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# Classification of Micropile Types

## 1 Short history of micropiles in Northern Europe, especially in Finland

Old rails have been used as impact driven piles for a long time. Also solid steel piles were used. Manufacturing of Gustavsberg's G-piles started in Sweden in the middle of 1970's started the use of circular pipes as micropiles. The use of G-piles enlarged to 200 000 m per year in the middle of 1980's. Development work of RR-piles, which are manufactured by Rautaruukki, started in 1987. In the 1990's the use of solid steel piles has almost ended. Special profiles like X-piles are still used in some special cases.

## 2 Classification of micropiles

Piles can be classified according several things. Main criteria for classification are pile material, shaft cross section, type of geotechnical bearing and method of installation.

Pile material can be wood, concrete or steel. Micropiles are mainly steel piles and they may be concreted to form composite structure. Concrete micropiles are not used in Northern Europe, but they are common in Middle and Southern Europe.

Cross sections of steel micropiles may be hollow, solid or profile (Fig. 1). Best one is circular pipe, because it has best and equal bending capacity to every direction. Hollow section can also be controlled after installation, which is very important. Using solid sections is just waste of steel in ground. If somebody is doing that, steel is not enough expensive.

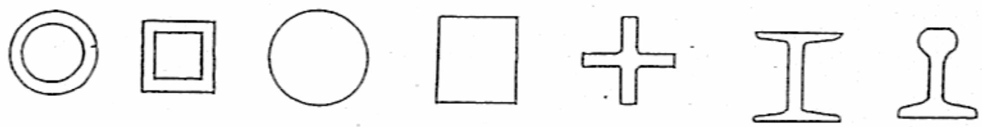


*Figure 1* Cross sections of steel micropiles.

Geotechnical bearing capacity may be gained by steel micropiles in Northern Europe:

- often totally end bearing in rock when drilled or in rock surface when driven by enough heavy impacts
- often mainly end bearing in ground when impact driven, jacked or screwed
- seldom mainly shaft bearing in ground in Northern Europe. Soil layers where more shaft bearing is formed are more common in Middle and Southern Europe. Shaft bearing may be improved by shaft grouting.

Installation methods are classified mainly in two categories: displacement and replacement. Displacement micropile installation is done by driving, which may be impact driving, jacking or screwing. Replacement micropile installation is done mainly by drilling. There are many pile classification tables. Quite complete Table 1 was presented by Linder, who was the chairman CEN-Standardization Working Group for Bored Piles.

After almost indefinite discussions in CEN-Standardization Working Group for Micropiles CEN Technical Committee TC 288 Execution of special Geotechnical Work has decided to put piles in three main groups according to Fig.2. Different limits in diameter for drilled and driven micropiles may look strange, but it may be based on environmental effects, which enlarge by driving. Pile design is always optimizing piling energy. When it is increased also bearing capacity in ground and environmental effects are increased. But when piles are drilled in rock, very high capacity piles, even micropiles, can be installed with minimized environmental effects.

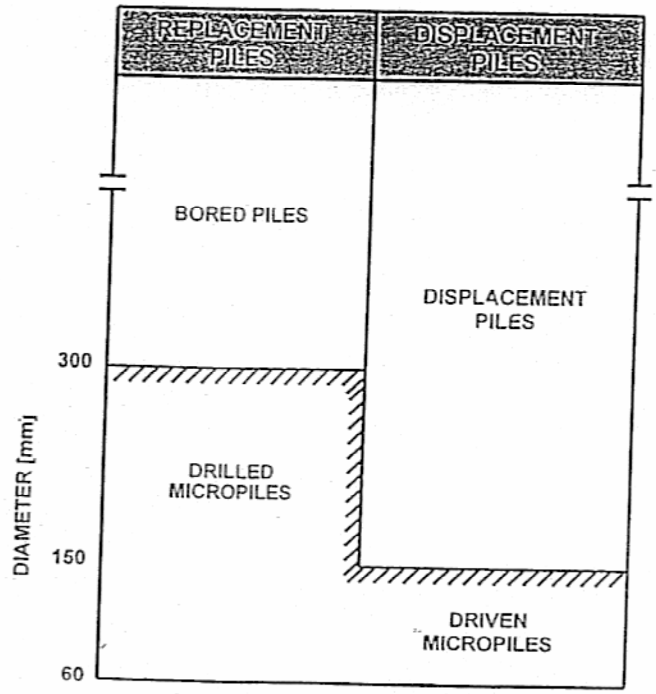
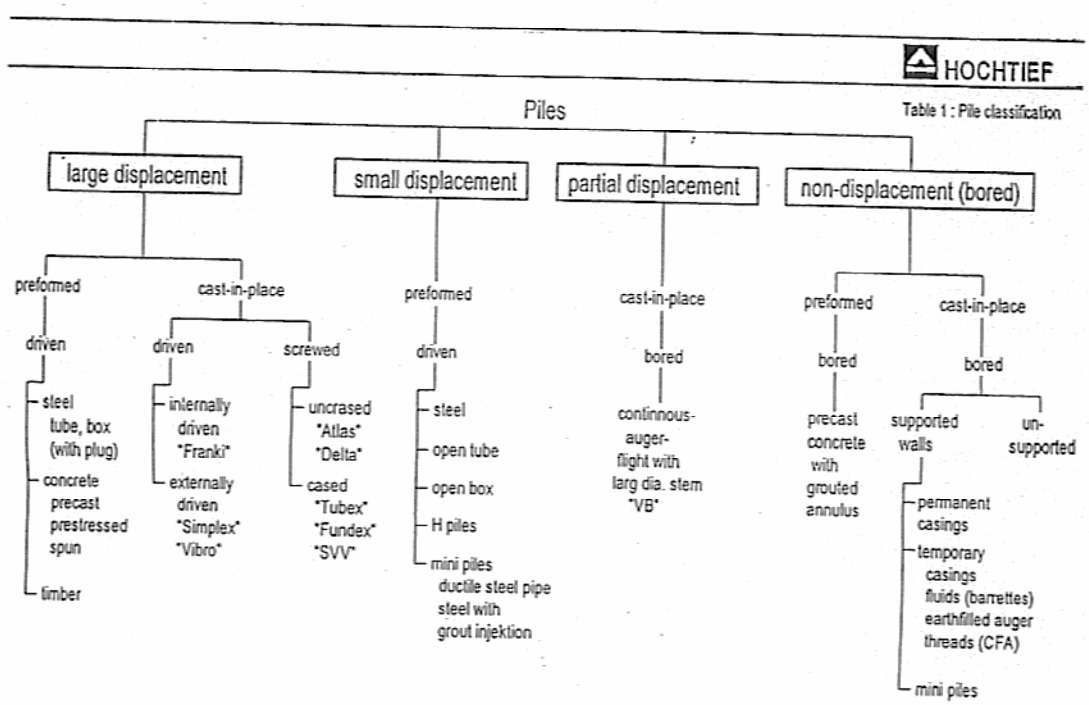



