STEEL DESIGN (2)
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STEEL PROPERTIES FOR MICROPILE DESIGN

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Abstract. Micropiles, specially driven piles, are commonly used in northern Europe for underpinning of existing structures. Several steel grades have been used for micropile purpose. Structural hollow sections are common for driven micropiles. So-called high strength steel is commonly in use for drilled piles. The load bearing capacity of micropiles correlates to the steel quality, mainly to yield strength, when the geotechnical bearing capacity of the pile is high enough.

1 Introduction

1.1 Micropiles in northern Europe

Driven micropiles are commonly in use in Scandinavia. RR and X piles delivered by Rautaruukki have been used in about 4500 objects mostly in Finland, Sweden, Norway, UK, Estonia, Latvia and Russia. The use of X piles was initiated in 1975, the use of RR piles in 1988. Driven micropile is normally lengthened with a mechanical friction joint.

Drilled micropiles have been in central and northern Europe commonly steel bars with a casing tube if needed. Recently there have been several applications concerning thick-walled casing tubes, diameter up to 508 mm. This type of micropile consists of a casing and concrete inside and reinforcement is according to the capacity requirements. The thin-walled casing tubes are lengthened by welding. The thick walled casing tubes and bars are commonly lengthened with a threaded joint.

Screw micropiles have been developed recently in Estonia. The load bearing capacity is enhanced by joining a bigger screw flange than the pile shaft. The screw pile can be equipped with a friction joint.

1.2 Typical applications of micropiles

Steel micropiles are generally used for underpinning of houses and bridges. In the case of soft soil layers, even new detached houses are built on slender driven micropiles in northern Europe.

The advantages of steel micropiles are great bearing capacity, easy handling even in narrow circumstances and environmental safety. The great bearing capacity is based on the possibility to make use of the so-called high strength steel qualities.

2 Steel as a material for micropiles

Steel can be used in micropiles for several purposes, see classification in Figure 1. Steel can be used as a material for casing tubes, bars, reinforcements, rock shoes or pile caps.

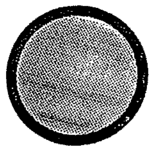
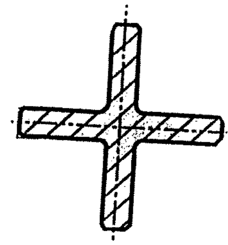
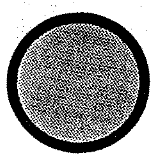
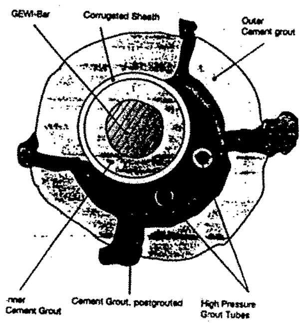
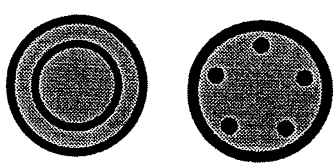
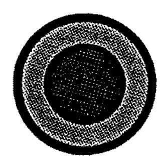
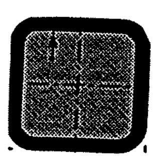
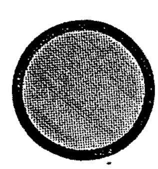
Driven A	Steel pipe pile (RR pile etc) A1 	Hot rolled sections (X pile etc) A2 
Drilled B	Thick walled casing B1 	Bar with or without casing B2 
	Casing and reinforcement B3 	Bar in thick walled casing B4 
Screw C	Lengthening with sleeves C1 	Without sleeves C2 

Figure 1. Classification of micropiles according to installation methods.

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Jouko Lehtonen 18.9.97

Table 1 **Typical steel grades for micropiles according to different standards [1]**

STRENGTH CLASS				STANDARDS AND STEEL GRADES						NOTES
$R_{eL\,min}$		R_m		JIS G3101	EN 10025	DIN	API 5CT	SEW 92	RAUTARUUKKI	
N/mm^2	ksi	N/mm^2	ksi							
235	34	340 – 470	49 – 68	SS34	S 235	St 37	–	–	S 235	General Structural Steels
275	40	410 – 560	59 – 81	SS41	S 275	St 44	–	–	S 275	General Structural Steels
355	51	490 – 630	71 – 91	SS50	S 355	St 52	J 55	–	S 355	General Structural Steels
440	64	490 – 630	71 – 91	–	–	–	–	–	S440 MEF SPEC	Special Steel for Piles
555	80			–	–	BSt 555	–	–	–	Weldable Reinforcing Steel
560	81	620 – 760	90 – 110	–	–	–	N 80	Q StE 550 TM	RAEX 560 HSF	High Yield Strength Formable Fine-Grain Steels
640	93	700 – 850	102 – 123	–	–	–	–	–	RAEX 640 HSF	High Yield Strength Formable Fine-Grain Steels

[1] For accurate comparison, the original standards are to be used

JIS G3101 Rolled Steel for General Structure
Japanese Standards

EN10025 Steels for General Structural Purposes
European Committee for Standardization

DIN 17100 Steels for general structural purposes
DIN Deutsches Institut für Normung e.V.

API 5CT Casing Tubes
American Petroleum Institute

SEW 092 High Yield Strength Formable Fine-Grain Steels
STAHL-EISEN Werkstoffblätter (SEW) des Vereins Deutscher Eisenhüttenleute

3 Steel grades used in micropiles

There are some typical steel grades in Table 1 according to different standards, which are commonly in use worldwide.

High strength steel grades, yield strength over 550 MPa, are commonly used in drilled piles. The driven and screw piles are typically manufactured of normal structural steel. Rautaruukki has developed special steel grade, S440 MEF SPEC, for driven piles.

Steel properties according to the installation method are presented in Table 2.

Table 2. Steel properties and installation of micropiles.

Installation method	Remarks	Typical yield strength
Driving	Tubes (RR piles etc) Hot rolled profiles (X piles etc)	355...440 N/mm2 275 N/mm2
Drilling	Bars Thick walled casings	235...590 N/mm2 355...640 N/mm2
Screw		355 N/mm2

4 Load bearing capacity

In general, a driving stress of no more than 90 % of the yield strength is allowed for the steel piles. The allowable load of 33...58 % of the axial pile capacity in compression is normally allowed for the steel cross section of the impact driven pile depending on the national standard. In general, the compression capacity of the micropile can be dimensioned with formula (1).

$$N_u = A_c f_c + \Sigma A_{si} f_{yi} \qquad (1)$$

where A_c, A_{si} the cross-sectional areas of concrete and the structural steel, respectively
f_c, f_{yi} compressive strength of the materials.

The risk of buckling is relevant, when the undrained shear strength of the soil is less than 10...15 kN/m2. Common method for dimensioning the failure load of micropiles in Scandinavian practice is for instance Bernander's formula (2).

$$P = B / 2 - (B^2 / 4 - C)^{½} \qquad (2)$$

where,

$$B = P_{cr} + N_u + 0{,}5 \cdot P_{cr} \cdot \delta_0 \cdot N_u / M_u$$
$$C = P_{cr} \cdot N_u$$

and

$$P_{cr} = 2 \cdot (M_h EI)^{½}$$
$$N_u = A_s \cdot f_{yd}$$

M_u is the bending resistance of a pile cross section, M_h is the modulus of horizontal subgrade reaction, and δ_0 is the initial deflection of the pile.

5 Conclusions

The steel grade has a straight influence on the load bearing capacity of micropiles. The risk of buckling depends on the steel property but on the stiffness of the cross section, as well.

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$$P = B / 2 - (B^2 / 4 - C)^{1/2} \qquad (2)$$

where,

$$B = P_{cr} + N_u + 0{,}5 \cdot P_{cr} \cdot \delta_0 \cdot N_u / M_u$$
$$C = P_{cr} \cdot N_u$$

and

$$P_{cr} = 2 \cdot (M_h EI)^{1/2}$$
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M_u is the bending resistance of a pile cross section, M_h is the modulus of horizontal subgrade reaction, and δ_0 is the initial deflection of the pile.

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Improved Competitiveness of Drilled Piling

Drilled piles have been used for decades in Scandinavia. In Finland, Norway and Sweden the main application has been so called steel core pile, stålkärnepåle, which is installed by drilling methods mainly used for water-well drilling. More recently as a result of research and development work, the competitiveness of drilled piling has been improved by new pile types and drilling methods as well as appropriate dimensioning methods.

Traditional Drilled Pile Practice in Scandinavia

The steel core pile consists of a round steel bar surrounded by cement grout and thin-walled casing tube which are generally considered as corrosion protection (Fig. 1). Frequently the diameter of steel bars ranges from 90 to 120 mm and casing tubes from 139.7 to 168.3 mm, respectively.

Drilled piles have been considered as special piles for difficult soil and environmental conditions in both new construction and underpinning of existing structures. Typical features are for example:
- hardly penetrable layers exist
- the bedrock is inclined
- a certain penetration depth has to be reached
- surrounding structures are sensitive for vibrations and heave from pile driving
- high pile loads are required
- only small settlements are allowed.

The very hard Scandinavian rock formation located at a reasonable depth is a favourable feature for end-bearing piles. This is contrary to the Central European conditions and practice.

In Central Europe, drilling is the main installation method for micropiles. However, the use of percussive drilling methods is not as usual as in Northern Europe because of different soil conditions. At the moment, the working group CEN/TC288 Execution of Special Geotechnical Works, WG8: Micropiles is trying to harmonize the execution practice for micropiles (d<300 mm).

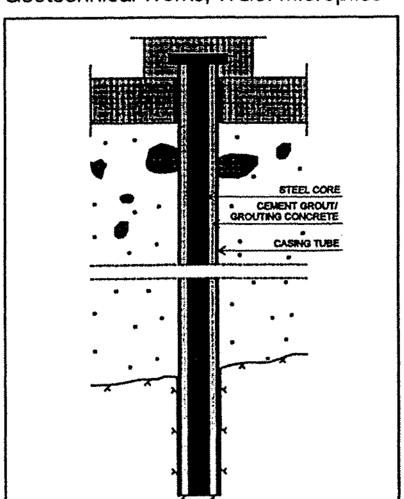

Fig. 1 *Traditional drilled pile resting on hard rock.*

Research and development work

Rautaruukki Oy is the Scandinavian biggest steel producer with a wide range of products. Metform is one of the six industrial divisions of Rautaruukki producing 500 000 tons of tubular products per year. As a result of purposeful research and development work, Rautaruukki is able to offer customers a wide product range of steel pipe piles from 60 to 1220 mm diameter.

Steel in Civil Engineering is the technology program carried out mainly in co-operation with the Geotechnical Laboratory of Tampere University of Technology. The technology program is financed by the Finnish Technology Development Center (TEKES) and Rautaruukki Oy. One part of this technology program was the research and development study concerning drilled piles. The study was carried out in 1996. The main goals of the study were elucidating suitable dimensioning method for drilled piles, developing suitable drilled pile products for certain application areas as well as creating contacts between builders, designers, contractors and drilling equipment manufacturers to find new solutions for piling in co-operation with each other. Further aims of the study were finding potential experimental construction sites, collecting international material and knowledge of drilled piles as well as increasing the knowledge concerning drilled piling in Scandinavia.

