2862	2913	2972			
	S550J2H	L_{cr}/400	2739	2908	3056	3192	3270	3361	1660	2214	2767
		L_{cr}/600	2877	3045	3187	3312	3381	3460			
RR320/12.5	S460MH	L_{cr}/400	3177	3559	3786	3997	4120	4261	1722	2296	2870
		L_{cr}/600	3483	3740	3966	4166	4279	4405			
	S550J2H	L_{cr}/400	3177	3883	4331	4636	4813	5016	2059	2745	3432
		L_{cr}/600	3663	4211	4542	4842	5010	5195			

Corrosion allowance 2.0 mm											
RR75	S460MH	L_{cr}/400	191	234	284	307	321	338	195	259	324
		L_{cr}/600	223	271	299	323	336	351			
RR90	S460MH	L_{cr}/400	251	308	350	376	391	408	230	307	384
		L_{cr}/600	292	341	368	393	408	424			
RR115/6.3	S460MH	L_{cr}/400	388	453	484	513	530	550	301	401	502
		L_{cr}/600	441	476	507	536	551	569			
RR115/8	S460MH	L_{cr}/400	435	532	623	671	699	732	376	502	627
		L_{cr}/600	506	604	655	703	730	761			
RRs115/8	S550J2H	L_{cr}/400	435	532	659	766	807	851	450	600	749
		L_{cr}/600	506	614	734	803	844	890			
RRs125/6.3	S550J2H	L_{cr}/400	464	567	631	676	701	731	402	536	670
		L_{cr}/600	535	614	662	706	730	757			
RR140/8	S460MH	L_{cr}/400	613	751	808	861	892	928	466	621	777
		L_{cr}/600	711	791	848	900	930	962			
RRs140/8	S550J2H	L_{cr}/400	613	751	915	991	1036	1088	557	743	929
		L_{cr}/600	711	863	961	1038	1082	1131			
RR140/10	S460MH	L_{cr}/400	675	827	999	1080	1128	1185	574	765	956
		L_{cr}/600	787	956	1051	1133	1180	1232			
RRs140/10	S550J2H	L_{cr}/400	675	827	1024	1228	1298	1380	686	915	1143
		L_{cr}/600	787	956	1171	1289	1359	1438			
RR170/10	S460MH	L_{cr}/400	929	1138	1274	1364	1417	1479	700	934	1167
		L_{cr}/600	1079	1242	1339	1428	1478	1535			
RRs170/10	S550J2H	L_{cr}/400	929	1138	1407	1564	1641	1730	837	1116	1396
		L_{cr}/600	1079	1310	1509	1640	1715	1799			
RR170/12.5	S460MH	L_{cr}/400	1016	1245	1542	1682	1762	1855	862	1149	1436
		L_{cr}/600	1185	1441	1630	1765	1844	1932			
RR220/10	S460MH	L_{cr}/400	1451	1663	1773	1876	1936	2005	925	1233	1542
		L_{cr}/600	1623	1748	1858	1957	2012	2075			
RRs220/10	S550J2H	L_{cr}/400	1451	1774	2024	2172	2259	2358	1106	1475	1843
		L_{cr}/600	1675	1962	2123	2271	2353	2444			
RR220/12.5	S460MH	L_{cr}/400	1594	1952	2187	2343	2434	2540	1142	1523	1904
		L_{cr}/600	1850	2132	2299	2452	2539	2636			
RRs220/12.5	S550J2H	L_{cr}/400	1594	1952	2414	2687	2819	2971	1366	1821	2277
		L_{cr}/600	1850	2248	2590	2816	2946	3091			
RR270/10	S460MH	L_{cr}/400	2050	2188	2312	2426	2492	2569	1163	1551	1939
		L_{cr}/600	2156	2297	2417	2542	2583	2651			
	S550J2H	L_{cr}/400	2055	2192	2313	2423	2487	2561	1391	1855	2319
		L_{cr}/600	2160	2297	2415	2517	2575	2640			
RR270/12.5	S460MH	L_{cr}/400	2308	2696	2881	3055	3156	3273	1441	1921	2401
		L_{cr}/600	2626	2835	3022	3188	3282	3387			
	S550J2H	L_{cr}/400	2308	2823	3282	3532	3678	3845	1722	2296	2871
		L_{cr}/600	2667	3174	3444	3693	3834	3988			
RR320/10	S460MH	L_{cr}/400	2221	2325	2416	2499	2548	2606	1389	1852	2314
		L_{cr}/600	2328	2427	2511	2586	2629	2678			
	S550J2H	L_{cr}/400	2508	2651	2775	2888	2954	3030	1660	2214	2767
		L_{cr}/600	2632	2772	2889	2992	3050	3116			
RR320/12.5	S460MH	L_{cr}/400	3069	3343	3546	3734	3843	3969	1722	2296	2870
		L_{cr}/600	3281	3512	3712	3889	3989	4101			
	S550J2H	L_{cr}/400	3069	3375	3579	3766	3875	3999	2059	2745	3432
		L_{cr}/600	3310	3542	3742	3919	4017	4128			

Table 23. Design values for structural compressive resistance of RD and RDs piles.

			Dimensioned as a steel structure												Dimensioned as a composite structure C30/37					
			Corrosion allowance 1.2 mm						Corrosion allowance 2.0 mm						Corrosion allowance 2.0 mm					
Pile	**Steel grade**	δ_0	Shear strength c_{uk} [kPa]						Shear strength c_{uk} [kPa]						Shear strength c_{uk} [kPa]					
			5	**7**	**10**	**15**	**20**	**50**	**5**	**7**	**10**	**15**	**20**	**50**	**5**	**7**	**10**	**15**	**20**	**50**
RD90/6.3	S460	$L_{cr}/400$	274	336	406	439	458	504	251	308	350	376	391	425	259	317	383	412	429	468
		$L_{cr}/600$	320	389	427	460	479	521	292	341	368	393	408	439	301	366	401	431	448	483
RD115/6.3	S460	$L_{cr}/400$	421	516	562	600	622	673	388	453	484	513	530	569	404	494	556	594	615	663
		$L_{cr}/600$	489	550	590	628	649	694	441	476	507	536	551	586	467	542	583	619	639	682
RDs115/6.3	S550	$L_{cr}/400$	421	516	636	690	722	795	388	474	551	593	618	673	404	494	586	622	642	684
		$L_{cr}/600$	489	593	668	723	754	821	448	533	579	620	644	694	467	568	610	645	663	699
RD115/8	S460	$L_{cr}/400$	464	568	694	751	786	865	435	532	623	671	699	764	446	546	672	726	758	830
		$L_{cr}/600$	541	657	730	788	822	895	506	604	655	703	730	789	520	632	706	760	791	857
RDs115/8	S550	$L_{cr}/400$	464	568	703	854	903	1017	435	532	659	766	807	900	446	546	676	758	789	855
		$L_{cr}/600$	541	657	807	896	946	1054	506	614	734	803	844	931	520	632	735	789	819	878
RDs125/6.3	S550	$L_{cr}/400$	504	616	729	787	821	896	464	567	631	676	701	759	486	594	687	726	748	793
		$L_{cr}/600$	582	704	766	823	856	925	535	614	662	706	730	782	561	669	714	751	771	809
RD140/8	S460	$L_{cr}/400$	653	799	901	965	1004	1090	613	751	808	861	892	964	635	777	905	969	1007	1091
		$L_{cr}/600$	758	877	947	1011	1047	1125	711	791	848	900	930	993	737	878	948	1012	1048	1124
RDs140/8	S550	$L_{cr}/400$	653	799	988	1107	1162	1286	613	751	915	991	1036	1138	635	777	951	1015	1050	1125
		$L_{cr}/600$	758	921	1066	1160	1213	1330	711	863	961	1038	1082	1175	737	895	991	1053	1086	1152
RD140/10	S460	$L_{cr}/400$	710	870	1078	1177	1233	1362	675	827	999	1080	1128	1239	691	847	1049	1155	1208	1328
		$L_{cr}/600$	829	1007	1140	1236	1291	1410	787	956	1051	1133	1180	1281	806	980	1119	1210	1261	1372
RDs140/10	S550	$L_{cr}/400$	710	870	1078	1334	1414	1600	675	827	1024	1228	1298	1458	691	847	1049	1204	1256	1368
		$L_{cr}/600$	829	1007	1237	1401	1482	1660	787	956	1171	1289	1359	1511	806	980	1164	1255	1305	1406
RD170/10	S460	$L_{cr}/400$	975	1194	1384	1488	1549	1690	929	1138	1274	1364	1417	1538	958	1173	1401	1507	1569	1707
		$L_{cr}/600$	1134	1343	1455	1559	1618	1746	1079	1242	1339	1428	1478	1587	1114	1353	1470	1575	1635	1760
RDs170/10	S550	$L_{cr}/400$	975	1194	1477	1700	1789	1992	929	1138	1407	1564	1641	1815	958	1173	1451	1575	1635	1760
		$L_{cr}/600$	1134	1377	1632	1784	1872	2061	1079	1310	1509	1640	1715	1876	1114	1353	1533	1637	1693	1805
RD170/12.5	S460	$L_{cr}/400$	1057	1295	1604	1797	1887	2094	1016	1245	1542	1682	1762	1946	1037	1271	1575	1777	1863	2058
		$L_{cr}/600$	1234	1501	1736	1887	1976	2169	1185	1441	1630	1765	1844	2014	1211	1473	1716	1863	1948	2128
RDs170/12.5	S550	$L_{cr}/400$	1057	1295	1604	2031	2158	2457	1016	1245	1542	1906	2021	2286	1037	1271	1575	1851	1936	2119
		$L_{cr}/600$	1234	1501	1844	2133	2263	2551	1185	1441	1770	2002	2118	2372	1211	1473	1783	1931	2014	2180
RD220/10	S460	$L_{cr}/400$	1519	1802	1929	2048	2118	2277	1451	1663	1773	1876	1936	2073	1513	1851	2060	2195	2272	2443
		$L_{cr}/600$	1751	1895	2023	2139	2204	2346	1623	1748	1858	1957	2012	2133	1751	2010	2157	2287	2360	2512
RDs220/10	S550	$L_{cr}/400$	1519	1858	2193	2367	2466	2693	1451	1774	2024	2172	2259	2453	1513	1851	2173	2303	2374	2523
		$L_{cr}/600$	1756	2117	2302	2474	2572	2778	1675	1962	2123	2271	2353	2529	1751	2111	2259	2384	2449	2578
RD220/12.5	S460	$L_{cr}/400$	1654	2026	2331	2505	2607	2841	1594	1952	2187	2343	2434	2642	1643	2012	2405	2587	2693	2932
		$L_{cr}/600$	1922	2265	2451	2624	2722	2934	1850	2132	2299	2452	2539	2727	1910	2321	2523	2704	2806	3022
RDs220/12.5	S550	$L_{cr}/400$	1654	2026	2506	2865	3013	3349	1594	1952	2414	2687	2819	3117	1643	2012	2489	2704	2806	3022
		$L_{cr}/600$	1922	2336	2752	3004	3151	3465	1850	2248	2590	2816	2946	3223	1910	2321	2632	2811	2906	3098
RD270/10	S460	$L_{cr}/400$	2188	2674	2518	2651	2728	2904	2050	2188	2312	2426	2492	2644	2211	2663	2844	3008	3102	3310
		$L_{cr}/600$	2332	2494	2635	2760	2831	2985	2156	2297	2417	2542	2583	2716	2548	2790	2970	3128	3214	3395
	S550	$L_{cr}/400$	2188	2674	2890	3082	3192	3441	2093	2485	2662	2827	2922	3135	2211	2702	3015	3169	3252	3424
		$L_{cr}/600$	2519	2820	3029	3216	3320	3542	2405	2608	2788	2947	3035	3224	2548	2948	3125	3268	3343	3490
RD270/12.5	S460	$L_{cr}/400$	2391	2867	3074	3268	3382	3641	2308	2696	2881	3055	3156	3387	2402	2939	3312	3533	3661	3945
		$L_{cr}/600$	2767	3016	3225	3414	3520	3751	2626	2835	3022	3188	3282	3487	2782	3226	3468	3685	3805	4057
	S550	$L_{cr}/400$	2391	2926	3491	3770	3934	4304	2308	2823	3282	3532	3687	4006	2402	2939	3489	3705	3823	4072
		$L_{cr}/600$	2767	3359	3665	3945	4101	4441	2667	3174	3444	3693	3834	4131	2782	3378	3630	3838	3947	4164
RD320/10	S460	$L_{cr}/400$	2750	2926	3082	3225	3308	3499	2540	2693	2827	2950	3021	3186	2966	3445	3661	3855	3965	4208
		$L_{cr}/600$	2892	3068	3218	3351	3425	3591	2669	2820	2949	3062	3125	3268	3354	3604	3817	4000	4100	4311
	S550	$L_{cr}/400$	2900	3334	3558	3765	3884	4152	2776	3080	3273	3451	3553	3783	2966	3624	3899	4075	4168	4362
		$L_{cr}/600$	3242	3499	3723	3921	4030	4266	3008	3421	3421	3589	3683	3884	3409	3827	4030	4191	4274	4438
RD320/12.5	S460	$L_{cr}/400$	3177	3559	3786	3997	4120	4400	3069	3343	3546	3734	3843	4093	3222	3944	4248	4507	4655	4983
		$L_{cr}/600$	3483	3740	3966	4166	4279	4526	3281	3512	3712	3889	3989	4208	3720	4157	4441	4691	4828	5117
	S550	$L_{cr}/400$	3177	3883	4331	4636	4813	5210	3069	3750	4068	4340	4497	4850	3222	3940	4492	4739	4872	5150
		$L_{cr}/600$	3663	4211	4542	4842	5010	5366	3533	3968	4264	4529	4677	4992	3720	4381	4663	4895	5016	5256

6. DESIGN OF PILE FOUNDATIONS

6.1 Attachment of piles to superstructure

The joint between a pile and the superstructure can be dimensioned as a hinge. The piles are cut so that the upper end of pile is embedded at least 50 mm inside the pile footing or concrete superstructure unless otherwise required by the structural design or attachment of piles. When joining a pile to the above concrete structure as mentioned, it is not necessary to fasten the bearing plate by welding to the pile pipe.

Short, under 3-metre long driven piles should always be attached rigidly to the superstructure. Depending on structure, longer piles may also be attached rigidly to the superstructure. RR75...RR/RD220 piles are attached rigidly to the superstructure when the upper end is embedded in the concrete at a depth of at least $2 \cdot d$, but not less than 200 mm. When empedding upper end of pile to concrete like descriped above, it's not necessary to connect bearing plate to pile by welding. When the upper end is attached directly to a steel superstructure, a rigid joint can be created by welding. Reinforced piles are usually attached to the superstructure by extending the internal reinforcements of the piles into the concrete structures. In rigid connection, the moment capacity of the upper end of pile must be verified.

The bearing plates presented in Table 16 can be used for axially compressed RR and RD piles.

6.2 Centre-to-centre distances between steel piles

The distances between piles are defined in design documents. Recommended minimum centre-to-centre distances for different pile diameters are presented in Table 24.

Table 24. Recommended minimum centre-to-centre spacing of SSAB's steel piles [mm] *according to PO-2016* [mm]*.*

Pile	min c/c [mm]
RR75	800
RR/RD90	800
RR/RD115	800
RRs/RDs125	800
RR/RD140	800
RR/RD170	800
RR/RD220	800
RR/RD270	800*
RR/RD320	850**
RR/RD400	1000
RR/RD500	1200
RR/RD600	1350
RR/RD700	1550
RR/RD800	1700
RR/RD900	1850
RR/RD1000	2050
RR/RD1200	2400

* According to PO-2016, the recommended minimum centre-to-centre distance 800 mm between RR/RD270 piles is valid up to a pile length of about 15 m. Thereafter, the minimum distance must be increased to 950 mm as pile length increases to 25 metres.

** correspondingly, the minimum centre-to-centre distance 850 mm between RR/RD320 piles is valid up to a pile length of about 10 m, after which the minimum centre-to-centre distance increases linearly to 1150 mm at a pile length of 25 m.

