# CSG PILE - A NEW APPLICATION FOR IMPACT DRIVEN MICROPILES

Jouko Lehtonen

Rautaruukki Ltd

## ABSTRACT

CSG or Continuously Shaft Grouted, impact driven micropiles have been developed since 1998 based on Scandinavian practice on slender steel piles. Impact driven, end bearing steel micropiles are common for underpinning, for light loading construction - for instance detached houses - and for industrial construction in restricted space. CSG piles have been tested in laboratory and field conditions, in sand, moraine and clay. Some installation methods have been studied including light percussive hammers and jacking. Test loadings have been implemented both in compression and in tension. Shaft resistance of CSG piles approximates to drilled and post-grouted micropiles.

## 1. INTRODUCTION

### 1.1 Micropile practice in Northern Europe

Micropiles are in common use in Scandinavia mainly for following purposes:

(i) Underpinning. There are hundreds of houses - detached or multi-storey houses - underpinned by impact driven, steel micropiles. The main reason for underpinning is decay of existing wooden piles, which were an acceptable ground engineering method for houses up 1970's. Typical applications are piles of type RR115 (114,3x6,3) or RR140 (139,7x10) giving a service load about 300…600 kN.

(ii) Light load on soft soil. Very soft soils, clay and organic clay, are typical soil condition constructing light loaded houses as detached or semi-detached houses in Scandinavia. Typical load under a structural wall is 20…30 kN/m giving a service load to a pile about 100…200 kN. A common application is a slender steel pile, as type RR60 (60,3x6,3) or RR90 (88,9x6,3).

(iii) Industrial construction. There are thousands of manufacturing buildings in Scandinavia locating on very soft soils. The first phase of construction of a factory is implemented typically with driven pre-cast concrete piles. Additional construction - between existing buildings and production machinery - is continued typically with steel micropiles of type RR140 or RR170 (168,3x10), a service load respectively about 500…700 kN.

Totally there are over 5000 objects implemented by impact driven, steel micropiles in Finland, Sweden, Norway, UK, Baltic countries and Russia.

Micropiles are almost always of end bearing type, without any additional grouting, due to very solid granite bedrock, which is possible to reach in depth of some metres under soft soil layers. Lengths of 5…20 m are most common, but there are deeper piles, as well, up to 50 m.

Impact driven micropiles have been equipped with a special coupler technique causing a friction joint due to double conic shape of the sleeve. Screw pile couplers are made of square hollow sections in order to get a good torque resistance.

### 1.2 Discussion of definitions

Micropiles are in Northern Europe commonly end bearing, in diameter 60…300 mm, drilled or impact driven, sometimes screwed piles. Steel piles represent over 90 % of micropiles.

According to a new proposal of CEN standard (prEN 12699) micropiles are in diameter under 300 mm for drilled piles and 150 mm for displacement piles; micropiles can be typically installed by means of small rigs; shaft resistance and base resistance may be improved, mostly by grouting.

According to definitions of FHWA-RD-96-016 micropiles are a small-diameter subset of cast-in-place replacement piles.

According to a new draft of DFI, micropiles are small-diameter, drilled, cast-in-place composite piles, in which the applied load is accepted by steel reinforcement, in different proportions and transferred to a suitable horizon by cement grout and frictional grout/ground bond.

In general, *micropile* is a compound of words *micro* and *pile*. *Micro* could concern both installation in micro-space and micro-dimension in diameter. Additional restrictions for installation or materials are not necessary.

### 1.3 Objectives to develop CSG piles

The research and development project of CSG piles, financed by Finnish government organisation Tekes and steel manufacturer company Rautaruukki Ltd., had following objectives:

(i) To improve shaft resistance of conventional impact driven steel piles type RR pile in order to develop a displacement pile with high shaft resistance.

(ii) Constant and even grout covering onto the pile core in order to manage grout location and consumption in any soil layer.

(iii) To combine new installation machinery, for instance a breaker-hammer type Rammer or a drilling hammer, to the driven micropile technology.