*Figure 2* Main groups of pile types in CEN-Standardization.

*Table 1* Classification of pile types.



# 3 Driven micropiles

## 3.1 Impact driven micropiles

Impact driven micropiles are commonly used in Northern Europe. There are several types of impact driven piles (Table 2). Piles are normally driven by drop hammer or compressed air hammer, sometimes by hydraulic hammer. Lengthening of impact driven piles is fast and efficient when piles are installed under restricted headroom. Sleeves are either straight and loose or friction joints by conic shape of the sleeve.

*Table 2* The most common impact driven pile types in Northern Europe.

| Pile type | Diameter | Sleeve |
|---|---|---|
| RR-pile | 60,3–219,7 | Double conic, friction |
| G-pile | 118-170 | Conic, friction |
| X-pile | 155-200 | Bolt/screw |
| Hercules steel piles | 76,1-88,9 | Straight, loose |
| Stålplastpåle | 60,3-88,9 | Straight |

Small diameter steel piles are used both in construction of new buildings and structures as well as in underpinning and repairing. The use of small diameter steel piles has been enlarging especially in pile slabs, because concrete piles are displacing the soil, which causes risks and problems for surrounding buildings and structures. Volumes of displaced soil are shown in Table 3.

*Table 3* Volumes of displaced soil by various pile types.

| Pile type | Displaced ground [$m^3$/10m] | Displaced volume % compared to pile sizes | |
|---|---|---|---|
| | | 250X250 | 300x300 |
| RR60 | 0,03 | 5 | 3 |
| RR75 | 0,05 | 7 | 5 |
| RR90 | 0,06 | 10 | 7 |
| RR115 | 0,10 | 16 | 11 |
| RR140 | 0,15 | 25 | 17 |
| RR170 | 0,22 | 36 | 25 |
| RR220 | 0,38 | 60 | 42 |
| Concrete pile 250x250 | 0,625 | 100 | 69 |
| Concrete pile 300x300 | 0,9 | 144 | 100 |

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

The large variety of bearing capacity of RR-piles offers considerable savings for house foundations. The smaller piles are suitably dimensioned to bear the weight of open shelters and parches, the larger ones for 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 can be made cost efficient on light foundations with RR-piles.

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

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

RR-piles are made 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 joint. 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 in only needed for the largest pipe diameters.

The pile tip is protected by a RR bottom plate or RR rock shoe. The pile is connected to the superstructure with a pile cap.

Installation of impact driven piles is nowadays mainly executed by drop and hydraulic rams but also by pneumatic or hydraulic hammers.

Particular code for designing and installation of RR-piles is under construction. In this code the structure of RR-pile is handled particularly as well as both geotechnical and structural dimensioning, installation and supervision of RR-piles.

## 3.2 Jacked micropiles

There are two main variations of jacked micropiles commonly used in Europe:

- Same elements as mentioned in Section 3.1. for impact driving are used for jacking.
- Jacked micropile can be made of thin-walled steel tube and lengthed by welding.

First method has been used mainly in Finland. Jacked piles in Finland are normally end-bearing piles. Second case is common in Netherlands and Lithuania. In this case the jacked pile has bigger diameter and it can have considerable shaft resistance.

Jacked micropiles are presented in more detail by Korkeakoski and Eronen /7,8/.

## 3.3 Screw piles

There are two groups of pile types, which are installed by screwing and compressing at the same time. The first group of piles is screwed steel piles, which remain in ground as a temporary or permanent structures. The other group of piles is cast in place concrete piles for which a hole is made by an auger

A helix plate and a shaft are the main components of screw piles of the first group (Fig. 3). The number of helix plates can be one or more and the helix plate diameter varies in different products. The shaft is usually a pipe, but it can also be a square section or a solid bar. The shaft diameter or the thickness of the shaft and the base type of the shaft vary also.