Smaller centre-to-centre distances than those presented in Table 24 may be used with caution with RD piles, if they can be installed straight or at the designed inclination and the piles bear securely on bedrock. When designing downward spreading pile groups, the upper ends of piles can be spaced closer than in the table.

In the case of intersecting end-bearing piles in a fine-grained soil layer close to ground level, a clearance equal to pile diameter can be considered sufficient, if the pile can be directed during installation so that it does not touch adjacent piles. In coarse-grained soil layers, especially with driven piles, the clearance must be considerably larger. Pile intersections should be located as close to ground level as possible. With large diameter RR piles the minimum distance between intersecting piles is determined by the equation:

$$e_r = 50\, l_r \geq e_i \qquad (3)$$

where
- e_r minimum distance between intersecting piles [mm]
- l_r depth of intersection [m]
- e_i shortest distance between parallel shaft surfaces = $300 + 0.7 \cdot d$ [mm]

6.3 Distance between side of pile footing and piles

The pile footing must be able to withstand the stresses from pile forces and there must be no risk of the side of the pile footing breaking off. Normally, the distance from the edge of the pile footing to the outer surface of the closest pile or the edge of the bearing plate must be at least half of the pile diameter or the length of the side of the bearing plate. The positional tolerances of a pile must be taken into account at the design stage.

6.4 Distances between piles and other structures

The minimum distances between piles and other structures are designed separately in each case considering the piling equipment, pile type, vibration caused by piling, compaction of soil, loosening or displacement of soil, and special requirements and restrictions posed by soil conditions and ambient structures.

If the only restricting factors are the piling equipment and available space, the minimum distance must be determined on the basis of the properties of used piling equipment and the site. Small diameter RR and RD piles can be installed quite close to an existing wall or footing line, etc. owing to the small-size installation equipment. However, without a closer analysis, it is not advisable to design piles in sizes RR/RD220 to RR/RD270 or smaller so that the distance between the pile edge and the structure is less than 200 to 300 mm (if there are no structures restricting piling, such as eaves, etc., above the piling level).

6.5 Pile inclinations

Raking piles can be used to increase the stability of the pile foundation as desired. However, stresses on the raking piles from possible deformations of soil layers must be taken into account.

The maximum deviation in pile positions from the vertical, or limit inclination, depends on used piling equipment and the structure of soil layers at the foundation. When RR piles are installed with equipment used also in precast concrete piling, or RD piles are installed with heavy piling equipment, both forward or backward tilting piles of this type may usually be installed to a maximum inclination of 3.5:1. With large diameter piles, especially (the mast) tilted forward, the maximum allowed inclination must be determined on the basis of the stability of the basic equipment, considering used pile length and bearing capacity of the subsoil separately in each case. When installing piles with light or medium-heavy equipment, small diameter RR and RD piles can be installed at a highly inclined angle, even horizontally, if the structure and stability of the installation equipment allow it. High inclinations usually require using short pile elements.

It is worthwhile looking into the properties of the installation equipment at the design stage, if the aim is to install piles at exceptional inclinations.

6.6. Allowed positional and angular deviations

Piles should be installed exactly in the planned position and at the planned angle. However, a pile must not be forced into its theoretical position during installation or thereafter.

The measurement accuracy of pile position before and after installation is 0.01 m, unless otherwise specified in the designs.

Unless otherwise required by structural requirements, detailed instructions on structures by the authorities, soil conditions, used piling equipment or a very deep cutting level, the following allowed positional deviations are used:

Small diameter RR, CSG-RR and RD piles (RR75– RR/RD320):

- individual vertical or raking pile, pile slab or bearing plate structure:
  $e \leq e_{max}$ = 0.10 m
- individual pile in a small pile group (4 to 8 piles): $e \leq e_{max}$ = 0.15 m, individual pile in a larger pile group: $e \leq e_{max}$ = 0.2 m, however, for the centre of gravity of the entire group $e \leq e_{max}$ = 0,05 m
- in pile foundations used in building construction $e \leq e_{max}$ = 0.15 m, in particularly exacting conditions, such as areas of pre-penetratable fills, relief drilling, etc., $e \leq e_{max}$ = 0.20 m
- for an individual pile in a pile row, $e \leq e_{max}$ = 0.15 m, however, for the centre of gravity of the entire row $e \leq e_{max}$ = 0.05 m in the direction perpendicular to the row (a pile row is defined as piles under an elongated pile footing when there is only a single pile in the cross direction of footing)
- for individual vertical or raking piles $i \leq i_{max}$ = 0.04 (0.04 m/m) in a group of parallel piles $i \leq i_{max}$ = 0.02 (0.02 m/m)
- the horizontal direction (horizontal projection) of inclined piles may differ at most 10° from the design direction.

At underpinning sites it is often necessary to use clearly deviating values.

Large diameter RR and RD piles (RR/RD400 to RR/RD1200):

- vertical and raking piles: horizontal position measured from the working level:
  $e \leq e_{max}$ = 0.10 m RR/RD400–RR/RD1000
  $e \leq e_{max}$ = 0.12 m RR/RD1200
- vertical and raking piles at an angle of $n \geq 15$ ($\Theta \geq 86°$): angular deviation
  $i \leq i_{max}$ = 0.02 (0.02 m/m)
- raking piles at an angle of $4 \leq n < 15$ ($76° \leq \Theta < 86°$): angular deviation
  $i \leq i_{max}$ = 0.04 (0.04 m/m)

RD piles, especially when using the concentric drilling method, easily achieve tolerances stricter than the above ones. Stricter tolerances are recommended for RD piles if stricter building tolerances are called for by the structure and loads, and the soil and installation conditions allow them. The attainment of stricter tolerances requires special care in both the in-place measurement and installation work.

From the viewpoint of the installation work, however, it is not advisable without justification to apply stricter tolerances to RD piles than those presented below:

- vertical and raking piles: horizontal position measured from the working level:
  $e \leq e_{max}$ = 0.025 m
- vertical or raking piles at an angle of $n \geq 15$ ($\Theta \geq 86°$) angular deviation:
  $i \leq i_{max}$ = 0.015 (0.015 m/m)
- raking piles at an angle of $4 \leq n < 15$ ($76° \leq \Theta < 86°$) angular deviation:
  $i \leq i_{max}$ = 0.025 (0.025 m/m)

In the case of Combi-wall and RD pile wall structures it is often practical to aim at tolerances considerably stricter than the above general positional and verticality tolerances. Used tolerances must be determined case by case and at least a preliminary plan of measures to be taken to attain the tight tolerances must be made already at the design stage. Recommended tolerances for these structures are presented in design and installation manual for RD pile wall.

Combi-wall structures are usually equipped with sufficiently sturdy templates made of steel beams or the like, which allow accurate positioning of the piles. In RD pile wall structures, the starting pile of the wall structure in practice determines the direction and inclination of the entire wall, which means that the installation of the starting pile(s) and used tolerances must be planned with great care. Procedures and important things during installation of these structures are presented in design and installation manual for RD pile wall.

Positional and angular deviations of piles due to installation are taken into account in the design of the pile foundation. After installation, the actual positions and inclinations of the piles are measured. If the positional tolerances allowed by the design are exceeded, the possible overloading of each structural members must be determined and necessary measures taken.

6.7 Impact of piling on previously installed piles, other foundation structures and immediate surroundings

The geotechnical works of the building site, piling included, are designed and executed so that they do not decrease the resistance of previously installed piles or cause damage or nuisance to the immediate surroundings of the site. If there are structures susceptible to damage in the immediate surroundings of the site, they must be charted to a sufficient extent in connection with geotechnical investigations, or in any case before piling. If necessary, the condition of nearby structures must be established through inspections.

The environmental impacts of driven and drilled piles can be estimated as described in PO-2016, Part 2, Sec. 4.7. The selection of pile type, piling method and piling equipment can have a significant effect on the environmental impacts.

Small-diameter driven RR piles displace very little soil in relation to their bearing capacity. Therefore, the increase in pore water pressure and lateral displacements and heave of soil usually remain very small. Owing to their small cross-sectional diameter, the piles can be driven below ground water level in loose silty and sandy soils with low impact energy, whereby the compaction of compacting soil layers due to piling remains minor. Correspondingly, penetration of dense soil layers that cause vibration can be achieved with relatively low impact energy, so that the vibration from piling is minor. Especially when using light piling equipment and pile drivers, RR piles can usually be installed safely very close to existing structures. The environmental impacts of pile driving may also be minimised by selecting piling class PTL3 and RRs piles.

If installed according to the installation instructions, RD piles, especially small diameter RD piles, do not displace soil or remove extra soil, which keeps the environmental impacts of piling, such as soil displacement and compaction, vibration, and increase in pore water pressure, very low. With large RD piles (≥RD400), due to the higher consumption of flushing agent (usually compressed air) and larger DTH hammer equipment, piling can have minor environmental impacts, which must be considered in design and implementation when RD piles are installed in the immediate vicinity of existing structures.

The jacked RR piles used in underpinning usually cause the least environmental impacts, whose installation also causes very little noise.

In soft subsoils, the movement of heavy (>40 to 60 t) piling equipment may cause more vibration than the pile installation itself.

7. PILING

7.1 Material needed for piling: working plan and quality plan

The material needed for piling, the working plan and quality plan, are presented in PO-2016, Ch. 2, Sec. 5.1.

7.2 Storage, handling, inspection and erection of steel piles

The storage and handling of piles on site are covered by a separate manual "Piles and pile accessories, recommendations for safe handling for the customer" (www.ssab.com/infra).

Inspection of delivered piles and their accessories takes place immediately after the delivery arrives on site.
A visual inspection is made to ensure that the shipment corresponds to the order and consignment note. The steel grade and dimensions of piles are verified from product descriptions and markings on the pile pipes. Pile elements and accessories must correspond to the products specified in designs. A faulty or wrong product must not be installed.

More detailed instructions for the handling of threaded RDT pile elements and threaded RDT sleeves are presented in Sec. 7.4.4.

Piles and their accessories are to be inspected once more before installation. The pre-installation inspection ensures that the piles have not been damaged during handling and storage on site.

Pile elements and pile pipes are usually erected by a lifting cable or the like attached near the head of the pile. Special care must be taken during erection to ensure, for example, that the lifting equipment/chain stays attached to the pile. It is recommended that pile erection is performed with the piling equipment positioned at the pile during erection so that it will not need to be moved except for minor adjustment when the pile stands upright in the piling equipment.

The stress from curvature caused by the dead weight of the steel pile is never a critical factor when lifting RR or RD micropiles. With large diameter piles, the length limit for piles that can be lifted from the head without closer analysis is 20 metres. The erection of longer piles must be planned case by case, considering pile dimensions. The stability of the piling rig must be considered in erection, and the weight and reach limitations and instructions for the rig must be taken into account in lifting.

7.3 Installation of RR piles

7.3.1 Piling equipment

7.3.1.1 General

General requirements for the piling equipment are presented in PO-2016, Sec. 5.4.2.1.

Pile driving equipment suitable for the installation of RR piles can be divided into the following main categories:

- drop and hydraulic hammers
- hydraulic rams and pneumatic hammers
- other driving equipment
- hydraulic jacks

In the case of piling classes PTL2 and PTL3, the manufacturer, importer or user of the pile driver must clarify the essential factors affecting piling, such as overall driving efficiency, suitable helmet, hammer cushion and pile cushion for pile driving, and the effect of helmet and cushions on the stresses transmitted to the pile. The above factors can be established, for example, by stress wave analyses, and it is recommended that piling contractors file and, if necessary, analyse their stress wave measurement results. The information is revised in connection with major changes to the driving equipment or when installing new pile types with the equipment in question.

When RR piles are installed with driving equipment suspended from a crane, the pile must be supported adequately by other support structures. The entire piling equipment must be supported and assembled so that it does not sway during piling.

7.3.1.2 Drop and hydraulic hammers

The drop height of a drop hammer can usually be selected freely considering equipment specific limitations. The suitable masses for drop hammers and hydraulic rams depend on used pile size and soil conditions.
A heavy hammer may be advantageous when driving RR micropiles into dense soil, but it also increases the risk of pile bending.

Recommended minimum and maximum masses of the ram blocks of the drop and hydraulic hammers are presented in Table 25.

Table 25. Recommended minimum and maximum masses of the ram blocks of the drop and hydraulic hammers used in the installation of RR piles

	Pile weight	**Ram block [kg]**	
Pile	**[kg/m]**	**min**	**max**
RR75	10.8	300	1000
RR90	12.8	350	1500
RR115/6.3	16.8	500	1500
RR115/8	21.0	500	2000
RRs125/6.3	18.7	500	2000
RR140/8	26.0	500	3000
RR140/10	32.0	500	3000
RR170/10	39.0	1000	4000
RR170/12.5	48.0	1000	5000
RR220/10	51.6	1500	5000
RR220/12.5	63.7	1500	6000
RR270/10	64.9	1500	6000
RR270/12.5	80.3	2000	8000
RR320/10	77.4	2000	8000
RR320/12.5	96.0	2000	9000
RR400 (10...12.5)	97.8...121.4	3000	9000
RR500 (10...14.2)	122.8...172.9	3000	12000
RR600 (10...18)	148.0...262.8	4000	-
RR700 (10...20)	172.9...340.8	4000	-
RR800 (10...20)	198.0...391.1	4000	-
RR900 (10...20)	222.9...440.9	4000	-
RR1000 (10...20)	248.1...491.3	4000	-
RR1200 (10...20)	298.4...591.9	4000	-

Pile cushion is usually not needed when driving RR piles. If a pile cushion is not used, a dolly made of a thick steel plate is used between the hammer and the pile.

The head of the pile is adjusted inside the lower part of the helmet to ensure that the impact is transmitted centrically to the pile.

If the used lower part of the helmet is the square shaped ”box” used with precast concrete piles, it is recommended that a steel adapter be always used on the pile head in piling class PTL3. The top of the adapter should be as close in size to the ”box” of the helmet as possible, and the bottom should ”sit” quite snugly inside or outside the pile pipe. The use of an adapter is recommended in piling class PTL2. In PTL2, when installing RR220 piles with a ”box” measuring 250x250, RR270 piles with a ”box” measuring 300x300, or RR320 piles with a ”box” measuring 350x350, sufficiently centric blows can also be achieved without an adapter.

When installing a pile with an external splice sleeve at the top, it's recommended to use an adapter piece that passes the stroke to the pile pipe trough the sleeve. By decision of installation crew, the embedding of pile in soft ground layers may also be done by striking directly to sleeve if it does not cause damages to the sleeve or its weld. In dense ground layers and during the end-of-driving, an adapter piece must be used to pass the stroke to the pile pipe through the sleeve.

In Finnish soil conditions large diameter end-bearing piles can usually be installed to a sufficient penetration depth with relatively small hammers. Thick friction soil and moraine layers require a sufficiently high impact energy for the pile to penetrate effectively. In preliminary analyses it can be estimated that when using the hammers and pile dimensions presented in Table 26, the installation equipment has sufficient impact energy and the hammer is able to mobilise sufficient static geotechnical resistance in PTL2 and PTL3 during loading tests. Actual mobilised resistances depend largely on pile size, pile length and soil conditions. Sufficient static resistance can be achieved more easily with short piles securely bearing on bedrock than with long piles bearing on moraine layers.

It is often practical to use a smaller hammer / lower impact energy to drive large diameter piles and perform the actual dynamic load test using a pile driving equipment of higher impact energy.

Table 26. Combination of hammer weight [t] – max. pile size that is normally able to mobilise sufficient static resistance in PTL2/PTL3.

Hammer [t]	max. RR pile
5	RR400...RR500
7	RR500...RR700
9	RR700...RR800

7.3.1.3 Hydraulic rams

Hydraulic rams are rapid percussion pile drivers extremely well suited for installing RR micropiles. They are also suitable for the installation of larger piles, if full geotechnical compressive resistance is not required of the piles. The advantages of hydraulic rams in the installation of RR piles include high blow rate and impact force, which makes for quick pile installation; piles can in most cases be installed very straight, and the installation equipment is light and mountable on many kinds of basic machines.

The suitability of different hammer types for different pile sizes and lengths has been determined by simulations based on the stress wave theory. Pile sizes and lengths suitable for different rams are presented in the end-of-driving instructions based on the above analysis.

