Development of Rautaruukki Micropiles

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ABSTRACT

Micropiles has been used for decades in Scandinavia. The most common execution method is impact driving. Other methods as drilling and jacking have been used only under special conditions. Nowadays need for underpinning has increased especially in the cities near coastline. For example there are about 400 multi-storey buildings founded on wooden piles in the city centre of Turku. Because of ground water lowering caused by various reasons, pile heads have started to decay. In some case the risk of the loss of the structural bearing capacity of old wooden piles requires methods which cause less displacement and vibration than impact driving.

1. INTRODUCTION

Rautaruukki Oyj is the Scandinavian biggest steel producer with a wide range of products. Metform is one of the five 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 diameters.

Research and development of the pile foundations and especially steel pipe pile foundations for difficult soil conditions and heavy loads have been the emphasis of activity of Geotechnical laboratory of Tampere University of Technology since more than 15 years. During this period the laboratory has acquired the leading position in this field in Finland.

Development of RR-micropiles was started in 1986.It was co-operation project with Rautaruukki Oyj and Tampere University of Technology to develop impact driven steel pipe micropile with internal sleeve joint (RR-pile). In 1989 first design instructions of RR –piles were published. Afterwards Rautaruukki has also developed an external joint for RR-piles.

During the last years development of micropiles has been very active in TUT. Several development and research projects have been carried out. The main financiers have been National Road Administration, Rautaruukki Oyj, State Railways and Tekes (the National Technology Agency). Most of them have been concerned on steel pipe piles. Installation methods of these piles have varied from percussive drilling, jacking, and screwing to impact driving. Some test has been made also with post and simultaneously grouting.

This paper will handle latest development projects of drilled and jacked micropiles.

2. DEVELOPMENT OF DRILLED PILES

2.1 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 displacement caused by pile driving
- high allowable pile loads are required
- only small settlements are allowed

The very hard Scandinavian rock formation at reasonable depth is favourable for end-bearing piles. Piles are drilled to bedrock by using percussive drilling methods. This is contrary to Central European practice where drilling is the main installation method for micropiles, because of different soil conditions.

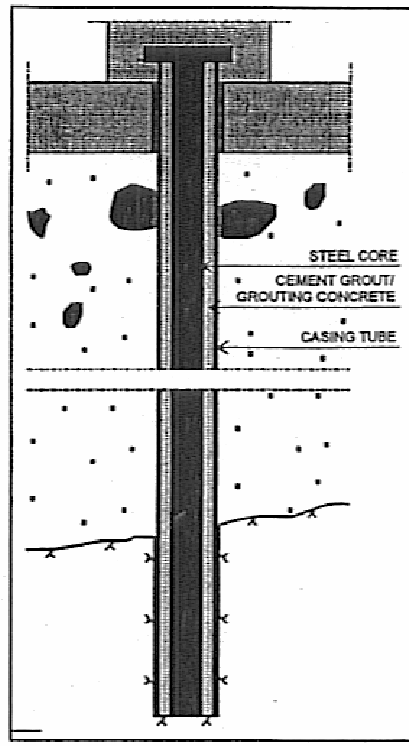

Figure 1. Traditional drilled pile resting on hard rock.

2.2 Research and development work

The research and development study of drilled piling was carried out 1996 - 1998 in co-operation with Geotechnical Laboratory of Tampere University of Technology and Rautaruukki Oyj. It was financed by Rautaruukki and Tekes (the National Technology Agency). The main goals of this study were elucidating suitable dimension methods for drilled piles, developing suitable drilled pile products as well as creating contacts between builders, designers, contractors and drilling equipment manufactures to find new solutions for piling in co-operation with each other. The product development was executed in close co-operation with actual construction sites.