*Figure 3* The schematic drawing of the screw pile with three helix plates. The helix plate diameter *D* ranges typically from 150 mm to 600 mm and the shaft diameter *d* ranges typically from 60 mm to 140 mm

The helix plate diameter and the shaft diameter or the thickness of the shaft must be small in hand-installed screw piles, because the larger are the shaft and the helix plate of the screw pile, the harder is the installation of the screw pile. Screw piles with the helix plate diameter of 150-200 mm may be installed by hands. That is why hand-installed screw piles are suitable foundation for light structures. Screw piles with larger helix plate and shaft can be used as the foundation of heavier structures. These screw piles must be installed by machines.

Screw piles act mostly as end bearing piles; they bear mostly by the helix plate and the shaft base. The helix plate looses the soil around the shaft during the screw pile installation, if enough compression force is not available. When screw piles are installed by hands, enough compression force is seldom available. The helix plate resists also the uplift of screw piles. That is why the tension resistance of screw piles is generally higher than for example the tension resistance of comparable impact driven piles.

The screw pile installation is easy and fast. It does not generally require removal of soil. The installation is vibration free. Only a little noise occurs during the installation by machines. The screw pile installation near existing foundations does not generally cause problems. These features make screw piles advantageous particularly on the sites, which are environmentally sensitive.

The installation by hands has further advantages. Noise does not occur at all during the installation by hands and hand-installed screw piles may be installed on sites, which machines are not able to enter.

Screw piles are removable and re-usable. They are suitable foundations for structures, which are not expected to be in the same place all of their lifespan. Screw piles are not suitable only for compression loads but also for tension loads. Screw pile foundations are fast to construct, because cast-in-place foundation structures are not needed. Protection against a freezing is not necessarily needed, if screw piles are installed so deep that helix plates are below a frost zone.

Screw piles can be used, when a ventilated ground floor is constructed. Drainage is not necessarily needed and moisture, mold and radon problems can be prevented, if the ground floor of a house is ventilated. Screw piles can not be installed through stones or boulders. That is why screw piles are not suitable for all soil conditions. The screw pile installation is not probably possible in moraine, because it contains often lots of stones and boulders.

Hand-installed screw piles can not be compressed enough during the pile installation, they have to be installed only by screwing. That is why the installation by hands is not probably possible in a dry crust, because screw piles may not penetrate the dry crust without compressing. The installation by hands may be too hard in dense soils, especially dense moraine and gravel may cause problems.

## 3.4 CSG pile

A continuesly shaft grouted or CSG pile is an improved version of RR pile in order to get higher shaft resistance compared with plain steel. CSG pile is presented in more detail by Lehtonen in this proceedings. Structure of the CSG pile is shown in Figure 4. The collar close to the pile tip has several functions as follows:

- To make an open space into the soil for grouting
- To protect grouting holes, during installation in order to avoid very loose or sensitive soil to fill the pile pipe
- To direct the pile to designed direction in soil. The collar is located 0,5 to 1 m above the pile tip and the pile pipe under the collar is a leading element of the pile.

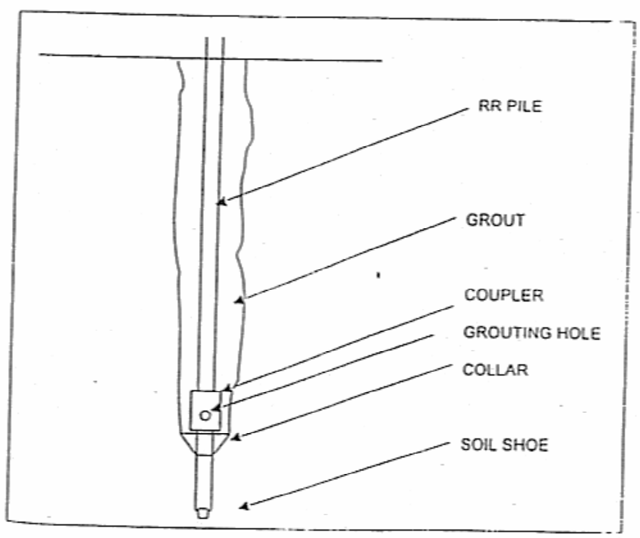



*Figure 4* Structure of a CSG pile /12/.

Grouting holes are located directly above the collar. Grouting holes have features as follows:

- To give an open access for grout fed from inside of the steel pipe to outside above the collar
- To give a grouting level in each locations where the ple tip and the collar are located during installation.

CSG piles are plugged with same soil or rock shoes as discussed with RR piles. Plugging is needed to keep the steel pipe open for grouting. CSG piles are lengthened wit same sleeve couplers as RR piles. The collar is located under the first sleeve, which installed onto the steel pipe using friction contact and welding.

# 4 Drilled piles

## 4.1 Foundations of bridges

The use of drilled piles in foundations of bridges is enlarging. Most of these are railway bridges. Railway bridges are usually constructed during short traffic interruptions. Therefore it is important that installation method is quick and reliable /1/. As a result, most of the bridges are founded on piles also in soil conditions with high enough bearing capacity for shallow foundations.