Hydraulic rams are effective in installing micropiles, and experience has shown that in certain conditions piles driven by hydraulic rams penetrate deeper than dynamic penetration test. Even if simulation does not indicate sufficient mobilised static geotechnical resistance due to the small settlement caused by a single blow, the pile toe often bears reliably on bedrock or very dense basal moraine. In conditions clearly suitable for end-bearing piles, it is therefore often possible to achieve sufficient reliability by a hammer/pile combination where the calculated mobilised static geotechnical resistance does not meet the end-of-driving criteria. In such a case, the geotechnical resistance of piles must be ensured by dynamic load tests (PDA measurements) or analyses based on pile driving formulas. A pile driving equipment of higher impact energy, such as a drop hammer or a hydraulic hammer, must be used in the load tests.

To centre the blow and protect the pile head, a steel adapter must be used between the pile and the tool of the hydraulic ram. (Figure 12)

Ensuring that the impact is aligned with the pile in piling class PTL3 requires use of piling equipment where the hydraulic ram moves along a piling mast. This driving mode is also recommended for other piling classes.

Figure 12. Example of an adapter between the striker of the hydraulic ram and the pile during impact.

7.3.1.4 Pneumatic hammers

Pneumatic hammers have a slightly lower blow rate than hydraulic rams. The suitability of different hammer types for different pile sizes and lengths has been determined by simulations based on the stress wave theory. Based on the above analysis, the end-of-driving instructions present pile sizes and lengths suitable for different hammers. On the basis of simulations, when using pneumatic hammers slightly underpowered for the pile load, geotechnical resistance can be ensured the same way as with hydraulic rams.

The bottom of the pneumatic hammer must be shaped for centric blows, or an adapter must be used. Ensuring that the impact is aligned with the pile in piling class PTL3 requires the use of piling equipment, where the pneumatic hammer moves along a mast. This driving mode is also recommended for other piling classes.

The true effectiveness of pneumatic hammers depends on operating conditions and wear of the equipment.

7.3.1.5 Hydraulic jacks

At foundation underpinning sites, jacked RR-piles are installed by hydraulic jacks. The installation equipment and jacking method used must allow safe compression of piles to the designed compression force without damage to nearby structures. The compression force indicator of the installation equipment must enable reliable measurement of the compression force.

7.3.1.6 Vibrators

The use of a vibrator in the installation of RR piles may be advantageous if the piles are installed to preset depths as, for instance, in the case of the pile foundations of noise barriers. The recommended vibrator frequency is over 25 Hz. The vibrator may be attached either to the pile head or the middle of the pile shaft. Pile penetration can be improved by pulling or pressing the pile downward. The suitability and selection of a vibrator for different pile sizes depends on soil conditions as well as pile length (mass). In soil conditions where the coarse-grained soil layers on top of the bedrock are stone-free, not especially dense, and relatively thin, RR piles can be installed quite reliably down to bedrock using a suitable vibrator. A vibrator may also be used to drive piles in other soil conditions, for example, to the top of a load-bearing moraine layer, after which the final blows are delivered by another pile driver, so that mechanical splices also tighten.

When installing piles with vibrators, the potential disturbance of the surrounding soil due to vibration should be taken into account. In some situations disturbance can lead to considerable large deviations in pile positioning. Vibrators also cause large fatigue loads on the pile to be installed. Fatigue load can cause pile damage and breakage during installation.

If significant vertical loads have been designed for piles to be installed by vibrators, the end-of-driving criterias must be ensured by control blows or load tests using other pile driving equipment. Control blows are also necessary when installing RR pile elements with mechanical splices with vibrators. The splices may remain loose without being subjected to a sufficiently high compressive force during the installation. In piling class PTL1 with clear and sufficiently well-known soil conditions, sufficient geotechnical resistance can be assumed if pile lengths and soil survey results support each other.

The use of vibrators in the installation of steel piles has been discussed in more detail, for example, in publication *Pålkommissionen, Vibratorers användningsmöjligheter vid drivning av pålar och spont, Rapport 99. Linköping 2000 (in Swedish).*

7.3.2 Start of installation

The pile is placed exactly in the designed position, and its straightness or inclination is checked, for example, by a bubble level or the inclinometer of in the piling equipment. Blows are directed centrically to the pile head in line with the longitudinal axis of the pile. The instructions of Sec. 7.3.1 for different piling equipment are followed in centring the blows. The position and inclination of the pile are checked in the early stage of installation when the pile tip has penetrated a small distance into the soil. If the positional deviation is estimated or measured to be too big, the pile is extracted and positioned again. Straightening of a pile that deviates slightly from the design inclination may be attempted by effecting minor changes to the inclination of the piling mast at the early stage of installation.

7.3.3 Penetration blows and allowed driving stresses

The impact energy used in soft soil layers is such that it causes moderate settlement per blow (about 100 mm), whereby the risk of the mechanical splices of micropiles coming apart can be avoided.

Suitable impact energy and blow rate, depending on resistance, are applied in penetration blows to ensure effective pile penetration.

Impact stresses during pile installation may not exceed 90 % of the yield strength of steel. The end-of-driving instructions present the maximum drop heights for drop hammers and hydraulic hammers for different pile sizes (up to RR400) and pile lengths (maximum specified drop height values in PTL3), which ensure that impact stresses do not exceed 90 %. This 90 % limit can be exceeded, if the stress levels in pile are measured during driving with PDA equipment. In these cases the stress level can even exceed the yield strength by 8 %. If a pile encounters a big stone before the final blows, it is recommended to use a slightly smaller drop heights than the table values (about 0.8-fold) as the maximum drop height for penetrating the stone to ensure that the risk of exceeding the allowed impact stresses does not become too high.

With hydraulic rams and pneumatic hammers, the impact stresses during installation may approach or exceed the 90 % limit in the case of hammer/pile combinations, where an efficiency value less than 80 % has been indicated in the end-of-driving graphs, or the impact energy of the hammer is too high and the penetration of the pile stops abruptly, for example, when the pile encounters a big stone. There, it is recommended to decrease the impact force of the hammer. The end-of-driving instructions present the smallest pile size recommended to be installed with each hammer. If a hammer is used to install piles smaller than the recommended pile size, impact force must be limited below the maximum.

When installing raking piles, it should be noted that the impact energy transmitted to the pile may be considerably lower than with vertical piles.

With large diameter piles and pile driving equipment/pile combinations that have not been analysed earlier, driving stresses may be evaluated by simulations based on the stress wave theory.

The magnitude of driving stresses and the centricity of the blow can be best determined by dynamic load tests.

If the cutting level of the pile is below ground or water level, a follower aligned with the longitudinal axis of the pile can be installed between the pile driver helmet and pile head. The follower pile should have about the same impedance as the actual pile, in other words, the follower should be a steel pipe of a steel cross section equal or almost equal (+/- 20 %) to that of the actual pile. The follower must be guided well and sit tightly on the end of the pile.

7.3.4 Additional installation instructions and splicing of RR75 to RR220 piles

The driving of RR75 to RR220 piles is usually started with an unspliced pile element, for example, a piece cut-off earlier. Before installation a shoe (bottom plate or rock shoe) is attached to the bottom of the pile, for example, by using a sledge-hammer. The hardened dowel of the rock shoe must not be hit due to the risk of chipping. The shoe has a machined groove and the dowel is positioned so that the groove coincides with the internal burr of the pile pipe. A friction shoe must be attached tightly enough to the pile pipe so that it cannot be loosened by tensile stress during the impact. The final “tightening” of the shoe occurs during the end-of-driving. It must be ensured that the shoe is aligned with the pile pipe during attachment.

If the piles have inadequate lateral support, the risk of buckling during installation is taken into account, for example, by selecting suitable installation equipment and element length for the pile.

The external splice sleeve of an RR pile can be either at the top or bottom of the pile element. While installing the pile with splice sleeve upwards, it's recommended to use adapter that transmits the blow past the splice sleeve to the pile pipe. While penetrating through soft soil layers, it's up to rig operators decision whether to use adapter or not. If adapter is not used, the splice sleeve or its fastening weld must not get damaged. During driving in dense soil layers and during end-of-driving blows the use of appropriate adapter is required.

Before pile splicing, the condition of the upper end of the pile is inspected and a damaged part is repaired or removed.

7.3.5 Additional instructions for the installation of RR270 to RR1200 piles

The pile must be supported at the beginning of driving so that it stays in the designed position and inclination. While the driving is under way, the pile support system must guide the pile so that it is continuously supported at the cutting level. If adequate support to the upper end of the pile is unreasonably hard to provide, the position and inclination of the upper end must be monitored during piling. If the pile is found to deviate from the designed position or inclination, an effort must be made to correct them. If the pile tip encounters a stone or boulder in the subsoil and consequently tends to change direction, it must be possible to relax the guidance so that the pile can circumvent obstacles without curving. If guidance needs to be relaxed more than the tolerances set for pile position and inclination allow, the structural dimensioning of the pile foundation must be revised.

RR270 to RR1200 piles are spliced by welding according to Sec. 7.5. Before splicing, the condition of the upper end of the pile is inspected and a damaged part is repaired or removed.

When large diameter piles with a closed shoe are installed in a water body or below ground water level, they are subject to a buoyancy force, which may exceed the weight of the pile and the resistance due to skin friction during an interruption in driving in cohesion soils or loose friction soils. Then, the buoyancy force may make the pile rise or hinder its penetration. A simple solution to that problem is to fill the piles partly or fully with water to achieve sufficient counterweight. The magnitude of the buoyancy force increases with increasing pile diameter (and decreasing wall thickness), and it is recommended that the buoyancy be taken into account already at the design stage starting from about pile size RR800.

When specifying pile order lengths, it should be taken into account that a “length” of $2 \cdot d$ at the upper end of the pile must be reserved for PDA measurement.

7.3.6 Additional instructions for rock shoes with hollow dowel

When using large diameter piles with hollow dowel rock shoes, the hole in dowel must be filled with concrete before installation to prevent the hole from contracting. After installation, the hole is drilled open for example to install an anchor bar.

In the installation, it is recommended to use a sufficiently heavy drop weight to keep the required drop height moderate. In addition, it is recommended to measure the impact stresses from the first piles during their installation with dynamic load testing equipment (PDA) to ensure that no harmful stresses are caused during the installation.

7.3.7 End of driving of an end-bearing pile with a drop or hydraulic hammer

The driving of an end-bearing pile can be stopped when the pile tip is close to the designed target level and the preset end-of-driving criteria are met. In piling class PTL2, the end-of-driving criteria presented in Appendix 3 can be used as end-of-driving criteria for pile sizes RR75 to RR400. Before the actual final blows, used drop height is gradually increased close to the values of the end-of-driving tables. The actual series of final blows involves dropping the hammer from the height specified in the tables where the permanent settlement caused by 10 blows is measured. When the permanent settlement due to 10 blows ≤ 10 mm, pile driving can be ended. **If the piles bear on a soil layer, at least 3 series of final blows must be delivered. In the case of piles bearing on bedrock with the rock point embedded in bedrock, one series of final blows is usually sufficient.** If the above-mentioned settlement is exceeded, pile driving is continued until the end-of-driving criterion is met.

No breaks in pile installation are allowed before the end of driving, and the final blows must be delivered without interruption. If the final blows need to be interrupted, and the geotechnical resistance of the piles cannot be considered sufficient on the basis of previous series of blows, penetration level or bearing capacity measurements on the site, the pile must be "detached" before proceeding with the final blows, for example, with three to five series of ten blows using an impact energy of about 50 to 70 % of the level required by the end-of-driving criterion.

When installing piles with a hardened rock dowel, the impact energy is set lower than that specified in the end-of-driving instructions when approaching the surface of bedrock. After reaching the bedrock surface, impact energy is gradually increased to the level specified in the end-of-driving instructions. In conditions of a relatively level bedrock surface and highly supportive friction soil and moraine layers on top of the bedrock, impact energy can be increased quite rapidly to the level needed for the final blows. If the tip tends to slip or the bedrock surface is inclined, impact energy must be reduced and the rock shoe dowel attached by driving it either fully or partly in bedrock using low impact energy, and then increasing the impact energy/drop height to the level specified in the end-of-driving criteria. With small piles, reliable attachment of the rock point requires at least 300 to 500 blows after the point has reached bedrock – with large piles even thousands of blows may be required. Similar principles are followed when driving RR400 to RR1200 piles with rock shoes and structural steel dowels into the surface of bedrock.

A pile extending to bedrock may bounce off the rock during driving causing the point to remain out of contact with the rock surface. In such a case, a few blows are delivered after the last series of final blows using a low drop height to ensure that the pile tip remains in contact with the bedrock.

In piling class PTL3, the end-of-driving criteria are determined on the basis of dynamic load tests according to Sec. 5.5.4.

7.3.8 End of driving of an end-bearing pile with a hydraulic ram or pneumatic hammer

The driving of an end-bearing pile can be stopped when the pile tip is close to the designed target level and the preset end-of-driving criteria are met. In piling class PTL2, the end-of-driving criteria presented in Appendix 3 can be used as end-of-driving criteria for pile sizes RR75 to RR170. Before the actual final blows, the used impact energy and blow rate are increased to the maximum values of the hammer if lower values were used during the driving. The actual series of final blows involves measuring the permanent settlement of the pile in 30 seconds while the pile is installed using the full impact force and blow rate of the hammer. Three series of final blows meeting the end-of-driving criteria are delivered. When RR piles clearly bear on bedrock, the duration of the series of final blows can be 10 seconds, which means that the settlement values of the end-of-driving tables must be divided by three. When the efficiency specified in the end-of-driving tables <80 %, final blows must not be delivered with full impact force due to impact stresses. Then the impact force must be as the specified efficiency.

No breaks in pile installation are allowed before the end of driving, and the final blows must be delivered without interruption. If the final blows need to be interrupted, and the geotechnical resistance of the pile cannot be considered sufficient on the basis of previous series of blows, penetration level or bearing capacity measurements done on site, the pile must be "detached" before proceeding with the final blows, for example, using a 60 second series of blows.

When installing RR piles with rock shoes, the impact force and blow rate are set lower than the maximum values for the hammer when approaching an inclined bedrock surface. After reaching the bedrock surface, impact force and blow rate are gradually increased to the maximum level for the hammer. If the tip tends to slip, impact force must be reduced, and the rock shoe dowel is attached partly or entirely into bedrock using a low impact force. Then, the impact force and blow rate are increased to the maximum level for the hammer. Reliable attachment of the rock shoe dowel to an inclined bedrock surface usually requires a series of blows of at least 1 to 2 minutes (at least 300 to 500 blows) at an impact force lower than the maximum. In piling class PTL3, the end-of-driving criteria are determined on the basis of dynamic load tests according to Sec. 5.5.4.

7.3.9 Preparation of end-of-driving instructions for large diameter piles in piling classes PTL3 and PTL2

In the beginning of piling, test piles are installed at spots highly representative of the soil conditions. One or more piles are usually installed where pile lengths are the longest or the soil conditions are most demanding in terms of driving. Test piles usually become part of the final structure, but separate test piles may be used, if necessary.

At the pile testing stage it is useful to drive piles with different end-of-driving criteria. Then, the "strictest" end-of-driving criteria used are the end-of-driving instructions or maximum drop heights presented in the end-of-driving tables for PTL3. Yet, it may advantageous to install piles, for example, using the end-of-driving criteria for PTL2. In the case of large diameter piles that have no general end-of-driving criteria, the criteria for final blows before load tests are defined case by case considering the pile driver, the pile (diameter, wall thickness and length) and soil conditions.

Dynamic load tests are made on the piles of the piling test stage. A special load test hammer is recommended for load tests on piles installed with hydraulic rams or pneumatic hammers in order to mobilise sufficient geotechnical resistance. If it is observed during piling that the piles bear on bedrock, the load tests can be made very soon or even immediately after pile installation. When piles bear on soil layers, the recommended interval between installation and testing is at least 24 hrs, preferably longer. The resistance measured from piles is generally the higher, the longer the waiting period. The target levels of dynamic load tests are defined at the design stage according to Sec. 5.5.4.

Suitable end-of-driving criteria for the site are determined on the basis of dynamic load tests. If pile lengths and soil conditions vary a lot, different end-of-driving criteria are assigned to different pile lengths and soil conditions.