R&D project of CSG piles has been implemented in co-operation with the Geotechnical Laboratory at Tampere University of Technology, TUT. The first research report of the project will be the post-graduate thesis of the author at TUT. Several patents are pending for CSG technology.

## 2. INSTALLATION OF CSG PILES

### 2.1 Phases of CSG method

Phases of CSG pile during test site installation are shown in Fig. 1. In practice there are not separated phases for impact driving and grouting. Several applications for simultaneous grouting during installation have been developed both for impact driving and jacking.

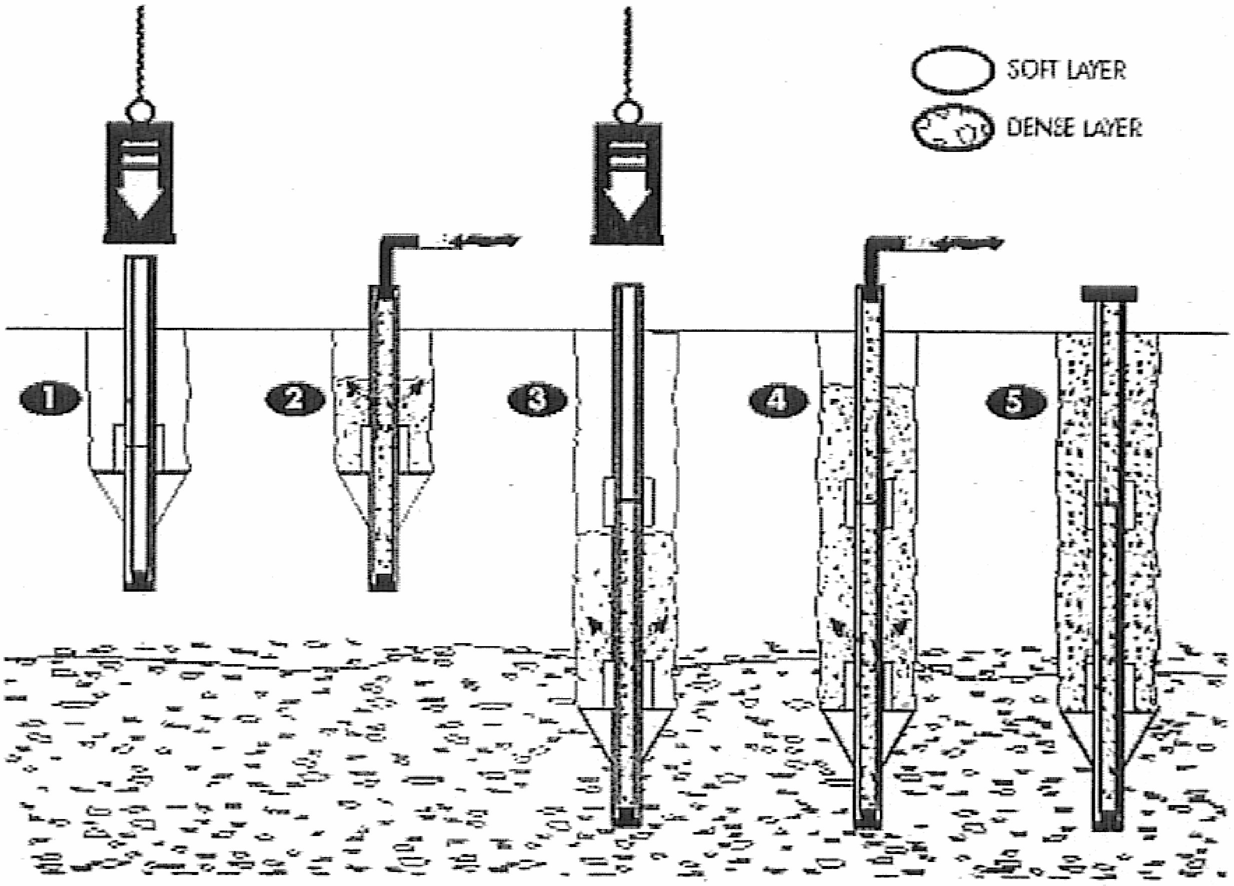


Figure 1. Installation phases of a CSG pile: (1) beginning of embedding, (2) grouting through the pipe core, (3) simultaneous impact driving, (4) continuous grouting until embedding in design depth, (5) a ready pile.