The most common pile type (Table 4) for bridge foundations have been driven steel pipes with a diameter from 500 mm to 1200 mm. However, in certain conditions the use of drilled piles instead of driven piles may be reasonable. For example reaching the desired depth (Fig. 5) with driven piles may be difficult, especially in conditions where compact soil layers are covering the bedrock, which is located near the ground surface. Also inclined bedrock surface results sliding problems to driven piles, even when they have bedrock shoe.

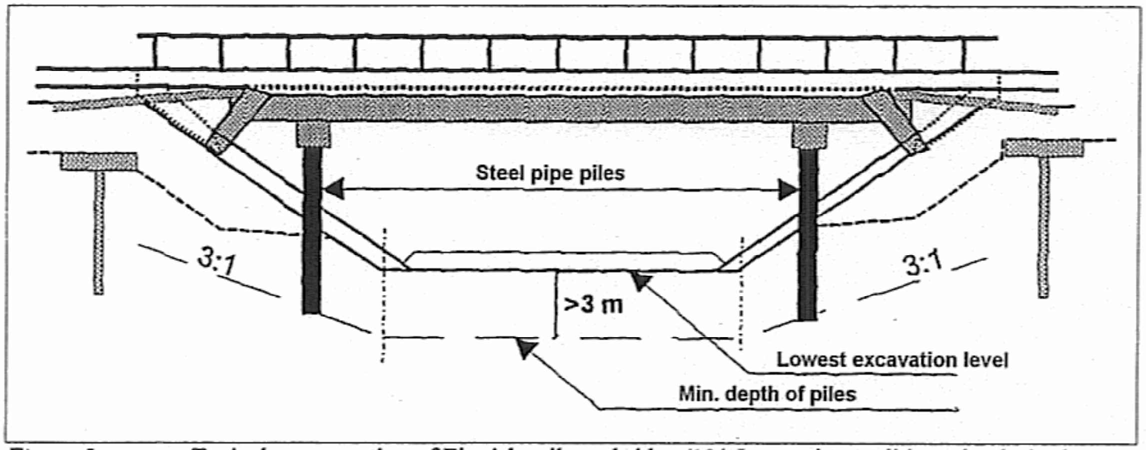



*Figure 5* Typical cross-section of Finnish railway bridge /13/. In certain conditions the desired (minimum) depth of pile is not reached with driven piles and the use of drilled pile will be reasonable.

*Table 4* Finnish railway bridges grouped according to piling types 1995-1999

| | 95 | 96 | 97 | 98 | 99 | Sum |
|---|---|---|---|---|---|---|
| Drilled piles | 2 | 1 | 1 | 2 | 3 | 9 |
| Driven steel pipe piles | 8 | 7 | 11 | 15 | 12 | 53 |
| Driven concrete piles | 6 | 5 | 9 | 6 | 1 | 27 |
| Driven wooden piles | 2 | 1 | 0 | 0 | 0 | 3 |
| Cast-in-situ piles | 3 | 0 | 0 | 4 | 1 | 8 |
| | 21 | 14 | 21 | 27 | 17 | 100 |

Drilling is a reliable way to penetrate those hardly penetrable soil conditions. Sliding problems can be avoided as well, when drilling is done deep enough in the bedrock. Installation deviations of drilled piles are typically much smaller than those of driven piles. According to the piling records from two piling sites, Tunnelipuisto underpass and Leppäkoski railway bridge, it can be noticed that both location and inclination deviations of drilled piles pass easily deviations accepted by Finnish code for Driven piling and High capacity piling (Fig. 6). Deviations of drilled piles are usually formed during measuring of piling site and adjusting of drilling equipment. When drilling has started, no more location deviations are formed during drilling.

In Finland, so far most of the drilled pile sites have been carried out with a pile type having 139,7 mm diameter casing tube, 3-4 mm thickness and $\phi$100 mm steel bar. As a result from that, piles have been quite slender and pile loads quite low compared to larger diameter driven steel piles.

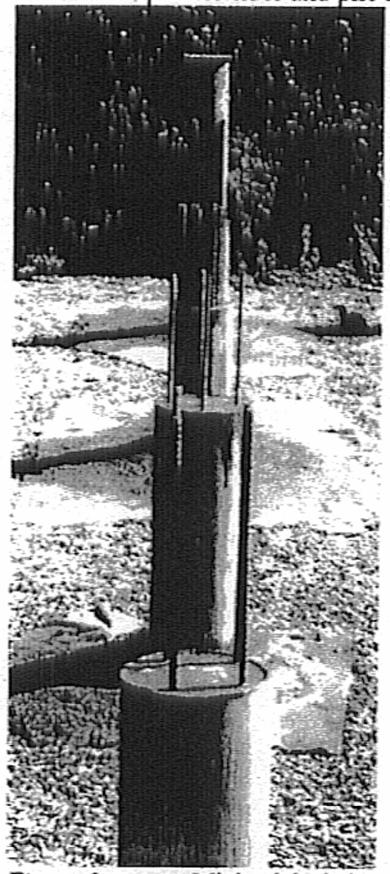


*Figure 6* Minimal deviations of drilled piles in Tunnelipuisto underpass.