7.3.10 Final blows on friction piles

In piling tests before or at the beginning of actual piling, friction piles are usually driven to the level designed on the basis of geotechnical investigations and static bearing capacity formulas and/or driving resistance based on a preliminary estimate or analysis based on the stress wave theory. Geotechnical resistance is measured by dynamic load tests using signal modelling (e.g. CAPWAP analysis). In coarse-grained soil layers skin friction usually develops in less than a week, but in silty soil it may take considerably longer. The target depth level and/or final driving resistance of piles are determined on the basis of the results of dynamic load tests.

7.3.11 Project-specific driving instructions

Project-specific driving instructions must always be prepared in piling class PTL3, and they must include at least the end-of-driving criteria and maximum drop heights for drop and hydraulic hammers. In the case of large diameter piles with no predefined end-of-driving criteria, project-specific driving instructions are also prepared in piling class PTL2. Project-specific driving instructions are recommended for friction piles also in PTL2. If necessary, detailed instructions are given for the following:

- drop height or impact energy used at different stages of driving
- instructions for filling closed top-driven piles with water
- detailed instructions on driving the dowel of a rock shoe into bedrock
- instructions on measures to be taken in the case of expected special events occurring during blowing
- instructions on reporting responsibilities and detailed instructions for a keeping piling record
- instructions on dynamic load tests (quantities, waiting periods, target levels)

7.3.12 Installation of jacked-RR piles

Jacked-RR piles are generally installed using hydraulic jacks. The installation equipment must conform to Ch. 2, Sec. 5.4.2.4 of PO-2016 and installation is to be done according to Ch. 2, Sec. 5.4.4.5 of PO-2016.

7.4. Installation of RD piles

7.4.1 Piling equipment and drilling methods

The general requirements for RD piling equipment are presented in Sec. 5.4.2.1 of PO-2016.

Top hammer or DTH hammer drilling equipment is used with RD piles. Both can use either the eccentric or concentric drilling method.

7.4.1.1 Top hammer-based equipment

The hammer drill of top hammer drilling equipment is generally pneumatic or hydraulic. The drilling equipment also includes a rotary unit and drill rods. Top hammer equipment can be used to drill piles up to diameter RD170.

The blow of the hammer drill generally strikes the drill rod inside the pile, which is being rotated simultaneously, and subsequently the casing shoe at the lower end of the RD pile. As a result, drilling capacity diminishes as pile length and the number of drill rod splices increase. The maximum pile length with top hammer equipment is generally about 30 m, although it is possible to install 50 m piles in thick, soft cohesion soil layers. With some top hammer equipment types, the RD pile pipe also takes part of the blow of the hammer drill.

7.4.1.2 DTH hammer-based equipment

The hammer drill of DTH hammer-based equipment is generally pneumatic or water powered. The equipment also includes a hydraulic rotary unit and drill rods.

A guide sleeve attaches the drill rods inside the RD pile to the DTH hammer, which, again, is attached to the drill bit by the shank adapter of the guide device above the pilot bit. Blows are transmitted via the guide device to the casing shoe, whereby the RD pile is "pulled" into the ground. The rotary unit above the head of the pile rotates the drill rods.

DTH hammer-based drilling equipment can drill large diameter piles up to RD1200 pile size. Pile length affects drilling capacity and installation speed minimally at practicable pile lengths.

Experience tells us that RD piles installed with a DTH hammer are generally somewhat straighter than RD piles installed with a top hammer.

7.4.1.3 The eccentric drilling method

The eccentric drilling method uses a pilot bit and an integrated eccentric reamer bit. The method is usable with both DTH hammer- and top hammer-based drilling equipment.

During drilling, an eccentric reamer bit enlarges the hole made by the pilot bit slightly bigger than the outside diameter of the RD pile. The RD pile is pulled into the ground with the drill bit and the casing shoe welded to the pile pipe.

The flushing agent transfers part of the soil to be removed to the surrounding soil. Part of the soil is flushed up along the outer surface of the RD pile to surface while part of it exits through the RD pile.

When the target depth is reached, the drill rods are rotated in the opposite direction to drilling whereby the drill bit's reamer portion closes and the drill bit, drill rods and any possible hammer drill can be removed from inside the RD pile. Drilling may be continued as rock drilling either using a separate rock bit or, in certain cases, with the same bit.

When using the eccentric drilling method and traditional single reamer bit equipment (ODEX or equivalent), the lower end of an RD pile installed in rock always ends up resting on a "shelf" whose dimensions are determined by the used drill bit. The impact of the rock shelf on the geotechnical resistance of a pile must be considered in pile design and inspection.

7.4.1.4 The concentric drilling method

In the concentric drilling method, three types of reamer bits are used. Reamer bit can be made of fixed or unattached ring bit. During drilling, the ring bit is locked onto the pilot bit. After drilling, the pilot bit is detached from the ring bit and extracted. Reamer bit can also be made of several concentric reamer wings. At the beginning of drilling, reamer wings are opened. After drilling, the drill rods are rotated in the opposite direction to drilling whereby the reamer wings close and whole drill bit can be removed from inside the RD pile. With reamer wings the casing shoe is not necessary part of load bearing structure of the RD pile.

Especially when using wing bits, but also when using ring bits, the compatibility of the tolerances of the pilot bit, the casing shoe and the pile pipe must be paid attention to. Particularly should be checked, if the tolerance between the head of the pilot bit and the casing shoe is suitable for the out of roundness tolerance of the pile pipe size in question.

When drilled piles are long or soil conditions are demanding with boulders or stony soils, casing shoe model has an effect on installation reliability. In such cases it has been found out that only surface hardened flat steel ring attached to inner surface of pile pipe is susceptible to deformations and also damaging during installation.

If necessary, drilling may be continued as rock drilling. There are also drill bit systems on the market that allow continuing rock drilling with the same pilot bit, so-called drill-through systems.

The method can be used with both DTH hammer- and top hammer-based drilling equipment. Experience tells us that the concentric drilling method generally produces straighter RD piles than eccentric methods based on a single reamer bit. In demanding conditions (boulders, stony soil) a concentric drilling with ring reamer is usually more reliable and faster than eccentric drilling or several concentric reamer wings.

7.4.2 Start of installation

The pile is placed exactly in the planned position and its verticality or inclination is checked, for example, by a bubble level. At sites where tight positional and inclination tolerances have been set for RD piles, special attention must be paid to measurements. In the initial phase of installation, when the tip of the pile has penetrated some distance into the ground, the inclination and position of the pile are checked. In case the positional deviation is estimated or measured to be too big, the pile is extracted and repositioned. Straightening of a pile deviating slightly from the planned inclination may be attempted by changing the inclination of the mast slightly in the early phase.

7.4.3 Drilling of RD piles

The instructions and recommendations of the hammer and drill bit manufacturer are followed in drilling RD piles. The casing shoe or integrated casing shoe/ring bit is generally welded to the RD pile pipe as per instructions of the manufacturer. The ring bit used with concentric drilling methods are attached to the casing shoe as per instructions of the manufacturer. The casing shoe and drill bit (ring bit) must be able to withstand the same loads during use as the pile. The manufacturer of the casing shoe and drill bit is liable for their strength according to Ch. 2, Sec. 3.8.4.3 of PO-2016.

During drilling, the pressure under the pilot bit due to the feed force is smaller than the flushing pressure, which means that the flushing holes of the bit remain open for the duration of the drilling. Should the flushing holes get clogged, their opening can be attempted by increasing flushing pressure to the maximum allowed and by altering rotation speed and feed force. Unclogging the holes may also be attempted by using air as the flushing agent instead of a liquid. If the unclogging of the flushing holes is unsuccessful, the pilot bit is extracted from the casing, the holes are cleared, and drilling is continued subsequently.

When an RD pile encounters a large stone, a boulder or bedrock, the feed force is kept low and rotation speed is increased. That reduces the risk of excessive lateral displacement, inclination and curvature of the pile.

If there is the risk of an RD pile encountering wood material in the soil during installation, it is recommended that special bits are used to speed up drilling and ensure successful penetration. Penetration is generally achieved using conventional drill bits with larger RD piles, but drilling speed decreases, and in the case of smaller RD piles, the risk of failing to drill through wood material is greater. Being able to drill through pieces of metal in the soil without significant risk of breaking the equipment is uncertain.

If an RD pile breaks or the drill bit or casing shoe gets damaged during drilling, so that driving is no longer possible, an attempt is made to extract the entire pile. If that is not possible, the pile is generally rejected. In foundation underpinning it is generally practical to make a separate assessment of the geotechnical or structural resistance of a damaged RD pile. The assessment can then be used as a basis for determining the capacity of the damaged RD pile to serve as a foundation pile.

The impacts of the installation on surrounding soil are monitored during drilling of RD piles, and any detrimental impacts are taken into consideration in subsequent installation.

Drilling through coarse-grained soil layers may cause loosening of compact soil layers or compaction of loose soil layers. The soil supporting the pile loosens if the volume of the removed soil material exceeds that of the RD pile.

Drilling in fine-grained soil layers may cause soil disturbance and an increase in pore water pressure. That results in lower soil layer strengths. Strength returns quite slowly and in the case of overconsolidated layers only partially.

Disturbance and an increase in pore water pressure can be prevented, for instance, by:
- selecting a drilling method suited to the ground conditions
- limiting used flushing pressure
- sequencing pile drilling or extending the duration of piling work.

Air, water, polymers or cement grout can be used as flushing agent in drilling. The volume of the soil material flushed out of the ground with the flushing agent should be slightly smaller, never larger, than the volume of the RD pile, while the amount of exiting water should equal the amount of water used in flushing.

The excess water and/or soil material rising up with the flushing agent may:
- disturb the soil layers around the pile
- result in a loss of strength in soil layers below the foundations of adjacent structures or ones to be underpinned
- damage unhardened mantles of near-by freshly installed grouted piles or other unhardened concretings in the ground.

The risk of soil material and/or water rising increases:
- in loose, even grained soil layers
- in soft, fine-grained soil layers
- in different soil layers
- when using DTH hammer-based drilling equipment and direct flushing beneath the water table.

If the air used as flushing agent does not exit the soil around the RD pile, drilling is suspended.

An RD pile is drilled to the design depth in bedrock. At the rock drilling phase, attention is paid to the colour of the drilling mud, the penetration rate and upflow of flushing water. It is possible to determine the type of the bedrock based on them.

When RD piles are extending to bedrock, it must be ensured that RD pile serving as a bearing structure bears reliably on rock after drilling has reached the target depth in rock. This has to be paid special attention with the eccentric drilling method and when using concentric reamer wings.

Control blows are imparted on the heads of RD piles bearing on rock always after extraction of the drill rods and the pilot bit. The RD pile pipe may lift off the surface of the bedrock when the pilot bit and drill rods are extracted from the RD pile. When using the eccentric drilling method and a drill bit based on a single reamer bit, or concentric drilling method with "wing bits", the RD pile always remains the height of the reamer portion of the pilot bit away from the bedrock.

Control blows can be imparted, for instance, by a hammer drill on the upper end of the RD pile.

7.4.4 Handling and installation of threaded RDT pile elements and threaded sleeves

7.4.4.1 Reception and inspection

Pile elements are delivered to site with the taper threads lightly oiled for protection and covered in plastic sheeting. The correspondence of the materials and dimensions of pile products to designs must be checked during reception.

It must also be checked that the threaded portions of pile elements have not been damaged in any way. Removal of protections from threaded sleeves and unnecessary cutting open of bundles of pile elements must be avoided before installation.

7.4.4.2 Thread handedness

The equipment used in pile installation determines the threading of piles. With DTH equipment, the direction of rotation of the drill bit is clockwise. Thus, the pile also tends to rotate clockwise during installation. In order to ensure that the splices hold, the threads of piles and sleeves must be left-handed. With top hammer equipment, the direction of rotation of the drill bit is counterclockwise meaning that the threads of piles and sleeves must correspondingly be right-handed.

Handedness can also be checked by turning the sleeve onto the pile. A right-hand thread tightens when turned clockwise. A left-hand thread tightens when turned counterclockwise.

7.4.4.3 Transport and storage

Pile elements are to be handled in transport and on site so that threads are not damaged. They can be stored outdoors, but are to be covered by tarpaulins to prevent rusting of threads. The tarpaulins should be placed so as to allow the bundles of piles to dry. It is recommended that threaded sleeves are stored indoors.

Careful handling and storage of pile products prevents damage to them and ensures smooth installation of splices.

7.4.4.4 Installation

Drill bits

It is recommended to ensure before drilling starts that the outside diameter of the used ring bit is compatible with the outside diameter of the splice sleeve. Table 27 shows drill bits recommended for normal soil conditions. In case the soil contains hard to penetrate obstacles like wood piles or concrete structures, special-purpose bits are to be used as deemed necessary.

Table 27. Dimensions, tightening torques and recommended reamer bit types and sizes of threaded sleeves.

Pile products							**Drill bits**			
RDT pile	**Splice sleeve** ***d*** **[mm]**	**Splice sleeve** ***L*** **[mm]**	**RDTs pile**	**Splice sleeve** ***d*** **[mm]**	**Splice sleeve** ***L*** **[mm]**	**Required tightening torque of splice, RD and RDs piles [kNm]**	**TerraRoc**	**Outside diameter of ring bit [mm]**	**Robit**	**Outside diameter of ring bit [mm]**
RDT90/6.3	101.6	160		-	-	**-**	Symmetrix P89/6.3-54 *	107	ROX+ XL 88.9/8 *	105
RDT115/6.3	126.9	160		-	-	**-**	Symmetrix P114/8-61 Symmetrix P114/10-75	132 129	DTH PRIME 114.3/10	135
RDT115/8	126.9	160	**RDTs115/8**	126.9	160	**1**	Symmetrix P114/8-61 Symmetrix P114/10-75	132 129		
			RDTs125/6.3	-	-	**-**	-	-	DTH-ROX+ XL 127/10	145
RDT140/8	152.4	160	**RDTs140/8**	152.4	160	**1**	Symmetrix P140/10-82 Symmetrix P140/10-100	158 160	DTH PRIME 139.7/10	161
RDT140/10	152.4	160	**RDTs140/10**	152.4	160	**1**	Symmetrix P140/10-82 Symmetrix P140/10-100	158 160		
RDT170/10	181.9	200	**RDTs170/10**	181.9	200	**1**	Symmetrix P168/12.7-103 Symmetrix P168/12.7-125	188 190	DTH PRIME 168.3/12.7	191
RDT170/12.5	181.9	200	**RDTs170/12.5**	181.9	200	**1**	Symmetrix P168/12.7-103 Symmetrix P168/12.7-125	188 190		
RDT220/10	234.9	200	**RDTs220/10**	234.9	200	**3**	Symmetrix P219/12.7-146 Symmetrix P219/12.7-171	240 242	DTH PRIME 219.1/12.7	241
RDT220/12.5	234.9	200	**RDTs220/12.5**	234.9	200	**3**	Symmetrix P219/12.7-146 Symmetrix P219/12.7-171	240 242		
RDT270/10	292.0	245	**RDTs270/10**	292.0	245	**3**	Symmetrix P273/12.7-227	302	DTH PRIME 273/12.7	303
RDT270/12.5	292.0	245	**RDTs270/12.5**	292.0	245	**3**				
RDT320/10	343.0	245	**RDTs320/10**	343.0	245	**3**	Symmetrix P324/12.7-273	353	DTH PRIME 323.9/12.7	350
RDT320/12.5	343.0	245	**RDTs320/12.5**	343.0	245	**3**				

Note: All ring bits are for DTH hammer equipment except those marked with an asterisk (*), which are meant for top hammer drilling equipment. When using a DTH hammer, the threads of the pile pipe and the sleeve are left-handed, but right-handed when a top hammer is used.

During the manufacture of longitudinally welded pipes, burr forms on their interior surface. Removal of the burr is generally unnecessary when using the most common drill bits, but the burr should be considered when choosing the pilot bit. The internal burr can be removed by special order during the manufacture of a pipe pile.

Protection of threads

Care must be taken not to damage the threads while raising a pile element upright. Light pile elements may be raised upright without mechanical protection of the ends. It is recommended to protect heavier elements, for instance, by a protective cap or sleeve of plastic or metal. The protection may be of the screw-on type or one that is locked mechanically onto the element.