The research was executed in close co-operation with builders, designers and contractors to ensure adequate contact with practice besides theoretical study. In addition, the product development was executed in close co-operation with actual construction sites that have been under planning and execution during the research.

Design

The determination of the bearing capacity of a pile contains always two separate phases which have to be verified. The structural bearing capacity (internal bearing capacity) represents the capacity of a pile body to transfer the applied load from the pile head to the pile toe with acceptable deformation. The geotechnical bearing capacity (external bearing capacity) represents the capability to transfer the applied load from the pile body to the surrounding ground with acceptable settlement.

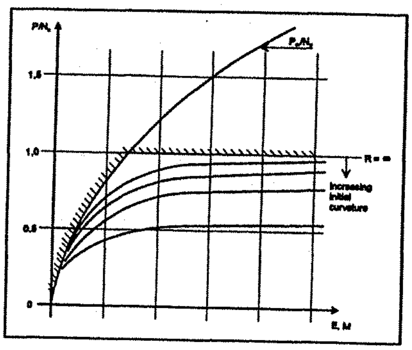

Fig. 2 *The structural bearing capacity of a pile is a function of the deformation characteristics of the surrounding soil.*

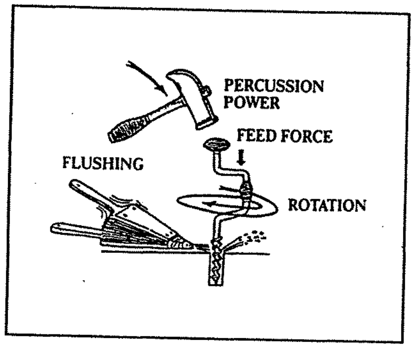

Fig. 3 *The main components of percussive drilling methods.*

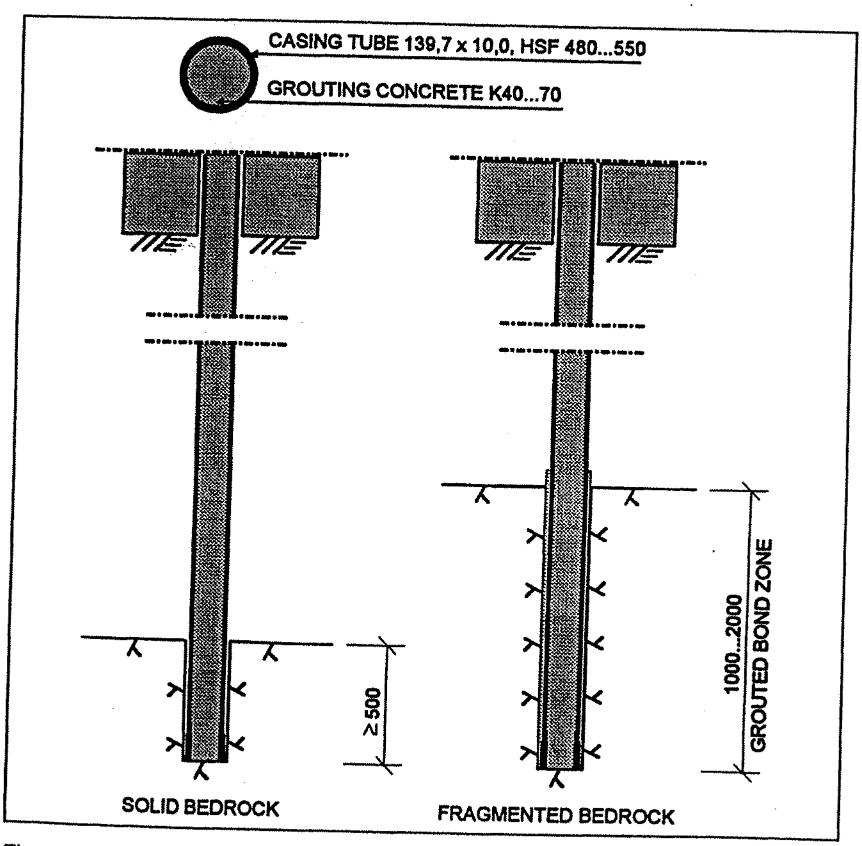

Fig. 4 *Pile type for underpinning of existing foundations in restricted headroom.*

In the case of geotechnical bearing capacity, the strength of the solid Scandinavian bedrock is commonly in excess of the design requirements. However, the importance of appropriate site investigations has to be emphasized. Depending on the quality of the bedrock, the pile can be designed as an end-bearing pile or shaft-bearing pile in the bedrock.

The main interest in dimensioning is related to the structural bearing capacity of a pile. A drilled pile is dimensioned either as a steel structure or as a composite steel and concrete structure depending on the shape of the cross section and the proportions of the steel and concrete (or grout/mortar) sections according to the national or CEN-dimensioning codes.

The structural model used in dimensioning of drilled piles is equal to the dimensioning of columns completely surrounded by an elastic medium. The buckling length and load of a pile is determined according to the bending stiffness of the pile and the stress-dependent deformation modulus of the surrounding soil. The critical buckling load of the pile is used as a parameter in the determination of bearing capacity (Fig. 2). The influence of buckling as a rejective factor of pile capacity depends always on the slenderness ratio of a pile.

Traditionally drilled piles have also been dimensioned according to the design codes for driven piles, which clearly underestimates the capacity of a drilled pile. Drilled piles are never subjected to similar driving stresses.

In the case of drilled piles, there are obvious prerequisites and requirements for high pile loads: installation method ensures small deviations, end product is nearly always constant, installation does not damage piles as well as piles are able to be entered down into the bedrock as well in conditions when piles have to be installed in restricted headroom.

During the study, the behaviour of

drilled pile contact into the bedrock was investigated with full-scale laboratory tests where piles were installed by different drilling methods and equipment. In addition, to evaluate the bond characteristics between steel and concrete, the full-scale composite structure tests have been performed at the Geotechnical Laboratory.

Drilling – Reliable and accurate installation method

Percussive drilling methods are based on four main components: feed force, rotation, percussion and flushing (Fig. 3). Drilling units can vary from very small crawler mounted drill rigs for underpinning purposes to truck mounted units operating in open space.

The drilling of boreholes can be performed by two different drilling systems: top hammer drilling or down-the-hole drilling. In the case of down-the-hole drilling, a hammer follows immediately behind the bit into the hole rather than remaining mounted on a feed as with top hammer drills. Therefore, little percussion energy is dissipated and the penetration rate is almost constant regardless of the depth of the hole. DTH drilling allows larger diameter holes at greater depths than with top hammer drills. However, the disturbance of surrounding soil is more probable than in the case of top hammer drilling.

Rotary percussive drilling methods can be devided into eccentric and concentric methods. Eccentric drilling method was developed in the early 1970's by Atlas Copco and Sandvik. Nowadays, the most common product names are ODEX and TUBEX. Eccentric drilling method features a pilot bit with eccentric reamer, which cuts a hole diameter slightly larger than the non-rotating casing.

The older one of the concentric methods typified by the Atlas Copco OD-system has much more emphasis on rotational power because of rotating casing tubes. More recently, concentric drilling methods, with non-rotating casing tubes, have been developed. The product names are for example, SYMMETRIX by Rotex and CENTREX by Sandvik.

In concentric drilling method, the casing tube is equipped with a reamer (ring) bit and the inner extension drill steels with a pilot bit slightly smaller than the inner diameter of the casing tube. Drilling, as an installation method, has significant advantages compared with other installation methods. Drilling ensures insignificant deviations for end-product resulting in decreased cost of superstructure. In addition, the schedule and cost of piling work can be predicted very accurately beforehand because the penetration

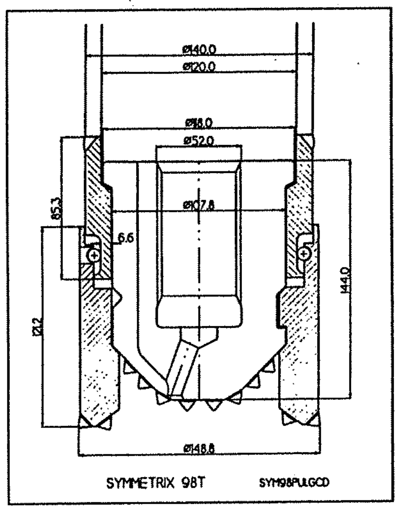

Fig. 5 *Drill bit for installation of drilled piles in underpinning of existing foundations.*