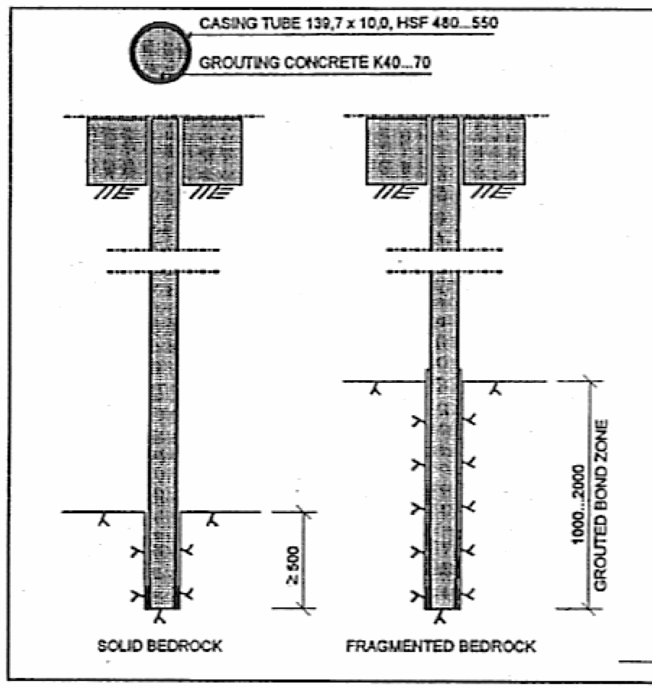

Figure 2. New pile resting on solid and fragmented rock.

2.3 Design

The determination of the bearing capacity of a pile contains always two separate phases, which have to be verified. The structural bearing capacity represents the capacity of a pile body to transfer the applied load from the pile head to pile toe with acceptable deformation. The geotechnical bearing capacity represent the capacity to transfer the applied load from the pile body to the surrounding ground with acceptable settlements.

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 emphasise. Depending on the quality of the bedrock the pile can be designed as an end-bearing pile or shaft-bearing pile in the bedrock. (Figure 2) The behaviour of drilled pile contact into the bedrock was investigated with full-scale laboratory tests were piles were installed by different drilling methods.

The main interest in dimensioning is related to 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.

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 in the determination of bearing capacity. (Figure 3). The influence of the buckling as a rejective factor of pile capacity depends always on the slenderness ratio of a pile. To evaluate the bond characteristics between steel and concrete, the full-scale composite structures tests have been performed.

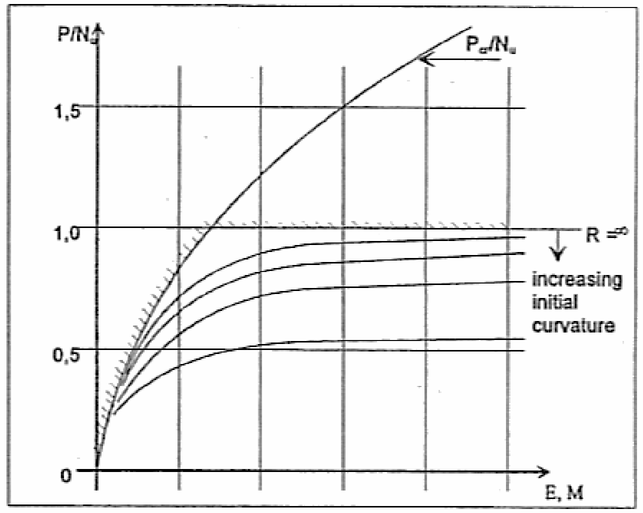

Figure 3. The structural bearing capacity of a pile is a function of deformation characteristics of the surrounding soil.

