Rakennusteollisuus

PRODUCT SHEET

FOR PO-2016-COMPLIANT PILING DESIGN AND WORK WITH RT BETONIPAALUT® PILES

17.11.2022

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This Product Sheet supersedes the previous Rakennusteollisuus ry publication titled “TUOTELEHTI PO-2011 mukaiseen paalutustyöhön” from 2013.

The RT Betonipaalut® piles described in this Product Sheet may be manufactured by members of the piles division (Paalujaos) of Rakennusteollisuus RT ry’s concrete industry department (Betoniteollisuustoimiala).
RT Betonipaalut® is a registered trademark of Betoniteollisuus ry (Betonia Oy).

Manufacturers and suppliers of RT Betonipaalut® piles
- HTM Yhtiöt Oy (www.htmyhtiot.fi)
- Lujabetoni Oy (www.lujabetoni.fi)
- Siikajoen Betonitukku Oy
- TB-Paalu Oy (www.jvb.fi)
- Kymppibetoni Oy (www.kymppibetoni.fi)

Manufacturers and suppliers of piling equipment
- Emeca Oy (www.emeca.fi)
- Leimet Oy (www.leimet.fi)

Other contributors to this publication

Olli Asp, A-Insinöörit Suunnittelu Oy
Jukka Haavisto, Tampere University of Technology
Henri Kiiski, YIT Oyj
Anssi Laaksonen, Tampere University of Technology
Teemu Riihimäki, A-Insinöörit Civil Oy

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1. GENERAL

This Product Sheet describes driven reinforced concrete piles (RT Betonipaalut®) in the following nominal sizes: 250 × 250, 300 × 300, and 350 × 350 mm^2.

Foundations built with RT Betonipaalut® provide many kinds of added value to a project's customer, designers, engineers and piling contractors.

A minimum service life of 100 years

Driven precast concrete piles make it possible to construct foundations on weak or low-bearing-capacity soils, which are fast to build and cost-effective, while ensuring a long service life. Foundations for buildings, particularly those on weak subsoils requiring piling, are extremely difficult to repair or strengthen during the building's service life compared with other structural components. Therefore, their intended service life is typically at least 100 years, which can already be achieved with standard RT® concrete pile products. With specialised products, an even longer service life can be attained. Precast concrete piles have demonstrated excellent durability in practice, supported by over one hundred years of international experience with their use.

Excellent load capacity

Individual precast concrete piles provide high load-bearing capacity and excellent buckling resistance, allowing the construction of foundations with high overall stiffness through rigid connections and splices that effectively stabilise the structure, including against horizontal loads. The load-bearing capacity of concrete piles is sufficient even for heavily loaded structures, and the maximum pile capacity can be optimised based on the results of PDA (Pile Driving Analyzer) measurements performed during piling operations.

Quick to install and cost-effective

Even long foundation piles can be installed rapidly thanks to the easy-to-connect and rigid splice joints. Combined with the highly competitive cost of concrete piles, particularly considering their excellent load-bearing capacity, this enables the construction of economic and long-lasting piled foundations.

Environmentally friendly low-emission foundations

On weak soil, driven concrete pile foundations can reduce CO_2 emissions during construction, and their long service life also reduces the total life cycle carbon footprint of the building, making them more environmentally friendly than other solutions. The steel reinforcing bars (rebar) of the piles are manufactured from recycled steel instead of virgin iron ore. RT Betonipaalut® products are manufactured by a nationwide network of pile factories, which also minimises the CO_2 emissions of their transport. High durability makes reinforced concrete piles suitable for reconstruction applications as well, but the condition of the old foundation must always be inspected. For more environmental information about RT Betonipaalut®, see subsection 2.4.

Resistant to the chemical environments found in soil

The RT Betonipaalut® product family features different types of piles for building durable foundations in various chemical and physical environments, the properties of which are analysed in advance with soil surveys.

Made in Finland

All RT Betonipaalut® products are made in Finland from domestic raw materials and components.

1.1 Product approval of RT Betonipaalut®

Reinforced concrete piles must be CE-marked and meet the requirements of Finnish national guidelines (Paalutusohje 2016, RIL 254-2016).

Suomen Betoniyhdistys ry has issued a product declaration for the rock shoes.

This Product Sheet is based on Paalutusohje 2016 (PO-2016, RIL 254-2016) and it supersedes all previous versions. All RT Betonipaalut® specified in this Product Sheet meet the requirements of the following standards and guidelines:

- SFS-EN 1992-1-1 Eurokoodi 2. structures - Part 1-1: General rules and rules for buildings
- SFS-EN 12794 Precast concrete products - Foundation piles
- SFS-EN 12699 Execution of special geotechnical works. Displacement piles
- SFS-EN 13369 Common rules for precast concrete products
- SFS-EN 206 Concrete - Specification, performance, production and conformity
- SFS 7022 Betoni. Standardin SFS-EN 206:2014 käyttö Suomessa
- Paalutusohje 2016 (RIL 254-2016)

All piles, equipment and accessories are manufactured in factory conditions. Quality control is audited by a third party.

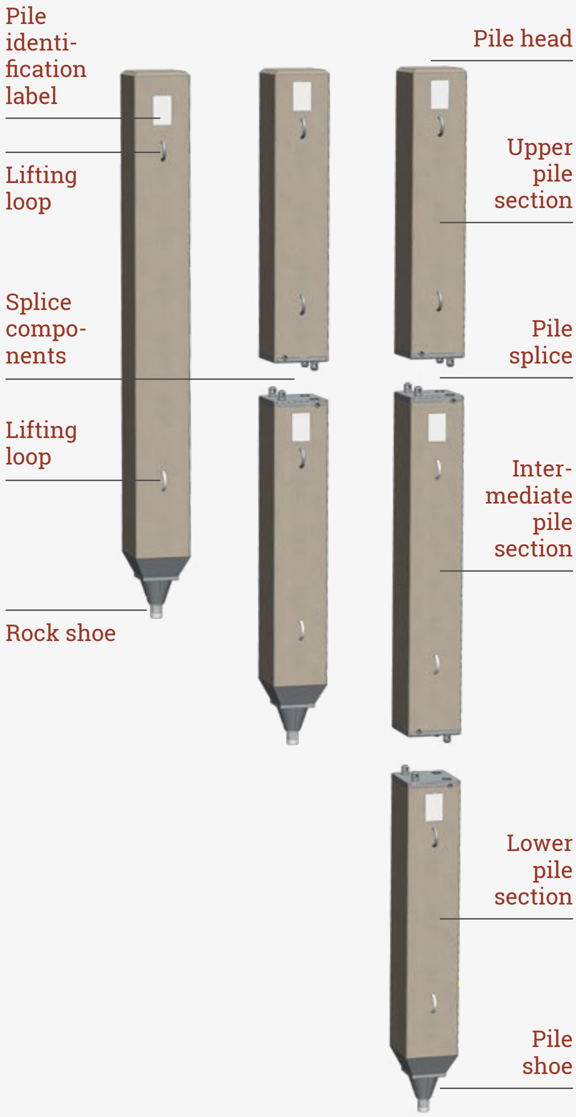


Figure 1.1 Concrete pile component names

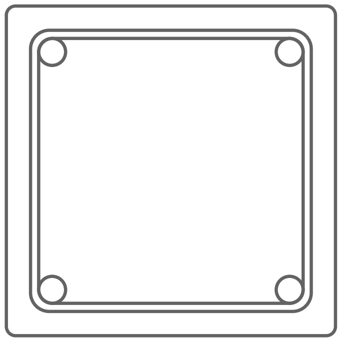
1.2 Applications

Reinforced concrete piles can be used in the foundations of both buildings and infrastructure. Typical applications include roads and other passages, industrial buildings, massive machine bases, and residential buildings, everything from single-family houses to multi-storey blocks.

Among other things, the benefits of the updated reinforced concrete piles include

- Excellent corrosion resistance
- High buckling strength
- Eco-friendliness
- Great load capacity
- Quick and safe rigid extensions
- Competitive pricing
- Nationwide network of pile factories

1.3 Pile types and equipment



The concrete used in RT Betonipaalut® is manufactured in accordance with SFS-EN 206. The strength of the concrete is either C40/50 (K-50) or C45/55 (K-55).

The reinforcement's main bars are type-approved ribbed bars that meet the technical requirements of Paalutusohje 2016.

RT Concrete Piles® are always equipped with rock shoes.
In accordance with the Paalutusohje 2016 (PO-2016), the toe of a driven pile shall be protected with a rock shoe whenever the pile is driven through coarse or boulder-rich soil layers (GEO classification: grain size d > 60 mm). Each rock shoe is fitted with a hardened steel tip, ensuring reliable anchorage of the pile into the rock surface.

1.3.1 Types, dimensions and materials

Table 1.1. Basic information for RT Betonipaalut® products

Paalutyyppi	**Side length** [mm]		**Weight** [kg/m]	**Cross section** [mm2]	**Skin area** [m^2/m]	**Concrete strength** [MPa]
RTB-250-16	250		156	62,500	1.00	C40/50
RTB-300-16	300	+15	225	90,000	1.20	C40/50
RTC-300-16	300	-10	225	90,000	1.20	C45/55
RTC-350-16	350		307	122,500	1.40	C45/55

1.3.2 Manufacturing tolerances

If a pile's side length exceeds the nominal size, the thickness of the concrete can be measured by using the nominal size.

Pile nominal length: + 150 mm/- 100 mm
RT Betonipaalut® products are made according to RT manufacturing drawings and PO-2016.

Stock lengths for extendable and monolithic RT Betonipaalut® piles

RTB-250-16	4–13 m
RTB-300-16	4–15 m
RTC-300-16	4–15 m
RTC-350-16	4–14 m

The stock lengths for reinforced concrete piles are specified as standard lengths at one metre intervals.