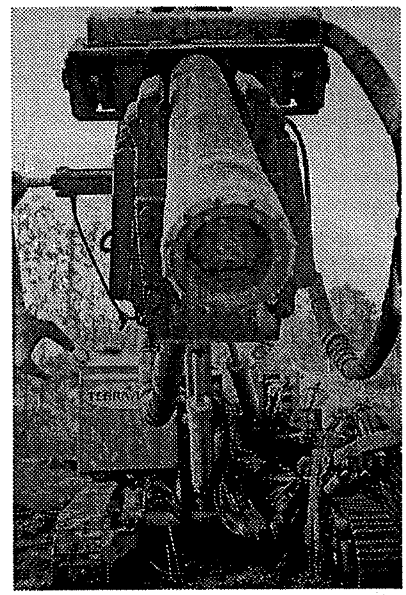

Fig. 6 *Testing of drill bits to penetrate old wooden piles.*

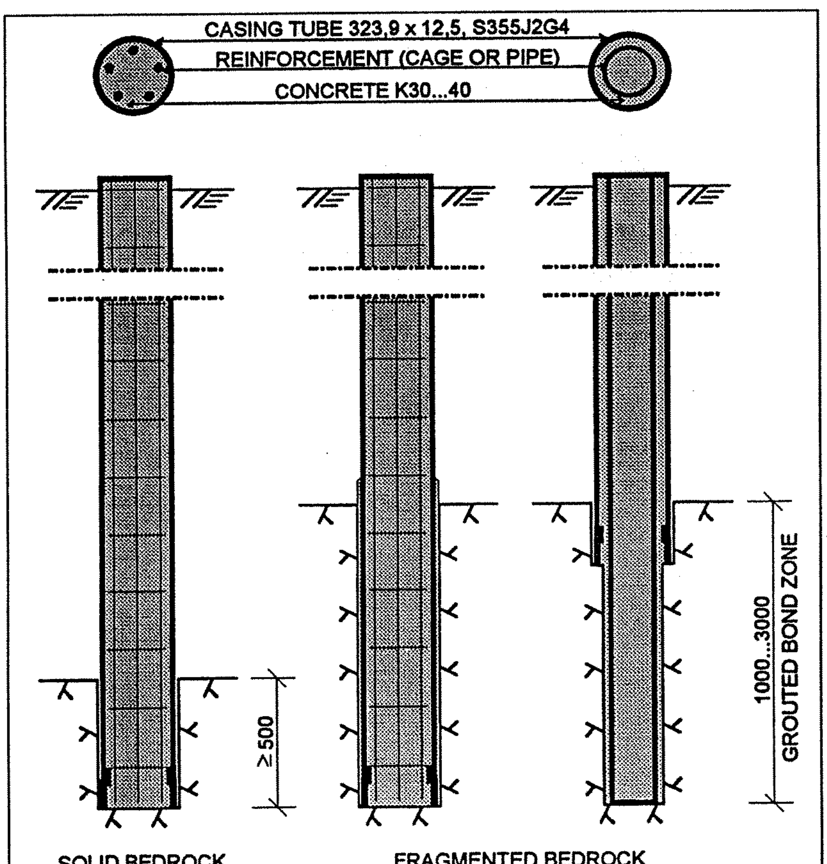

Fig. 7 *Pile type for bridge foundations.*

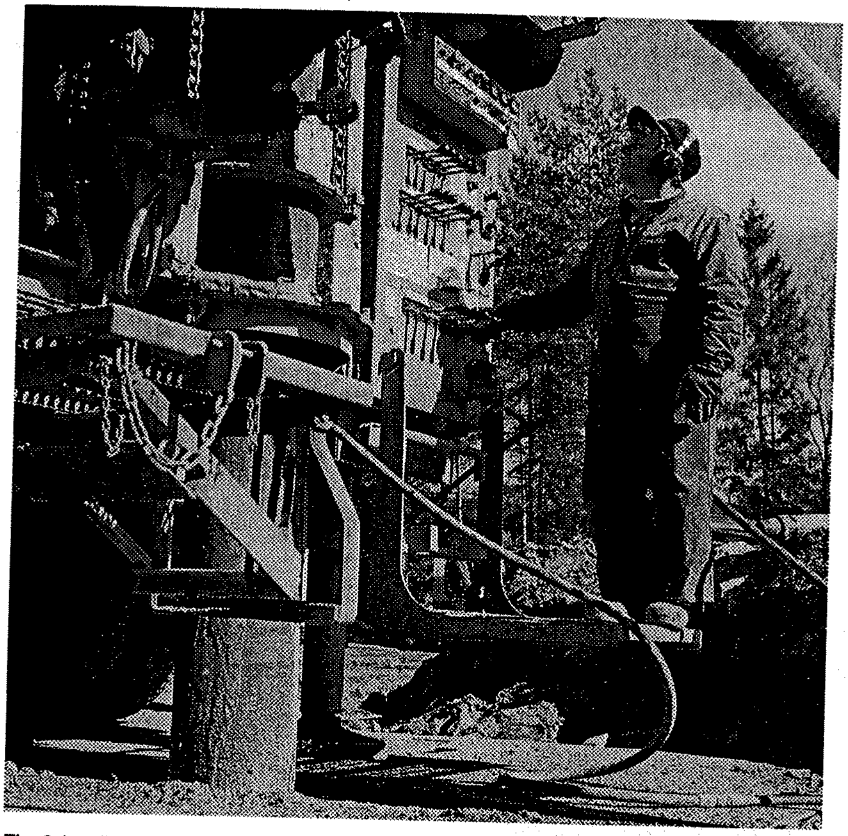

Fig. 8 *Insallation of large diameter drilled piles at the piling site of Tunnelipuisto Underpass.*

of all ground layers as well as the bedrock contact can be performed reliably. In the case of larger hole diameters, the speed of installation is superior compared with bored piles, for instance.

New pile products – more simple and effective piling

During the study, particular attention has been paid to certain application areas of pile foundations. These areas have been of current interest during the research in the form of actual construction sites and actual needs for new pile types.

The first interest has been in the growing need for underpinning of existing multi-storey buildings in Finnish cities at the coast. The second interest has been finding new solutions for piling of railway bridges in the case of hardly penetrable soil layers, inclined bedrock formations and construction during short traffic interruptions within a tight schedule.

In certain conditions, there are some problems related to the use of traditional underpinning pile types. For example, existing wooden piles can not be penetrated without large deviations as well as long piles and restricted headroom cause problems in mobilizing enough capacity.

The new pile type for underpinning purposes is presented in Fig. 4. On the contrary to the traditional drilled pile, the pile consists of a thick-walled casing tube filled with grouting concrete. In this special case, the minimization of working phases has been of primary importance because of extensive pile lengths. The installation method with the concentric percussive drilling and the drill bits (Fig. 5) designed especially for these purposes guarantee the minimum deviations and the reliable end-bearing into the bedrock (Fig. 6).

In addition, by the use of high strength structural steel and by dimensioning the permanent casing and concrete inside the casing as a composite structure, the utilization of high working loads is possible. In the case of 1.5 m element lengths, one of the most crucial tasks is to find the most effective splicing technique. Two different splicing techniques have been proposed and also tested: a threaded splice in a casing tube and the welding of casing tubes by an automatic welding machine.

Compared to the traditional steel core pile, adequate capacity in compression is reached without a steel core. The bending stiffness as well as the bending resistance has increased. Furthermore, one working phase is spared in installation because separate inner reinforcement is not used.

Railway bridges are typically constructed during short traffic interruptions resulting in demand for quick installation methods. As a result, most of the bridges are also founded on piles in soil conditions with higher bearing capacity.

The Tunnelipuisto Underpass in Järvenpää, Finland is the first site where high-capacity drilled piles based on thick-walled casing tube (323.9x12.5) and concentric drilling method have been used (Fig. 7). Totally 18 piles are end-bearing piles drilled at least 0.5 m into the solid bedrock (Fig. 8). The structural bearing capacity of the piles has been achieved by dimensioning the permanent casing, concrete inside the casing and reinforcement as a composite structure. The bridge is a jointless bridge transmitting bending moment to the piles. In addition, the vertical working load of the piles is 2.2 MN.

The new pile concept enables more effective use of large diameter piles installed by percussive drilling. At the moment in Finland, pile diameters up to 500 mm are possible to be executed by percussive drilling methods being able to compete with traditional high capacity pile types.

The Tunnelipuisto Underpass was the successful experimental construction site of the research related to the bridge foundations. At the moment, the experimental construction sites related to the underpinning of multi-storey buildings are under prepare and development. Hopefully, the test pilings will take place in autumn/winter 1997.

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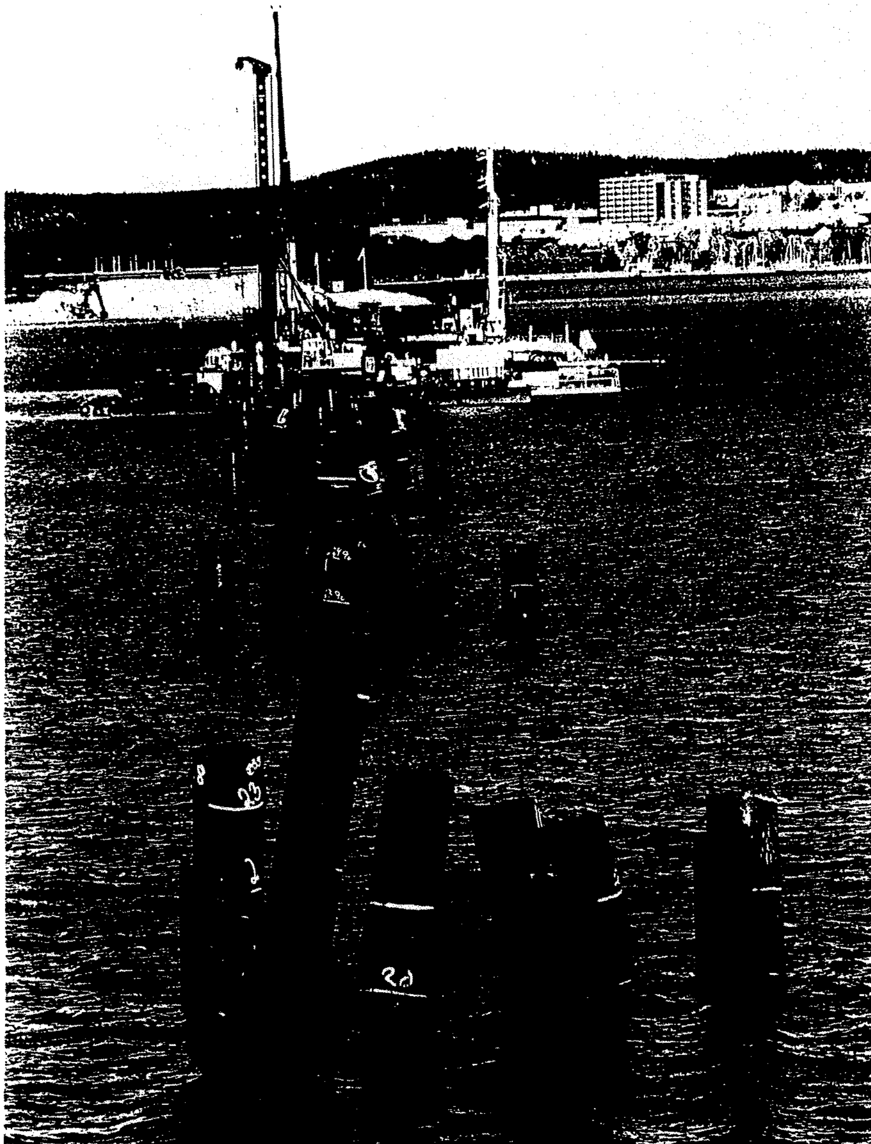
STEEL PIPE PILES



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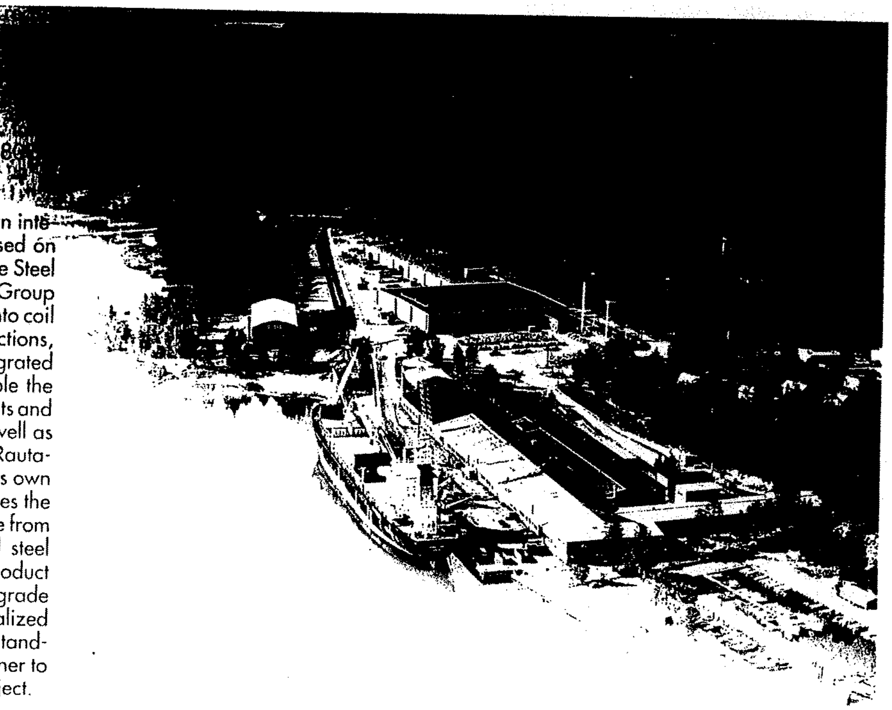
RAUTARUUKKI - AN OUTSTANDING STEEL SUPPLIER