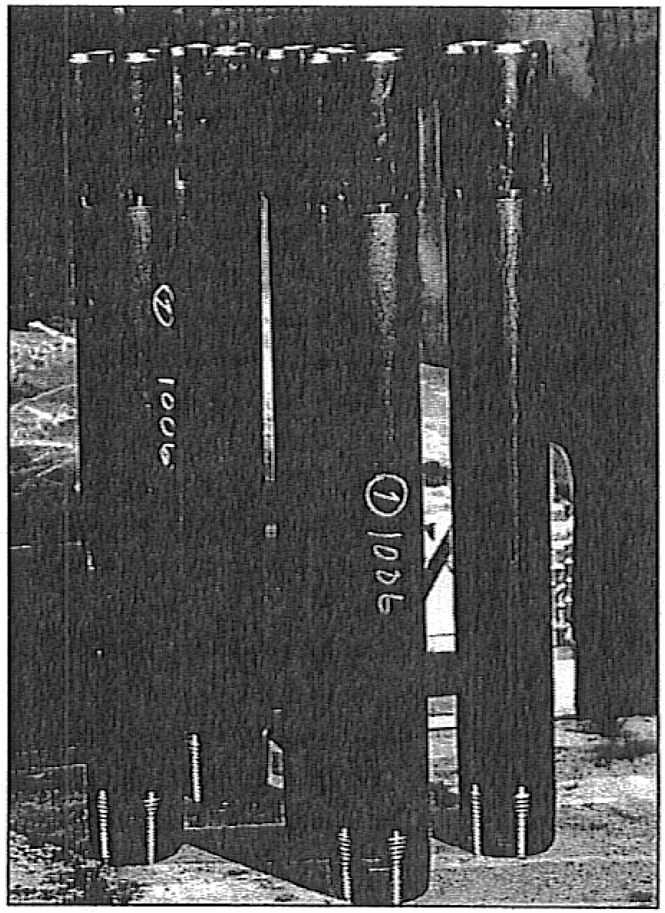

Figure 4. Drilled pile elements with threaded joints.

2.4 New pile products

The first interest has been in the growing need for underpinning of existing buildings in Finnish cities at the coast. The second interest has been finding new solutions for piling of railway bridges.

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 causes problems in mobilising enough capacity. The new pile type for underpinning purposes is presented in figure 3. On the contrary to traditional drilled pile, the pile consists of thick-walled casing tube filled with concrete grouting. In this special case, the minimisation 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 designed especially for these purposes guarantee the minimum deviations and the reliable end-bearing into the bedrock.

In addition, by the use of high strength structural steel and by dimensioning the permanent casing as a composite structure, the utilisation of high allowable loads is possible. In the case of short element lengths

(~1,5 m) one of the most critical tasks is to find the most effective splicing techniques. Two different splicing techniques have been proposed and also tested: a threaded joint (fig. 4) 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 steel core. The bending stiffness as well as bending resistance has been increased. Furthermore one working phase is spared in installation, because separate inner reinforcement is not used.

3 DEVELOPMENT OF JACKED PILES

3.1 Background

In Finland jacked piles were used quite a lot in underpinning until the end of 70's. At that time it was recognised, that bearing capacity of jacked piles was not satisfactory. In those days jacked piles used to be prefabricated concrete piles. Since those days the use of jacked piles has been limited only for special conditions, when use of other installation methods have been impossible or very difficult.

Nowadays need for jacked piles has increased especially in the cities near coastline. There are about lot of multi-storey buildings founded on wooden piles. For various reasons the groundwater level has lowered. As a result, the upper end of the piles beneath many buildings stand higher than the groundwater level, and piles have started to decay. During the next few years the decaying wooden piles must be replaced with new underpinning piles. The pile installation method shall be chosen on the basis of the condition of the piles, ground and environmental and the space available for the underpinning. Jacked piles are used when it is important to minimise any disturbance caused by the installation, for example, in the case when the existing wooden piles are badly decayed.

3.2 Research and development work

Due to advantages the jacked piles in 1996 a research and development project of the jacked piles was started in Tampere University of Technology to minimise the risks of jacked piles. The main financiers have been Rautaruukki Oyj and Tekes (the National Technology Agency). The main goals of the study was to minimise the risks of the jacked piles, which are

- to find out the suitable pile products,
- to find out effective and safety execution procedure.
- decrease the pressure under the toe of a pile
- to find out the effects of load variation to jacked piles.

The loading and installation tests were carried out in two sites as well as in laboratory test bit.

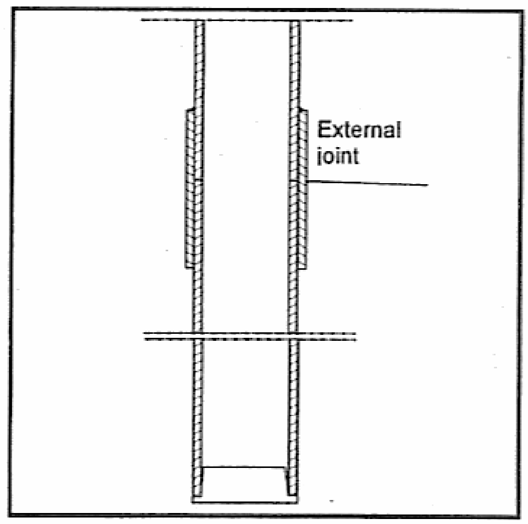

Figure 5. The external double cone friction joint

3.3 Pile type

In Finland the jacked pile type usually used for underpinning is steel pipe pile with a diameter of 139.7 mm and a wall thickness of 10 mm. The piles have external sleeve joints (Fig. 5). The joint is double cone friction joint.