1.4 Product identification

RT Betonipaalut® products manufactured according to this Product Sheet are marked with the RT marking of Rakennusteollisuus RT ry, the pile cross section measurement, the publication year of the Paalutusohje used, and a durability marking, if required..

Example: RTB-300-16SR

- “RTB” refers to the type of RT Betonipaalut® pile (RTB or RTC). B or C indicates the pile’s load capacity.
- “300” refers to the pile’s cross section (250, 300 or 350 mm).
- ”16” refers to Finnish Piling Guideline Paalutusohje 2016.
- Further markings (here “SR” for sulphate resistance) indicate that the pile is a special design for exceptional exposure (none, SR, E or SR-E) instead of the typical (XC2).

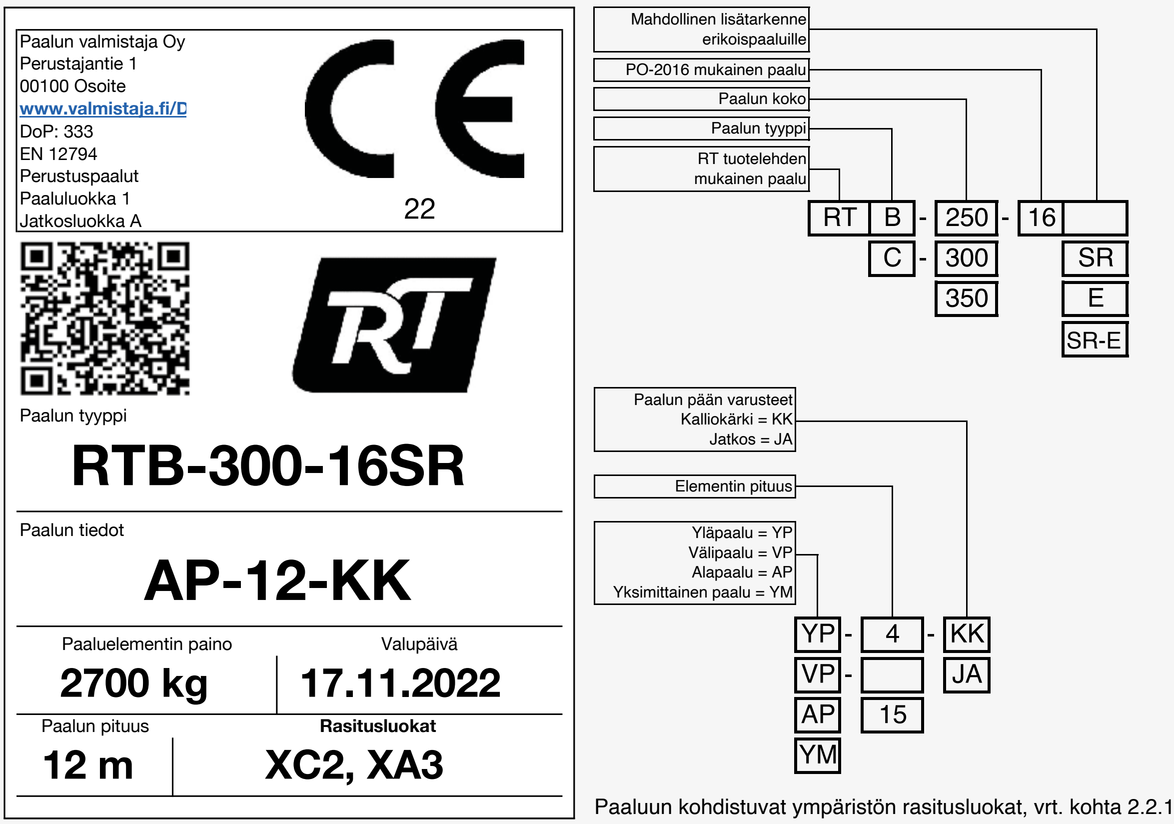


Figure 1.2 Example concrete pile product markings.

2. DESIGN AND ENGINEERING

2.1 Geotechnical surveys

2.1.1 Ground surveys

For the general requirements for ground surveys, see standards SFS-EN 1997-1 and SFS-EN 1997-2 as well as any relevant national documents. Paalutusohje 2016 includes detailed instructions and recommendations for ground surveys.

2.1.2 Soil surveys

The properties of the soil surrounding reinforced concrete piles must be known to determine the effects on pile durability. If other surveys and reports prove insufficient, the soil should be tested.

The results of soil and groundwater analysis are used to determine the exposure classes and the required characteristics of reinforced concrete piles. For more information, see Paalutusohje 2016, part 1, subsections 3.2.4 and 4.7.6.2.

2.2 Durability

2.2.1 Exposure classes

Concrete structures are designed to have a specified service life, which means planning for their durability. Service life design requires data on the materials and structures, but also the environmental conditions of the soil (exposure classes) and the length of time that the structure is required to stand (design service life).

Reinforced concrete piles can bear the stresses of soil well, and their high-strength concrete carbonises very slowly, which protects the reinforcing steel from corrosion. The soil also protects the concrete from the effects of atmospheric carbon dioxide. If the soil or groundwater surrounding the piles causes exceptional chemical stress, such as sulphate attacks in acidic sulphide clay or a corrosion risk due to the high chloride content of groundwater, the RT Betonipaalut® pile type must be selected accordingly to resist the exposure and guarantee an adequate service life.

A high soil sulphate content may compromise the durability of regular concrete piles if it reacts with oxygen due to soil uplift or groundwater depletion. This produces sulphuric acid and acidifies the soil ($pH < 4.0$), which requires the use of SR piles. Acidic sulphide soil is primarily found in Finland's coastal areas, below the 100 metre contour line in northern Finland and below the 40 metre line in southern Finland, in the bottom sediments of the post-glacial Littorina Sea.

The standard RT Betonipaalut® piles have a design service life of 100 years and their exposure class is XC2, which covers the risk of steel corrosion induced by the carbonation of concrete under normal conditions. Soils with exceptional chemical stress (e.g. high chlorinity) require the use of E or SR-E piles, depending on the exact properties of the exposure.

The environmental conditions (stresses and loads) facing concrete structures over their service life are described by exposure classes:

1. **XC, corrosion induced by carbonation**
   - XC1: piles are continuously submerged below the surface of (ground)water.
   - XC2: wet, rarely dry. The most common exposure class for piles. For pile durability, XC2 is more demanding than XC1.

2. **XD, corrosion induced by chlorides (non-seawater; de-icing salt etc.)**
   - This type of exposure is extremely rare in piles.
   - XD2: groundwater with a chlorinity exceeding 1,000 mg/L.

3. **XS, corrosion induced by chlorides (seawater)**
   - XS2: groundwater with a chlorinity exceeding 1,000 mg/L.

4. **XF, freeze-thaw attacks**
   - Typically not found in piles.

5. **XA, sulphate attack**
   - Determined according to PO-2016, part 1, subsections 3.2.4 and 4.7.6.2 based on ground and groundwater surveys or similar analysis.

6. **XA, other chemical attack**
   - Requirements are determined case by case (e.g. chemical soil pollution).

The standard exposure class for piles is XC. Supplementary classes are used, if required, i.e. if there is the possibility that the soil or groundwater contains enough sulphates, chlorides, or other aggressive chemicals. In this case, the contents must be determined by analysing the soil and groundwater. See the website of the Geological Survey of Finland at www.gtk.fi for the results of general regional surveys of acidic sulphide soils. The above can be used to plan actual soil testing, but they are not accurate enough to design the durability of foundations.

In practice, the only potential chloride exposure classes are XD2 and XS2. Even in such cases, the chloride content measured in groundwater must reach at least 1,000 mg/L. For example, the chloride content of groundwater in the immediate vicinity of seawater must be measured before the exposure class is determined. If the chloride content is less than 1,000 mg/L, XD2 and XS2 are unnecessary, and the standard exposure class for steel corrosion, XC2, is sufficient.

Because piles are installed underground, they are usually safe from freeze-thaw attacks, which would require the XF exposure class. De-icing agents (XD) do not normally reach piles, even in the case of roads, for example.

However, if piles are used to build quays or other structures exposed to seawater and freezing, their durability must be designed according to the appropriate principles (port construction etc.).

The XA exposure class is chosen based on soil and groundwater analysis. XA classes other than sulphate attack, as well as other requirements for chemical stress, must be determined by the designer on a case-by-case basis, according to the results of the soil or groundwater analysis.

2.2.2 Pile products and their suitability for different exposure classes

Table 2.1. Appropriate types of RT Betonipaalut® piles for different exposure classes.

	Standard pile	Standard pile + SR cement	E pile	E pile + SR cement
Pile type	RTx-xxx-16	RTx-xxx-16SR	RTx-xxx-16E	RTx-xxx-16SR-E
RTB-250-16	XC2	XC2 + XA2	-	-
RTB-300-16	XC2	XC2 + XA2	XC2 + XS2/XD2 + XA1	XC2 + XS2/XD2 + XA2
RTC-300-16	XC2	XC2 + XA2	XC2 + XS2/XD2 + XA1	XC2 + XS2/XD2 + XA2
RTC-350-16	XC2	XC2 + XA2	XC2 + XS2/XD2 + XA1	XC2 + XS2/XD2 + XA2
	STANDARD PILE			

- **Piles other than standard are made to order. The standard piles include rock shoes.**
- **Maximum design service life: 100 years.**
- **Pile type product markings, see subsection 1.4.**
- **The table applies to cases where the chemical stress of exposure class XA1 or XA2 is caused by sulphate attacks.**

Standard piles are designed to meet the requirements of exposure class XC2 (design service life of 100 years).