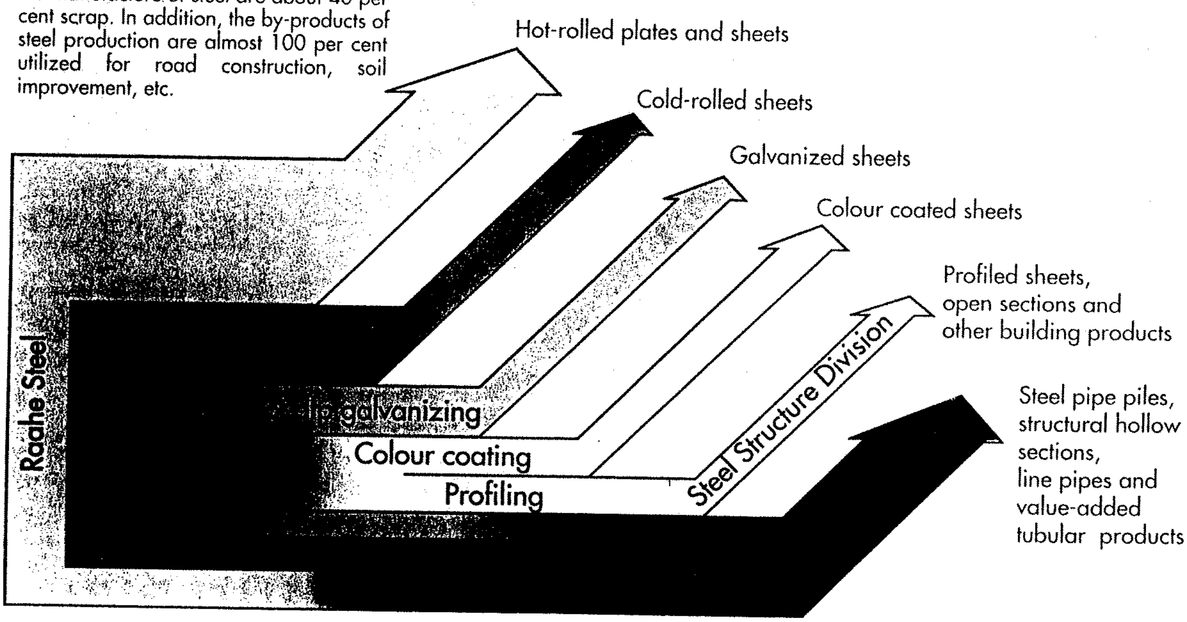


Rautaruukki is an internationally [illegible] nized steel producer with quality [illegible] made by almost 13,000 fully trai[illegible] fessionals. The Rautaruukki Group [illegible] duction facilities in eleven countr[illegible] sales companies on three continents [illegible] national operations represent about [illegible] cent of Group sales.

The strength of Rautaruukki lies in an integrated production chain that is based on the manufacture of steel at the Raahe Steel Works. This steel is used at other Group plants for rerolling and upgrading into coil coated sheet, tubular products, sections, building products, etc. It is this integrated production chain that makes possible the great variety of Rautaruukki's products and the high degree of value added as well as the reliability and promptness of Rautaruukki as steel suppliers. The Group's own research and development guarantees the high quality of products at each stage from the steelmaking process to finished steel products. This policy of continuous product development to secure the high-grade input materials for ever more specialized products makes Rautaruukki an outstanding steel supplier - a resourceful partner to contribute to the success of your project.

Steel is an environment-friendly material

Steel is a recyclable material and about 60 per cent of it is reused. If steel is left in the natural environment, it will gradually degrade into iron oxides or rust without leaving any harmful substances. Rautaruukki has for a long time systematically worked for environmental matters and environmental protection is being taken into consideration at all levels of Group operations and decision-making. The raw materials used by Rautaruukki in the manufacture of steel are about 40 per cent scrap. In addition, the by-products of steel production are almost 100 per cent utilized for road construction, soil improvement, etc.



METFORM - MASTERS OF STEEL TUBE

Rautaruukki Metform is one of six industrial divisions of the Rautaruukki Group. Rautaruukki Metform uses about one fifth of Rautaruukki's output of steel for the manufacture of precision tubes, structural hollow sections, line pipes, pipe piles and value-added tubular products. The products of the Metform division are used for a wide variety of applications in construction, heavy engineering, the manufacture of household appliances, automobiles, furniture and leisure-time appliances as well as pipelines for water, district heating and natural gas.

Steel pipe piles - our expertise in steel for your advantage

The excellent quality and finish of our steel pipe piles has been achieved through dedicated research and development. The customer can specify the exact dimensions, fittings and steel grades for the prefabrication and delivery of steel pipe piles as complete units. Steel pipe piles from Rautaruukki Metform are type approved in Finland and Sweden. Each of the plants that supply the pipes for piles have an EN ISO 9001 quality system.

The environment is important for us

Like Rautaruukki in general, Metform takes environmental protection into consideration in all its operations. Together with the other industrial divisions of Rautaruukki, Metform is committed to various national and international obligations aimed at protecting environment.

Due to the nature of Metform's operations, they have no major impact on the environment. Waste material from the production lines is 100 per cent returned to the steel-making process. Waste oil and solvents are forwarded to hazardous waste disposal plants.

MULTIPURPOSE RR PILES - SAFE FOR THE ENVIRONMENT

RR piles are suitable for a number of applications. They are used as bearing piles, for example, on underpinning sites, under machine bases and for the foundations of industrial premises, detached and terraced houses.

Economic house foundations

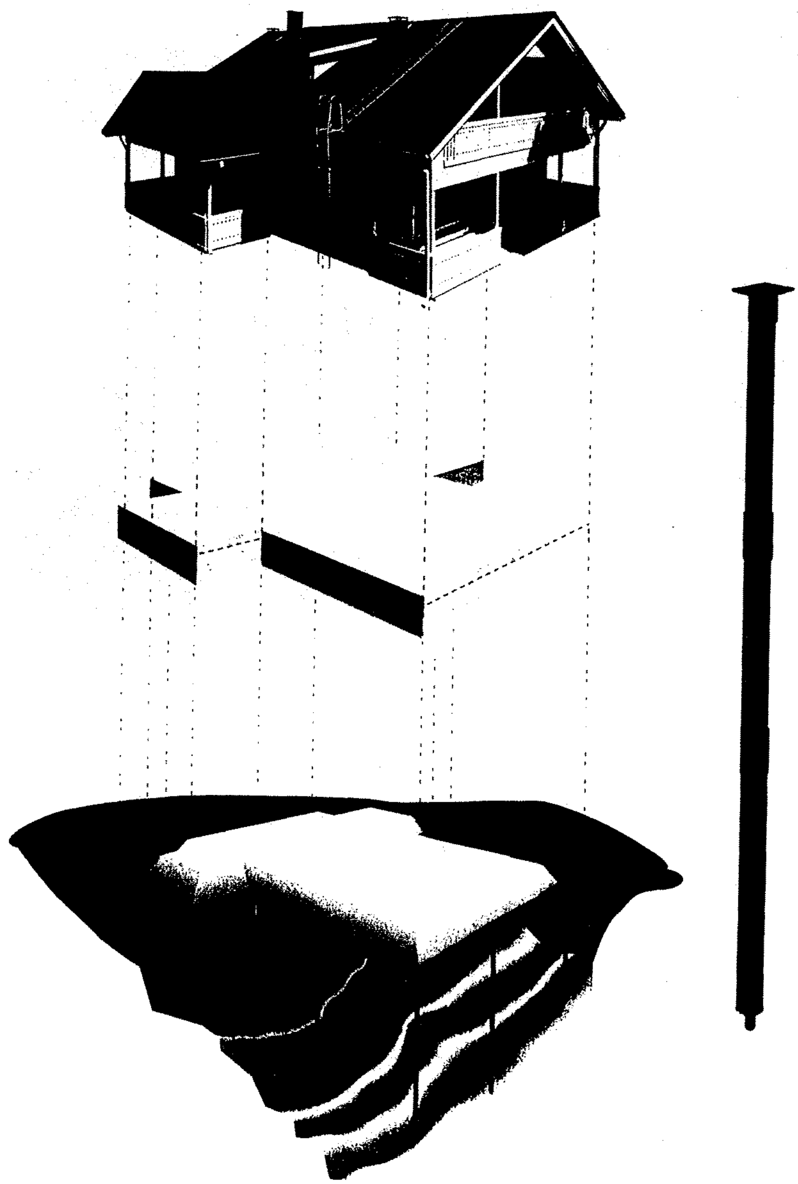
The large variety of bearing capacity of RR piles offers considerable savings in house foundations. The smaller piles are suitably dimensioned to bear the weight of open shelters and porches, the larger ones for use under the load-bearing structures. The installation equipment is suitable for the smallest of sites and pile driving causes no significant ground vibration. Low-rise buildings are made stable on light foundations with RR piles at maximum cost efficiency.

Efficiency in reconstruction

RR piles are ideal for refurbishing projects. Low-weight piles are easy to handle even in narrow spaces, like cellars, and can be driven via holes drilled through existing structures.

A special pile for industrial sites

RR piles are very suitable for the foundations of industrial buildings and have sufficient bearing capacity even for major loads. In proportion to the pile weight, the bearing capacity obtained with steel is many times higher than with other materials.



Technical properties

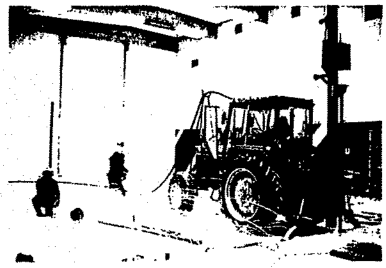
RR piles are made of longitudinally welded steel pipes supplied by Rautaruukki Metform. The external pipe diameter is 60.3...323.9 mm and the piles are extendable with mechanical joints. The installation can be carried out without risk, either by means of light piling equipment or jacking. Small-diameter RR piles cause a minimum of displacement or disturbance of the surrounding soil.

