DUCTILE IRON PILES – The TRM Piling System – Data sheet

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Ductile Iron Piles are a proven, viable alternative to conventional piles, and for the past 30 years have been successfully used throughout the whole world. The installation process of TRM piles lends itself to both large and small projects. Because of their installation efficiency they provide a substantial cost and time savings for the project.

Background

The driven ductile cast iron pile is a simple, fast and highly effective pile system. Over the last 30 years over 5 million meters of this pile system has been installed worldwide predominantly in Europe. TRM piles are a pre-fabricated driven pile system utilizing high strength ductile iron pipes which are manufactured using a spun-cast process having outside diameters of 118 and 170 mm. The standard pile lengths are 5,0 m long. The pipes are manufactured with a tapered socket with an internal shoulder for full engagement at top and a tapered spigot at the bottom. The individual pile sections can be connected with this Plug and Drive® connection to drive a pile of any length.

The TRM system's inherent advantage is the simplicity of the installation process. The piles are driven to refusal or to a required penetration depth with the use of a high-impact high-frequency hydraulic hammer (ie. Breaker hammer).

In most applications the hydraulic hammer is mounted on an appropriately sized excavator.

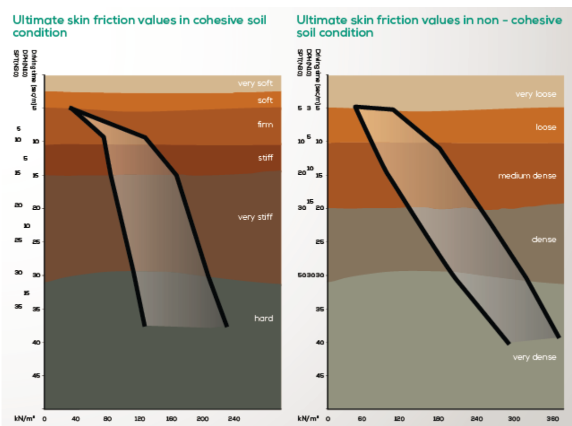
At the completion of driving the pile, the pile is cut off and the remaining section of pile is fitted with the appropriate driving shoe and serves as the lead section for the next pile.

Being able to reuse all the cut off section. The pile is then fitted with an appropriate pile cap plate to receive the load from the superstructure.

Based on job specific soil conditions, the pile can be installed as an end-bearing (non-externally grouted) pile or a friction (externally grouted) pile. Design loads according EuroCode (EC) up to 1,200 kN are possible for the 118mm diameter piles and around 2,400 kN is possible for the 170mm piles.

Externally grouted or friction piles are installed with an oversized patented conical grout shoe attached to the base of the lead pile section. As the pile is driven, the annulus created between the pile shaft and the soil is filled simultaneously with a sanded grout bonding the pile shaft to the surrounding soil. Grouted friction piles have external grout diameters of 220mm, 270mm, 320mm and 370mm. These friction piles can be used as tension elements with the addition of tension reinforcing within the pile annulus.

When considering skin friction piles, STP values should exceed 3 blows for cohesive soils and 4 blows for non-cohesive soils. Advancing piles in cohesive materials with blow counts exceeding 40 blows in cohesive soils and 60 in non-cohesive soils becomes difficult.



The load carrying capacity for skin friction piles should be based on a maximum friction embedment length of up to 15m. This limitation will prevent a progressive failure developing between the pile shaft and the surrounding soil.

Due to their small diameter, ductile iron piles, like other small diameter piles, have limited capacity to transfer lateral loads. Larger lateral load dissipation can be achieved by passive soil forces or raked piles.

Due to the relatively small diameter of TRM piles, buckling of the pile shaft must be considered in soft soil conditions with SPT values of less than 2, a buckling check is required. In cohesive soils with an un-drained shear strength with C_u<15kPa buckling needs to be investigated. In non-cohesive soils it can be assumed that lateral support provided by embedment in generally adequate.