XA1- and XA2-rated piles are manufactured by modifying the composition of the pile's concrete. Exposure classes XS and XD also require structural changes to the piles (E piles).

2.2.3 Design service life

The standard design service life of reinforced concrete piles is 100 years. Case-specific durability design is required if a longer service life is desired.

Further information on pile durability design (only in Finnish)

Paaluinfo 2/2016: Teräsbetonipaalujen säilyvyyssuunnittelu and Paaluinfo 1/2019: Kloridirasitusten (XD- ja XS-rasitusluokat) huomioiminen betonipaalujen suunnittelussa (available for download at betoni.com)

by68 Betonin valinta ja käyttöikäsuunnittelu – Opas suunnittelijoille, Suomen Betoniyhdistys ry

2.3 Design process and characteristics

The following must be considered and declared in designs:

- Pile type.
- Shoe type.
- Pile extensions, their locations and instructions for extension.
- Piling work class.
- Acceptable tolerances (see PO-2016, part 2, subsection 4.4.3).
- Design service life.
- Exposure classes (including justification if other than XC2).
- Plane of truncation/attachment to base (by pile).
- Piling order (test piling, if required).
- Required working bed (including increased deviation when using a rocky or heterogeneous bed).
- Maximum pile load in the ultimate limit state (Fcd).
- Pile list (pile numbering, locations (X, Y, Z), type, size, shoe, batter pile angles (degrees), target level, truncation plane, and attachment to base (by pile).
- Necessary information for PDA or the final strike condition.

Additional instructions for designers

- Pile loads must be calculated according to Paalutusohje 2016 (RIL-254-2016), part 1, subsection 4.2.
- Any piles or pile groups requiring PDA must be specified. If PDA is used, the average and minimum load capacity values must be declared in the designs by pile group. PDA can be used to determine the final strike condition and to ensure the correct target level.
  - The analysed pile group should include identical piles installed in similar geotechnical conditions.
- In Finland, piles should be equipped with rock shoes (PO-2016, subsection 3.9.4.1). End-bearing piles must always have rock shoes.
- If a non-standard pile (per this Product Sheet) is produced by adding structural capacity with a higher concrete strength class and/or additional rebar, the capacity of the pile's equipment must be checked.
- The typical pile exposure class is XC2. If another class is chosen, the justification must be included in the design documents.
- Piles should be cut along the same plane in line with the bottom of the foundation, and they should reach at least 50 mm inside the base. For base penetration capacity, the plate thickness must be chosen according to the section of plate overlying the head of the pile.
- The plane of truncation must be about 20 cm above the ground, depending on the equipment used to cut the piles.
- The effects of the working bed on the piling work and pile installation order must be taken into account. For example, the last piles must be driven from an even working bed.
- Any environmental obstacles and piledriving machine limitations for batter piling in different orientations must be taken into account.

- The bounds for pile angles must be specified according to the piledriving machine. The maximum rake (angle) is also limited by the pile's length and weight per metre as well as the direction of the angle in relation to the piledriving machine. For batter piling, extra care should be exerciced to assess the load capacity of the piledriving bed.
  - Typically, a rearward rake can achieve the greatest angle: short piles can reach up to 3:1, typically 4:1 or 5:1.
  - A sideward rake can achieve 10:1 or 20:1.
  - A forward rake can achieve 8:1 with short piles, typically 10:1 or 20:1.

The design guideline and AutoCAD blocks for standard pile bases can be downloaded free of charge at betoni.com under Paalut.

The Tekla Structures design application for pile foundations (includes the Finnish Geotechnical Society's standard piling report template) can be downloaded from the Tekla Warehouse under Concrete (BEC)/BEC Pile (RT Betonipaalut).

Further information for pile foundation design (only in Finnish):

Paaluinfo 1/2021: Täydentäviä ohjeita teräsbetonipaalutuksen suunnitteluun ja toteutukseen (available for download at betoni.com)

2.3.1 Pile-to-structure connection and anchorage of reinforcement

A flat-headed pile transfers only compressive axial force.

If piles and rebar are cut off flush or the anchorage length is less than the minimum ($_{lb.min}$), the connection between pile and structure is calculated as a flexible joint unfit for tensile stress. If the effective length of the pile is less than three metres, rigid attachment is required between the pile and the overlying structure.

If necessary, the pile may be anchored to the structure by exposing its main bars. In this case, the anchorage length is determined according to the pile's main bars and the properties of the concrete in the overlying structure.

Table 2.2. RT Betonipaalut® main bar anchorage lengths on overlying structures for different structural concrete strength classes. Steel reinforcement tensile strength.

	Bond length [mm]				$F_{t.d.min}$	$F_{t.d.max}$
Pile type	$l_{b.min}$	C25/30	C30/37	C35/45	[kN]	[kN]
RTB-250-16	140	560	490	450	93	370
RTB-300-16	160	670	560	510	110	490
RTC-300-16	250	960	850	770	190	750
RTC-350-16	280	1100	970	880	240	980

$F_{t.d.min}$ = total ultimate limit state tensile strength of pile rebar, including all main bars, at the minimum anchorage length of $_{lb.min}$ (concrete type C25/30).
$F_{t.d.max}$ = maximum ultimate limit state tensile strength of pile rebar, including all main bars and with a straight pulling force in line with the pile.
$l_{b.min}$ = minimum value of main bar anchorage length.

The values given in the table have been calculated at the full tensile strength of the ultimate limit state for the concrete type listed in the column with a yield limit of 700 MPa and execution class 2. Good bond conditions are assumed between the rebar and the structure.

The anchorage length may be determined according to the forces present in the rebar by linear interpolation, as long as the minimum length lb.min is achieved. The calculation of the structure's anchorage length must include that portion of rebar where the concrete has no cracks in parallel with the reinforcing bars (the portion of rebar located above the base slab's bottom rebar, for example).

Example, RTB-300-16 piles: The maximum tensile strength for the rebar is 490 kN. If the pile's rated tensile strength is 100 kN, the bond length for type C30/37 concrete must be (100 kN / 490 kN) × 560 mm = 114 mm, which is less than the minimum (lb. min = 160 mm). In this case, the minimum value must be used. Calculated with the minimum value, the pile's anchorage must have a tensile strength of 160 mm / 560 mm) × 490 kN = 140 kN. The maximum tensile strength of driven piles is calculated according to the weight of the pile and the skin resistance of the pile's sides.

The anchorage length can be reduced by bending the rebar or by welding in crossbars or head anchors. The anchorage length is calculated according to standard SFS-EN 1992-1-1.

2.3.2 RT Betonipaalujen® compressive capacities

$R_{d:str}$ = the structural resistance of the pile against failure caused by a loss of pile stability due to the failure of surrounding soil or exceeding the capacity of the pile's cross section.

$R_{d;geo}$ = the geotechnical resistance of the pile, meaning the greatest compressive capacity in the ultimate limit state demonstrable by striking in different piling work classes, according to the driving criterion of this document.

Note! The definition of $R_{d:str}$ is equivalent to the N_{Rd} of Eurocodes.

Table 2.3 presents the rated compressive capacities of RT Betonipaalut® piles for structural resistance ($R_{d:str}$) and maximum geotechnical resistance ($R_{d:geo}$), according to the final strike table of this Product Sheet. The smaller of the two values must be used as the pile's final compressive capacity.

The compressive capacity listed in Table 2.3 can be used for RT Betonipaalut® piles for all execution classes specified in standard SFS-EN 13670. .

The maximum geotechnical resistance values have been calculated with the correlation coefficient specified in PO-2016, $\xi_5 = 1.47$ (geotechnical compressive capacity by shock wave analysis). The maximum geotechnical resistance is chosen according to the piling work class (PTL1–PTL3).

The structural resistance of piles, $R_{d:str}$, has been determined by using a dimensioning procedure developed by the Tampere University of Technology. The structural resistances listed in the table apply to axially loaded reinforced concrete piles attached from the head to structures without lateral shifts.

The structural resistance values have been calculated for four or five different undrained shear strength values (c_u = average undrained shear strength of soil based on soil surveys) and three different ratios of long- and short-term loads in service limit states (P =long-term loads, L = short-term loads). The resistance value can be determined between the two by linear interpolation. For long-term loads, the table uses the long-term portion of loads in Eurocode (SFS-EN 1990).

The table presents structural resistance values for both extended and unextended piles. Considering the above, the geometric initial deflection, δ_g, is $L_{cr}/300$ for unextended piles and $L_{cr}/150$ for spliced piles, where Lcr is the critical length for buckling, according to PO-2016, part 1, formula 4.52.

Table 2.3. RT Betonipaalut® piles' compressive capacity in the ultimate limit state.
For buckling, the compressive capacity was analysed separately for bending along the side and along the diagonal and the lower value was selected for the table.