Cleaning and lubrication

Before screwing the sleeve into place, it must be ensured that the end of the pile element and the threads in the sleeve are clean and undamaged. The threads are to be cleaned with a brush, water or compressed air, if necessary. If surface rust has formed in the threads during storage, it is recommended to remove the rust before installation, for example, by a steel brush.

To ensure proper tightening of the threaded sleeve, the cleaned threads of the pile element and/or threaded sleeve should be lubricated, for instance, with a biodegradable lubricant before installing the sleeve. Use of viscous lubricating grease may, especially under cold conditions, make tightening of the splice more difficult.

Tightening

When installing the splice, proper engagement of the threads must be ensured. The sleeve is screwed manually onto the pile element and is then pre-tightened by chain tongs or the rotary unit of the piling equipment. Then the upper pile element is installed and final tightening to at least the required tightening torque is performed. The minimum values of required tightening torques are presented in Table 27. Use of the minimum values requires that threads are clean and there are no mechanical damages to the threads.

During final tightening care must be taken not to squeeze the splice which prevents its tightening. The lower and upper pile elements should be gripped when tightening, not the sleeve, especially when tightening is done by piling equipment.

The threaded sleeve splice is dimensioned so as to meet the set requirements at the minimum tightening torque values presented in Table 27 even if the heads of the pile elements are not in contact. Bringing the heads into contact normally requires a higher than recommended tightening torque.

7.5 Splicing of steel pipe piles by welding

All steel grades used in SSAB steel piles are thermomechanically rolled. SSAB does not produce steel piles made of normalized steel (NH grades). All steel grades are highly weldable.

7.5.1 Welding Plan

A detailed welding plan is drawn up as part of the piling plan. The welding plan is to include the following:

- steel grade
- weld quality level
- welding procedure
- welding consumables
- possible preheating
- welding conditions
- types of joint preparation
- welding positions
- a welding procedure specification (WPS)
- welding procedure tests, when required
- production weld test, when required
- welder qualifications
- after-treatment of welds, if required
- weld inspection instructions

7.5.2 Welding quality requirements

The welding, inspection, testing, and related functions are to meet at least the requirements of standard EN ISO 3834-4.

Welded joints are usually sufficiently strong and ductile provided that the welding procedure has been carried out carefully. In exacting applications, the mechanical properties of welded joints may also be ensured through welding procedure tests and/or production weld tests.

Unless otherwise specified in the designs, the weld quality levels required for pile splices according to standard EN ISO 5817 are determined as indicated in Table 28.

Table 28. Weld quality levels required of steel pile splices (EN ISO 5817)

Piling work class	Consequence class		
	CC1	CC2	CC3
PTL3	C	C	B
PTL2	C	C	C
PTL1	D	-	-

If a RR or RD pile only acts as a casing (not a load-bearing structural member), weld quality class is D.

If the weld quality level requirement of Table 28 is not observed, the weld quality level is to be selected considering static and dynamic loads on the structure, the operating conditions of the structure, as well as the consequences of possible damage and treatments after welding. Concerning loads on the structure, both loads at the pile installation stage and those occurring during operation must be considered.

7.5.3 Qualification of Welders

The welders must have passed the test indicated in Standard EN ISO 9606-1 (Qualification test of welders. Fusion Welding. Part 1: Steels). The welding contractor must ensure that the welders carry valid certificates of qualification. Qualification tests must correspond to the requirements of the work. Factors to be considered include welding procedure, type of joint, steel grade, material thickness, external pipe diameter, and welding position as indicated in the standard. Qualification test welds are normally to be made on pipe. Test welds on plate are acceptable with pile diameters over 500 mm.

In the case of manual metal arc welding with covered electrode, the welder's competence can be ascertained, for example, by a single-sided test weld on pipe without backing.

Table 29. Example of qualification test for manual metal arc welder

EN ISO 9606-1: 111 T BW W01 B t10.0 D168 PC ss nb	
Explanation:	
111	Manual metal arc welding
T	Pipe
BW	Butt splice
2.1	Group of basic materials according to CEN ISO/TR 15608 and CEN ISO/TR 20172:2009 (qualifies for SSAB steel grades S355 to S460 and X60)
B	Base-coated electrode
t10.0	Weld test on pipe of 10 mm wall thickness, qualifies for thicknesses t = 3 to 20 mm
D168	Test on pipe 168 mm in diameter, qualifies for diameters D ≥ 84 mm
PC	Welding position PC, pipe in upright position, qualifies also for splice welding
ss	Single side welding
nb	No backing (qualifies also for welding with backing)

Welding of steel grades S550J2H and X70 requires passing a qualification test with the steel of the group of basic materials 2.2

Table 30. Selection of welding consumable

Steel grade	**Mechanical properties of weld metal (EN ISO 2560 and 18275 covered electrodes and EN ISO 14341, 17632 and 18276 for tubular cored electrodes)**			
	Yield strength[1]	**Impact strength[2]**	**Covered electrode, examples**	**Tubular cored electrode, examples**
S355J2H	35	2	ESAB OK 48.00	TRI-MARK TM-770, ESAB OK Tubrod 15.14
S440J2H and S460MH	46	2	ESAB OK 55.00, ESAB OK 48.08	TRI-MARK TM-770, ESAB OK Tubrod 15.14
S550J2H	55	2	ESAB OK 74.78	TRI-MARK TM-881 K2, ESAB Dual Shield 55
X60	42	2	ESAB OK 48.00	TRI-MARK TM-770, ESAB OK Tubrod 15.14
X70	50	2	ESAB OK 74.78	TRI-MARK TM-881 K2, ESAB Filarc PZ 6138

[1] Yield srength values of all-weld metal
[2] Testing temperature of 47 J impact energy of all-weld metal: 0=0 °C, 2=-20 °C.
35 = minimum yield strength: 350 MPa
42 = minimum yield strength: 420 MPa
46 = minimum yield strength: 460 MPa
50 = minimum yield strength: 500 MPa
55 = minimum yield strength: 550 MPa

7.5.4 Welding Procedures

Manual metal arc welding is the conventional welding procedure for splicing steel piles on sites. It is a versatile and flexible method that uses simple, easily transportable equipment.

Flux cored arc welding is a more modern welding procedure. Its advantages include high efficiency, consistent weld quality and suitability for mechanised production. Different types of welding nozzle conveyors attachable to the pipe are available for mechanised flux cored arc welding. These devices facilitate work in cramped spaces, such as underpinning sites, where piles must be positioned close to a wall. The space between pile and wall may be as narrow as 150 mm. When welding with shielding gas, it may be necessary to use screens to prevent the detrimental effect of wind and draught. There are also cored filler wires on the market that can be used without shielding gas.

Workshop welding may be carried out by any welding procedure for non-alloy steels.

7.5.5 Welding Consumables

The standards for covered electrodes are EN ISO 2560 (Welding consumables. Covered electrodes for manual metal arc welding of non-alloy and fine grain steels. Classification) and EN ISO 18275 (Welding consumables. Covered electrodes for manual metal arc welding of high strength steels. Classification).

The standards for cored wires and rods are EN ISO 17632 (Welding consumables. Tubular cored electrodes for metal arc welding with and without a gas shield of non-alloy and fine grain steels. Classification), EN ISO 14341 (Welding consumables. Wire electrodes and weld deposits for gas shielded metal arc welding of non alloy and fine grain steels. Classification) and EN ISO 18276 (Welding consumables. Tubular cored electrodes for gas-shielded and non-gas-shielded metal arc welding of high-strength steels. Classification.)

Filler materials are to meet the above standard specifications.

Filler materials are chosen on the basis of the strength and impact-strength requirements of the steel grade of the piles according to Table 30 or SSAB's manual "Kuumavalssatut kelat ja -levyt, Materiaalivalinta, Hitsausaineet". The complete classification specifications of the welding consumables presented in Table 30 according to EN standards are as shown in Table 31:

Table 31. Designation of welding electrodes and cored electrodes.

Covered electrodes:
ESAB OK 48.00: EN ISO 2560: E 42 4 B 42 H5 ESAB OK 48.08: EN ISO 2560: E 46 5 1Ni B 32 H5 ESAB OK 55.00: EN ISO 2560: E 46 5 B 32 H5 ESAB OK 74.78: EN ISO 18275: E 55 4 MnMo B 32
Tubular cored electrodes:
TRI-MARK TM-770: EN ISO 17632 T 42 2 P M 2 H10 TRI-MARK TM-881 K2: AWS E81T1-K2J, E81T1-K2 MJ H8 ESAB OK Tubrod 15.14: EN ISO 17632 T 46 2 P M/C 2 H10 ESAB Dual Shield 55: EN ISO 18276-A, T55 4 Z P M H5 ESAB Filarc PZ 6138: EN ISO 17632-A, T 50 6 1Ni P M21 1 H5

When welding together pile elements of different strength or type, the filler is generally selected according to the softer or less alloyed steel grade. However, when for instance welding fixtures, etc. to a pile, the filler is selected on the basis of the more alloyed steel (pile) in order that the filler to be incorporated into the pipe wall is sufficiently alloyed.

Covered electrodes must be of the basic type, indicated by the letter B (basic) in the designation.

When necessary, subject to agreement between the parties, the root run can be welded with filler material of lower strength than the parent metal. The coatings of covered electrodes and some cores of tubular cored electrodes being hygroscopic, they easily absorb moisture from ambient air. Moisture may cause gas pores, splatter and, in the worst case, hydrogen cracking in the weld. Therefore, it is important to handle and store these products carefully. The contractor is obliged to ensure that filler materials remain dry on site. They are to be stored in a dry and warm space which prevents moisture from condensing inside the package due to variations in temperature.

At the actual welding site, filler materials are to be protected from rain, etc. and electrodes to be kept in a separate heated quiver from which the welder withdraws them one at a time. Electrodes are also available in hermetically sealed packages. Each package contains just a few electrodes which can be used within 4 hours of opening the package without the risk of humidification.

Moist or otherwise damaged filler materials must not be used. Wet electrodes can be dried according to the manufacturer's instructions, for example at +300 °C to +400 °C for 2 to 3 hours.

When welding is finished, the coils of tubular cored electrode should be removed from the machine and taken to a dry and warm place for storage.

7.5.6 Welding Conditions

Weather is a major factor affecting weld quality and the welders' working conditions. Welding conditions that enable attaining the planned quality level must be provided.
If necessary, the welding site should be appropriately protected against wind and rain, and it should also be

sufficiently lit. Anvils should be level and stable so the welder can carry out his work properly and safely.

For welding in sub-zero conditions, it is important to provide tolerable working conditions for the welder. When ambient air is cold, moisture condenses on metal surfaces which requires preheating them to +50 to +100 °C to remove the moisture, even though the steel itself requires no preheating.

Proper earthing is essential in assuring weld quality. The earth cable must be dimensioned to match the weld cable and be connected directly to the workpiece. The earthing point must be metallically clean.

Under humid and wet conditions, the welder must be properly protected against electrical accidents.

7.5.7 Joint Preparation

Pile pipes are usually delivered from the works with the ends beveled for welding (30°) and a root face of 1.6 mm ± 0.8 mm. On site, piles are usually cut by a flame cutting or grinding. It is recommended that the cutting line is marked all the way around the pile circumference in order that the cut is made perpendicular to the pile's centre line. Manual cutting often leaves a ragged pile end and which is not sufficiently straight. Such defects must be repaired with a grinder. The bevels are to be produced by flame cutting and/or grinding. Flame-cut surfaces must always be ground to render them clean for welding. For mechanised welding bevels are to be made by turning.

As pipe piles are welded from the outside, the type of joint preparation must be such as to enable sufficient penetration and an even root reinforcement on the inside. It is particularly important to have a proper air gap to ensure full penetration.

Recommendations for correct types of joint preparation are given in Standard EN ISO 9692-1 (Welding and allied processes. Recommendations for joint preparation. Part 1: Manual metal-arc welding, gas-shielded metal arc welding, gas welding, TIG welding and beam welding of steels). Single bevel preparation and single V preparation are the most common types of joint preparation. Single V preparation is suitable for welding in all positions. Single bevel preparation is preferable for welding upright piles. Single V joint preparation is used to splice full-length piles delivered from the works. If piles need to be crosscut on site, the groove may also be prepared as a single bevel preparation, that is, a square edge against a beveled edge. Pile ends damaged during transport or installation must be repaired before splicing. Recommendations for correct types of joint preparation for welding without backing are presented in Figure 13.

In splice welding of piles, the use of backing on the inside of the groove is recommended. A fixed backing should be of the same steel as the pile elements to be connected. Ceramic backings can also be used. The backing should be of sufficient width, usually no less than 50 mm, and at least 5 mm thick. The backing is to be fitted symmetrically in relation to the groove and fastened in advance by intermittent welds (fixed backing) or, for instance, with adhesive tape (ceramic backing) inside the pile.

When backing is used, the weld reinforcement inside the pipe is to be ground level with the pipe surface. No air gap is allowed between the backing and the pipe wall. Recommended types of joint preparation for welding with backing are shown in Fig. 14.

The types of joint preparation presented in Figure 13 can be used for mechanised welding, provided that the root run is deposited manually. The types of joint preparation shown in Figure 14 can be used in fully mechanised welding. There, also the root run is preferably deposited by machine. A special type of joint preparation has been developed for that where a machined "tongue" functions as backing (See Fig. 15). With this type of joint preparation, the welding parameters should be selected so that the machined backing ("tongue") melts, full penetration is achieved, and lack of fusion and incomplete penetration ("root defects") are avoided.

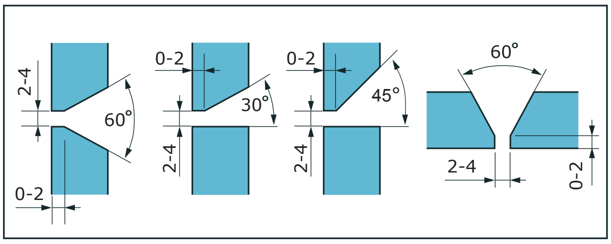


Figure 13. Types of joint preparation for welding without backing.

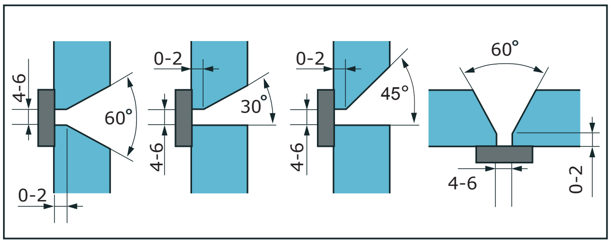


Figure 14. Types of joint preparation for welding with backing.

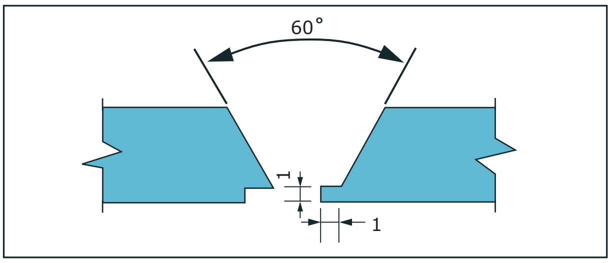


Figure 15. Joint preparation for fully mechanised welding.

7.5.8 Preheating

Preheating decelerates the cooling of the welded joint and lessens the degree of hardening. This prevents the formation of a hard and brittle zone in the HAZ, and thereby the development of hydrogen cracks. The need of preheating depends on steel grade, material thickness, filler metal (hydrogen content), heat input and welding conditions. High-strength steel, thick material, high hydrogen content (e.g. moist electrodes) and low heat input are factors that increase the need of preheating. More detailed instructions for the selection of preheating of SSAB pile products are given in Appendix 5. According to Appendix 5 no preheating is usually required when welding SSAB pile products, provided that dry basic electrodes are used. Moist electrodes must always be dried before use. When welding at temperatures below +10 °C, the pile ends are to be preheated to +50 to +100 °C before starting the work.

7.5.9 Welding

Pile ends must be clean inside and out for a distance of about 50 mm on each side of the groove. If necessary, any impurities, grease, moisture, rust, etc. is to be removed as they are likely to cause welding defects and thereby impair the quality of the weld. Any possible backing must also be cleaned, if necessary.