In recent years, drilling techniques and equipment have rapidly advanced and pile type and dimensions, particularly the wall-thickness of casing tubes, can be chosen more appropriately for piling purposes. Also larger diameters will be more common, because of advanced drilling equipment. The use of traditional steel core pile is decreasing, because installation of steel core pile has so many working phases and it is always possible that casing tube is lost, when trying to be withdrawn.

Piles, which have thick-walled permanent casing tubes, are replacing steel core piles. Diameter of drilled piles for bridge foundations is enlarging. In Finland, a typical diameters of casing tubes are between 323,9 mm or 457,0 mm and wall-thickness is normally 12,5 mm. Normal drilled pile, which is made by traditional DTH, has a diameter maximum 500 mm because of a need for large air volumes and the danger of disturbing railway embankments. Today it is possible to install drilled pile up to 920 mm for example with Dual Fluid System drilling method, which is developed together by Finnish Nordic Drilling Systems and American Numa /6/.

Bearing capacity of such a large diameter pile is of course enormous compared to commonly used piles of same diameters, because they are supported in solid rock, which gives higher geotechnical capacity than structural capacity. When permanent casing may be reinforced and it is concreted to form a composite pile structure, a very high structural capacity is reached as well.

## 4.2 Underpinning of existing foundations

The main reason for underpinning of existing foundations and structures is the inadequate structural bearing capacity of existing decaying wooden piles /1/. The loss of structural capacity is resulting from the lowering of the ground water table. Decaying may be accelerated by contaminated ground water. The shortage of bearing capacity may result also from initial geotechnical under-dimensioning.

In Finland, greatest problems with decayed wooden piles are in the city of Turku. There are about 400 buildings founded on wooden piles in Turku and dozens of them must be repaired in a near future. Many of these buildings are leaning and sinking also because of uneven soil conditions and increased traffic load.

The main idea of underpinning of old foundations is that all loads from upper structures must be transferred to new piles, which are installed to the bearing stratum, commonly to the bedrock. In Scandinavia, the underpinning of old structures has mostly been made by small diameter steel piles, which are either driven, drilled or jacked down to the bearing stratum. Driven piles have been most common ones /1/.

However, there have been some problems, when using driven piles for underpinning. In conditions, like in Turku, where there are lots of existing wooden piles in the ground, driven piles are not very suitable (Fig. 7). Driven piles do not penetrate the old piles, but they pass them somehow. That's why driven piles cannot be installed without large deviations. Same problem occurs, when pile is installed by jacking.

Another problem in underpinning of old structures and foundations has been restricted headroom. Piling has to be done quite often in the basement of a multistory building, where height of a room can be less than 2,5 m and where can be lots of bearing walls. Piling equipment has to be small, but still it has to have enough capacity for effective working. Piling conditions are often inhumane and therefore the piling method should be effective and functional so that piling would be successful and easy.

Drilling rigs, specially designed for underpinning, have been developed. These rigs are small, so they can work in a very little space. Still they have enough torque for effective drilling. The hydraulic power unit is separated from the rig and connected to it via hydraulic hoses to reduce weight of the rig. Because of low weight and small overall dimensions drilling rig can be moved through ordinary doors and down the stairs to the basement, where drilling has to take place. In extremely tight spots, it is possible to use only the drill mast with its rotary head and control panel on the drilling site, leaving the remaining parts outside the building.

Because of restricted headroom, the length of one pile element used in underpinning is normally very short, commonly about 1000 mm. In Turku, for instance, the bedrock is often in the depth of 30-50 meters, so there may be over 50 joints in one single pile /4/. The amount of joints underlines the importance of reliable and fast jointing technique.

Casing tubes are most commonly joined by welding. The conditions for welding in cellars are inhumane. That is why also the quality of hand welded joints were bad. Recently has a welding automate been developed, which suits very well for welding of casing tubes in underpinning. High quality welding seams are done fast and joints are reliable.