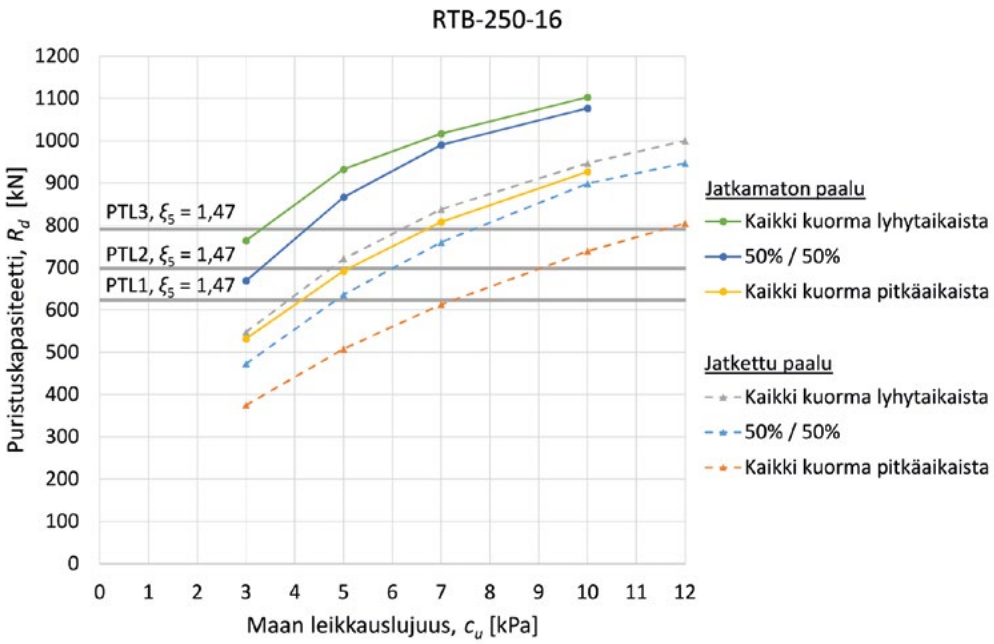
Pile type		$R_{d;str}$ [kN]						$R_{d;geo}$ [kN] *)		
		P [%]	L [%]	c_u [kN/m2] 5	7	10	12	PTL1	PTL2	PTL3**)
RTB-250-16	Extended pile	100	0	508	613	739	805	624	698	791
		50	50	636	760	899	(947)			
		0	100	721	838	(947)	(1000)			
	Unextended pile	100	0	692	808	(927)				
		50	50	867	990	(1077)				
		0	100	933	1017	(1103)				
RTB-300-16	Extended pile	100	0	733	885	1063	1149	895	1001	1134
		50	50	916	1093	1282	(1344)			
		0	100	1036	1204	(1357)	(1431)			
	Unextended pile	100	0	995	1161	(1325)				
		50	50	1247	1415	(1532)				
		0	100	1338	1455	(1574)				
RTC-300-16	Extended pile	100	0	788	957	1163	1277	1026	1147	1300
		50	50	987	1184	1427	(1549)			
		0	100	1121	1324	(1526)	(1622)			
	Unextended pile	100	0	1087	1283	1498				
		50	50	1369	1595	(1778)				
		0	100	1496	1661	(1821)				
RTC-350-16	Extended pile	100	0	1077	1307	1589	1746	1394	1558	1765
		50	50	1346	1616	1946	(2092)			
		0	100	1529	1805	(2078)	(2209)			
	Unextended pile	100	0	1484	1750	2043				
		50	50	1868	2174	(2411)				
		0	100	2039	2260	(2478)				

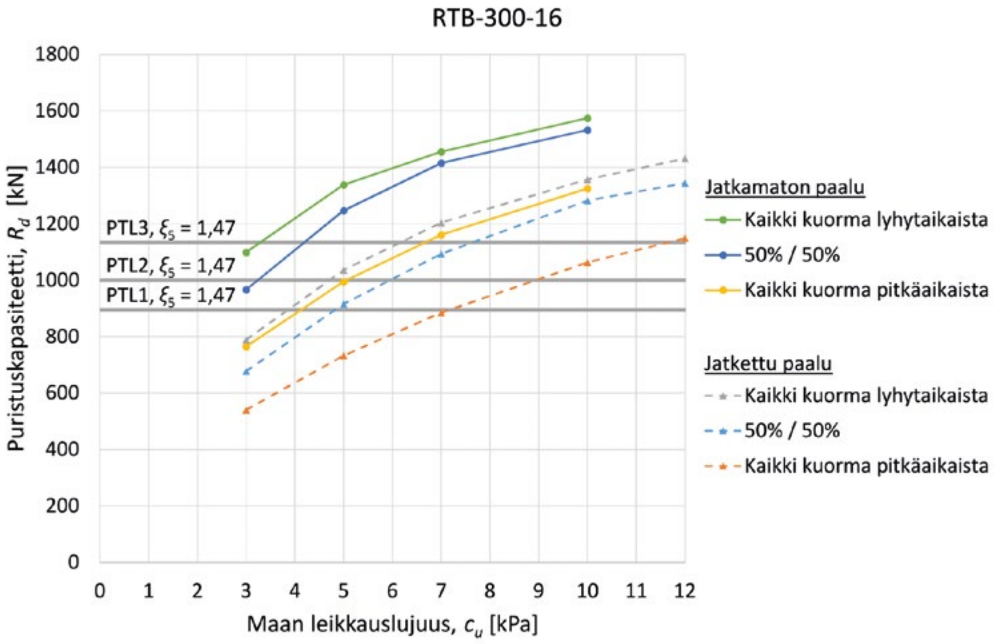
*) Correlation coefficient ξ_5 = 1,47
**) In PTL3, the geotechnical resistance, $R_{d:geo}$, of piles must be verified with either dynamic or static load testing.

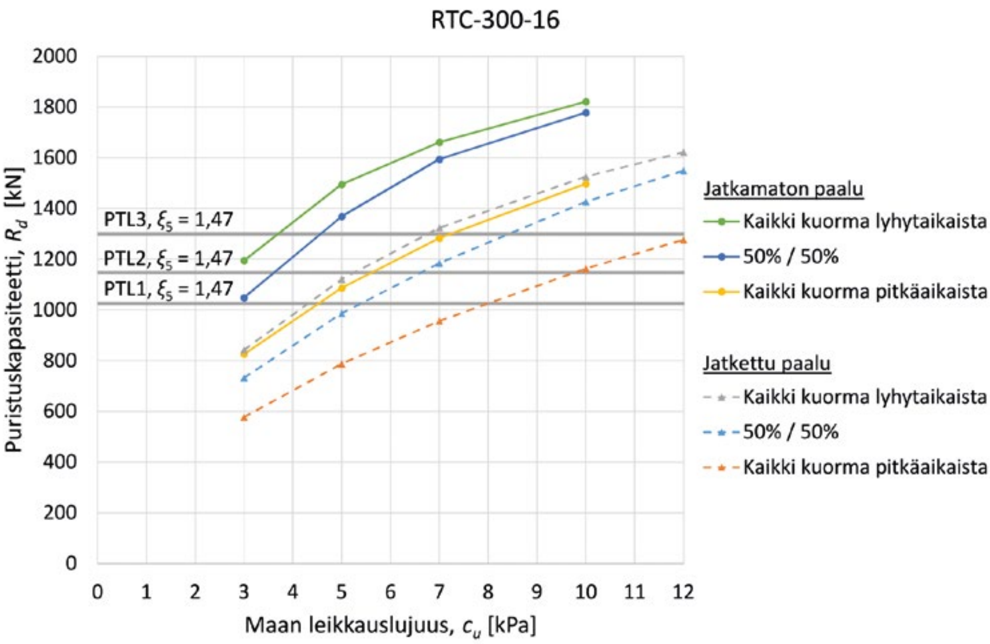
A structural resistance ($R_{d:str}$) value given in brackets (or no value) indicates that the pile's compressive capacity is determined according to the pile's maximum geotechnical resistance in all cases when using this Product Sheet's end of drive criteria.

The figure below shows the structural compressive capacity of different RT Betonipaalut® pile types in the ultimate limit state as a function of the soil's shear strength for extended and unextended piles for three ratios of short- and long-term loads (100%, 50% and 0%).

The horizontal lines indicate the geotechnical resistances for different piling work classes.







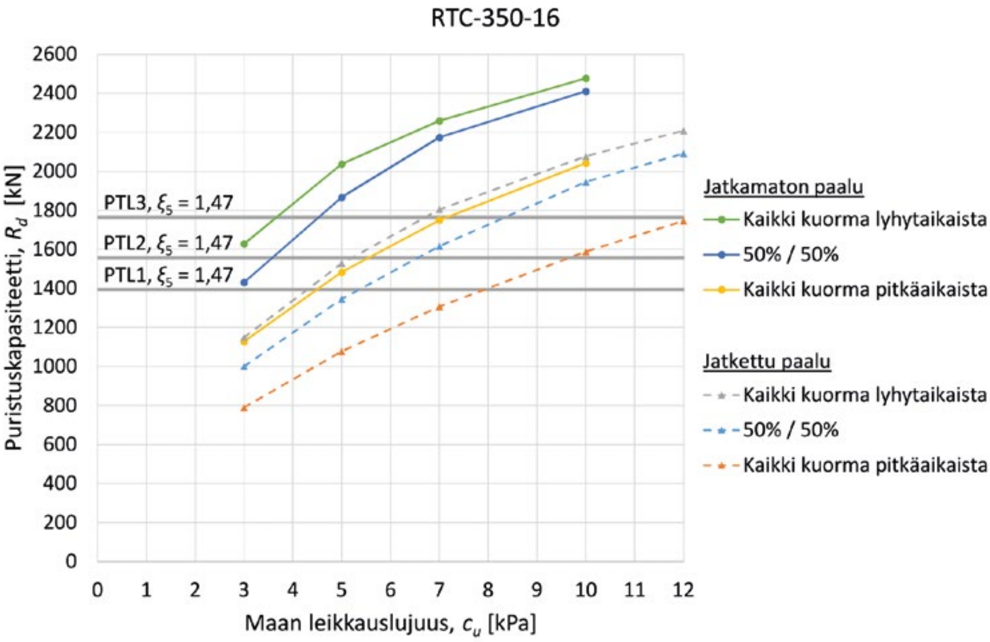


Figure 2.1 Structural compressive strength of different RT Betonipaalut® pile types in the ultimate limit state as a function of the soil's shear strength and geotechnical resistance in different piling work classes, according to the final strike conditions of subsection 3.4.