After joint preparation and cleaning, the pile ends are centred and carefully fitted together so that the inner surfaces of the two pile elements are aligned and the required air gap remains between them (see Figures 13 and 14). The fitting of the pile ends together can be facilitated by welding guide blocks onto one pile; they are removed after tacking. There also are special devices on the market for centring pipes. Wedges, electrode core wires (e.g. 3.2 mm), etc. can be used to ensure the required gap width; they are removed after tacking.

If the gap width varies, it must be ensured that it meets the minimum requirement even at its narrowest point. Any difference in root face height must be eliminated by grinding before aligning the pile elements. Thereafter, the pile ends are connected by short tack welds. If a tack weld is left in the groove as part of the root run, the ends of tack welds must be carefully ground to remove any crater pipes and to ensure full penetration.

A 2.5 mm electrode is recommended for the manual welding of root runs. Filling and capping runs are usually made with 3.2 mm electrodes. With thick-walled pipes, even thicker electrodes may be used for filling and capping runs. The most common wire diameter of a tubular cored electrode is 1.2 mm. However, tubular cored electrodes ranging from 0.9 mm to 1.6 mm are available depending on the intended application and requirements.

The supplier of the welding apparatus provides the necessary training for mechanized welding.

Piling can be continued when the weld is cooled below 500 °C.

7.5.10 Inspection of Welded splices

Inspection of welds is conducted in accordance with the requirements and scope of inspection specified in the design documents. Unless otherwise specified, the following is to be observed in the inspection requirements and scope:

In piling class 1 sites, all welds of piles are first examined visually. Visual inspection is aimed to detect any imperfections in weld dimensions, misalignments, undercuts, defects breaking the surface, etc.

At piling class 2 sites, the welder is usually required to make a so-called production weld test before starting the work, where two pile pipes are joined by welding according to the welding instructions. The result must meet the requirements of the required weld quality level in terms of observable errors. The results of the production weld test are recorded in the piling inspection documents.

Besides the production weld test and visual inspection, piling class 3 sites usually require inspecting at least 10 % of the welds by a non-destructive test (NDT), such as an ultrasound test. Test length is the entire weld, that is, one weld out of ten is inspected entirely, unless otherwise agreed.

Table 32 presents the number of NDT tests on welded splices in different welding quality levels and consequence classes.

Table 32. Number of NDT tests on the welded splices of compression loaded steel piles in different piling classes and consequence classes.

Piling class	Number of NDT tests, percentage of welds		
	CC1	CC2	CC3
PTL3	-	10	15
PTL2	-	-	10

NDT tests on compression loaded piles can usually be made right after the welding when the weld has cooled down sufficiently for the test. With tension piles the minimum cooling times of Table 23 in EN 1090-2 are to be observed before performing NDT tests, unless otherwise agreed for an individual project. More detailed information on minimum cooling times are given in Appendix 5.

If mechanised welding is used, for example, in foundation underpinning projects where the number of splices per pile is large, the number of tests is always indicated in the designs. Generally tests are made for 10 % of all piles and for at least two welds per pile. The test is started with the first weld and cover, for example, internal defects of the weld and defects of the root side of the weld. Defects exceeding the limit values of weld quality levels specified in standard EN ISO 5817 and affecting strength are repaired. Repaired welds are tested anew, and two other welds are also tested.

NDT tests may be carried out and rated only by an inspector with adequate qualification. Level 2 of standard EN 473 can be considered adequate qualification. The tests are documented for each joint in a test record to be attached to the inspection record of the piling.

7.6 Pile cut-off

Steel piles are cut at the design cut-off elevations at right angles to their longitudinal axis. Cutting may be performed by a cutting wheel or a flame cutter. Any possible burrs from cutting are removed by a grinding wheel. The required squareness of the finished cut-off end is <2.0 % and flatness <2 mm in relation to the perpendicularity of the axis of the pile unless otherwise indicated in the design.

Working in the immediate vicinity of the cut off of the piles is prohibited. Safety distance to pile cutting is 2x the length to be cut or at least 5 m.

If possible, the piles are cut while still attached to the piling rig. The piles are recommended to cut immediately after the installation, so the piling rig can safely lift the removed part away. The length of the pile pipe should be optimized before installation to prevent long stumps and to make cutting easy. Long stumps (vertical piles over 3 m and inclined piles over 2 m) are cut and lifted in co-operation with excavator one pile at the time. When the length of the stump is 1-3 m, for examples wedges or other tools are used to guide the falling to right and safe direction.

It is recommended that ends of steel piles are closed after cutting so that no foreign matter gets inside. Reliable closing of the pile ends of RD pile wall structures is essential for job safety since there is the risk of compressed air and drilling sludge suddenly discharging up through already installed piles when drilling close to the target level.

The rules of procedure must be paid particular attention when cutting RR/RD piles in special situations when the part to be removed can not be normally lifted / fell directly away (for example if piling rig and drill pipes are still attached to pile while the pile is cut). In this case the part which will be removed must be "peeled open". Due to the manufacturing methods of pile pipes, there might be stresses left in them. Therefore cutting of pile by "peeling" must be made in sequences shown in Figure 16. Longitudinal cut, for the whole length of the part to be removed, must be made first. After the longitudinal cut has been made, the pile can be cut normally from the design cut-off elevation. Cutting must be started from the point where longitudinal cut has ended.

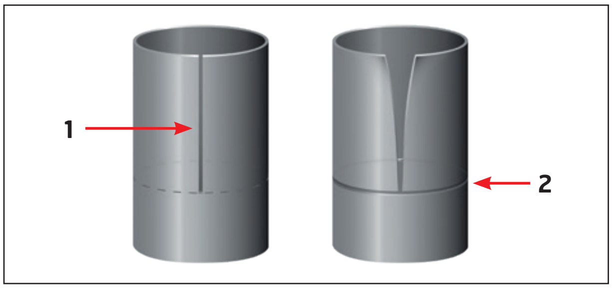


Figure 16. Cutting a pile by "peeling".

7.7 Pile cleaning

The cleanness of RR and RD piles with a closed lower end to be concreted is checked before concreting and any possible impurities are removed.

RD piles are generally flushed with compressed air in connection with the extraction of the pilot bit. Any possible drilling mud in the piles is rinsed off with water. A pile can normally be assumed to be clean when the water rising up is clean.

The possible cleaning of piles with an open lower end is planned and implemented case by case.

7.8 Reinforcement and concreting of piles

Reinforcement steels are to conform to EN 10080; other steels can be used if their properties meet the requirements of EN 1992-1.

Bar reinforcement of steel piles is done according to Ch. 2, Sec. 4.6.2 of PO-2016, taking into account, for instance, the minimum amounts of longitudinal steels, clearance between steel bars, limitations on concentric longitudinal bar layers, and transverse steels. According to Standard EN 12699 (Displacement piles), the thickness of the concrete cover between the inner surface of a pile and the outer surface of principal reinforcement must be at least 40 mm. When smaller diameter pipe is used as reinforcement, the minimum concrete cover is 25 mm according to PO-2016.

The assembly and joining of rebar cages is done according to Ch. 2, Secs. 5.5.1 and 5.5.2 of PO-2016 whereas the jigs and centralisers and installation are in accordance with Secs. 5.5.3 and 5.5.4 of PO-2016. It must be ensured that the pile is clean before the reinforcement is installed in it.

The portions of Secs. 5.7.1, 5.7.2, 5.7.3 and 5.7.4 of PO-2016 applicable to steel pipe piles are observed in concreting.

Concrete is mixed and its compliance verified according to Standard EN 206-1.

The design strength class of concrete, grouting mortar or injection grout must be at least C20/25, and the mixing ratio and consistency of fresh concrete must conform to Ch. 2, Tables 3.1 and 3.2 of PO-2016, when steel piles are dimensioned as composite structures. If the concrete or grouting mortar serves only as a filler to prevent potential slight corrosion inside piles, strength class C16/20 is also possible – even C12/15 with RR piles with a closed lower end – assuming that the concrete is not subject to chemical or freeze-thaw stress.

The ingredients used in the production of the concrete, grouting mortar and injection grout must conform to PO-2016 as follows:

- cement EN 197-1
- aggregate EN 12620
- water EN 1008
- admixtures EN 206-1 and EN 934-2.

When grouting mortar is used, the grain size distribution must be the following:
$d_{85} \leq 4$ mm
$d_{100} \leq 8$ mm
The maximum water-cement ratio of grouting mortar is 0.6.

With pile diameters under 200 mm (RR75 to RR/RD170), grouting mortar is used in pile concreting. Concrete can be used with larger diameters.

Dry concreting is used whenever possible. Prior to concreting, it must be ensured that the pile pipe is clean. Water-filled pile pipes are pumped empty before concreting. Water may enter driven piles equipped with mechanical shoes and splices through them. Generally water enters a pile pipe so slowly that dry concreting is possible as long as the pile is pumped empty a little before concreting.

In the case of RD piles drilled in bedrock, the amount of water coming in through the open bottom may be so large that dry concreting is impossible. Then, a concrete plug can be cast at the bottom of the pile by tremie. Separation of the concrete must then be minimised, for instance, by proportioning or suitable admixtures or a flexible dropchute. When the bottom of the pile has been made water-tight, the water is pumped out and the pile is reinforced and concreted.

When piles are dimensioned and implemented as composite structures, or when a high capacity steel pile serves only as a mould in the final structure, the concrete at the upper ends of piles is revibrated over a distance of 1.5 m. Before revibration, separated low-grade mass has to be removed from the surface of the concrete.

7.9 Bearing plate installation

Standard bearing plates (Table 12) are installed centrically on pile pipes using the bush in the plate, see Sections 2.7 and 6.1. In the case of piles to be concreted, the bearing plate is pressed centrically onto the pile head after concreting. When vibrating concrete structures to be suspended on piles, it must be ensured that the bearing plate does not rise.

Special care must be taken in casting piles dimensioned as composite structures and installing the bearing plates. No clearance is allowed between the underside of the bearing plate and concrete. If necessary, perforated bearing plates are to be used to enable post-injection
of any possible void under the plate.

7.10 Installation of shaft grouted CSG-RR piles

7.10.1 Installation equipment

A shaft grouted driven CSG-RR pile can be installed with the same driving equipment as an ungrouted RR driven pile. Use of slow-stroke drop or hydraulic hammers to install a pile may cause cement separation and impede grout feed. With pneumatic hammers and hydraulic rams the risk is considerably smaller.

Shaft grouted RR piles can also be pressed in the ground by hydraulic jacks. Then, grout must be fed with a separate pressurising pump.

7.10.2 Driving of pile into soil and its splicing

A grouted driven RR pile must be installed without interruption or damage to the pile. Driving must be effected by blows centric to the long axis of the pile. The instructions for RR piles are to be followed in the driving (Sec. 7.3).

Before driving a pile, the tip of the guiding section is plugged by a bottom plate or rock shoe attached using, for example, a sledge hammer.

A grouted driven RR pile is spliced the same way as an ungrouted one. If the pile remains bearing on soil layers, sufficient tightening of splices must be ensured. If necessary, a splice must be welded to the pile pipe to secure the splice.

Pile driving is stopped at target depth. Driving of a grouted pile designed to be mainly end-bearing can also stop as the end-of-driving criteria have been met.

The installation of a grouted driven RR pile is described in Figure 16.

7.10.3 Grout injection

Injected grout is fed into the pile pipe in a continuous stream during pile driving. Pile penetration rate should be adjusted to correspond to grout injection rate. In the case of shaft grouted CSG-RR piles and jacked-RR piles, the grout from the mixer is fed inside the piles through an adapter attached to their upper end.

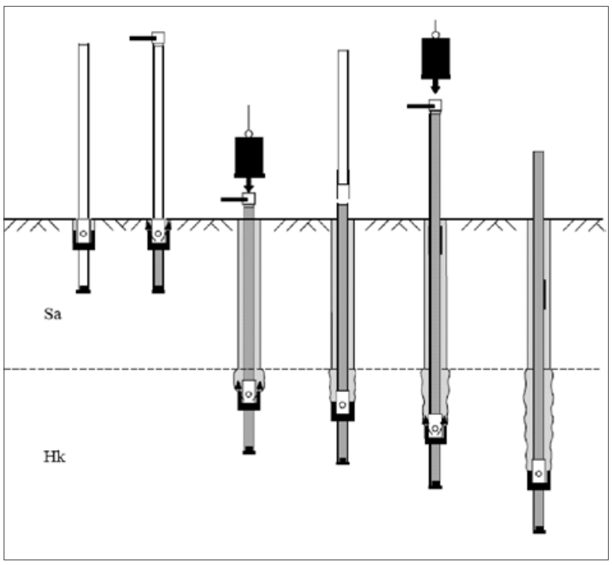


Figure 17. Installation of a shaft grouted CSG-RR pile: 1) initiation of driving, 2) grout feed, 3) pile driving and grout feed, 4) extension of pile by an external splice sleeve, 5) continuation of pile driving and grout feed,
6) finished pile.

The blows imparted by the equipment used to drive shaft grouted CSG-RR piles cause short pressure shocks in the grout, even in excess of 1 MPa, which increase its penetration efficiency into hole around the pile pipe.

Grouting may be either gravity grouting, where the grout flows freely into the pipe pile, or pump pressurised. Gravity grouting is used most often. In the case of long piles (over 15 m), or those extending substantially below the water table, pressurised grouting is recommended. The injection rate of gravity pumping equipment may be insufficient with long piles. Groundwater pressure pushes water into the pile pipe if grouting pressure is less than prevailing water pressure.

The pressure used to pressurise the grout depends on the soil layers to be penetrated and their possible shearing. The average recommended pressure for pressurising grout is 0.5 to 2.5 MPa.

The grout may be either injection grout or grouting mortar. Injection grout is a mixture of water and cement that may contain a maximum amount of aggregate (max. grain size <2 mm) equal to the amount of cement expressed as percentage by weight. Grouting mortar consists of aggregate (max. grain size normally <2 mm) in addition to water and cement.

The water-cement ratio of the grout must be suitable for the ground conditions, in any event lower than 0.55. The compressive strength of grout at 28 days must be at least 25 MPa (C20/25). Used grout must not contain ingredients that predispose to corrosion or aggravate it.

The pile designer gives instructions for the mixing of the grout, its admixtures, and the tests to be conducted prior to its use to determine its consistency, separation and shrinking. Grouting mortar is always mixed according to the instructions of the designer.

8. SUPERVISION AND QUALITY CONTROL OF PILING WORK, MEASUREMENTS

8.1 Supervision and monitoring of piling work

Supervision and monitoring of the installation of steel piles is implemented according to Ch. 2, Sec. 6.1 of PO-2016. The quality control of steel pile installation is based on the implementation and quality plan of the site (PO-2016, Ch. 2, Sec. 5.1). The piling manager is responsible for quality control and related measures. The piling manager may be assisted in the monitoring of piling work by an external supervisor and/or the site's responsible foundation engineer who provides expert monitoring services. The valid rules and regulations of the Finnish Transport Infrastructure Agency are observed in the supervision and monitoring of piling in infrastructure projects.

8.2 Quality control of materials

Quality control of materials is implemented according to Ch. 2, Sec. 6.1.2 of PO-2016 and their documentation according to Ch.2, Sec. 7.3 of PO-2001.

8.3 Monitoring measurements during installation

Monitoring measurements during installation are done according to Ch.2, Sec. 6.2 of PO-2016. Valid guidelines of the Finnish Transport Infrastructure Agency are observed in infrastructure projects. Monitoring measurements are documented as defined in Ch. 2, Sec. 7.3 of PO-2016.

The straightness of RR and RD piles is checked and documented after their installation. Straightness can be evaluated by the so-called torch method. It involves lowering a torch down a pile pipe suspended on a tape measure and measuring the depth at which the source of light can no longer be seen. Figures 18 and 19 show radii of curvature calculated for various piles based on the torch method. The formula presented in the figures expresses pile diameter and wall thickness in millimetres.