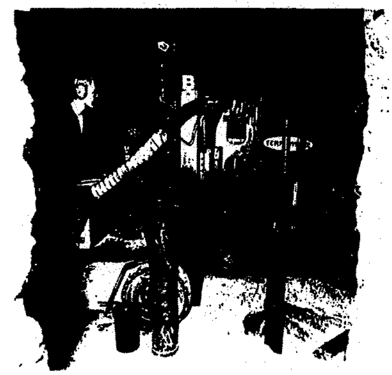
Fittings

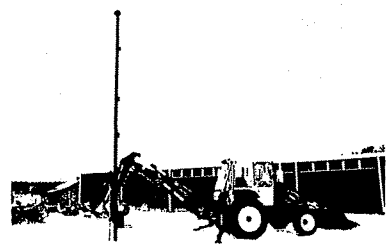
RR piles are easily spliced by means of friction joints that have the type approval of the Finnish Ministry of the Environment in accordance with the decisions 159/5331/93 and 4/6121/96. The Swedish type approval number is TG0656/94. Welding is only needed for the largest pipe diameters.

The pile tip is protected by an RR bottom plate or RR rock shoe.

The pile is connected to the superstructure with a pile cap.







Bearing capacity

The determination of bearing capacity and pile driving should be carried out in accordance with the pile manufacturer's design instructions as ratified in the decision on type approval. The allowable bearing capacity of an RR pile is determined by selecting the lowest of the following ratings:

- maximum allowable central structural compression load
- allowable bearing capacity in respect of buckling
- geotechnical bearing capacity.

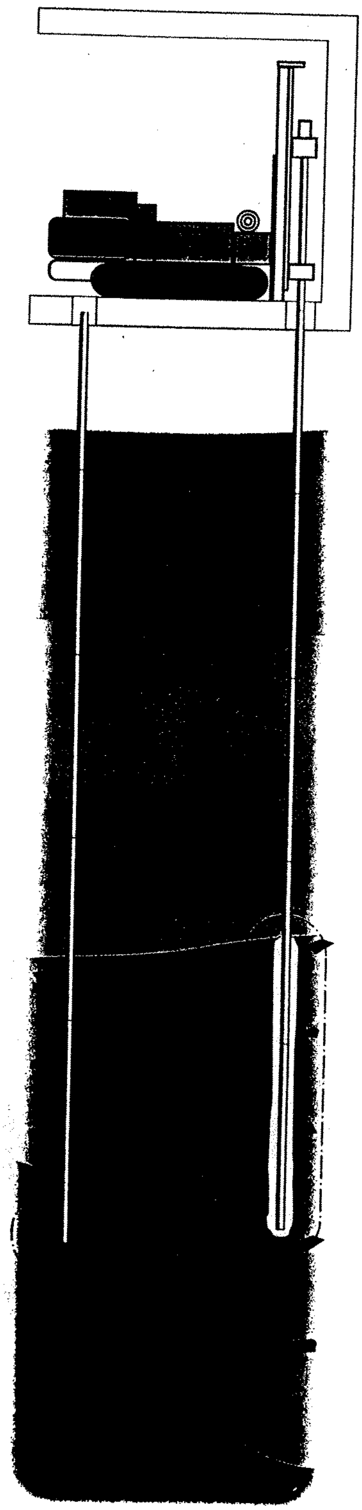
Where the pile is embedded in cohesive soil layers, buckling must he taken into account when calculating the bearing capacity. The shear strength of the surrounding soil is determined by means of a vane test, for example. Table 1 shows the allowable bearing capacities of RR piles in respect of buckling.

Table 1. The allowable bearing capacities of RR piles in respect of buckling.

Type of pile	Piling class	Initial radius of curvature R	Allowable bearing capacity in respect of buckling kN Undrained shear strength of the soil kN/m^2			
Ø/t mm		m	7	10	15	20
RR60	III	70	76	99	107	107
60,3/6,3						
RR75	IB	150	150	187	205	216
76,1/6,3	II	100	125	163	188	197
RR90	IB	200	208	237	256	267
88,9/6,3	II	150	186	223	234	234
RR115	IB	200	296	320	343	256
114,3/6,3	II	150	296	302	306	306
RR140/6	IB	200	330	354	377	391
139,7/6,3	II	150	277	298	313	313
RR140/8	IB	200	402	437	471	491
139,7/8	II	150	337	367	397	407
RR140/10	IB	200	439	571	637	645
139,7/10	II	150	380	500	596	626
RR170	IB	300	680	738	789	789
168,3/10	II	200	550	599	631	631
RR220	IB	350	740	785	828	854
219,1/10	II	300	673	716	758	783
RR270	IB	400	922	972	1020	1049
273,0/10	II	350	845	893	939	968
RR320	IB	450	1095	1150	1202	1234
323,9/10	II	400	1011	1063	1114	1145

R represents the initial radius of the pile curvature after installation prior to loading.
Piling class according to the Finnish Code for Driven Piles, LPO-87.
The corrosion allowance is 1 mm.
Ø = Pipe diameter t = Wall thickness

DRILLED MICROPILES - FOR DIFFICULT CONDITIONS

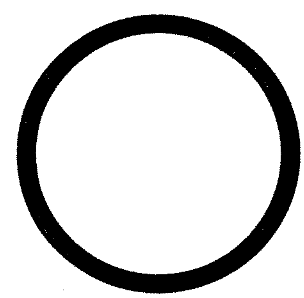


A drilled micropile consists of a casing tube and a steel core, if required. The steel core can be either a solid round bar or a pipe. The casing tube is drilled into the bearing stratum. Boulders and landfills do not prevent the drilling. The drilling equipment can be taken even into basement premises. The drilling work is safe for the environment, because the pile does not displace any of the surrounding soil.

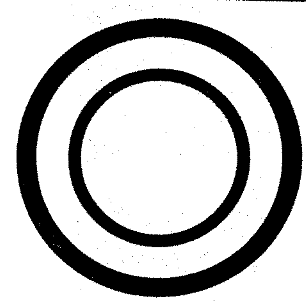
Rautaruukki has developed the drilled micropile for increased efficiency and economy. When the casing tube is made of special high strength steel (yield strength up to 640 N/mm2) with substantial wall thickness, the conventional solid steel core can be replaced by a lighter structure, for example, an RR pile, if required.

Rautaruukki micropiles can be spliced by welding or by means of threaded joints. Welding is a suitable splicing technique if the casing tube is thin-walled while the splicing of thick-walled pipe is quickly carried out with threaded joints.

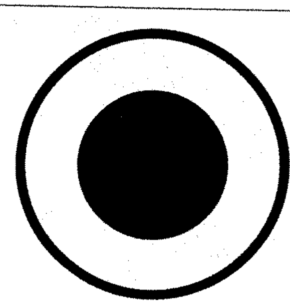
A drilled pile is retained on the bearing stratum either by its tip or both by the tip and shaft. If necessary, the bearing stratum contact can be secured by grouting the pile shaft over the length embedded in the bearing stratum. Drilled micropiles feature superior bearing capacity in proportion to their cross section area. The bearing capacities of 139.7...323.9mm diameter drilled micropiles are in the range 500...3000kN.



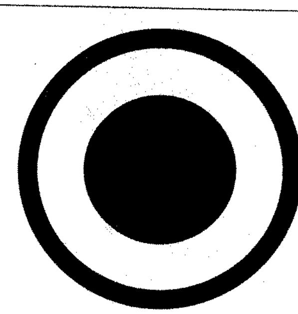
A drilled micropile of simple implementation especially for the underpinning of foundations.



A conventional solid steel core can be replaced, for example, by an RR pile or concrete reinforcement.

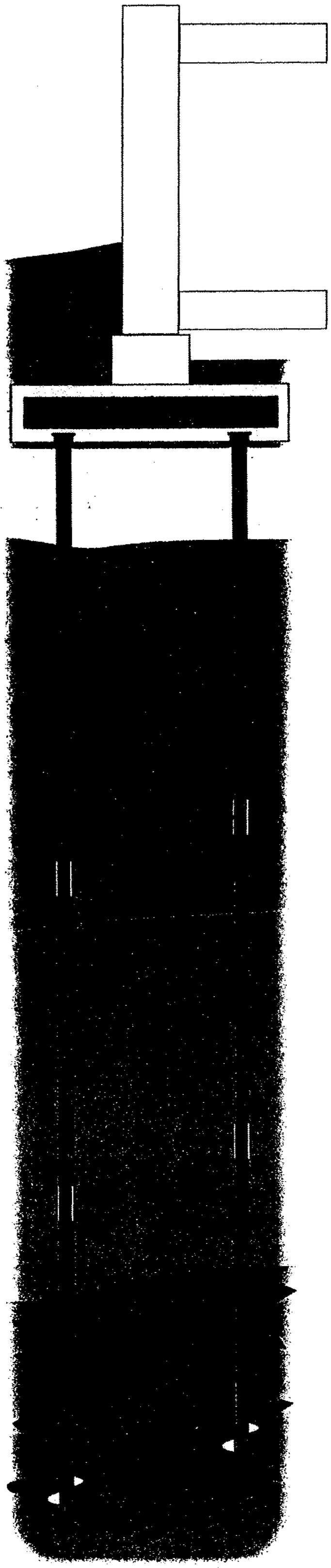


A conventional micropile has a thin-walled casing tube.



Very high bearing capacities are achieved with piles consisting of a thick-walled casing tube and a solid steel core.

SCREW PILES GIVE INCREASED SKIN FRICTION



Friction piles are cost-effectively made of screw piles. Screw piles are literally screwed down into the ground. The pile size is selected according to the load, but the bearing capacity may be increased by means of a screw blade attached near the pile end. Screw piles are environmentally safe. The installation causes practically no vibration.

Screw piles are suitable for the purposes of both underpinning and new construction. Splicings are quickly carried out and if the piles are supplied in short lengths, the installation can be carried out even in low headroom basements. Outdoors in open space, the splicing is more easily carried out on the ground in the horizontal position.

Sami Eronen and Jouko Lehtonen, Rautaruukki Metform, Hämeenlinna

"Although we have already acquired a leading position as manufacturers of steel pipe piles, we seek to serve our customers by developing our products still further."

PIPE PILES FOR HEAVY FOUNDATIONS

Pipe piles with outside diameters of 355.6...1220mm are made of Rautaruukki spirally welded steel pipes. Prefabricated pile units complete with fittings are available in lengths up to 26 m for delivery direct from the works to the site.

Pipe piles are used in the foundations of buildings, bridges and harbour constructions. The tubular shape and the strength of steel give pipe piles high capacity against vertical and horizontal loads.

Technical properties

Pipe piles are made of general structural steels and high-strength gas pipeline steels in accordance with Standard EN 10025, Table 2. The steel grade most commonly used for pipe pile is S355J2G4.

The dimensional tolerances (DIN 17120) are shown in Table 3.

Splicing

Pipe piles are spliced by welding. The pipes are generally supplied with bevelled ends to facilitate welding.

Concreting

If a pipe pile is to be concreted, the structure can be designed as a composite structure.

Table 2. Pipe piles. Steel grades.

Steel grade	Standard	Chemical composition Maximum				Mechanical properties				
		C	Mn	P	S	R_{eH} Min.	R_m	A_5 Trav.	Imp. strength	
		%	%	%	%	N/mm²	N/mm²	min. %	T °C	KV J min
S355J2G4	EN 10025	0,20	1,60	0,035	0,035	355	490-630	22	- 20	27
X60	API 5L	0,15	1,60	0,04	0,05	413	≥ 517	18	- 20	27
X70	API 5L	0,15	1,70	0,04	0,05	482	≥ 565	18	- 20	27

Table 3. Dimensional tolerances for deliveries of round pipe piles in accordance with Standard DIN 17120.