If the geotechnical compressive capacity of the pile is to be verified by means of dynamic load testing instead of the end of drive criteria specified in this Product Sheet, the pile capacity shall, at the design stage, be determined using the Rc;max values given in Table 2.4. Rc;max denotes the maximum geotechnical compressive resistance that can be assigned to a pile based on the driving work. The design geotechnical compressive capacity of the pile shall not exceed the value obtained by dividing $R_{c;max}$ (defined according to the piling work class) by the correlation factor ξ_5 and the partial factor for piles γ = 1.2. The correlation factor ξ_5 depends, among other things, on the number of test piles and is defined in more detail in PO-2016, Part 1, Clause 4.5.2.4.

The achieved design value of the geotechnical compressive resistance shall ultimately be determined based on the average or minimum result of the dynamic load tests, and it shall always be at least equal to the design value of the geotechnical compressive capacity defined at the design stage. During installation and dynamic load testing, the driving force (measured maximum force FMX) and the mobilised static resistance may exceed the $R_{c;max}$ values. However, the concrete compressive stress during driving shall not exceed 80 % of the characteristic compressive strength of concrete (or 88 % if the stresses are measured directly).

If the final strike instructions in subsection 3.4 of this Product Sheet are used, it can be assumed with reasonable certainty that the compressive stress of concrete remains within acceptable limits during installation. During dynamic load testing, exceeding the maximum stress with a single load test blow is acceptable as long as no damage is visible on the pile and the pile's integrity is confirmed with a new test blow after the excessive blow.

It should also be noted that in soft soil conditions, the pile capacity may be governed by the structural capacity of the pile rather than by its geotechnical compressive capacity. The corresponding structural capacity values are presented in Table 2.3.

Table 2.4. RT Betonipaalut® piles' maximum compressive strength determined by impact strength, $R_{c:max}$.

	$R_{c;max}$ [kN]		
Pile type	**PTL1**	**PTL2**	**PTL3**
RTB-250-16	1101	1231	1395
RTB-300-16	1579	1765	2000
RTC-300-16	1811	2024	2293
RTC-350-16	2459	2748	3114

2.3.3 RT Betonipaalut® N–M interaction diagram

The combined effect charts (normal force and bending moment) of different RT Betonipaalut® pile types are presented in Figures 2.2 through 2.5. The charts indicate the strength of the piles for a bending moment along the side of the pile or along the diagonal of the pile. The diagonal chart is recommended because it is typically difficult to ascertain that the side of a pile is installed in the direction of the bending moment. The strength indicated by the combined effect chart is compared to the design loads of the pile. The charts also indicate the maximum values for the pile's geotechnical resistance by piling work class, according to the final strike conditions of this Product Sheet.

The combined effect charts are drawn up according to the bilinear material model of concrete in Eurocode SFS-EN 1992-1-1.

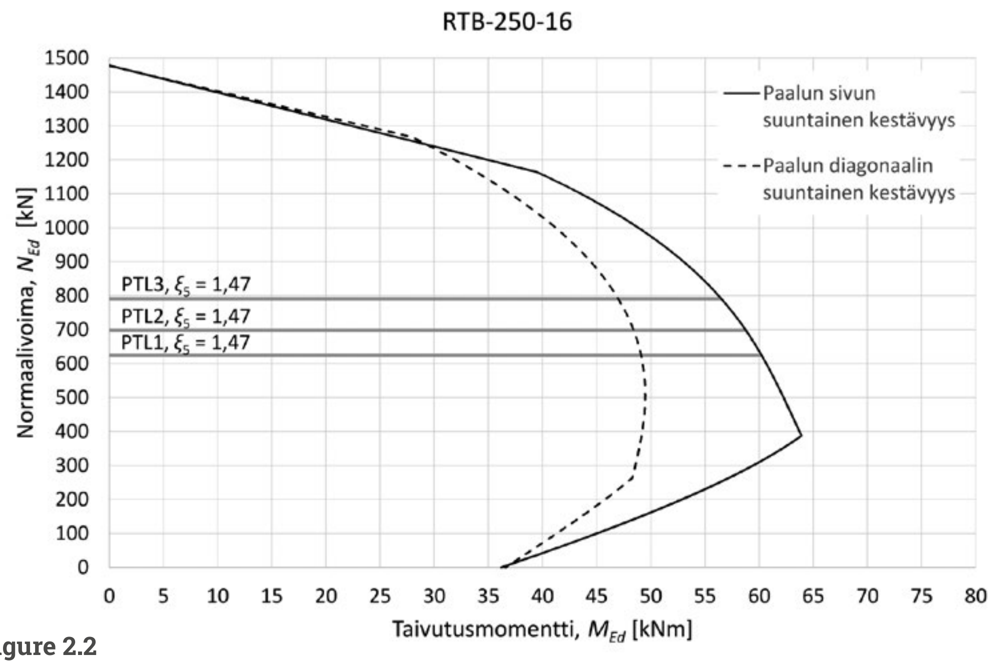


Figure 2.2
Pile Type RTB-250-16
ξ_5 = correlation coefficient (PO-2016, 4.5.2.4)
PTL1 = piling work class 1
PTL2 = piling work class 2
PTL3 = piling work class 3

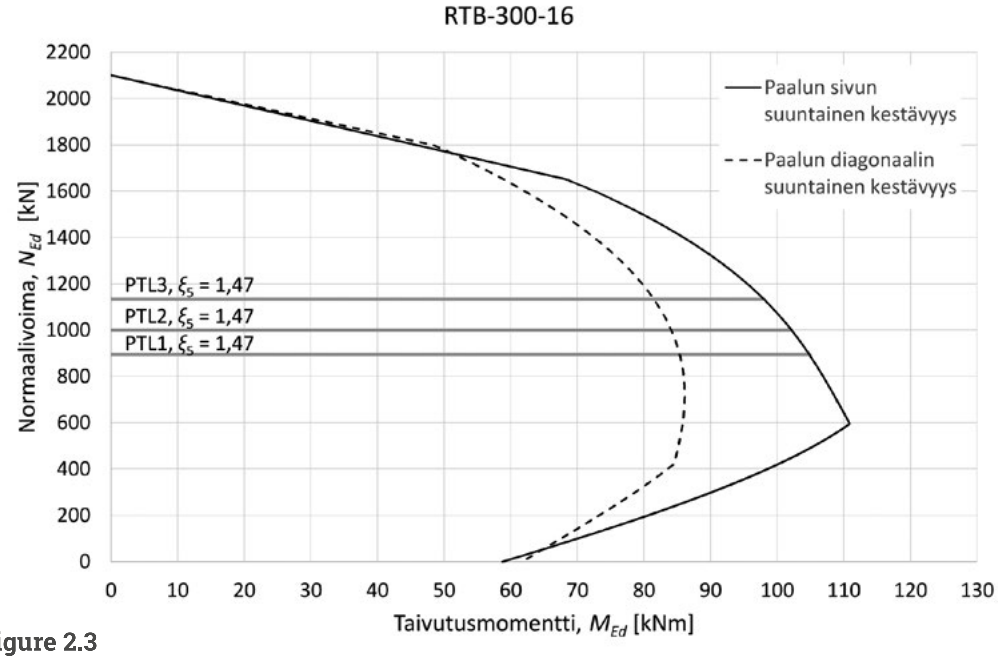


Figure 2.3
Pile Type RTB-300-16
ξ_5 = correlation coefficient (PO-2016, 4.5.2.4)
PTL1 = piling work class 1
PTL2 = piling work class 2
PTL3 = piling work class 3

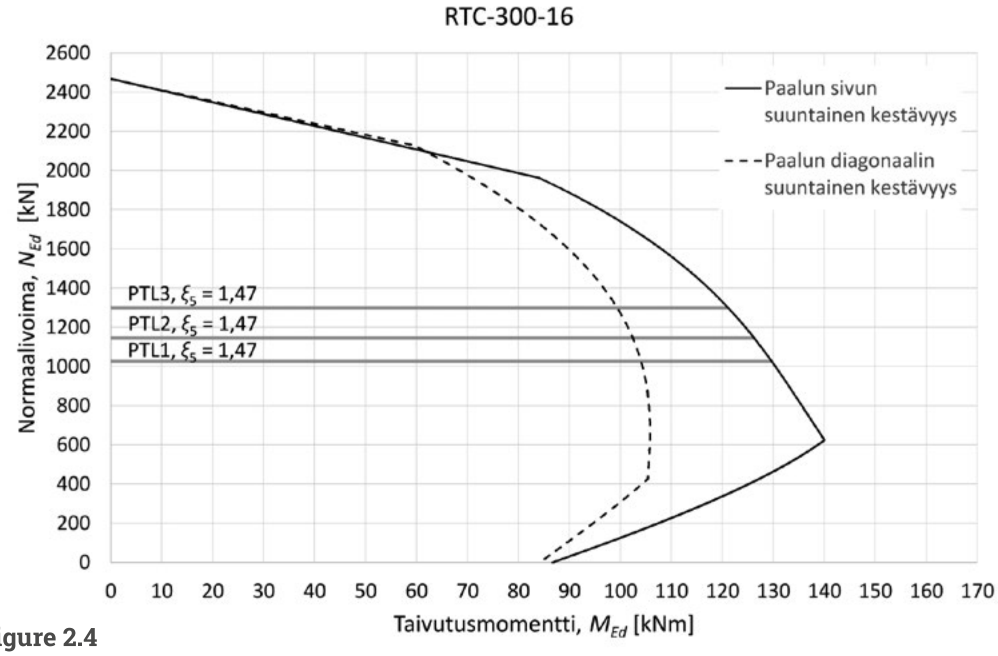


Figure 2.4
Pile Type RTC-300-16
ξ_5 = correlation coefficient (PO-2016, 4.5.2.4)
PTL1 = piling work class 1
PTL2 = piling work class 2
PTL3 = piling work class 3