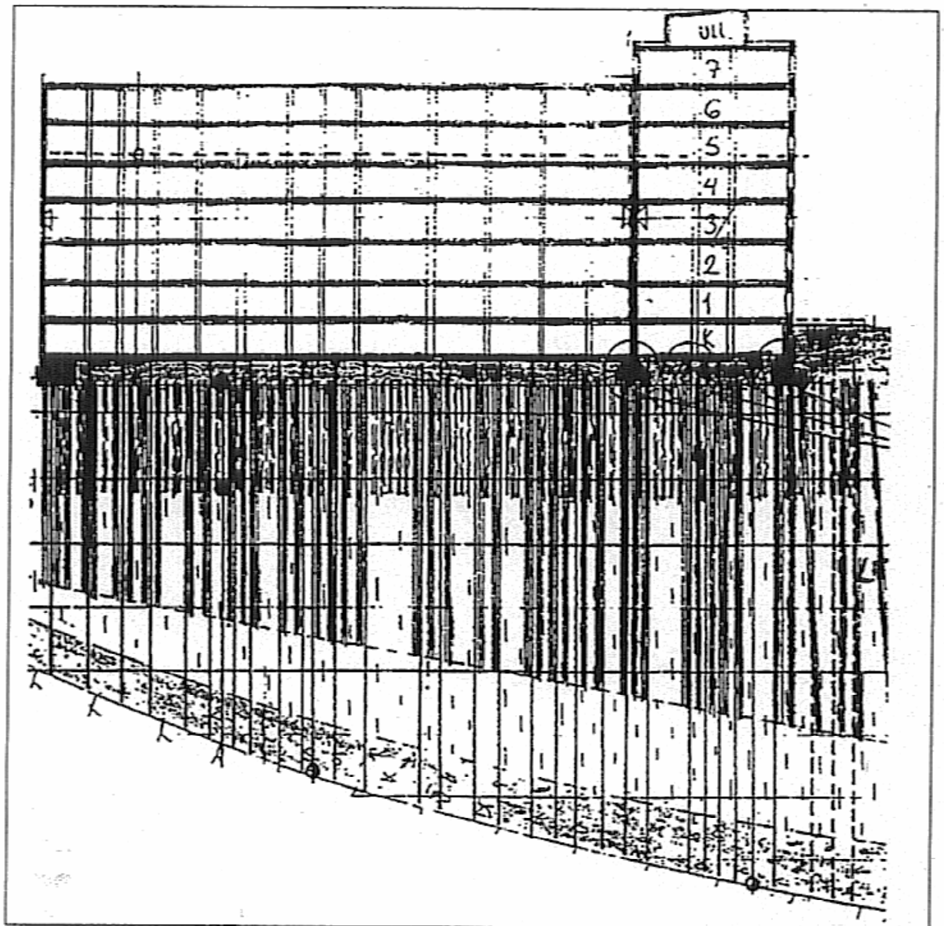



*Figure 7* Typical cross-section from Turku (As. Oy Brahenkulma) including lots of old wooden piles on the ground.

Underpinning with drilled piles in loose sands may be risky, because it may cause sand flushing up, which causes settlements of structures. Also when drilling is done under pressure level of the ground water, ground water is punched up through the casing. Compressed air, when released to the ground in those conditions, has sometimes lifted up large volumes of soil and water. That could cause environmental problems because of lowering of ground water.

Some authorities have forbidden the use of such drilling equipment, which release air to the ground while drilling. Releasing air to the ground has also other disadvantages than mentioned-above mammouthing. For example wooden piles can loose their shaft friction with a result of loosing also their bearing capacity, when compressed air contacts the pile. That causes settlements and breakage of structures. This problem is common on underpinning sites.

American NUMA and Finnish NDS have developed together so-called Dual Fluid System hammer /6/. The idea of this NUMA-NDS drilling system is that the compressed air is used only to run DTH hammer when needed. Air returns inside the casing tube without having a ground contact. Flushing is done with water or bentonite and flushing media returns outside the casing tube. Problems with air flushing, which were mentioned above, can be avoided. This new drilling method should also be suitable for drilling in polluted soil, because exhaust air and drill cuttings can be handled properly and pollution from the soil does not spread into the environment.

## 4.3 New foundation systems of houses

Research and development project for ventilated foundation structures of houses has begun in Geotechnical Laboratory in 1998. First reports from project have been published. This project includes for example the use of CSG-piles i.e. continuous shaft grouted RR-steel pipe piles. Trial pilings and test loads for CSG-piles have been made in Lappeenranta and in Mikkeli. Alternative solutions for ventilated ground floor will be introduced in the research mentioned-above (Fig. 8 and Fig 9). First stage of research will be ready in 2000.