PROPERTY	**TOLERANCE** DIN 17120
STAND. LENGTH ≥ 6000 mm	± 500 mm 1)
SPECIFIC LENGTH	To be agreed in connection with the order
STRAIGHTNESS	≤ 0,2 % of pipe length 2)
OUTSIDE DIAMETER D	When D<200mm: ±1%, however, minimum ±0,5mm 2) When 200mm ≤ D<1000mm: ± (0,005 x D+1) mm 2) When D ≥ 1000mm: ± 6 mm 3)
WALL THICKNESS t	When t ≤ 3 mm: - 0,25 mm / + 0,30 mm When 3 mm < t ≤ 10 mm: - 0,35 mm / + 0,45 mm When t > 10 mm: - 0,50 mm / upper limit set by the mass tolerance
MASS - Deviation in an individ. pipe - Deviation in one 10-tonne lot	 ± 6 % - 4 % / + 6 %

1) Rautaruukki guarantees a tolerance of -0/+50 mm for the standard length.
2) When D/t >100: The tolerance for off-roundness is a maximum of 2%.
When D/t >100: The tolerance is agreed separately.

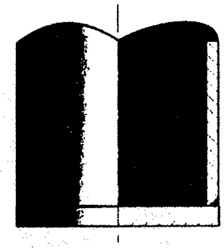
Pile shoes

Pipe piles can be equipped with pile shoes according to the specified bearing capacity and ground conditions.

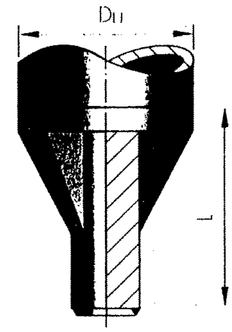
Open-ended piles can be fitted with external or inside reinforcement rings.

Bottom plates are used where the piles are mainly end bearing in a boulder-free soil layer.

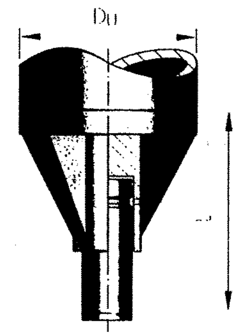
When the piles are to be driven through rocky moraine or into the bedrock, rock shoes fitted with a structural steel dowel are used to prevent damage to the pile end and to center the load. Rock shoes with a hardened steel dowel are used especially to prevent the pile dowel from skidding on a sloping rock surface.



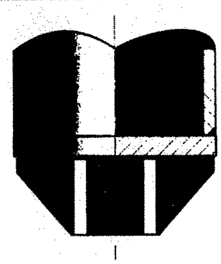
BOTTOM PLATE



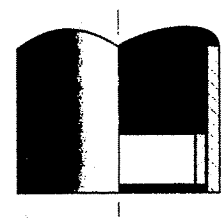
STRUCTURAL STEEL DOWEL



HARDENED STEEL DOWEL

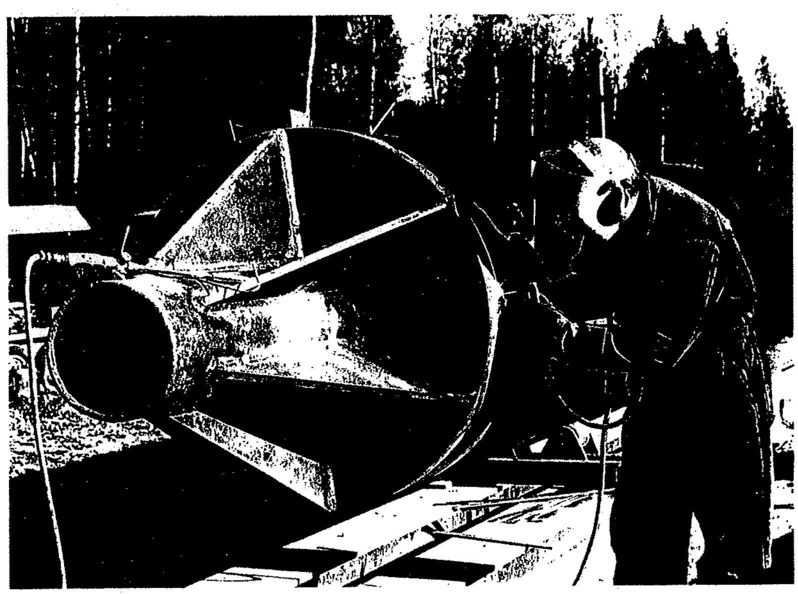


REINFORCED BOTTOM PLATE



REINFORCEMENT RING

D_u mm	L_{max} mm
350	475
400	525
500	615
600	700
700	785
800	890
900	950
1000	1040
1200	1215

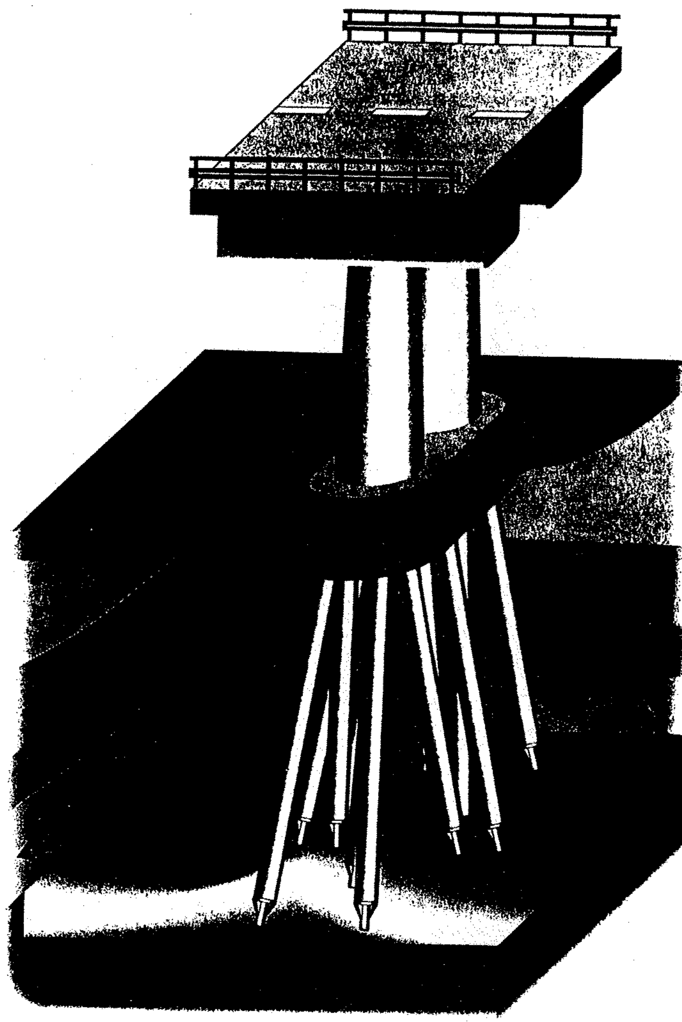


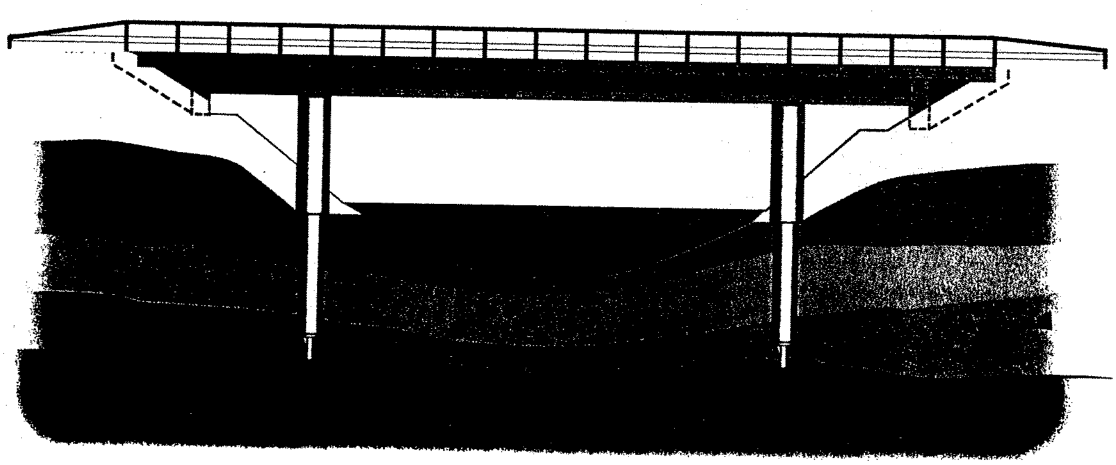
PIPE PILES FOR EFFICIENT BRIDGE CONSTRUCTION

Steel pipe piles are nowadays commonly used in bridge foundations. The number of projects so far completed in Finland is about 200, including some of the biggest and most beautiful road and railway bridges: The Tähtiniemi Bridge in Heinola, Southern Finland, the Saami Bridge in Utsjoki, Lapland, and the Kärkistensalmi Bridge in Korpilahti, Central Finland.

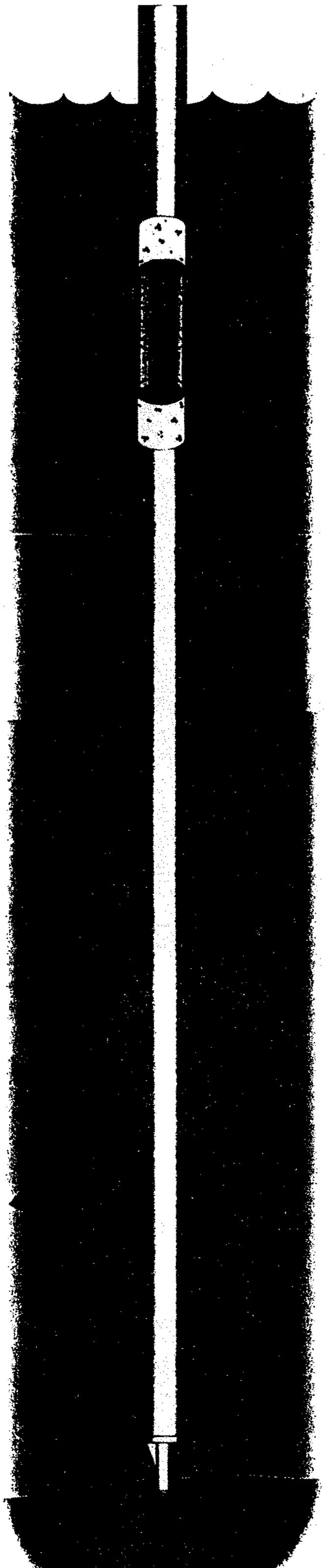
The foundations of large bridges are provided as dolphins with the piles positioned diagonally at different angles and in different directions, and also vertically, if needed. Because steel pipe piles concreted to function as a composite structure have high resistance to bending and buckling, the pile footings can be built in water. The use of caisson techniques allows all concreting down to the lowest pile tip to be carried out in dry conditions. This facilitates inspection and thereby ensures proper quality control.