### 2.2 Installation methods

CSG method has been tested with impact driving and jacking. Correspondingly there is a R&D project in Estonia in order to develop a new screw pile application for Tubex piles originally made by Fundex.

In one case, at Lappeenranta test site, there was a combined installation with drilling and impact driving in order to penetrate a very dense top layer with boulders. The drilling hammer was utilised for impact driving after pre-drilling with a casing tube.

Lengthening of CSG piles is very fast due to friction sleeve technique: ends of pile elements meet each other in a coupler within 5…10 blows, or in less than 10 seconds in other words.

### 2.3 Installation machinery

Several hammer types have been tested in order to find out differences concerning embedding speed and grouting features, Table 1. Piling tests have shown that high-frequency driving gives both efficient pressure peaks and reliable grout consumption procedure.

## 2.4 Installation speed

Installation speed of CSG piles have been monitored until now only concerning test sites without people being trained for a new technology. Installation speed, including impact driving and simultaneous grouting, seems to be reasonable, Table 2.

Table 1. Installation equipment tested for CSG piles.

| | Drop hammer | Compressed-air hammer | Hydraulic breaker hammer | Drilling hammer |
|---|---|---|---|---|
| Test pit in laboratory, TUT, Tampere | 800 kg | McKiernan Terry MK6 | Rammer S54 | |
| Mikkeli field test | 360 kg | | | |
| Hämeenlinna field test | 360 kg | | | |
| Lappeenranta field test | | | | Aquadrill 500 RT |
| Turku field test | | Atlas PH5 | | |

Table 2. Installation speed of CSG piles at test sites 1998…1999.

| Site | Installation speed (m/h) | Soil layer surrounding the bond |
|---|---|---|
| Mikkeli | 6 | Dense moraine |
| Hämeenlinna | 5,7 | Silt or soft clay |
| Lappeenranta | 4 | Sand |
| Turku | 16 | Soft clay |

# 3. TEST SITES 1998…1999

## 3.1 Laboratory tests in Tampere University of Technology (TUT)

Laboratory tests of CSG piles were implemented to the depth of 3,5 m in a test pit filled with dense moraine, Fig. 2. Tests were done in dry conditions. RR75 pile was tested as a pile core. Test piles were loaded to failure and excavated open and up-lifted for monitoring afterwards, Fig. 4.

One of most interesting observations done in the first laboratory tests was a remarkable pressure peak of grout caused by blow impacts during embedding, Fig. 3. Pressure peaks were high, 2...4 MPa, and repeated hundreds or thousands of times during installation depending on impact frequency of the machinery. Up-lifted samples of CSG piles appeared rough in shaft surface, due to - at least partly - repeated grout pressure.