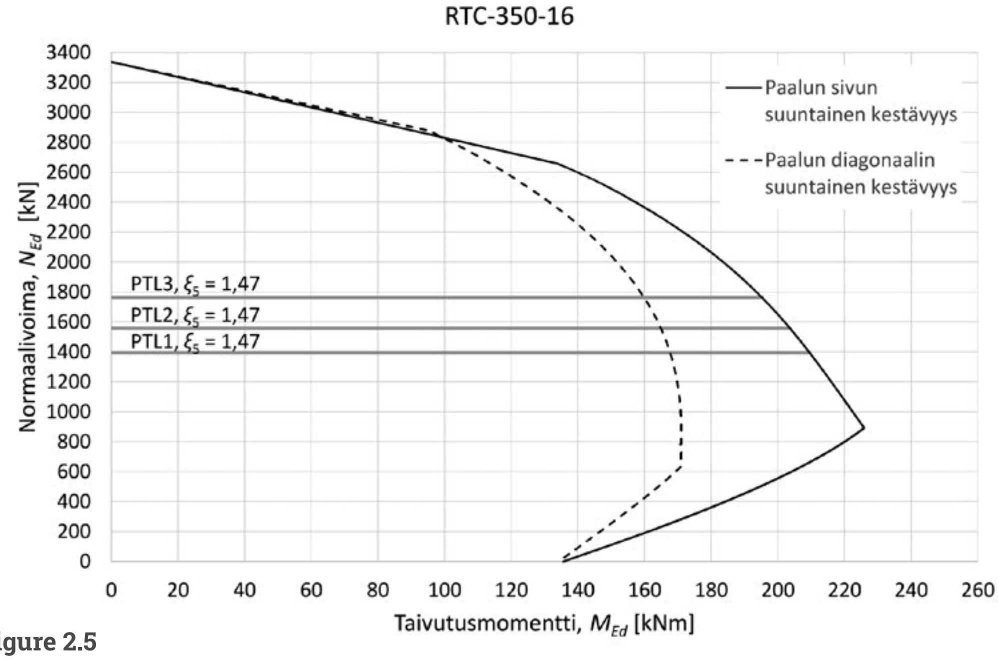


Figure 2.5
Pile Type RTC-350-16
ξ_5 = correlation coefficient (PO-2016, 4.5.2.4)
PTL1 = piling work class 1
PTL2 = piling work class 2
PTL3 = piling work class 3

Further information for design in exceptional situations

Paaluinfo 1/2021: Täydentäviä ohjeita teräsbetonipaalutuksen suunnitteluun ja toteutukseen (available for download at betoni.com).

2.3.4 Design guidelines for exceptional situations

Pile diving

A pile may dive unexpectedly during driving, meaning the toe only reaches the desired load capacity below the target level. Normal extensions of reinforced concrete piles must be designed in advance and fitted during manufacturing – if unforeseen extensions are required on site, an alternative solution is needed. One option is to add an extension to the pile in order to attach the head to the structure.

If an on-site extension is used, the connection to either the structure or the extension should be rigid to avoid creating a mechanism. If a pile is supported below its target level, its head will fall below the piling level because the design pile length is no longer sufficient. In this case, the installation will probably be finished with an auxiliary pile with the head of the pile supported below the piledriving bed. The head of the pile must be dug out, the steel exposed by drilling (Figure 2.6 a), and a mould prepared for casting the extension. Alternatively, the pile may be placed 50 to 100 mm inside the extension without exposing the steel (Figure 2.6 b) and the connection treated as a flexible joint. In this case, the extension must be attached rigidly to the overlying structure.

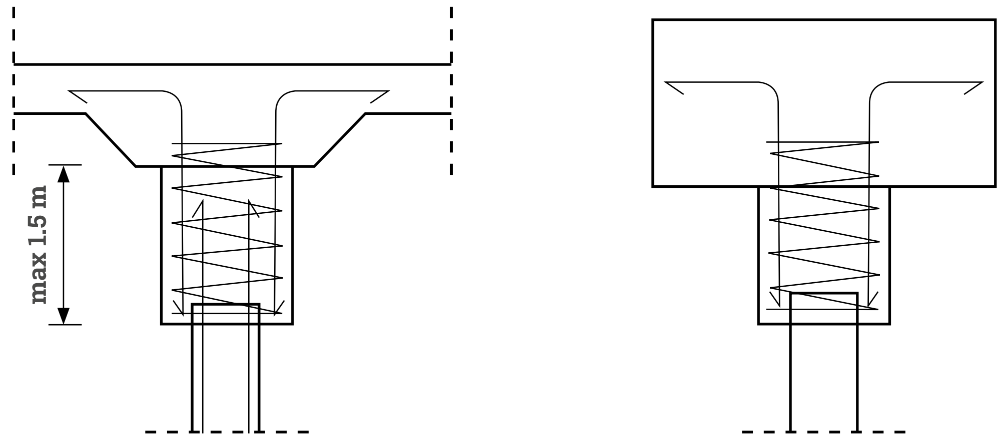


Figure 2.6. Connection between a sunken pile and base.
a) Rigid joint, transmits moment (pile main bars attached to the base).
b) Flexible joint, no moment transmission (pile main bars unexposed).

If a pile sinks unexpectedly by more than 1.5 metres below the target level, exposing the pile will be very difficult because the walls of the pit must be retained or the pit dug very wide. In this case, installing a longer replacement pile that accounts for the deviation in penetration is probably more economical than attempting to extend the first pile. The effects of replacement piles on the overlying structure must be assessed on a case-by-case basis.

Recommendations for designers:

- If the penetration depth of piles is uncertain, discuss the matter with the contractor to prepare for potential issues in advance.
- If necessary, plan test piling to confirm the expected pile penetration depth.
- If possible, design the structure to allow the installation of additional replacement piles. This is also recommended because piles may need to be abandoned due to damage or snapping.

Axial spin during installation

If a compressed pile spins around its axis, this does not affect its capacity in terms of buckling. Piles will always buckle in the weaker direction.

The direction of bending affects the bending moment capacity of a pile, especially if normal force is present simultaneously. Bending may occur at the head of a pile under the following circumstances:

- The pile is connected rigidly to the base.
- The pile comes under a bending moment due to shifting in relation to the surrounding soil, causing mobilised resistance on the pile's side.
- The pile is twisted in relation to the base by its rigid connection due to movement of the base.
- The pile comes under load due to an eccentric force or moment at its head.

The moment capacity of a pile is always weaker along its diagonal. The mode of failure in bending is the tensile breaking of the rebar, same as perpendicular bending against the pile's side. Therefore, the pile must be attached to the base in the same way in both cases, i.e. the bond length must be designed for fully loaded rebar if the full bending break capacity is used. In this case, the difference in capacities shown by the combined effect charts in subsection 2.3.3 must be considered for bending in different directions.

The area of projection is larger for piles that shift in relation to the soil along their diagonal. This affects how the structure and soil work together. As a result, the maximum side resistance achieved in the ultimate state is the same in both cases, according to PO-2016. However, a diagonally loaded pile is able to mobilise greater forces per unit of length due to its larger area. Accordingly, the maximum side resistance (movement required to break the soil) is greater along the diagonal.

If a pile is under a bending moment along the diagonal, this must be accounted for in dimensioning by selecting the corresponding capacity. The risk of pile rotation makes it impractical for new designs to dimension piles according to the maximum of their bending moment capacity – a safety margin should be allowed for deviations during execution. The mode of failure in bending at the pile-base interface remains the tensile breaking of the steel despite the concrete of the base having a lower strength compared to the pile. Insufficient bond length will result in anchorage failure, which can be considered to be similar to the tensile breaking of rebar in terms of the pile connection.

Recommendations for designers:

- Active horizontal loads borne by side resistance should be avoided with reinforced concrete piles.
- The risk of pile spin should be accounted for in designs by choosing a lower bending capacity, for example.
- Pile anchorage bars are sufficient for attachment, but oblique bending will result in lower capacity and must be analysed separately.

2.4 Betonipaalut® CO_2 emissions (carbon footprint)

In weak soil, driven reinforced concrete pile foundations already have the lowest carbon footprint in terms of CO_2 emissions during construction, but their long design service life also reduces the building's total life cycle carbon footprint.

Life cycle assessments (LCA, SFS-EN 15804 + A1) are available for all standard RT Betonipaalut® piles. The LCA describes the product's environmental impacts, which can be useful for a projects environmental impact analysis, for example. The LCA also lists the global warming potential (GWP) of the product, which is used to calculate the foundation's CO_2 emissions during construction. The GWP figure includes the pile's product stage CO_2 emissions ("from cradle to gate," life cycle modules A1–A3) from raw material supply (including rebar), transport and manufacturing. In this case, GWP does not include the emissions of transporting the pile product to a worksite.