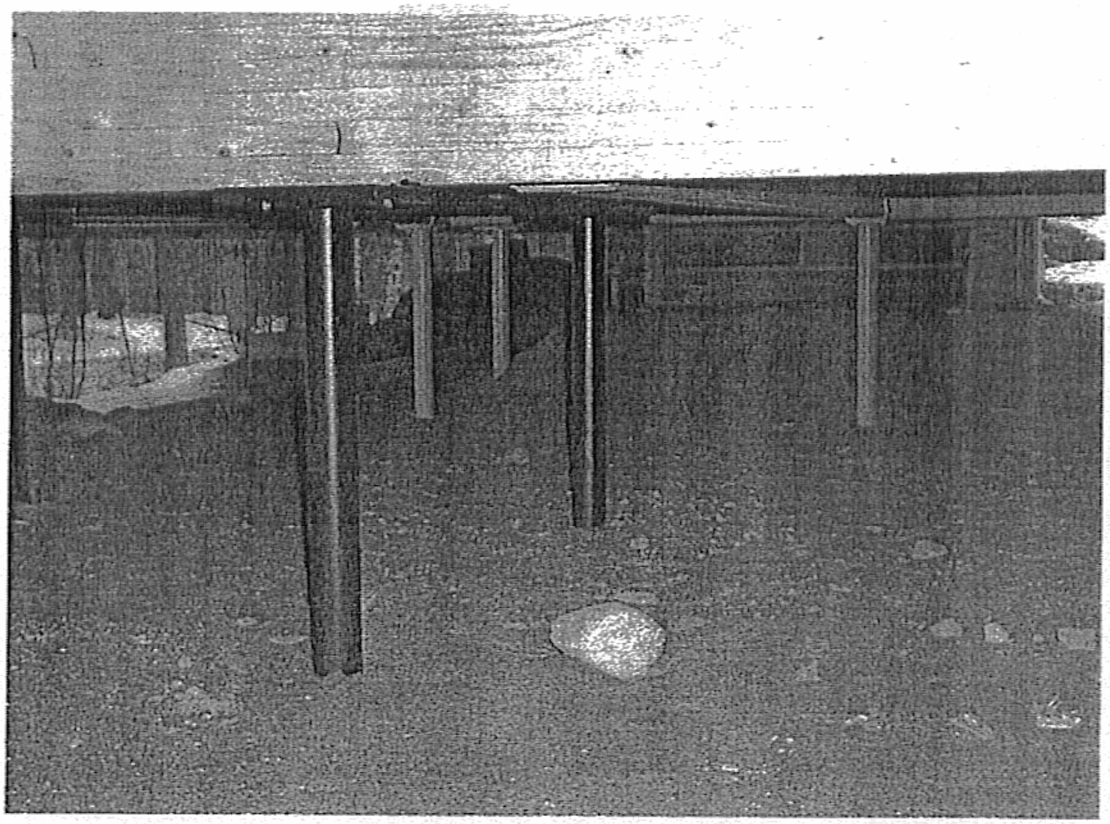


*Figure 8* Ventilated ground floor with piles in Lappeenranta /5/.

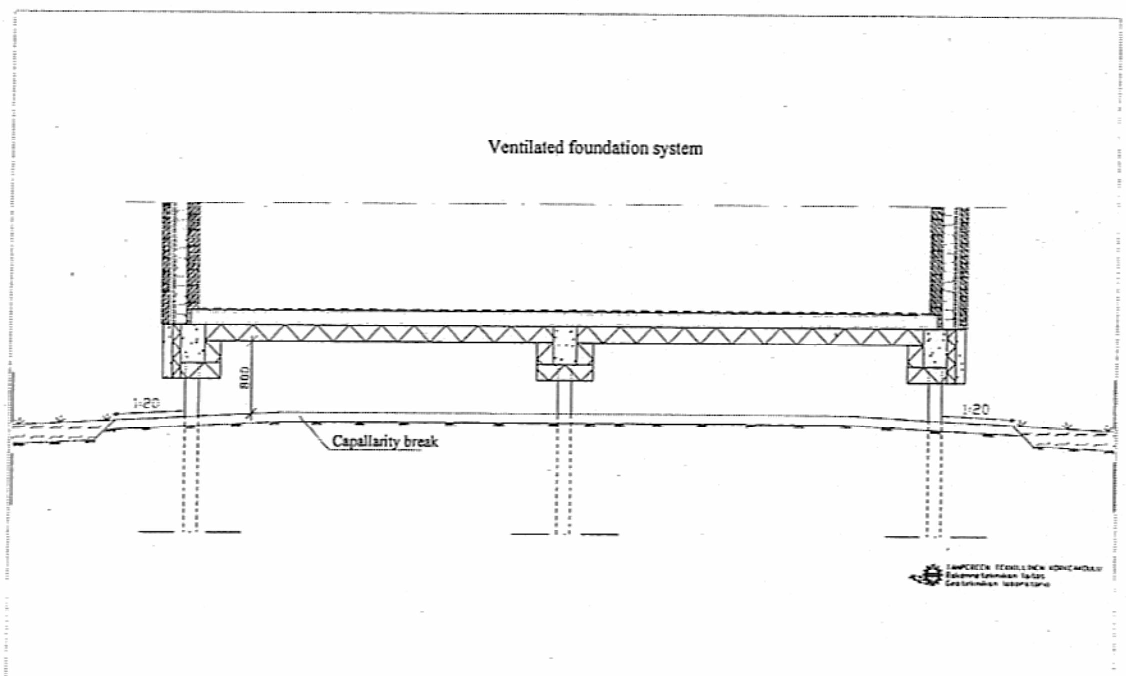



*Figure 9* Example of ventilated ground floor with drilled piles /10/.

## 4.4 Foundations of laterally loaded structures

In Finland the use of laterally loaded drilled piles has been quite small. Experiences from other countries, mainly from Scandinavia, have however showed that drilled piles are most applicable, when fast and reliable foundation installation methods are required. But the use of drilled pipe pile as a foundation of laterally loaded structures will increase in Finland in the future, when lateral capacity is increased by enlarging diameters of drilled piles.

Foundations for noise barriers, portals, railway power-poles, railway signal portals and lightning poles are examples from such kind of laterally loaded structures. Lateral load may be caused by wind, water waves, ice, earthquake or collision. Also changes of temperatures in bridges cause lateral load to the piles.

### 4.4.1 Railway power-poles

Only about half from Finnish railways is electrified so far. In the near future many important railway lines will be electrified. Railway power-poles are nowadays founded mainly on concrete foundations or elements, which are excavated in the embankment.

In the present foundation method the excavation is made near to the railway track. The excavation loosens soil and afterwards soil compaction causes settlements to the railway track. Repairing of the track has to be done several times during maintenance, which causes extra costs. Tracks have to be reserved during repairing, which also causes expenses. When foundation is installed by drilling, those problems can be avoided.

In order to install railway power-pole foundations, the rail has to be reserved from railway traffic, which causes expenses. Therefore the installation method should be fast and any delays and problems should not appear. Drilling is a reliable installation method, because drilling penetrates all materials and the desired depth for a pile can be reached.
Research of foundations for railway power-poles is very active in Geotechnical laboratory. Recently has so-called twin-pipe foundations been developed and test loaded in co-operation with drilling contractor LP-Palvelu. This twin-pipe foundation is presented more detailed in this proceedings by Heinonen

### 4.4.2 Noise barriers

Location accuracy requirements of noise barrier structures are quite tight. Therefore also the foundations of noise barrier structures should locate just in the right place. When using driven steel pipe piles in a ground with boulders, driving is difficult and location deviations may be large. Using drilled piles instead of driven ones, location deviations can be reduced.