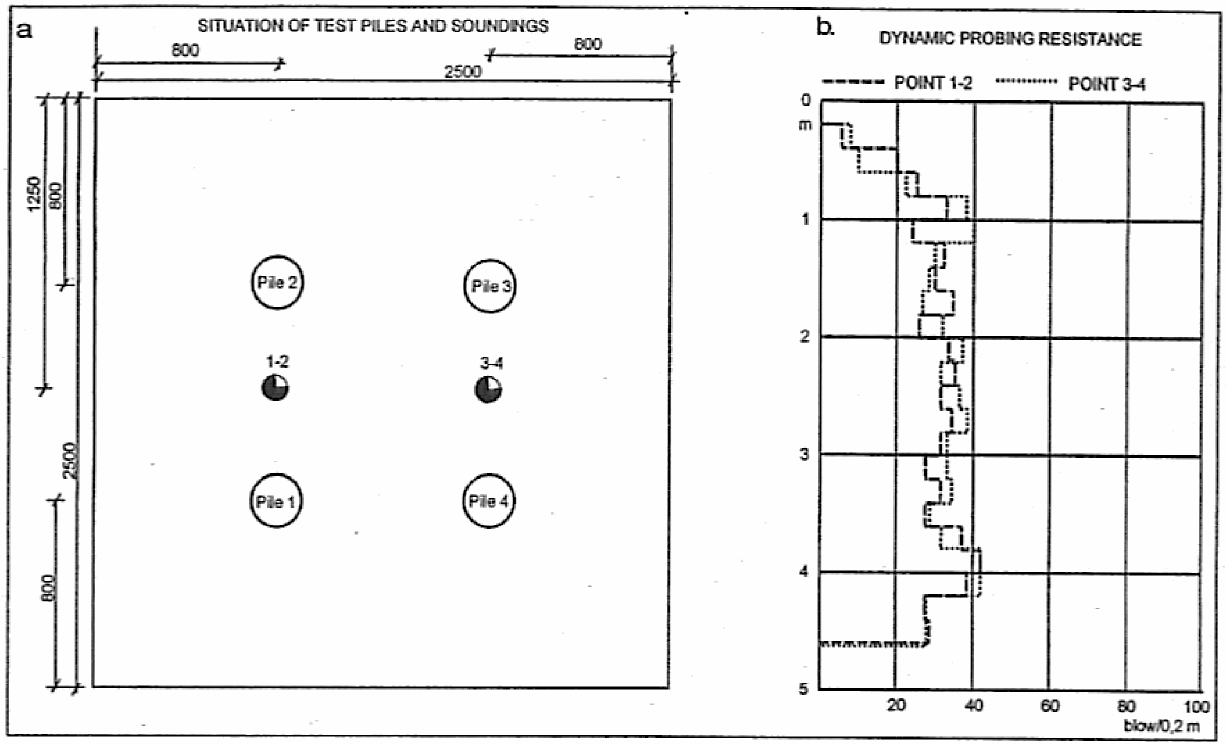


Figure 2. The test pit with CSG test piles and dynamic probing tests.