The sleeve joints of jacked piles have been similar to impact driven piles. During the development work was found out that joints of jacked piles has to be less tight than the joints used for driven piles. Joint can be looser because jacked piles are not subjected to tensile stresses during installation. Looser sleeve joints can be closed with a lower pressing force and therefore no extra stresses are caused to the superstructures and to temporary jacking structures during closing. Very tight joints require high pressing forces for closing the joint, which causes noise and vibration during the sudden closing of a joint. This may cause damages to superstructures and temporary jacking structures.

3.4 Geotechnical bearing capacity

In the case of jacked piles the main importance in dimensioning is the geotechnical bearing capacity. The structural bearing capacity has to dimension for the jacking forces and it will also be tested during the jacking. The structural bearing capacity of a jacked pile has to be dimensioned taking into account corrosion allowance during the designed lifetime.

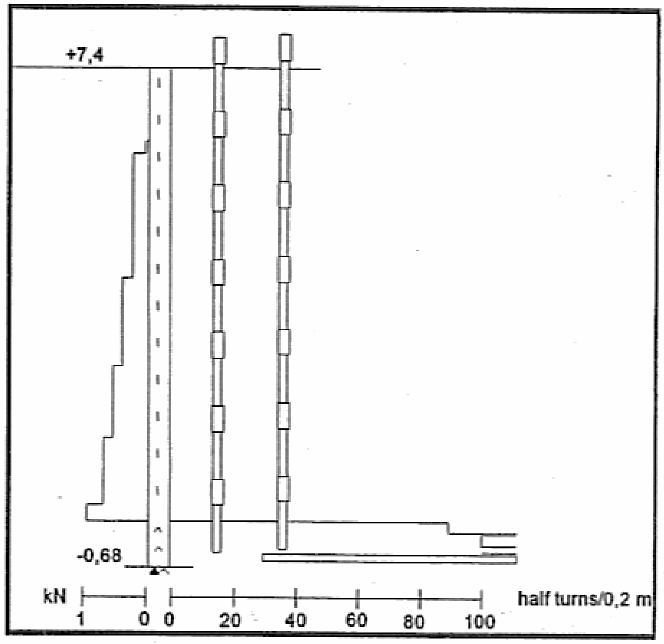

Figure 6. Example of soil conditions In Turku

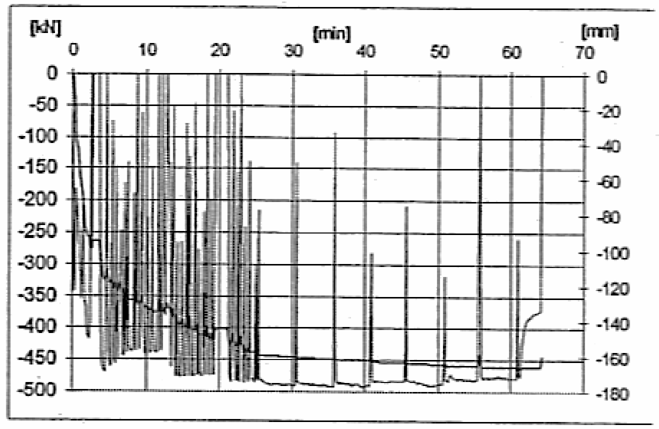

Figure 7. Load variation during the end-jacking procedure

Geotechnical capacity is almost never the same as the maximum jacking force of the pile. Geotechnical bearing capacity depends, certainly, on soil conditions. One example of typical soil conditions in Turku region is shown in figure 6. On top of it is a very soft layer of clay and below it a stony glacial till layer rests on the bedrock. These kind of soil conditions might cause troubles for jacked piles, because jacked piles are not able to penetrate into bearing layers. The pressure beneath the toe of a jacked pile is very high when same pile loads as for driven piles are used. Driven piles will penetrate into bearing layer, transferring part of the load to ground by shaft of a pile. Because behaviour of granular structures of soil is poorly known at high stresses some tests have been done to ensure the capacity of jacked piles in those soil conditions. (Chapter 3.5)