Most bridges, such as small cross-water bridges, over- and underpasses, flyovers, etc., can be built on foundations consisting of a single steel pipe pile which in most cases can be connected to the deck directly without bearings. This contributes to safe, economical and rapid construction. For example, the pipe pile foundations of railway bridges can be built during short traffic interruptions. With the largest (Ø 1220 mm) steel pipe piles, when properly installed, an allowable bearing capacity of 9 MN can be achieved, enough even for heavy bridges.





Jouni Järkkälä and Esa Moilanen, Rautaruukki Metform, Hämeenlinna



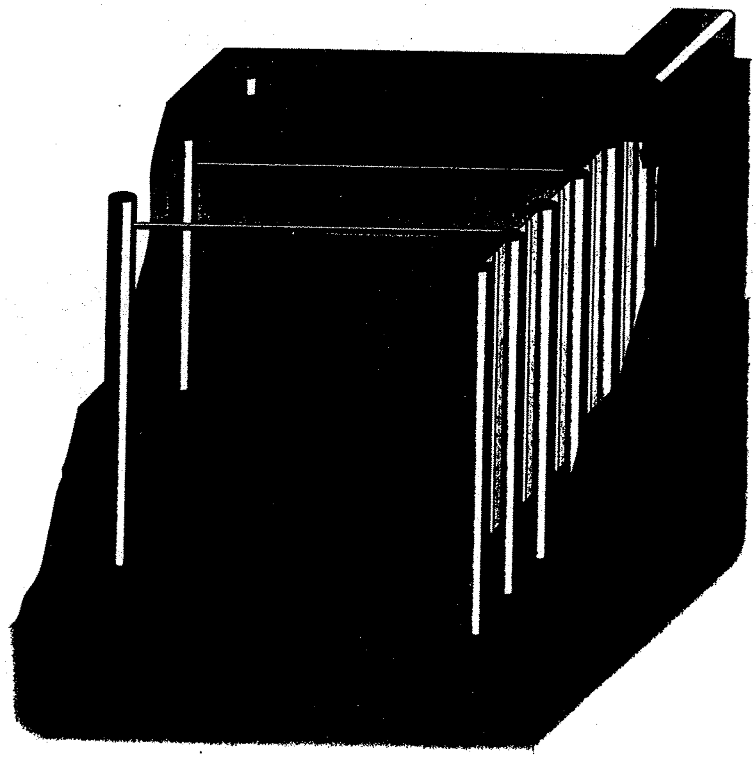
"We have been successful in combining the requirements of builders, the steel industry, piling contractors, design engineers and pile-driver manufacturers into an excellent product range of steel pipe piles. It is not surprising that about 200 complex bridge structures in Finland have already been built on steel pipe pile foundations."

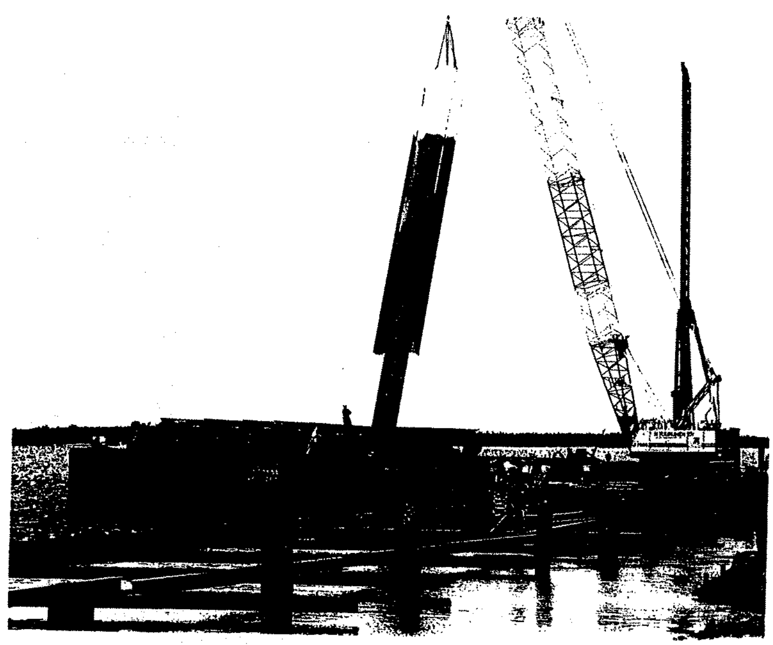
STABLE FOUNDATIONS FOR HARBOUR CONSTRUCTIONS

Pipe piles manufactured by Rautaruukki Metform are commonly used in the construction of retaining walls for wharf foundations. The open-ended pipe piles are typically driven into compact bearing soil layers.

Rautaruukki Metform has delivered pipe piles for a number of harbour projects in several countries, including:

- Oulu, Kokkola, Turku and Kotka, Finland
- Tallinn, Estonia
- Tussendahl, Norway
- Gothenburg, Sweden
- St. Nazaire, France
- Belfast, Northern Ireland.

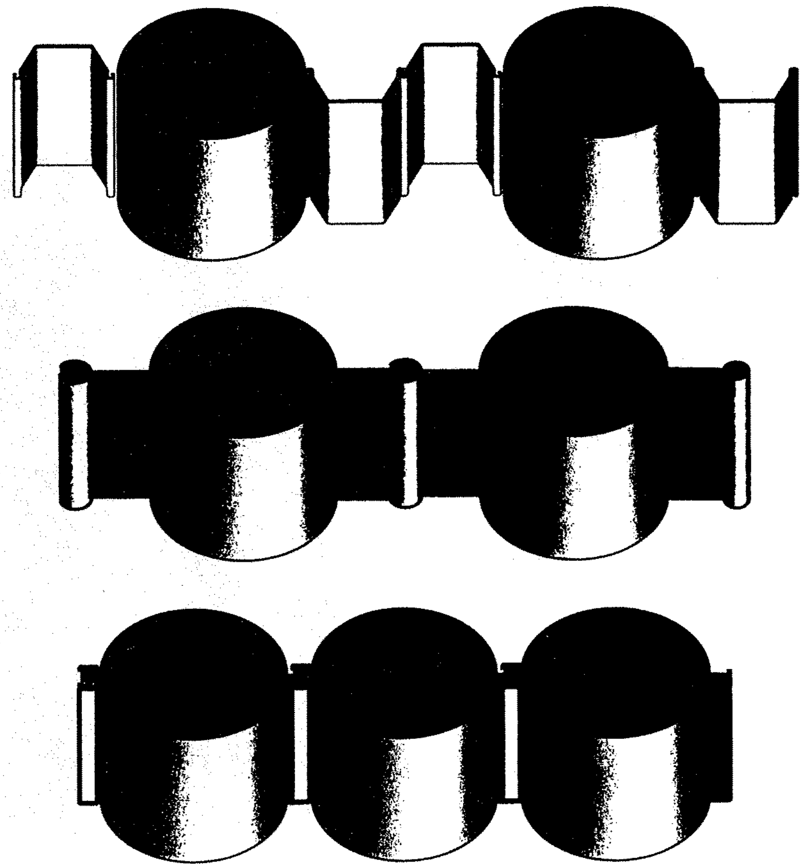


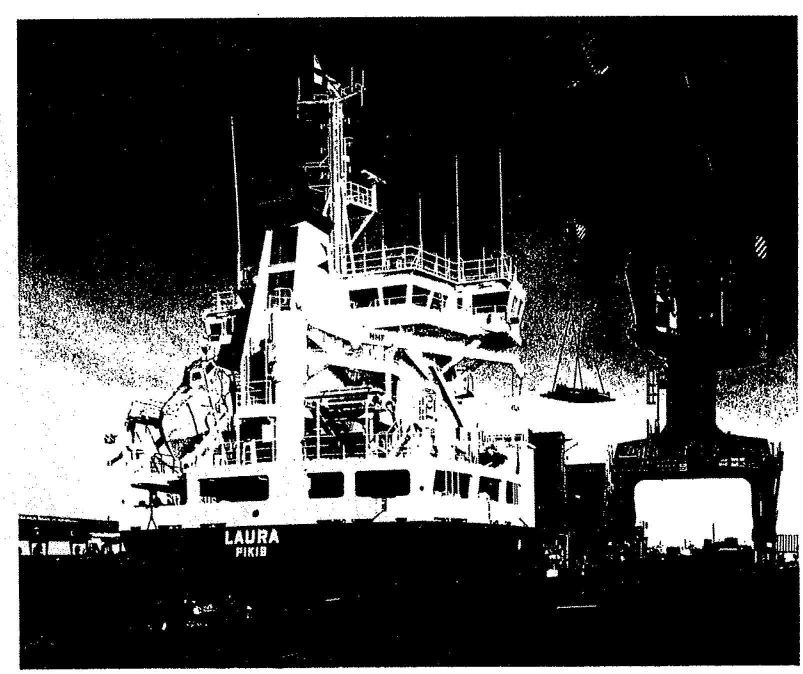


Pipe pile walls and combined walls

Pipe piles can be joined into a continuous retaining wall by connecting them with weld-on interlocking sections or into a combined wall comprising, for example, conventional sheet piles as intermediate sections. Such pile walls and combined walls have enhanced resistance to vertical and horizontal loads compared with conventional sheet pile sections. The pipe piles in a retaining wall are usually open-ended, but can be equipped with pile shoes, if necessary.

An advantage of steel pipe pile walls is that they can be driven into most hard-to-penetrate soil.





CORROSION PROTECTION OF STEEL PIPE PILES

The corrosion protection of steel pipe piles varies according to their ambient conditions. The corrosion is generally taken into account as a corrosion allowance for material thicknesses. The extent of the corrosion allowance depends on the planned design working life of the structure and on the estimated corrosion rate.

Corrosion in soil is usually so low and uniform in the different soil layers that the protection of piles is achieved simply by slightly over-dimensioning the wall thickness.

Under aquatic conditions, the corrosion rate is directly proportional to the electric conductivity of the water. The conductivity of sea water is high, involving higher corrosion rates than in fresh water. The corrosion protection of steel pipe piles in sea water has to be evaluated separately in different zones. The corrosion rate is at its highest in the splash water zone and immediately under the water level.

For exceptionally hard conditions, protection is provided by an external or internal concrete structure. In that case, the piles can also be designed as composite structures. Separate protection may be made alternatively by painting or by using epoxy or polyethylene coating and cathodic protection. No allowance is necessary for corrosion on the inside of steel pipe piles, as this is insignificant.

Table 4. Recommended corrosion allowances (mm) under normal conditions.