Research of the use of single steel pipe piles as foundations of noise barriers was made of Geotechnical laboratory of Tampere University of Technology. This research introduces steel pipe pile foundation for noise barrier structures (Fig. 10). As a conclusion from the research, the type drawings were published and recommended diameters of steel pipe piles were $\phi$193,7-273 mm and lengths of piles were 4-6 m.

In other research test noise barrier structure were founded on drilled piles. The size of the piles were 139,7 x 5,0 and the length of the piles were 3 000 mm. Upper structure, 250 x 250 x 8 mm steel plate, was jointed to pile pipe by threaded steel bar, which was put into fresh concrete.

Experiences from this research were variable. Location tolerances of drilled piles were quite good, but still there must be some allowance for adjusting, usually some centimeters, in upper structures.

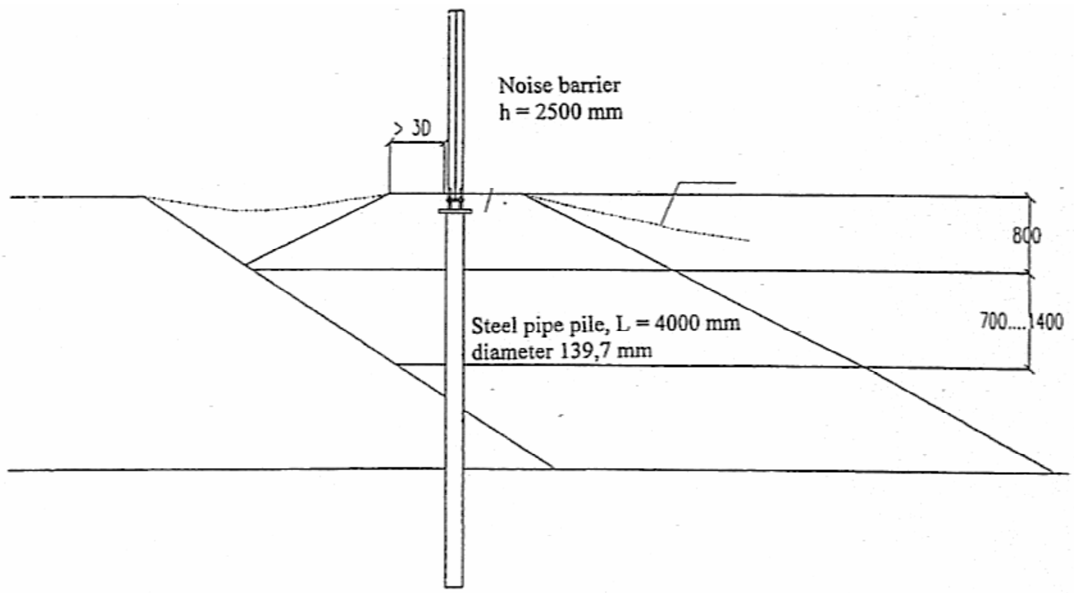



*Figure 10* Example of noise barrier structure with steel pipe piles.

The used drilling method was eccentric (ODEX), which loosens the surrounding soil quite much. Because of that, surrounding of one pile loosened so much, that the pile inclined a little during end drivings. When separate steel pipe is used and pile is grouted, and finally the casing is withdrawn, the influences of loosening can be reduced. However this installation method causes extra working phases. Another choice to reduce influences of loosening would be soil packing in pile surrounding. Packing could be done with vibrating plate for example.

### 4.4.3 Portals and lightning poles

Foundations of portals and lightning poles are quite similar to those of railway power-poles. Portals and lightning poles are nowadays founded mainly by concrete foundations or elements, which are excavated to the ground. However that loosens the embankment and working method is quite slow. Geotechnical Laboratory of Tampere University of Technology has studied foundations of portals with drilled piles for example in Hirsikangas traffic interchange in Highway 3 between Toijala and Valkeakoski. Lightning poles, which are founded on drilled piles, were studied in Joensuu.

### 4.4.4 Electricity transmission nets and telecommunication towers

The research for foundations of electricity transmission nets and telecommunication towers will start at Geotechnical Laboratory in summer 2000. Foundation research is based on drilled piles.

# 5 Future of micropiles

The future of micropiles is very promising because of many application areas like:

- Underpinning
- Small house foundations
- Bridge foundations
- Machine foundations
- Pole and tower foundations

In underpinning the use of micropiles, especially drilled micropiles, is increasing fast because of many needs for example in Turku.

Totally ventilated ground floor applications to avoid moisture problems increase the need of micropiles for small house foundations especially on very soft and wet areas. Similar applications can be used on radon areas, polluted areas, natural or war hazard areas.

Bridge foundations can be done fast and reliable by using drilled piles as composite structure. Diameter of those piles in Finland is 200-500 mm depending from size of the bridge. Application for pole and tower foundation is also very rapidly developing.

# 6 Acknowledgement

I am grateful to Rautaruukki Ltd for 16 years continuous co-operation in developing steel pipe piles. This development has been supported by Finnish Road and Railway authorities and by many Finnish contractors.

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