For non-grouted TRM piles the minimum spacing between piles can be as little as 3d where "d" is the outside diameter of the pile. For grouted TRM piles the same rule applies.

Materials

Cast iron in the form of grey cast iron has been used for commercial pipeline construction since the 1800's in Europe. Grey cast iron has high resistance to mechanical and chemical influences. However, it is a very brittle material with low impact strength. Through a refined manufacturing process the tensile strength and flexural stiffness are dramatically improved. With the addition of magnesium graphite into the grey cast iron melt, graphite flakes are transformed into spherical graphite nodules and with appropriate heat treatment the embrittlement is prevented yielding a material of increased ductility and strength. Ductile cast iron is composed of 90-95% iron in the form of scrap metal. Table A lists the material properties of ductile cast iron. It should be noted that the high dynamic stresses generated by driving in some cases exceed the service level design stresses. The driving process can be thought of as a quality control measure of wall thickness and crystalline structure.

TABLE A

Ductile Cast Iron Material Properties	
Tensile Strength	420 MPa
Yield Strength	320 MPa
Compressive Strength	900 MPa
Modulus of Elasticity	170,000 MPa

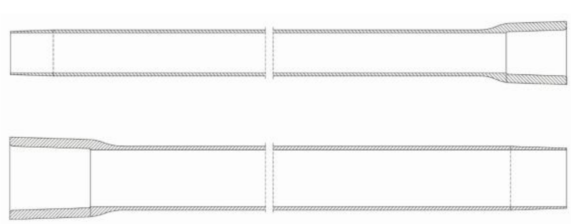
Manufacturing Process

Ductile iron piles are manufactured using a centrifugal spin-casting process. After magnesium is added to the cast iron melt the molten iron is placed into the rotating mold and a pile shaft of nearly uniform thickness is formed. The spigot end is formed with the use of a sand mold. The still glowing pipe is removed from the centrifugal mold and directed to an annealing furnace for a slow and steady cooling to ensure that the tensile and elongation properties are maintained. This annealing process creates also the very thick and high corrosion protection oxyd-layer which protect the DIPs much better as normal construction steel. Once the material has properly cooled the manufactured material is sampled and tested for material properties in accordance to factory quality control procedures (ISO 9001). In addition, the wall thickness of each pile is measured at 32 different locations with ultrasonic methods.

The pipes are then labeled with date and time of manufacture, then bundled and stored for shipment.

Components

The ductile iron pile system is a very simple pile system. The key element of the system is the Plug and Drive® jointing system. The lead end of the 5,0 m pile is a tapered socket with the drive end being a tapered spigot.

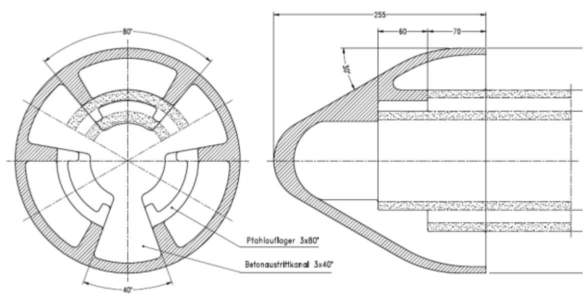


This joint system develops the full capacity of the pile shaft and offers a high degree of axial and bending stiffness. The manufactured 5,0m long elements can be jointed to form a pile of any length. During the driving process the high vertical driving forces cause high hoop stresses to develop in the tapered socket and friction-weld the two pile shafts. Testing of the joint has concluded that the joint system has a strength greater than the pile shaft. In fact, testing revealed that if the tapered spigot was shortened by 2.0 cm, the joint still maintained an axial strength higher than the base shaft.

The lead pile section is fitted with an appropriate pile driving shoe. For friction piles this is a conical grout point and for end bearing piles it a standard driving shoe or end plug. In normal unobstructed soils a flat shoe is used to form an end plug. For soils that contain obstructions that are to be penetrated a steel end plug with a rock point may be considered. The piles can also be driven with an open end. When driven in this manner, approximately 1.5 m of the lead section will be filled with soil during driving.