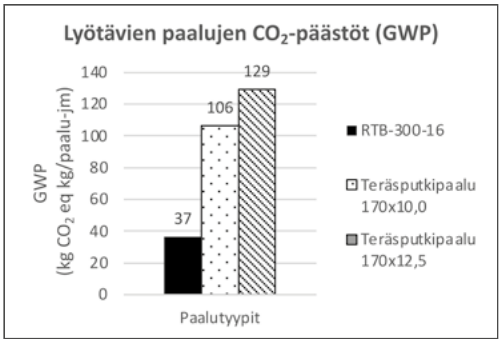
RT-Betonipaalujen® CO2 emissions GWP_{TOTAL}:
- RTB-250-16: GWP = 26,3 kg CO_2 eq/per pile-metre
- RTB-300-16: GWP = 36,6 kg CO_2 eq/per pile-metre
- RTC-350-16: GWP = 52,1 kg CO_2 eq/per pile-metre

Special pile CO_2 emissions (examples only, vary by case):
- RTB-300-SR GWP = 37 kg CO_2 eq/per pile-metre
- RTB-300-E GWP = 41–43 kg CO_2 eq/per pile-metre
- RTC-300-16 GWP = 39–41 kg CO_2 eq/per pile-metre

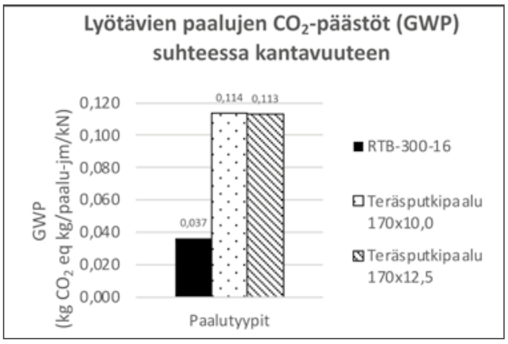
RT Betonipaalut® products are manufactured by a nationwide network of pile factories, which minimises the CO_2 emissions of their transport.

Figure 2.7 shows the CO_2 emissions of different pile types, including the CO_2 emissions of their raw materials, transport and manufacturing (GWPTOTAL) per metre of pile. The second part of Figure 2.7 shows the emissions of piles per load capacity (kg/per pile-metre/kN), allowing for comparisons that account for differences in load capacity.

Driven pile CO_2 emissions (GWP)



Driven pile CO^2 emissions (GWP) per load capacity



Sources:
1. Teräsbetoninen lyöntipaalu, Verifioitu elinkaariarvio (LCA), Vahanen Environment Oy, 30 April 2021.
2. SSAB, Steel piles EPD (S-P-02243, version 1.0), Ecobio Oy, 2020.

Figure 2.7. CO_2 emissions of drive piles (modules A1–A3).

Further information about the environmental impacts of RT Betonipaalut® piles

The RT Betonipaalut® LCA report can be downloaded here

3. PILING WORK

Piles must be transported, stored and handled according to
the instructions givenin this Product Sheet.

3.1 Occupational safety

This Product Sheet includes recommendations for the handling of piles and their equipment. The manufacturer is not liable for any accidents or damage that occurs at the worksite. This Product Sheet is not exhaustive nor does it include all general or specific matters that must be considered in the handling of piles and their equipment. Above all, piles must be handled according to the relevant rules and regulations, the PO-2016 guidelines, and worksite instructions.

All personnel working with piles must wear safety helmets, safety shoes, safety gloves, other safety clothing, and eye protection according to their worksite's instructions.

3.1.1 Pile transport

The roadways and unloading point of the worksite must be drivable (maximum gradient 1:7, gritted and free of snow in winter), stable (load bearing), and spacious enough for the vehicles delivering piles.

The working area and surface for receiving deliveries must be sufficiently level, spacious, firm and insulated to allow the deliveries to be completed safely without endangering the delivery personnel, bystanders or the environment. Before the work may begin, the buyer must inform the party delivering the piles of factors affecting performance and safety in the delivery area such as structures affecting the working area's load capacity (excavations, drains, etc.) and installations above the unloading point (power lines etc.) that must be accounted for to ensure occupational safety.

Lifting and hoisting must always be carried out according to the relevant general safety rules and regulations. Likewise, lifting equipment and accessories must be used according to the supplier's instructions. Only certified lifting accessories may be used for lifting and moving work. Standing or passing under a suspended load is strictly prohibited. Piles must be supported during transport and storage and tied down carefully during transport to avoid damage.

Piles and their accessories are not fragile, but careless handling can still damage them enough to affect their properties and usefulness. During the handling of pile products, permanent deformation and other damage must be avoided.

3.1.2 Pile storage and handling at worksites

At worksites, piles and their equipment must be stored and handled in ways that do not damage them. The recommended method for moving a pile on site is to use both lifting lugs with the correct sling angle. Table 3.1 shows the minimum lifting chain lengths for different lengths of pile.

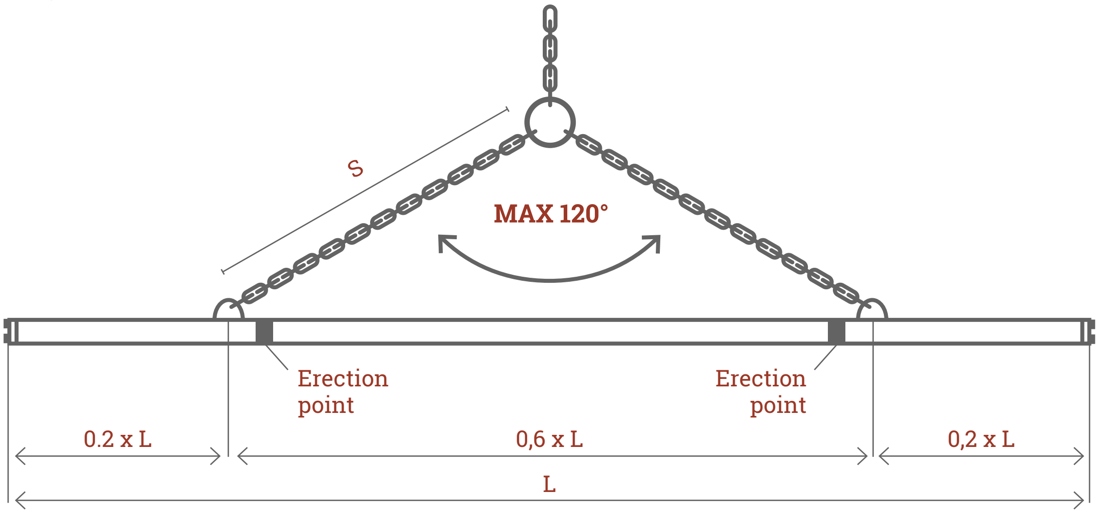


Figure 3.1 Moving a pile on site.

For safety reasons, piles may never be moved on site by dragging from the lifting lug because the lug may fail unexpectedly. Piles may only be dragged on a level surface by tying a lifting chain as explained in subsection 3.1.3 Pile Erection at Worksites.

If piles are laid on a surface, it must be level enough to not risk damaging the piles during storage. For storage, piles must be lifted onto (wooden) supports located at the lifting lugs or side by side on level ground. Piles should be stored close their driving locations at the worksite. Storing piles in multiple layers is not recommended.

Unloading piles at worksites

- Scaffolding may not be placed next to the vehicle because piles are unloaded onto the ground.
- Personnel must remain standing on the vehicle's bed while attaching lifting hooks to
- the lifting lugs (for a working height under two metres).

3.1.3 Pile erection at worksites

To erect a pile, attach a tightening lifting chain around the pile outside the area between the lifting lug and the pile's head. Figure 3.1 shows the correct area for attaching a lifting chain (= erection point).

The lifting lug cannot be used to erect piles because it is not rated to operate in that direction and may fail.

Further information on safe piledriving practices (only in Finnish)

Finnish Transport Infrastructure Agency: Paalutustyön turvallisuusohje 2020

Finnish Transport Infrastructure Agency: Paalutustyöturvallisuuden huomioiminen suunnitteluvaiheessa, Väyläviraston oppaita 1/2020/2020

3.2 Pile installation

Sufficient working area must be provided to carry out piledriving safely without endangering the environment. The project supervisor is responsible for preparing a written use plan for the construction site (PO-2016, 5.3.1).

For documentation, the standard piling record template created by the Finnish Geotechnical Society is recommended. The template is available free of charge in the RIL web shop under Paalutusohje.

3.2.1 Piling platform

The piling platform must always be designed separately in each case, according to the strength of the soil and the equipment in use. The site's responsible ground engineer is responsible for designing the piling platform.

Before commencing the piling works, the parties involved in the piling contract shall jointly inspect the site conditions, including the bearing capacity and inclination of the piling platform, any excavations, and the designated storage area for piles.

Further information for piling platformdesign:

- Finnish Transport Infrastructure Agency: Paalutustyöturvallisuuden huomioiminen suunnitteluvaiheessa, Väyläviraston oppaita 1/2020

3.2.2 Pile cushions and driving plate

PILE CUSHIONS

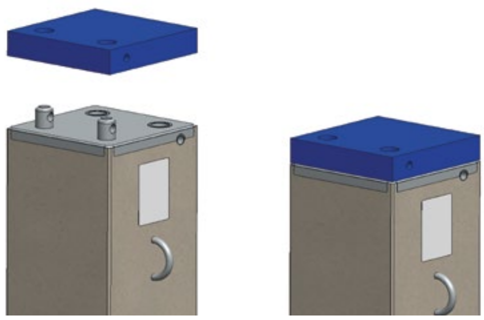
Cushions reduce the compressive waves generated in a pile by the ram's strikes and also protect the head of the pile. The cushioning material should retain its properties as long as possible during driving strikes, especially the modulus of elasticity (MOE). The cushion must have an MOE of less than 1,000 MPa and remain stable under striking.

One common material is dry hardwood (birch, beech or oak) with the grain set perpendicular to the pile. If a wooden cushion may not be used due to environmental or safety concerns (combustion gases, smoke or flame), an industrially manufactured special material is recommended to achieve the desired melting point or fire resistance at operating temperature.

The cushion must be inspected before driving each pile and monitored during pile installation to spot excessive wear in time.

DRIVING PLATE

A driving plate is used to protect pile extensions when driving the lower segment into firm soil. The purpose of the driving plate is to protect the locking components of the extension.



Extended piles must be driven with a driving plate that is locked in place to prevent it from falling off.

3.3 Driving blows

Driving generates both compressive and tensile stresses in piles. These may not exceed the limits specified in standard SFS-EN 12699 at any point during installation.