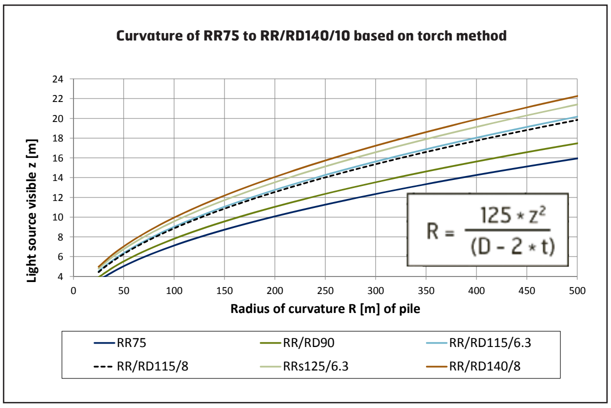


Figure 18. Assessment of curvature of RR75 to RR/RD140/10 piles by the torch method.

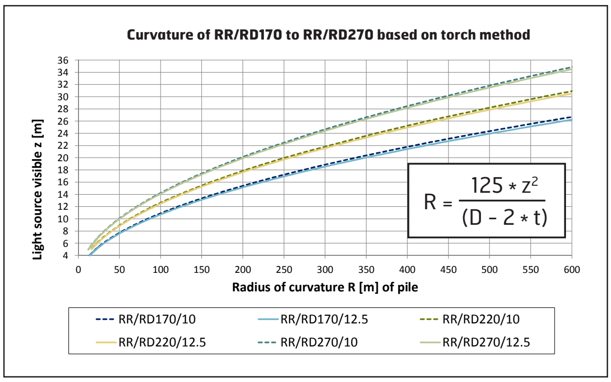


Figure 19. Assessment of curvature of RR/RD170/10 to RR/RD270/12.5 piles by the torch method.

The torch method provides an estimate of the radius of curvature of the upper pile end to the depth at which the light source vanishes from sight. In the case of long piles, the radius of curvature below the vanishing point cannot be estimated by the method. When the light source is visible at the bottom of the pile, the minimum radius is as shown in Figures 18 or 19, but it is generally considerably larger, especially as pile size increases. With larger pile diameters the light source allows determining visually, for example, the existence of local more curved sections towards the bottom of the pile.

If necessary, the curvature of piles can be determined more accurately by an inclinometer. Inclinometer measurements are generally used with piles driven in thick cohesion soils primarily at foundation underpinning sites.

Piles that do not meet straightness requirements are reported to the responsible foundation engineer of the site who decides on further measures.

The radius of curvature estimated by the torch method or measured by an inclinometer is compared to the radius used in dimensioning. The comparison must consider the soil layers: the strength of the pile structure has generally been dimensioned for the weakest soil section. Pile curvature may be considerably smaller in coarse-grained than in cohesion soil layers thanks to the strong lateral support. If the radius of curvature is, or is estimated to be, smaller than in dimensioning, a dimensioning value is calculated for pile strength based on it, which is compared to the design value of the load taken by the pile.

8.4 Testing of piles

Implemented according to Ch.2, Sec. 6.3 of PO-2016. The test methods applicable to steel piles are indicated in Sec. 5.5. Tests are documented according to Ch. 2, Sec. 7.3 of PO-2016.

9. DOCUMENTATION OF PILING WORK

9.1 General

In building construction projects all piling documents are compiled into a construction inspection document according to Ch. 2, Sec. 7.1 of PO-2016. In infrastructure projects documentation is done according to the valid rules and regulations of the Finnish Transport Infrastructure Agency

9.2 Piling records

Documentation of piling is done according to standard EN 1997-1 and Ch. 2, Sec. 7.2 of PO-2016. Piling records applicable to SSAB's steel piles are presented in Appendix 4.

9.3 Outcome drawing and other piling documents

The piling outcome drawing is made after completion of piling works. The content and preparation of the outcome drawing are according to Ch. 2, Sec. 7.4 of PO-2016. Monitoring measurements are documented according to Ch. 2, Sec. 7.3 of PO-2016.

10. WORK SAFETY AND ENVIRONMENTAL PROTECTION

Work safety and environmental protection are according to Ch. 2, Sec. 8 of PO-2016.

Instructions on the safe handling of SSAB's steel piles are found in “Piles and pile accessories, recommendations for safe handling on site” which advise on safe handling of pile products and accessories before actual piling. Section 7 of these instructions is observed in piling.
A special work safety aspect concerning steel pipe piling is the reliable closing of the ends of open pile pipes after installation.

11. END-OF-DRIVING TABLES

11.1 General

The end-of-driving tables and graphs have been prepared on the basis of analyses made using the GRLWEAP program built on the one-dimensional wave theory according to the main principles of Ch. 1, App. 2 of PO-2016.

The end-of-driving tables present five different ultimate geotechnical resistance values (R_c) for each pile size, pile length and driving equipment. In addition to the $R_{c,max}$ values corresponding to piling classes PTL1 to PTL3, the tables also present the smaller than maximum values corresponding to PTL2 and PTL3. The reduced value of PTL2 is about 88 to 90 % of its maximum value, and the reduced value of PTL3 is the average of the maximum values of PTL2 and PTL3 corresponding to 80 % of the yield strength of steel. The reduced values are presented to facilitate setting appropriate end-of-driving criteria in situations where the goal is not to attain the maximum values of the piling class in question. End-of-driving curves have also been drawn for hydraulic rams and pneumatic hammers as function of geotechnical resistance and end-of-driving settlement. The end-of-driving tables and graphs are suitable for steel piles serving as end-bearing piles.

The end-of-driving tables present the design geotechnical resistance values (R_d) of piles. The R_d values apply in the case of so-called non-rigid structures. In PTL3, R_d values are calculated using a correlation coefficient ξ_5 of 1.47.

End-of-driving criteria have been calculated for four pile lengths: 5, 10, 20 and 30 m.

11.2 Drop and hydraulic hammers

11.2.1 Basics of modelling

In connection with the building of the soil model, the number of final blows imparted with drop and hydraulic hammers was determined using a shaft resistance of 10% of the total ultimate geotechnical resistance of a pile and shaft resistance distributed evenly in the form of a downward expanding triangle. The used Smith damping factor (J_s) is 0.23 s/m, which corresponds to the typical piling conditions for the above-mentioned shaft resistance distribution where about half of the pile lies in cohesion soil and the rest in friction soil. Otherwise, the dynamic soil parameters of App. 2 of PO-2016 are used in creating the soil model.

- elastic compression of soil under the tip before quake $q_t = d/120$ [mm]
- elastic compression of soil around pile before quake $q_s = 2.5$ mm
- Smith's damping factor at pile tip, $J_t = 0.5*(25/\sigma_t)$ [s/m], (σ_t [MPa] = soil failure stress under pile tip)

Drop and hydraulic hammers up to 2000 kg have been analyzed using the SELF PJ hammer model created for GRLWEAP using typical moving part dimensions based on hammer weight. Drop and hydraulic hammers have been calculated with the same driving equipment model using 80 % as the efficiency of the drop hammer and 90 % for the hydraulic hammer.

In the modelling of 3000 to 9000 kg drop and hydraulic hammers, the Junttan HHK hammer models have been used as follows:

- the efficiency assigned to drop hammers was 80 %
- the efficiency assigned to hydraulic hammers was 95 %

Pile cushion values of Junttan have been used in modeling 3000 and 4000 kg hammers up to pile size RR170/12.5. With other driving equipment/pile combinations calculations have been made ignoring pile cushions.

11.2.2 Instructions for use of end-of-driving tables

The end-of-driving settlement of piles driven by hammers is always 10 mm/10 blows in PTL1 and PTL2, while in PLT3 it is 7 mm/10 blows.

The tables present with an accuracy of 0.05 m the required drop height for the combination of hammer weight, pile size and length, and intended geotechnical ultimate resistance and design value of resistance of each pile. The maximum allowed drop height used is the highest value suggested for each combination. When a value is given in parentheses in connection with maximum drop height, it refers to the fact that when maximum drop height is used, the maximum stress on the pile is 90% according to modelling, and that using the drop height in calculation will produce the ultimate geotechnical resistance indicated in parentheses. Drop heights can be interpolated on the basis of pile length.

The drop heights of the end-of-driving tables of piling class PTL3 are tentative. Mobilising geotechnical resistance and stresses on the pile during driving must be determined on the basis of PDA measurements.

In case the driving equipment includes an impact energy tester found reliable, the required impact energy can be determined as follows: required impact energy [kNm] = hammer weight of table [kg] x drop height [m] x efficiency given in table [-] x 0.00981. If the efficiency of the driving equipment is known from measurements to be something other than the 80 % or 95 % of the tables, drop height can be changed to correspond to actual efficiency.

Example 1:

Pile RR170/10, length 20 m, driving equipment: 4 t hydraulic hammer, design value of geotechnical resistance is the maximum value for PTL2 (R_d = 893kN).

According to the end-of-driving table drop height is 0.65 m, end-of driving settlement ≤10 mm/10 blows.

Example 2:

Pile RR170/10, length 17 m, driving equipment: 4 t accelerated hydraulic hammer (measured efficiency 100%), R_d = 893kN.

Drop height is interpolated based on 10 and 20 m pile lengths -> 0.6 m, efficiency of driving equipment is considered, drop height is 95 %/100 % * 0.6 m = 0.57 m, rounded to 0,55 m, end-of-driving settlement ≤10 mm/10 blows.

11.3 Hydraulic rams and pneumatic hammers

11.3.1 Principles of modelling

The magnitude of the shaft resistance of a pile used in creating the soil model was 1 % of the total ultimate resistance of the pile, and shaft resistance was distributed evenly in the form of a downward expanding triangle. Otherwise, the dynamic soil parameters presented in App. 2 of PO-2016 were used.

The hammers for the program were modelled based on data and properties provided by importers or manufacturers. The efficiencies of the ram and hammer, again, were based on opinions or measurements. Used hammer efficiency was 80 %. With certain hammer/pile combinations lower efficiency was used. In those cases, efficiency has been indicated in connection with the end-of-driving graph and table for the combination in question.

11.3.2 Instructions for use of end-of-driving graphs and tables

The end-of-driving settlement (mm/30 s) corresponding to the ultimate geotechnical resistance (R_c) and the design value (R_d) of geotechnical resistance is presented in the end-of-driving tables for each hammer, pile size and pile length. In case calculated end-of-driving settlement exceeds 100 mm/30 s, the magnitude of end-of-driving settlement is limited to 100 mm/30 s in the table. An end-of-driving settlement exceeding 100 mm/30 s can be used case-specifically, but then it must be taken into account that the actual number of hammer blows may decrease as settlement increases. If simulation indicates that a hammer is unable to mobilise the required geotechnical resistance, the table shows the mobilised geotechnical ultimate resistance when settlement <2 mm/30 s.

End-of-driving graphs show the calculated geotechnical ultimate resistance (R_c) with respect to end-of-driving settlement. If the targeted design value (R_d) of geotechnical resistance in piling classes PTL1 and PTL2 deviates from tabulated values, it can be interpolated based on the values of the table or determined from the end-of-driving graphs as follows: design value of geotechnical resistance (R_d) is multiplied by the factor 1.764 (1.47 x 1.2) to arrive at the corresponding geotechnical resistance (R_c), which allows reading the end-of-driving settlement from the graph.

In case the hammer cannot mobilise sufficient geotechnical resistance based on simulation, geotechnical resistance is to be ensured, for instance, by a separate test loading hammer and dynamic bearing capacity measurement or alternately by elasticity measurement and a dynamic bearing capacity formula.

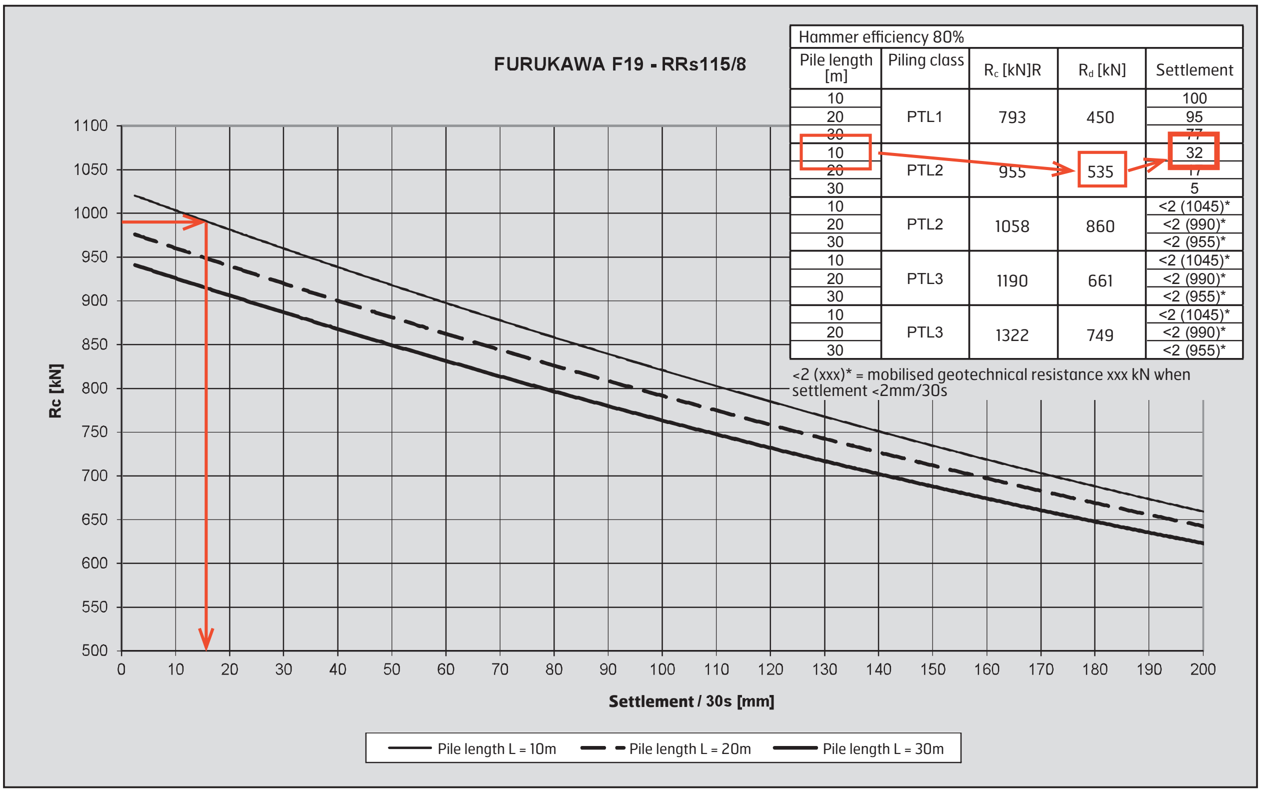
In piling class PTL3 the geotechnical ultimate resistance must be determined on the basis of dynamic bearing capacity measurements.

If the end-of-driving graphs indicate an efficiency below 80%, the instructions of Sections 7.3.3 and 7.3.7 of the manual are to be followed in pile installation.

Example: Furukawa F19 hydraulic hammer, pile RRs115/8, piling class PTL2, pile length 10 m.
Piles have two R_d values: 535 kN *and 560* kN.

The end-of-driving settlement corresponding to R_d value 535 kN *given in the table is 32* mm/*30* s.

The R_d value 560 kN *is converted to a geotechnical ultimate resistance (R_c) as follows: 1.764 * 560* kN = *988* kN. *Based on the end-of-driving graph, the end-of-driving settlement is about 16* mm/*30* s.