The end plug seals the pile against water and soil infiltration into the pile. With the base sealed the grout can be used to provide additional structural capacity and limits the corrosion exposure to the outside face of the pile.

For friction grouted piles a patented conical grout shoe is fitted onto the lead section.



The grout shoe is available in 220mm, 270mm, 320 mm and 370 mm diameters. The 220 mm grout shoe can be used only with the 118 mm diameter piles. The 270 mm, 320 mm and 370 mm shoes can be used with either the 118 mm or the 170 mm piles.

The friction pile driving process starts by laying the grout shoe at the proper location and inserting the spigot end of the pile shaft into the conical point. The pile is kept in place by a series of keeper plates within the conical grout shoe. As the pile is driven the conical grout shoe creates an annulus between the pile shaft and the surrounding soils. This annulus is immediately and consistently filled with a sand grout that is pumped down the pile shaft and exits within spaced between the keeper fins in the conical points. The breaker hammer driving tool is fitted with a special grout box adapter to allow the grout to flow from the grout pump through the driving tool down into the upper most pile shaft. The pumping rate of the grout should slightly exceed the take rate of the grout. In softer soils the grout takes tend to be higher due to outward bulging of the grout column.

For lighter loaded piles the load transfer from the foundation to the pile can occur through the pile and inner grout interface. With higher loads an appropriately sized bearing plate is seated onto the pile with a reinforcing bar or other required termination hardware. For tension piles, a threaded bar extends beyond the pile cut off.

In restricted headroom conditions the 5,0 m long shaft may prove to be too long for installation. Coupler hardware is available that allows the pile to be cut into shorter lengths resulting in reduced headroom requirements for driving.

The splice hardware is a friction connection that provides the full flexural resistance of the pile shaft.

Corrosion

The high carbon and silicon content in conjunction with the annealing process allows the nodular ductile cast iron to have a much higher corrosion resistance to structural steel. As with any other pile system the corrosiveness of the host soils needs to be considered. These corrosion concerns are eliminated with the use of externally grouted friction pile due to the encasement of the pile shaft in grout. For end bearing piles by filling the pile annulus with grout corrosion is limited to the exterior surface of the pile shaft.

Grout Materials

For end bearing piles, the pile annulus is filled with either a neat cement grout or sanded grout. The neat cement grout is tremied to the base of the pile. A sanded grout is pumped into the pipe annulus at the top of the pile. The choice of grout for end bearing piles depends on the size of the job, equipment and crew preferences. Either grout can fulfill the strength requirements.

For friction piles a sanded grout is the most suitable. The grout flows through two constriction areas. The first is at the driving point and the second is at the pile grout shoe. Experience indicates that the flowability of grout can be maintained by having grout with a minimum cementitious content of about 500 kg per cubic meter and a slump in the range of 180 mm. The shape of local sand aggregate will have an influence on the mix design.

Conclusion

Ductile iron piles have been successfully used on a range of projects throughout the world. Designs in accordance with the EuroCode (EC) have proved to be competitive with drilled micropiles and various other types of end bearing piles. TRM piles have been designed in both friction and end bearing applications. The TRM pile system provided both financial, as well as operational benefits to completed projects. For example, mobilizing an excavator versus a pile driving rig provided substantial logistical and driving advantages. When soil conditions differ adding pile length proves to be an easy task. We believe that the TRM system will not only have great advantages on tight sites with deep depths to the end bearing stratum we believe as well that the TRM system will be used very efficiently on projects where loads can be shed in friction at shallower depths. Both end bearing and friction TRM piles will prove to be cost-effective, adaptable to varied site grading conditions and the simplicity of mobilization. The virtually vibration free driving process allows the installation of piles immediately adjacent to existing structures.

General Information according:

ON 2567 (Austrian Standard)

Piles of ductile iron Dimensions, installation and quality assurance - Datasheet:

Ductile cast iron has to comply with the material specifications laid down in Table 1.