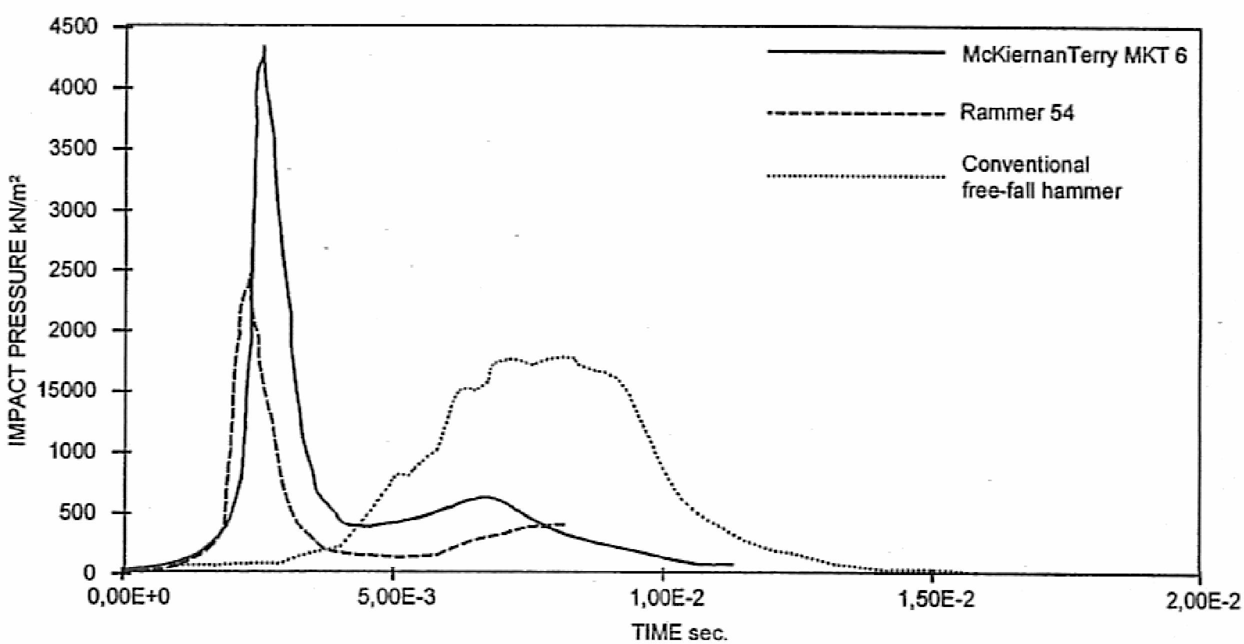


Figure 3. Pressure peaks of grout measured during impact driving.

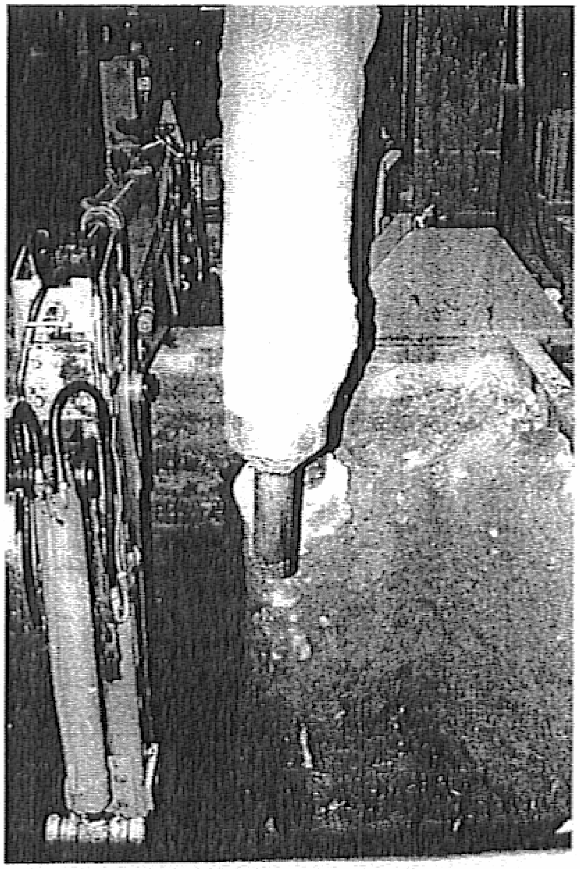

Figure 4. An up-lifted sample of CSG piles at laboratory test.

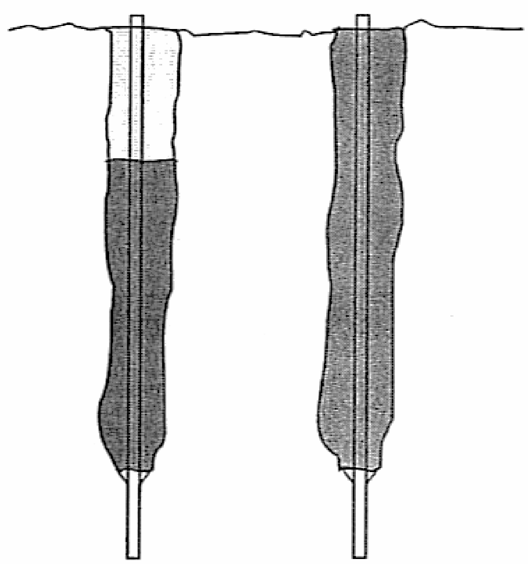

Figure 5. A partially grouted and a totally grouted CSG pile.

### 3.2 Field tests of impact driven piles

Objectives of field tests of impact driven CSG piles have been shown in Table 3. Piles at Mikkeli, Hämeenlinna and Lappeenranta were of type RR75, at Turku RR90. A part of CSG piles were only partially grouted, when the upper part of a pile was surrounded by sand or gravel fill, Fig. 5.