Hammer efficiency 80%				
Pile length [m]	Piling class	R_c [kN]R	R_d [kN]	Settlement
10	PTL1	793	450	100
20				95
30				77
10	PTL2	955	535	32
20				17
30				5
10	PTL2	1058	860	<2 (1045)*
20				<2 (990)*
30				<2 (955)*
10	PTL3	1190	661	<2 (1045)*
20				<2 (990)*
30				<2 (955)*
10	PTL3	1322	749	<2 (1045)*
20				<2 (990)*
30				<2 (955)*

<2 (xxx)* = mobilised geotechnical resistance xxx kN when settlement <2mm/30s

$R_{c;max}$ values of driven piles and informative design values R_d of large diameter RR piles

Table 1A: $R_{c;max}$ values of driven RR75 to RR320 piles, that is, maximum impact resistance values by piling classes

Table 1B: Corresponding values of RR400 to RR1200 piles and design values for centric load resistance of standard RR400 to RR1200 rock shoes

Table 1C: Informative design values for geotechnical resistance R_d [kN] of piles RR400 - RR1200

Table 1A. $R_{c;max}$ values [kN] of RR75 to RR320 piles

Paalu	Teräslaji	PTL1	PTL2	PTL3
RR75	S460MH	343	458	572
RR90	S460MH	406	541	677
RR115/6.3	S460MH	531	708	885
RR115/8	S460MH	664	885	1106
RRs115/8	S550J2H	793	1058	1322
RRs125/6.3	S550J2H	710	946	1183
RR140/8	S460MH	822	1096	1370
RRs140/8	S550J2H	983	1311	1638
RR140/10	S460MH	1012	1350	1687
RRs140/10	S550J2H	1210	1614	2017
RR170/10	S460MH	1235	1647	2059
RRs170/10	S550J2H	1477	1969	2462
RR170/12.5	S460MH	1520	2026	2533
RR220/10	S460MH	1632	2176	2720
RRs220/10	S550J2H	1951	2601	3252
RR220/12.5	S460MH	2015	2687	3359
RRs220/12.5	S550J2H	2410	3213	4016
RR270/10	S460MH	2052	2737	3421
RR270/10	S550J2H	2454	3272	4090*
RR270/12.5	S460MH	2541	3388	4235*
RR270/12.5	S550J2H	3038	4051	5064*
RR320/10	S460MH	2450	3266	4083
RR320/10	S550J2H	2929	3905	4881*
RR320/12.5	S460MH	3038	4050	5063*
RR320/12.5	S550J2H	3632	4842*	6053*

* With RR270 and RR320 standard rock shoes resistance of the rock shoe is lower (Sec. 2.3.3)

Table 1B. $R_{c;max}$ values [kN] of RR400 to RR1200 piles

Pile	Piling class PTL1			Piling class PTL2			Piling class PTL3			Standard rock shoe $R_{d,L}$
Steel grade	**S355J2H**	**S440J2H**	**S550J2H**	**S355J2H**	**S440J2H**	**S550J2H**	**S355J2H**	**S440J2H**	**S550J2H**	
RR400/8	1919	2379	2974	2559	3172	3965	3199	3965	4956	4900
RR400/10	2387	2959	3699	3183	3945	4931	3979	4931	6164	4900
RR400/12.5	2965	3675	4594	3954	4900	6125	4942	6125	7657	4900
RR450/8	2163	2681	3352	2884	3575	4469	3605	4469	5586	5920
RR450/10	2692	3337	4171	3589	4449	5561	4487	5561	6951	5920
RR450/12.5	3346	4147	5184	4462	5530	6912	5577	6912	8640	5920
RR500/8	2409	2986	3732	3212	3981	4976	4015	4976	6220	7550
RR500/10	2999	3717	4647	3999	4956	6195	4999	6195	7744	7550
RR500/12.5	3730	4623	5779	4974	6164	7705	6217	7705	9632	7550
RR500/14.2	4223	5234	6543	5631	6979	8723	7038	8723	10904	7550
RR500/16.0	4741	5876		6321	7835		7901	9793		7550
RR550/8	2655	3290	4113	3540	4387	5484	4424	5484	6855	7940
RR550/10	3306	4098	5122	4408	5464	6830	5511	6830	8537	7940
RR550/12.5	4114	5099	6374	5485	6799	8499	6857	8499	10623	7940
RR550/14.2	4659	5775	7218	6212	7699	9624	7765	9624	12030	7940
RR550/16	5232	6485		6976	8647		8720	10808		7940
RR600/8	2900	3595	4494	3867	4793	5991	4834	5991	7489	9680
RR600/10	3613	4479	5598	4818	5972	7464	6022	7464	9331	9680
RR600/12.5	4498	5575	6969	5997	7433	9292	7497	9292	11615	9680
RR600/14.2	5095	6315	7894	6794	8420	10525	8492	10525	13157	9680
RR600/16	5724	7094	8868	7632	9459	11824	9540	11824	14780	9680
RR600/18	6418	7954		8557	10605		10696	13257		9680
RR650/8	3141	3893	4867	4188	5191	6489	5236	6489	8111	10060
RR650/10	3915	4852	6065	5219	6469	8086	6524	8086	10108	10060
RR650/12.5	4874	6042	7552	6499	8055	10069	8124	10069	12586	10060
RR650/14.2	5523	6845	8556	7364	9127	11409	9205	11409	14261	10060
RR650/16	6206	7691	9614	8274	10255	12819	10343	12819	16024	10060
RR650/18	6960	8626		9279	11501		11599	14376		10060
RR700/8	3387	4198	5247	4516	5597	6997	5645	6997	8746	11610
RR700/10	4222	5233	6541	5629	6977	8721	7036	8721	10901	11610
RR700/12.5	5258	6517	8147	7011	8690	10862	8764	10862	13578	11610
RR700/14.2	5959	7386	9232	7945	9848	12310	9932	12310	15387	11610
RR700/16	6697	8300	10376	8929	11067	13834	11162	13834	17293	11610
RR700/18	7512	9311	11639	10017	12415	15519	12521	15519	19398	11610
RR700/20	8323	10316		11097	13754		13872	17193		11610
RR750/8	3633	4503	5628	4844	6003	7504	6055	7504	9380	12340
RR750/10	4529	5613	7017	6038	7484	9355	7548	9355	11694	12340
RR750/12.5	5642	6993	8742	7523	9324	11655	9404	11655	14569	12340
RR750/14.2	6395	7926	9908	8527	10568	13210	10658	13210	16513	12340
RR750/16	7188	8910	11137	9585	11879	14849	11981	14849	18562	12340
RR750/18	8065	9996	12495	10754	13328	16661	13442	16661	20826	12340
RR750/20	8937	11077		11916	14770		14895	18462		12340
RR800/8	3878	4807	6009	5171	6409	8012	6464	8012	10015	12530
RR800/10	4836	5994	7492	6448	7992	9990	8060	9990	12487	12530
RR800/12.5	6026	7469	9336	8035	9959	12448	10044	12448	15561	12530
RR800/14.2	6831	8467	10584	9108	11289	14111	11385	14111	17639	12530
RR800/16	7680	9519	11898	10240	12692	15864	12800	15864	19830	12530
RR800/18	8618	10682	13352	11491	14242	17803	14364	17803	22253	12530
RR800/20	9552	11839		12735	15785		15919	19731		12530
RR800/23	10943	13563		14590	18084		18238	22605		12530
RR900/10	5444	6748	8435	7259	8997	11246	9074	11246	14058	14890
RR900/12.5	6787	8411	10514	9049	11215	14019	11311	14019	17524	14890
RR900/14.2	7695	9537	119ç22	10260	12717	15896	12825	15896	19870	14890
RR900/16	8653	10725	13406	11537	14300	17875	14422	17875	22344	14890
RR900/18	9713	12039	15048	12951	16051	20064	16188	20064	25080	14890
RR900/20	10768	13346		14357	17795		17947	22244		14890
RR900/23	12342	15297		16456	20396		20570	25495		14890
RR1000/10	6059	7509	9387	8078	10012	12515	10098	12515	15644	15690
RR1000/12.5	7554	9363	11704	10073	12484	15605	12591	15605	19507	15690
RR1000/14.2	8567	10619	13273	11423	14158	17698	14279	17698	22122	15690
RR1000/16	9636	11943	14929	12848	15924	19905	16060	19905	24881	15690
RR1000/18	10819	13409	16761	14425	17879	22348	18031	22348	27936	15690
RR1000/20	11997	14869		15996	19826		19994	24782		15690
RR1000/23	13755	17048		18340	22731		22924	28413		15690
RR1200/10	7287	9032	11290	9716	12043	15053	12145	15053	18817	19260
RR1200/12.5	9090	11267	14083	12120	15022	18778	15150	18778	23472	19260
RR1200/14.2	10312	12781	15976	13749	17041	21301	17186	21301	26627	19260
RR1200/16	11602	14379	17974	15469	19173	23966	19336	23966	29957	19260
RR1200/18	13030	16150	20188	17374	21533	26917	21717	26917	33646	19260
RR1200/20	14454	17915		19272	23886		24090	29858		19260
RR1200/23	16580	20550		22107	27400		27634	34251		19260

Table 1C. Informative design values for geotechnical resistance R_d [kN] of piles RR400 – RR1200
Values in table 1C are calculated from table 1B $R_{c;max}$ values by using the correlation coefficient ξ_5 = 1.47 and the partial factor γ_t=1.20. The correlation coefficient used with large diameter piles is usually defined according to number/percentage of PDA measurement done. Due to this, the R_d values vary somewhat compared to the values presented in table.

Pile	**Piling class PTL1**			**Piling class PTL2**			**Piling class PTL3**			**Standard rock shoe $R_{d,L}$**
Steel grade	**S355J2H**	**S440J2H**	**S550J2H**	**S355J2H**	**S440J2H**	**S550J2H**	**S355J2H**	**S440J2H**	**S550J2H**	
RR400/8	1088	1349	1686	1451	1798	2248	1814	2248	2810	4900
RR400/10	1353	1677	2097	1804	2237	2796	2256	2796	3495	4900
RR400/12.5	1681	2084	2604	2241	2778	3473	2802	3473	4341	4900
RR450/8	1226	1520	1900	1635	2027	2533	2044	2533	3167	5920
RR450/10	1526	1891	2364	2035	2522	3152	2543	3152	3941	5920
RR450/12.5	1897	2351	2939	2529	3135	3919	3162	3919	4898	5920
RR500/8	1366	1693	2116	1821	2257	2821	2276	2821	3526	7550
RR500/10	1700	2107	2634	2267	2810	3512	2834	3512	4390	7550
RR500/12.5	2115	2621	3276	2819	3495	4368	3524	4368	5460	7550
RR500/14.2	2394	2967	3709	3192	3956	4945	3990	4945	6182	7550
RR500/16.0	2688 *	3331 *		3583 *	4441 *		4479 *	5552 *		7550
RR550/8	1505	1865	2332	2007	2487	3109	2508	3109	3886	7940
RR550/10	1874	2323	2904	2499	3097	3872	3124	3872	4840	7940
RR550/12.5	2332	2891	3613	3110	3854	4818	3887	4818	6022	7940
RR550/14.2	2641	3274	4092	3522	4365	5456	4402	5456	6820	7940
RR550/16	2966 *	3676 *		3955 *	4902 *		4944 *	6127 *		7940
RR600/8	1644	2038	2547	2192	2717	3397	2740	3397	4246	9680
RR600/10	2048	2539	3174	2731	3385	4232	3414	4232	5289	9680
RR600/12.5	2550	3160	3951	3400	4214	5267	4250	5267	6584	9680
RR600/14.2	2888	3580	4475	3851	4773	5967	4814	5967	7458	9680
RR600/16	3245	4022	5027	4326	5362	6703	5408	6703	8378	9680
RR600/18	3638	4509		4851	6012		6063	7515		9680
RR650/8	1781	2207	2759	2374	2943	3679	2968	3679	4598	10060
RR650/10	2219	2750	3438	2959	3667	4584	3699	4584	5730	10060
RR650/12.5	2763	3425	4281	3684	4567	5708	4605	5708	7135	10060
RR650/14.2	3131	3880	4851	4174	5174	6467	5218	6467	8084	10060
RR650/16	3518	4360	5450	4690	5814	7267	5863	7267	9084	10060
RR650/18	3945	4890		5260	6520		6576	8150		10060
RR700/8	1920	2380	2975	2560	3173	3966	3200	3966	4958	11610
RR700/10	2393	2966	3708	3191	3955	4944	3989	4944	6180	11610
RR700/12.5	2981	3695	4618	3975	4926	6158	4968	6158	7697	11610
RR700/14.2	3378	4187	5234	4504	5583	6978	5630	6978	8723	11610
RR700/16	3796	4705	5882	5062	6274	7842	6327	7842	9803	11610
RR700/18	4259	5278	6598	5678	7038	8797	7098	8797	10997	11610
RR700/20	4718	5848		6291	7797		7864	9747		11610

*) pile size not in normal production, check availability from SSAB sales

Pile	Piling class PTL1			Piling class PTL2			Piling class PTL3			Standard rock shoe $R_{d,L}$
Steel grade	**S355J2H**	**S440J2H**	**S550J2H**	**S355J2H**	**S440J2H**	**S550J2H**	**S355J2H**	**S440J2H**	**S550J2H**	
RR750/8	2059	2552	3191	2746	3403	4254	3432	4254	5318	12340
RR750/10	2567	3182	3978	3423	4243	5304	4279	5304	6629	12340
RR750/12.5	3199	3964	4956	4265	5286	6607	5331	6607	8259	12340
RR750/14.2	3625	4493	5617	4834	5991	7489	6042	7489	9361	12340
RR750/16	4075	5051	6313	5433	6734	8418	6792	8418	10522	12340
RR750/18	4572	5667	7084	6096	7556	9445	7620	9445	11806	12340
RR750/20	5066	6280		6755	8373		8444	10466		12340
RR800/8	2199	2725	3406	2932	3633	4542	3664	4542	5677	12530
RR800/10	2742	3398	4247	3655	4531	5663	4569	5663	7079	12530
RR800/12.5	3416	4234	5293	4555	5646	7057	5694	7057	8821	12530
RR800/14.2	3873	4800	6000	5163	6400	8000	6454	8000	10000	12530
RR800/16	4354	5396	6745	5805	7195	8993	7256	8993	11242	12530
RR800/18	4886	6055	7569	6514	8074	10092	8143	10092	12615	12530
RR800/20	5415	6711		7220	8948		9025	11185		12530
RR800/23	6203 *	7689 *		8271 *	10252 *		10339 *	12814 *		12530
RR900/10	3086	3825	4782	4115	5100	6376	5144	6376	7969	14890
RR900/12.5	3847	4768	5961	5130	6358	7947	6412	7947	9934	14890
RR900/14.2	4362	5407	6758	5816	7209	9011	7270	9011	11264	14890
RR900/16	4905	6080	7600	6540	8106	10133	8176	10133	12666	14890
RR900/18	5506	6825	8531	7342	9099	11374	9177	11374	14218	14890
RR900/20	6104	7566		8139	10088		10174	12610		14890
RR900/23	6996 *	8672 *		9329 *	11562 *		11661 *	14453 *		14890
RR1000/10	3435	4257	5321	4579	5676	7095	5724	7095	8869	15690
RR1000/12.5	4283	5308	6635	5710	7077	8847	7138	8847	11058	15690
RR1000/14.2	4857	6020	7524	6476	8026	10033	8095	10033	12541	15690
RR1000/16	5463	6770	8463	7283	9027	11284	9104	11284	14105	15690
RR1000/18	6133	7602	9502	8177	10135	12669	10222	12669	15837	15690
RR1000/20	6801	8429		9068	11239		11335	14049		15690
RR1000/23	7797 *	9664 *		10397 *	12886 *		12996 *	16107 *		15690
RR1200/10	4131	5120	6400	5508	6827	8534	6885	8534	10667	19260
RR1200/12.5	5153	6387	7984	6871	8516	10645	8589	10645	13306	19260
RR1200/14.2	5846	7245	9057	7794	9661	12076	9743	12076	15095	19260
RR1200/16	6577	8152	10190	8769	10869	13586	10961	13586	16983	19260
RR1200/18	7387	9155	11444	9849	12207	15259	12311	15259	19074	19260
RR1200/20	8194	10156		10925	13541		13656	16926		19260
RR1200/23	9399 *	11650 *		12532 *	15533 *		15665 *	19416 *		19260

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SSAB is a Nordic and US-based steel company. SSAB offers value added products and services developed in close cooperation with its customers to create a stronger, lighter and more sustainable world. SSAB has employees in over 50 countries. SSAB has production facilities in Sweden, Finland and the US. SSAB is listed on the NASDAQ OMX Nordic Exchange in Stockholm and has a secondary listing on the NASDAQ OMX in Helsinki. **www.ssab.com**

The accuracy of this instruction sheet has been inspected with utmost care. However, we do not assume responsibility for any mistakes or direct or indirect damages due to incorrect application of the information. The right to make changes is reserved.

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