Table 1 — Specifications for the pile tube material

Characteristics	Material characteristics[a]
Tensile strength	≥ 450 MPa
Proportionality limit; 0,2% yield strength	≥ 320 MPa
Elongation at rupture	≥ 10%
Brinell hardness	≤ 250 HB
Compressive strength	≥ 900 MPa
Elasticity modulus *E*	170000 MPa[b]

[a] The values shown are 5 % fractile values.
[b] Orientation values for structural analysis

The dimensions shown in Table 2 have to be fulfilled.

Table 2 — Main pile tube dimensions

Section	Main dimension		Dimensions	Type 118	Type 170
Pile tube	Outside diameter	*E*	mm	118	170
	Pile tube length	*D*	mm	5000, 5500, 6000	5000, 5500, 6000
Socket	Inside diameter	*A*	mm	118.5	171.5
	Outside diameter	*B*	mm	≥ 162	≥ 220
	Cone			1 : 10 to 1 : 18	1 : 12 to 1 : 18
	Cone length	*C*	mm	155	215
Pile shaft	Wall thickness[a]	*S*	mm	7,5	9,0
				9,0	10,6
				10,6	–
	Straightness			according to ÖNORM EN 545:2011, clause 4.2.4	according to ÖNORM EN 545:2011, clause 4.2.4
Spigot	Cone			1 : 10 to 1 : 18	1 : 12 to 1 : 18
	Cone length	*F*	mm	110	150

[a] The wall thickness values shown are standard values; in case of (prior) structural analysis, other wall thickness values are also acceptable.

NOTE Pile tube length *D* is the effectively useable length of the pile not considering cone length *C* .

Figure 1 shows a system drawing, including main dimensions.

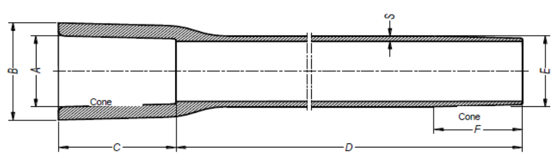


Figure 1 — System drawing of pile tube with socket and spigot

Table 7 shows Pile tube tolerances in general.

Table 7 — Pile tube tolerances

Section	Main dimension		Dimensions	Type 118	Type 170
Socket	Inside diameter	*A*	mm	± 0,5	± 0,5
	Cone length	*C*	mm	± 1,0	± 1,0
Pile shaft	Outside diameter	*E*	mm	+1,5 or –1,0	+2,5 or –1,0
	Wall thickness	*S*	mm	-0,8	–0,8
	Pile tube length	*D*	mm	± 100	± 100
	Straightness			according to ÖNORM EN 545:2011, clause 4.2.4	according to ÖNORM EN 545:2011, clause 4.2.4
Spigot	Outside diameter	*E*	mm	+1,5 or –1,0	+2,5 or –1,0
	Cone length	*F*	mm	–20,0	–20,0

NOTE A shipment of ductile cast iron piles may contain up to 10% short lengths. Shortening in 0,5-m-increments is permissible up to 1m.

Structural design and constructive execution

In the course of the ramming process, the individual pipe elements are assembled to form a pile and constitute a rigid, pressure-resistant connection. Project-specific pile lengths are acceptable, subject to prior structural analysis.

Depending on soil characteristics, the pile system is designed as an end bearing pile or as a skin friction pile. The load-bearing capacity of the pile depends on local subsoil conditions.

The following types of design can be distinguished:

– pile, unfilled

– pile filled with concrete

– pile filled with concrete, shaft grouted

– pile filled with concrete, shaft grouted with additional tensile reinforcement

The following partial safety factors are specified for piles made of ductile cast iron (in analogy to ÖNORM EN 1993-5 and ÖNORM B 1993-5, respectively):

– γ_{M0} = 1,00;

– γ_{M1} = 1,10 and

– γ_{M2} = 1,25.