Soil conditions	Design working life, years				
	5	25	50	75	100
Undisturbed natural soils (sand, silt, clay, schist, etc.)	0,00	0,30	0,60	0,90	1,20
Polluted natural soils and industrial grounds	0,15	0,75	1,50	2,25	3,00
Aggressive natural soils (swamp, marsh, peat, etc.)	0,20	1,00	1,75	2,50	3,25
Non-compacted and non-aggressive fills (clay, schist, sand, silt, etc.)	0,18	0,70	1,20	1,70	2,20
Non-compacted and aggressive fills (ashes, slag, etc.)	0,50	2,00	3,25	4,50	5,70

- The corrosion rate in compacted landfill is slower than in uncompacted landfill. The design for compacted landfill can be made using the corrosion allowances for non-compacted landfill divided by two.
- The values given are for guidance only. Local conditions should be taken into consideration.
- The values given for 5 and 25 years are based on measurements. The other values have been obtained by linear extrapolation and are therefore on the safe side.

Source: European Committee on Standardization Draft prEN 1993-5. Eurocode 3: Design of Steel Structures-Part 5: Piling. CEN 1995

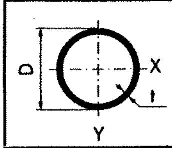
Table 5. Corrosion in different soil and water zones. Design working life 100 years.

WATER	Corrosion mm		SOIL (Groundwater)	Corrosion mm
Zone	Sea	Freshwater	Zone	
> HW +1,5m	4	3	Ground level+1,0m	3 1)
HW+1,5m...NW+1,5m	10	6	Ground level+1,0m...HW+1,0m	4 1)
NW+1,5m...Bottom-1,5m	4	3	HW+1,0m...NW+1,0m	4
< Bottom-1,5m	2	2	< NW-1,0m	2

1) If the piles are exposed to anti-icing salt, the corrosion protection or corrosion allowance must be evaluated individually.
HW = High Water, NW = Normal Water

Source: The Finnish National Road Administration, Bridge Centre. Steel Pipe Piles FinnRA 2173448. Painatuskeskus Oy, Helsinki 1993

Table 6. Steel pipe piles. Dimensions and cross-sectional values.



M = Weight
A = Cross-section area
A_u = External area
I = Moment of inertia
W = Section modulus

W_p = Elastic modulus
i = Radius of gyration
I_v = Torsion modulus
W_v = Section modulus in torsion
Theoretical density = 7,85 kg/dm³

The cross-sectional rates have been calculated using nominal dimensions D and t.

	D mm	t mm	M kg/m	A cm²	A_u m²/m	I cm⁴	W cm³	W_p cm³	i cm	I_v cm⁴	W_v cm³
	60,3	6,3	8,39	10,69	0,189	39,49	13,10	18,45	1,92	78,97	26,19
	76,1	6,3	10,8	13,81	0,239	84,82	22,29	30,78	2,48	169,64	44,58
	88,9	6,3	12,8	16,35	0,279	140,24	31,55	43,07	2,93	280,47	63,10
	114,3	6,3	16,8	21,38	0,359	312,71	54,72	73,57	3,82	625,43	109,44
1)	139,7	5,0	16,6	21,16	0,439	480,54	68,80	90,76	4,77	961,08	137,59
	139,7	6,3	20,7	26,40	0,439	588,62	84,27	112,20	4,72	1177,24	168,54
	139,7	8,0	26,0	33,10	0,439	720,29	103,12	138,93	4,66	1440,58	206,24
2)	139,7	10,0	32,0	40,75	0,439	861,89	123,39	168,55	4,60	1723,79	246,78
1)	168,3	5,0	20,1	25,65	0,529	855,85	101,70	133,38	5,78	1711,69	203,41
2)	168,3	10,0	39,0	49,73	0,529	1563,98	185,86	250,92	5,61	3127,97	371,71
1)	193,7	5,0	23,3	29,64	0,609	1320,23	136,32	178,08	6,67	2640,46	272,63
2)	193,7	10,0	45,3	57,71	0,609	2441,59	252,10	337,79	6,50	4883,18	504,20
2)	219,1	10,0	51,6	65,69	0,688	3598,44	328,47	437,56	7,40	7196,88	656,95
2)	219,1	12,5	63,7	81,13	0,688	4344,58	396,58	534,20	7,32	8689,16	793,17
2)	273,0	10,0	64,9	82,62	0,858	7154,09	524,11	692,02	9,31	14308,19	1048,22
2)	273,0	12,5	80,3	102,30	0,858	8697,45	637,18	848,90	9,22	17394,90	1274,35
2)	323,9	10,0	77,4	98,61	1,018	12158,34	750,75	985,67	11,10	24316,68	1501,49
2)	323,9	12,5	96,0	122,29	1,018	14846,53	916,74	1212,78	11,02	29693,06	1833,47
	355,6	6,3	54,3	69,13	1,117	10547,20	593,21	768,75	12,35	21094,41	1186,41
	355,6	8,0	68,6	87,36	1,117	13201,37	742,48	966,78	12,29	26402,75	1484,97
	355,6	10,0	85,2	108,57	1,117	16223,50	912,46	1194,73	12,22	32447,00	824,92
	355,6	12,5	106	134,74	1,117	19852,18	1116,55	1472,12	12,14	39704,35	2233,09
	406,4	8,0	78,6	100,13	1,277	19873,89	978,05	1269,95	14,09	39747,79	956,09
	406,4	10,0	97,8	124,53	1,277	24475,81	1204,52	1571,66	14,02	48951,63	2409,04
2)	406,4	12,5	121	154,68	1,277	30030,67	1477,89	1940,12	13,93	60061,33	2955,77
	457,0	8,0	88,6	112,85	1,436	28446,36	1244,92	1612,98	15,88	56892,73	2489,83
	457,0	10,0	110	140,43	1,436	35091,32	1535,73	1998,42	15,81	70182,65	3071,45
	457,0	12,5	137	174,55	1,436	43144,80	1888,18	2470,40	15,72	86289,61	3776,35
	508,0	8,0	98,7	125,66	1,596	39279,96	1546,46	2000,17	17,68	78559,92	3092,91
	508,0	10,0	123	156,45	1,596	48520,25	1910,25	2480,37	17,61	97040,49	3820,49
2)	508,0	12,5	153	194,58	1,596	59755,40	2352,57	3069,65	17,52	119510,80	4705,15
	508,0	14,2	173	220,29	1,596	67198,62	2645,62	3463,46	17,47	134397,25	5291,23
	559,0	8,0	109	138,48	1,756	52564,94	1880,68	2428,98	19,48	105129,89	3761,36
	559,0	10,0	135	172,47	1,756	65001,14	2325,62	3014,34	19,41	130002,28	4651,24
	559,0	12,5	168	214,61	1,756	80161,82	2868,04	3733,93	19,33	160323,63	5736,09
	559,0	14,2	191	243,04	1,756	90230,71	3228,29	4215,61	19,27	180461,42	6456,58
	610,0	8,0	119	151,30	1,916	68551,35	2247,59	2899,40	21,29	137102,71	4495,17
	610,0	10,0	148	188,50	1,916	84846,56	2781,85	3600,33	21,22	169693,13	5563,71
	610,0	12,5	184	234,64	1,916	104754,73	3434,58	4463,23	21,13	209509,47	6869,16
	610,0	14,2	209	265,79	1,916	118003,90	3868,98	5041,64	21,07	236007,79	7737,96
	660,0	8,0	129	163,87	2,073	87087,94	2639,03	3401,00	23,05	174175,89	5278,06
	660,0	10,0	160	204,20	2,073	107870,51	3268,80	4225,33	22,98	215741,02	6537,61
	660,0	12,5	200	254,27	2,073	133306,41	4039,59	5241,35	22,90	266612,83	8079,18
	660,0	14,2	226	288,10	2,073	150263,08	4553,43	5923,17	22,84	300526,15	9106,85
	711,0	8,0	139	176,68	2,234	109162,15	3070,67	3953,84	24,86	218324,30	6141,33
	711,0	10,0	173	220,23	2,234	135301,41	3805,95	4914,34	24,79	270602,81	7611,89
	711,0	12,5	215	274,30	2,234	167343,25	4707,26	6099,43	24,70	334686,49	9414,53
	711,0	14,2	244	310,85	2,234	188735,23	5309,01	6895,48	24,64	377470,47	10618,02
	762,0	8,0	149	189,50	2,394	134683,01	3534,99	4548,30	26,66	269366,01	7069,97
	762,0	10,0	185	236,25	2,394	167028,35	4383,95	5655,37	26,59	334056,71	8767,89
	762,0	12,5	231	294,33	2,394	206730,99	5426,01	7022,53	26,50	413461,99	10852,02
	762,0	14,2	262	333,60	2,394	233271,23	6122,60	7941,66	26,44	466542,46	12245,21
	762,0	16,0	294	374,98	2,394	260973,25	6849,69	8905,62	26,38	521946,50	13699,38
	813,0	8,0	159	202,32	2,554	163900,55	4031,99	5184,37	28,46	327801,09	8063,99
	813,0	10,0	198	252,27	2,554	203363,90	5002,80	6448,42	28,39	406727,81	10005,60
	813,0	12,5	247	314,36	2,554	251860,34	6195,83	8010,65	28,31	503720,69	12391,65
	813,0	14,2	280	356,35	2,554	284314,90	6994,22	9061,71	28,25	568629,80	13988,43
	813,0	16,0	314	400,62	2,554	318221,72	7828,33	10164,71	28,18	636443,45	15656,67
	914,0	8,0	179	227,70	2,871	233651,32	5112,72	6566,86	32,03	467302,64	10225,44
	914,0	10,0	223	284,00	2,871	290147,16	6348,95	8172,49	31,96	580294,31	12697,91
	914,0	12,5	278	354,02	2,871	359708,40	7871,08	10159,43	31,88	719416,80	15742,16
	914,0	14,2	315	401,41	2,871	406344,46	8891,56	11497,84	31,82	812688,92	17783,13
	914,0	16,0	354	451,38	2,871	455141,80	9959,34	12903,83	31,75	910283,61	19918,68
	1016,0	10,0	248	316,04	3,192	399849,67	7871,06	10120,69	35,57	799699,33	15742,11
	1016,0	12,5	309	394,07	3,192	496123,06	9766,20	12588,30	35,48	992246,11	19532,40
	1016,0	14,2	351	446,91	3,192	560761,98	11038,62	14252,12	35,42	1121523,96	22077,24
	1016,0	16,0	395	502,65	3,192	628479,38	12371,64	16001,37	35,36	1256958,76	24743,28
	1219,0	10,0	298	379,82	3,833	694014,28	11386,62	14617,14	42,75	1388028,57	22773,23
	1219,0	12,5	372	473,79	3,833	862180,91	14145,71	18196,18	42,66	1724361,82	28291,42
	1219,0	14,2	422	537,47	3,833	975333,95	16002,20	20612,87	42,60	1950667,90	32004,40
	1219,0	16,0	475	604,69	3,833	1094091,08	17950,63	23156,71	42,54	2188182,16	35901,27

1) As drilled piles only 2) Both as driven piles and drilled piles