To improve geotechnical bearing capacity it is necessary to do same kind of end driving as with impact driven piles. In Finland the end driving system for jacked piles has been following: "The installation of piles is completed by raising the pressing force at the till layer to a level that is two times the design load specified in the geotechnical design. The load is kept constant for about five minutes, increasing the pressure in the jack as necessary. After this the settlement is measured, the load is decreased to 0 kN and the procedure is repeated. The loading is repeated at least ten times. When the permanent settlement for five consecutive loading runs stays below 5 mm, the loading is ended"

The effect of end-jacking can be seen from figure 7. In the end-jacking the settlement of the pile takes place during the variations of load. During a constant loading of five minutes there is virtually no settlement. The main point in the end-jacking is that the loading is varied frequently, because changes in the load always cause settlement in the piles. Figure 7 shows that dozens of loading changes are required to fulfil the terminating condition.

3.5 Load tests

Static load tests

A few piles were test loaded using the slow maintained load test method. Table 1 shows the results calculated from the static load tests. The results were obtained by four graphic methods, which allow determining the ultimate geotechnical load from the load-displacement curve.

The force used for the end-jacking at the As. Oy Ursinikatu 10 was 2.0 times the allowable load. At As. Oy Yliopistonkatu 36 the load used in the end-jacking was 1.8 times the allowable load. The average safety factor of the allowable load in relation to the ultimate geotechnical capacity of the piles was slightly less than 2.0 at As Oy Ursinikatu 10 and slightly less than 1.8 at Yliopistonkatu 36. This reveals that the geotechnical ultimate capacity of jacked piles is close to the force used in the end-jacking, provided that the end-jacking is performed properly.

Table 1. Results of static load tests at As Oy Ursininkatu 10

Pile number	24		53		100		101	
Allowable load [kN]	240		240		253		218	
Maximum load [kN]	480		480		505		435	
Ultimate load	[kN]	safty	[kN]	safty	[kN]	safty	[kN]	safty
SPO-95	>480	>2	390	1,6	500	2,0	450	2,1
Davisson	>480	>2	310	1,3	480	1,9	410	1,9
Butler and Hoy	>480	>2	390	1,6	480	1,9	400	1,8
Fuller and Hoy	>480	>2	390	1,6	480	1,9	410	1,9
Average of safety		>2		1,5		1,9		1,9

Table 2. Results of static load tests at As Oy Yliopistonkatu 36

Pile number	8		67		70		164 A		165 A	
Allowable load [kN]	280		280		280		280		280	
Maximum load [kN]	500		500		500		500		500	
Ultimate load	[kN]	safty	[kN]	safty	[kN]	safty	[kN]	safty	[kN]	safty
SPO-95	500	1,8	530	1,9	540	1,9	550	2,0	440	1,6
Davisson	490	1,8	490	1,8	540	1,9	540	1,9	440	1,6
Butler and Hoy	470	1,7	480	1,7	500	1,8	505	1,8	440	1,6
Fuller and Hoy	490	1,8	530	1,9	540	1,9	520	1,9	490	1,8
Average of safety		1,7		1,8		1,9		1,9		1,6

Load variation test

The settlement of piles caused by variation of wind load was studied at As. Oy Ursininkatu 10. A simulation of the wind load variation was performed on two piles. The range of the variation of wind load was assumed to be 0 kN - allowable load, which was the range given by the structural engineer of the underpinning project.