The general calculation is carried out according to Eurocode 3 and Eurocode 4

Table 3, Table 4, Table 5 and Table 6 show the design values for normal load-bearing capacity N_{Sd} as a function of the type of ductile cast iron pile, its constructive design, the soil and the decrease in thickness due to corrosion (Δt).

Table 3 — Design value N_{Sd} for grouted piles and those non-grouted piles for which no decrease in wall thickness has to be considered (Δt = 0 mm)

Type	Nominal wall thickness	Normal load-bearing capacity design value N_{Sd}		
		Pile	Pile + Concrete (C20/25)	Pile + Concrete (C25/30)
	mm	kN		
118	7,5	833	944	972
	9,0	986	1091	1117
	10,6	1144	1243	1267
170	9,0	1457	1699	1759
	10,6	1699	1930	1988

Table 4 — Design value N_{Sd} for non-grouted piles in undisturbed, naturally grown soils with a standard useful life of 50 years (Δt = 0,6 mm)

Type	Nominal wall thickness	Normal load-bearing capacity design value N_{Sd}		
		Pile	Pile + Concrete (C20/25)	Pile + Concrete (C25/30)
	mm	kN		
118	7,5	762	873	901
	9,0	915	1020	1046
	10,6	1074	1172	1196
170	9,0	1355	1596	1657
	10,6	1596	1828	1886

Table 5 — Design value N_{Sd} for non-grouted pipes in non-compacted, non-corrosive backfillings with a standard useful life of 50 years (Δt = 1,2 mm)

Type	Nominal wall thickness	Normal load-bearing capacity design value N_{Sd}		
		Pile	Pile + Concrete (C20/25)	Pile + Concrete (C25/30)
	mm	kN		
118	7,5	692	803	831
	9,0	845	950	976
	10,6	1004	1102	1126
170	9,0	1253	1495	1555
	10,6	1495	1727	1785

Table 6 — Design value N_{Sd} for non-grouted piles in corrosive, naturally grown soils with a standard useful life of 50 years (Δt = 1,75 mm)

Type	Nominal wall thickness	Axial load-bearing capacity design value N_{Sd}		
		Pile	Pile + Concrete (C20/25)	Pile + Concrete (C25/30)
	mm	kN		
118	7,5	629	740	768
	9,0	782	886	913
	10,6	940	1038	1063
170	9,0	1161	1403	1463
	10,6	1403	1634	1692

Testing

The mechanical material characteristics are tested according to the test methods laid down in ÖNORM EN 545:2011, clause 6.3 and 6.4.

The tests have to be carried out according to the test methods in Table 8.

Table 8 — Scope and frequency of testing for initial testing, factory production control and inspection

Characteristics	Requirement according to	Test method	Initial testing	Factory production control	Inspection
Material	Table 1	according to ÖNORM EN 545:2011, clause 6.3 and 6.4	4 pile tubes	1/600 pile tubes	4 pile tubes
Outside diameter	Table 2, Table 7	according to ÖNORM EN 545:2011, clause 6.1.2	4 pile tubes	100% pile tubes	4 pile tubes
Connection dimensions		analogous to ÖNORM EN 545:2011, clause 6.1.2	4 pile tubes	1% pile tubes	4 pile tubes
Wall thickness		according to ÖNORM EN 545:2011, clause 6.1.1	4 pile tubes	1% pile tubes	4 pile tubes
Length		according to ÖNORM EN 545:2011, clause 6.1.4	4 pile tubes	1% pile tubes	1 pile tube
Straightness		according to ÖNORM EN 545:2011, clause 6.2	1 pile tube	1% pile tubes	1 pile tube

Data sheet

Data sheet – ductile pile

Dimension	Wall thickness	Cross-section	Resistance moment	Tension f_{yk}	Bending moment M_{Rd}
mm	mm	cm^2	cm^3	N/mm^2	kNm
118	7.5	26.04	68	320	21.7
118	9.0	30.82	78	320	25
118	10.6	35.77	88	320	28.2
170	9.0	45.52	174	320	55.7
170	10.6	53.08	199	320	63.7