Typically, piles experience the greatest tensile stress during driving strikes when the pile's toe enters soft soil layers. The RT Betonipaalut® products included in this Product Sheet have been analysed for tensile strength in accordance with PO-2016.

- For driving a pile through cohesive soil, the lowest possible drop height is recommended; a limit of 10 cm is suggested for all rams between three and five tons.
- When driving a pile through a fill layer underlain by a cohesive soil layer, special caution shall be exercised, and the drop height shall be kept as low as possible.

3.4 End of drive criteria for RT Betonipaalut®

The final driving blows presented in the Product Sheet have been calculated in accordance with the method presented in PO-2016. The calculations for the end of drive criteria have been made for 3-tonne, 4-tonne, and 5-tonne hammers. The hammer types are divided into three categories: non-accelerated (all freely falling hammers), accelerated (hydraulically accelerated hammers, e.g. Junttan HHK A/S series) and accelerated > 1 g (hydraulically accelerated hammers with an acceleration greater than 1 g, e.g. Junttan SHK series).

All pile types shall be driven to a permanent set of **20 mm or less in 10 blows**, using the driving energy or drop height specified in the tables. For piling rigs equipped with energy monitoring systems, the driving energy shall be used as the primary criterion. In the tables, the drop height has been rounded to the nearest 5 cm. A more precise specification of the drop height is not considered practical, as the determination of the drop height during piling work is generally based on visual estimation.

The end of drive criteria tables may be used for hammers provided that the pile cushion complies with Section 3.2.2, i.e. the elastic modulus of the cushion is approximately 1 000 MPa.

For piles in class PTL3, the end of drive criteria shall always be verified by PDA measurements. The table presents indicative end of drive drop heights corresponding to PTL3 requirements, which may be used for preliminary assessment only.

When the pile toe reaches a bearing soil layer and the pile penetration per blow decreases, end of drive blows are applied, typically 3 to 5 series of ten blows each. The number of end of drive series shall be determined according to the prevailing conditions: if the pile penetration decreases gradually, more series shall be applied, whereas if the penetration decreases rapidly, fewer series are sufficient.

If the pile penetration is less than 10 mm in 10 blows, driving shall be stopped immediately to prevent damage to the pile. Driving may be terminated if the pile is close to the target level, or if there are no specific reasons to continue driving, for example when the pile is still far above the target level or is intended to bear on rock etc. If driving is continued, a maximum drop height of 0.2 m shall be used.

Effect of pile length on driving energy / drop height.

Short piles

- Piles between 5 and 10 metres: the driving energy may be reduced by 10%, which in practical terms corresponds to a 5 cm reduction in drop height.
- Piles under 5 metres: the driving energy may be reduced by 20%, which in practical terms corresponds to a 10 cm reduction in drop height.

Long piles

- Piles equal to or greater than 50 metres: the driving energy shall be increased by 10%, which in practical terms corresponds to a 5 cm increase in drop height

If the drop height specified in the table exceeds 50 cm, it is recommended to use a heavier or more efficient hammer, or to verify the end of drive criterion by means of a PDA measurement.

Table 3.1. RTB-250-16 drop height and blowing energy. H = drop height, E = blowing energy

Piling work class	Ram mass	Unaccelerated		Accelerated		Accelerated >1g	
		H[cm]	E[kNm]	H[cm]	E[kNm]	H[cm]	E[kNm]
PTL1	3 t	35	9	30	9	25	9
	4 t	30	9	25	9	20	9
	5 t	25	10	20	10	20	10
PTL2	3 t	40	11	40	11	30	11
	4 t	35	12	30	12	25	12
	5 t	30	13	25	13	20	13
PTL3	3 t	55	14	45	14	40	14
	4 t	45	15	40	15	30	15
	5 t	40	16	30	16	25	16

Table 3.2. RTB-300-16 drop height and blowing energy. H = drop height, E = blowing energy

Piling work class	Ram mass	Unaccelerated		Accelerated		Accelerated >1g	
		H[cm]	E[kNm]	H[cm]	E[kNm]	H[cm]	E[kNm]
PTL1	3 t	50	12	40	12	35	12
	4 t	40	13	35	13	30	13
	5 t	30	14	30	14	25	14
PTL2	3 t	60	15	50	15	45	15
	4 t	45	16	40	16	35	16
	5 t	40	17	35	17	30	17
PTL3	3 t	75	19	65	19	55	19
	4 t	60	20	50	20	40	20
	5 t	50	21	40	21	35	21

Table 3.3. RTC-300-16 drop height and blowing energy. H = drop height, E = blowing energy

Piling work class	Ram mass	Unaccelerated		Accelerated		Accelerated >1g	
		H[cm]	E[kNm]	H[cm]	E[kNm]	H[cm]	E[kNm]
PTL1	3 t	60	16	55	16	45	16
	4 t	50	16	40	16	35	16
	5 t	40	17	35	17	30	17
PTL2	3 t	75	19	65	19	55	19
	4 t	60	20	50	20	40	20
	5 t	50	21	45	21	35	21
PTL3	3 t	90	24	80	24	65	24
	4 t	70	25	65	25	50	25
	5 t	60	26	55	26	45	26

Table 3.4. RTC-350-16 drop height and blowing energy. H = drop height, E = blowing energy

Piling work class	Ram mass	Unaccelerated		Accelerated		Accelerated >1g	
		H[cm]	E[kNm]	H[cm]	E[kNm]	H[cm]	E[kNm]
PTL1	3 t	80	21	75	21	60	21
	4 t	65	22	55	22	45	22
	5 t	55	23	45	23	40	23
PTL2	3 t	100	26	90	26	75	26
	4 t	75	26	65	26	55	26
	5 t	65	27	55	27	45	27
PTL3	3 t	125	31	110	31	90	31
	4 t	95	33	85	33	70	33
	5 t	80	34	70	34	60	34

Uusi JPAD-lyöntisuoja teräsbetonipaaluille

Junttan on kehittänyt uuden JPAD-lyöntisuojan puisten tai muista puun kaltaisista materiaaleista valmistettujen lyöntisuojien korvaamiseksi paremmin toimivalla ratkaisulla. Uuden konseptin mukainen JPAD-lyöntisuoja valmistetaan PE-erikoismateriaalista.

PE-ERIKOISMATERIAALISTA VALMISTETUN JPAD-LYÖNTISUOJAN EDUT:

- Testaustyön tuloksena on löydetty materiaali, joka omaa optimaalisen energian siirtymisen paaluun jokaisella lyönnillä homogeenisen rakenteen ja erityisesti tarkoitukseen kehitetyn kimmokertoimen avulla. Kimmomoduli pysyy vakiona lähes koko käyttöiän < 1000MPa koko elinkaari.
- Puhtaampaa ja turvallisempaa paalutusta, ei pala tai savua, ei haitallisia päästöjä. Työntekijöiden altistus savukaasuille ja pienhiukkasille vähenee verrattuna puun käyttöön paalun ja iskutyynyn välissä. Savua ei myöskään leviä paalutustyömaan lähialueille. Riippuvan taakan alla työskentely myös vähenee.
- Paalun suojaus, sulan lyöntisuojan näkee visuaalisesti valumana paalun päällä.
- JPAD-lyöntisuoja on helppo vaihtaa, ja kulunut pehmike sulaa paalun päälle eikä pakkaudu paalupesään.
- JPAD-lyöntisuoja kestää pidempään ja on tasalaatuista.
- JPAD-lyöntisuoja on täysin kierrätettävää materiaalia, ja syntynyt jäte voidaan hävittää energiajätteenä tai toimittaa muihin muovin kierrätyspalveluihin uuden muovin valmistamiseksi. EC jätekoodi 120105 ja 200139, EWC: ei vaarallinen aine.
- Materiaali on varastointikelpoinen, vähäiset mitta- ja ominaisuuksien muutokset.

MUITA OMINAISUUKSIA:

- ei liukene veteen DIN ISO 62
- laaja käyttölämpötila -40...+40 Cels.
- muokkautumislämpö +80 Cels.
- sulamislämpö +200 Cels.
- syttymislämpö +340 Celsius, materiaalin palaessa haisee steariinille
- REACh luokittelu ja rekisteröint ei rekisteröitävä aine
- paalukoot 250*250, 300*300, 350*350, 400*400 tai erillinen paalukoko/malli
- yhtäjaksoinen lyöntimäärän kesto 3000 - 5000 lyöntiä, pienemmillä lyöntimäärillä lyöty 63kpl 350*350 paalua L=12m
- lyöntimäärä kahdella s=40 mm JPAD-lyöntisuojalla (käytetään parina) on noin 9000 lyöntiä

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Tuomas Uusheimo

Notes

The 2018 Product Sheet for RT Betonipaalut® products is an updated version of "TUOTELEHTI PO-2011 mukaiseen paalutustyöhön" that meets contemporary needs and requirements. This update was set in motion by the publishing of Paalutusohje 2016 by RIL ry and the completion of an extensive study of pile load bearing design commissioned by the Finnish Transport Agency and RTT ry from Tampere University of Applied Sciences. The study has resulted in a more accurate model for pile dimensioning and the development of a new product family, RT Betonipaalut®, which allows for higher loads than previous pile products. This Product Sheet is an updated guide for the design of concrete pile foundations with RT Betonipaalut®, including complementary occupational safety guidelines. This Product Sheet provides a concise manual for the use of RT Betonipaalut® piles and the design of pile foundations in accordance with the updated Paalutusohje 2016 guidelines and relevant standards. This Product Sheet presents new products and solutions for various conditions as well as working instructions for piledriving.

This updated version supersedes the previous Product Sheet published on 18 September 2018. Among other things, this new version includes CO2 emission information for RT Betonipaalut® products.

RT Rakennusteollisuus