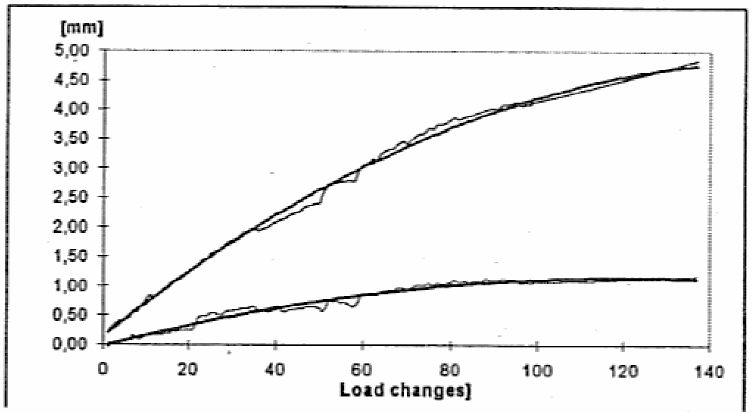

Figure 8. The development of settlement during the load variation test

The pile loading was raised to the design load of 235 kN and then decreased back to zero. This was repeated 140 times. Figure 8 shows the development of settlement due to loading variation. The Figure reveals that the slope of the trend line also decreases when the number of loading runs is increased. This result also suggests that within this variation the piles are on the safe side of geotechnical failure, but the loading variation will still cause some settlement of piles in the future.

3.5 Jacked piles for underpinning

Jacking of piles is very convenient for the residents, because it produces virtually no noise or vibration. Because jacking of a pile does not produce any vibrations and therefore does not any involve settlement risk to the underpinned building, but minor settlement is possible after piling

The end-jacking procedure used in the testing of the piles achieves a safety factor for the pile that is sufficient against geotechnical failure. Now the piles display an elastic behaviour under the design load in the static loading tests.

However, end-jacking procedure discussed above does not necessarily ensure that the pile will not settle under the service load, since the stress under the pile on the glacial till layer is high. The strength of the granular soil structure is poorly known at such high stresses. Some slow after-settlement can still occur. The settlement may be caused by loading variations or even permanent loads. The load variation test to simulating wind loads revealed that the growth of permanent settlement decrease slightly when the loading variations were continued. This leads to the conclusion that within this loading variation the piles are on the safe side against geotechnical failure, but loading variation will cause minor settlement of piles in future. Varying load during end-jacking is important for the achieving the geotechnical capacity of piles, since load changes at high stress levels always cause some restructioning of grain skeleton which cause settlement of piles.

It is also possible to install jacked piles very near or even inside the bearing structures. That will reduce the cost of load transfer structures. Major cost savings will also be realised in demolition and rebuilding because the jacking equipment does not need so much space as other types of pile installation equipment.

4 DEVELOPMENT OF OTHER PILE TYPES

Lot of development work also for other pile types has been accomparised than drilled and jacked piles by Tampere University of Technology and Rautaruukki Oyj. The development of grouted driven piles stared 1998. The development project and results of the projects has described in other paper. The topic of this paper is CSG Pile- A New Application for Impact Driven Piles.

5 CONCLUSIONS

Drilled piles

In order to achieve economic structures, advantages of high pile capacity should be taken in consideration. Drilling techniques have developed over the last years giving opportunities for developing new and different pile types. The diameter of a casing tube in respect to the wall-thickness may be chosen with out restrain. Wooden piles can be also be penetrated by special drilling tools. A safe bed rock contact can be secured. Drilled piles may be installed in restricted headroom.

The pile capacity corresponding to the traditional steel core pile can be achieved by pipe cross section when thick walled casing and high strength structural steel are utilised.

The implementation of the pile splices is crucial issue in pile type for underpinning purposes. There are two alternative solutions as an option for conventional hand made welding: a welding by robot and threaded joint.

Jacked piles

Friction joints of jacked piles have to be less tight than the joints used for impact driven piles. Joint can be looser because jacked piles are not subjected to tensile stresses during installation. Looser sleeve joints can be closed with a lower pressure and therefore during closing no extra stresses are caused to the superstructures and temporary jacking structures.

The end-jacking procedure of the test piles achieves a safety factor for the pile that is sufficient against geotechnical failure. The tested piles display an elastic behaviour under the service load in the static loading tests.

Jacking of a pile does not produce any vibrations and therefore does not involve the risk of settlement to the underpinned building, but minor after-settlement may occur after the piling.

It is also possible to install jacked piles very near or even inside the bearing structures. That will reduce the cost of load transfer structures. Major cost savings will also be realised in demolition and rebuilding because the jacking equipment does not need as much space as other types of pile installation equipment.

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