Table 3. Objectives of field tests of CSG piles.

| Objective/site | Mikkeli | Hämeenlinna | Lappeenranta | Turku |
|---|---|---|---|---|
| Load bearing capacity | 1) compression<br>2) tension | tension | 1) compression<br>2) tension | |
| Grouting | 1) fully grouted<br>2) partially grouted | 1) fully grouted<br>2) grouting in soft soil | 1) fully grouted<br>2) partially grouted<br>3) deep grouting | 1) fully grouted<br>2) grouting in very soft soil<br>3) extremely deep grouting |
| Driving | drop hammer | drop hammer | drilling hammer | compressed air hammer |
| Applications | 1) compression piles<br>2) tension piles | compression piles | compression piles | compression piles |

### 3.3 Field test of jacked piles

A jacking installation of CSG piles was arranged with objectives:

- A new installation method. Other tests of CSG were implemented only by driving.
- Grouting with additional pressure. Driven piles were installed without additional pressure when a mortar pump was used only transfer of mortar. There is no pressure caused by driving impacts when piles are installed by jacking, so therefore grout must be pressured by a pump.
- Improved behaviour of jacked piles in long term loading. End bearing jacked piles have a risk of further settlement when stress in the soil under the pile tip is very high.
- A new steel core of CSG pile. Impact driven piles were constructed by steel core of RR75 or RR90 pile when as for jacking there was a RR140 pile in order to develop a bending resistant core for CSG piles.

## 4. LOADING TESTS

### 4.1 Laboratory tests

Totally four test piles were loaded up to failure. An example of load-settlement curves is shown in Fig. 6. The observed capacities were much higher than allowable or yield load of corresponding RR75 pile, Table 4. The failure was developed between the grouted shaft and surrounding soil. Structural capacity of a test pile was never reached. In practice, the cross-section of a CSG pile should be optimized according to existing soil conditions of a site in order to get a balance between structural and geotechnical capacities. Grout thickness have been varied between 10...60 mm in CSG pile tests.

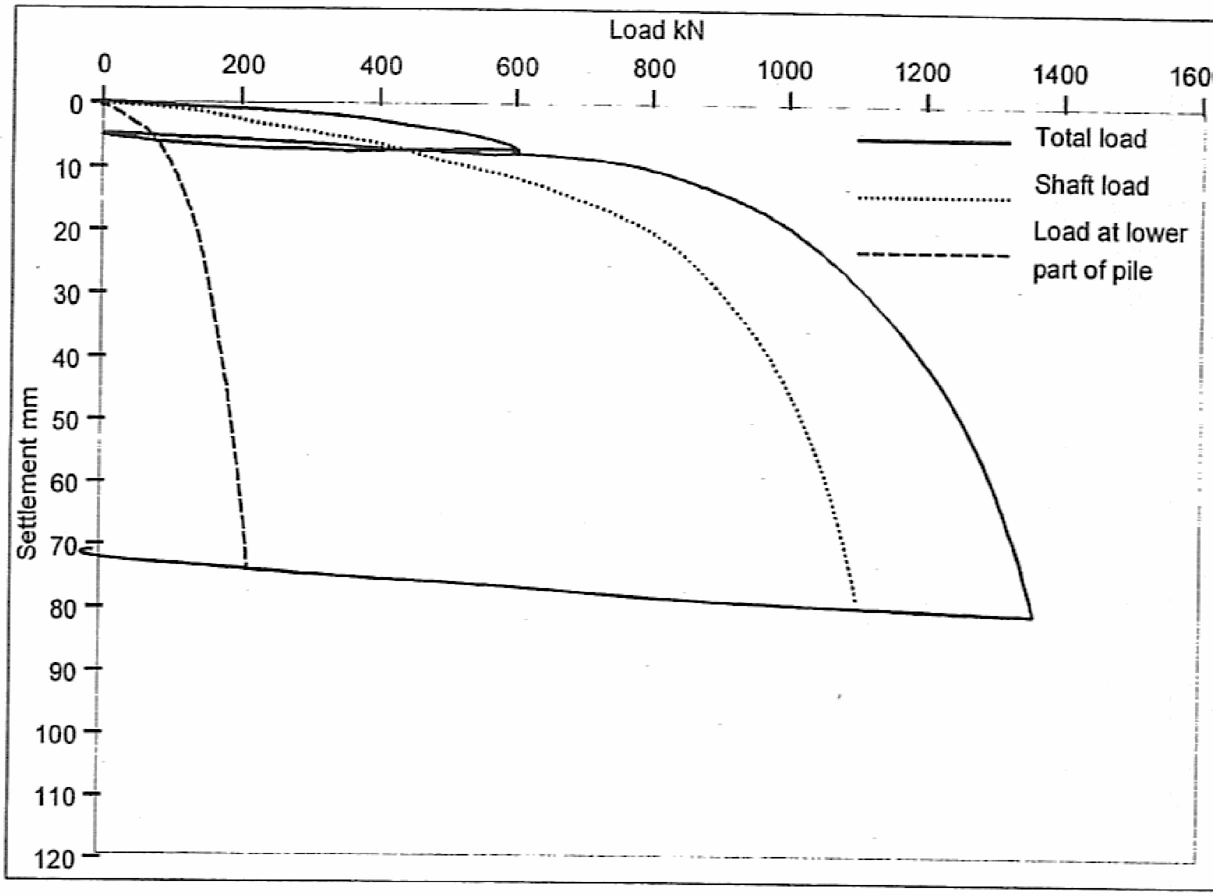


Figure 6. Load-settlement curve of a CSG pile at laboratory test.

Table 4. Comparison between load bearing capacity of conventional impact driven micropiles according to the Finnish driven pile standard LPO-87 and measured values of CSG piles at laboratory test.

| Pile type | Allowable load according to Finnish code LPO-87 (kN)<br>Structural load | | Yield load (kN)<br>σ=440 MPa<br>Structural load | Failure load at laboratory test (kN)<br>Geotechnical failure |
|---|---|---|---|---|
| | Piling class II<br>σmax=0,4x440 MPa | Piling class IB<br>σmax=0,5x440 MPa | | |
| RR75 | 243 | 304 | 607 | |
| CSG pile | | | | 630…990 |

## 4.2 Field tests

Several test loadings have been implemented in field conditions both in saturated and dry conditions. Test sites, located in Southern Finland, are introduced in Table 5.

Table 5. Test pilings of CSG method in field conditions.

| Site | Number of test piles | Embedding method |
|---|---|---|
| Mikkeli | 42 | Impact driving |
| Hämeenlinna | 7 | Impact driving |
| Lappeenranta | 40 | Impact driving |
| Turku, Vähä-Hämeenkatu | 3 | Jacking |
| Turku, Asikainen | 1 | Impact driving |
| Totally | 93 | |

# 5. SHAFT RESISTANCE

## 5.1 Laboratory conditions

Shaft resistance of CSG piles in laboratory conditions varied between 250…395 kPa. The proportionality coefficient β, see Eq. 1, varied correspondingly between 7,1…11,2.

$$R_s = A \cdot \beta \cdot \sigma'_v \qquad (1)$$

where
- $R_s$ is shaft resistance of a pile
- $A$ the area of the bond
- $\beta$ a proportionality coefficient depending on installation methods and soil conditions
- $\sigma'_v$ effective vertical stress at bond depth.

## 5.2 Field conditions

Shaft resistance in field conditions appears lower than in laboratory conditions. However shaft resistance in non-cohesive soils have been measured between 150…300 kPa. Values approximate to values published concerning Type B, Type C and Type D of drilled micropiles.

# 6. CONCLUSIONS

## 6.1 Definition of micropiles

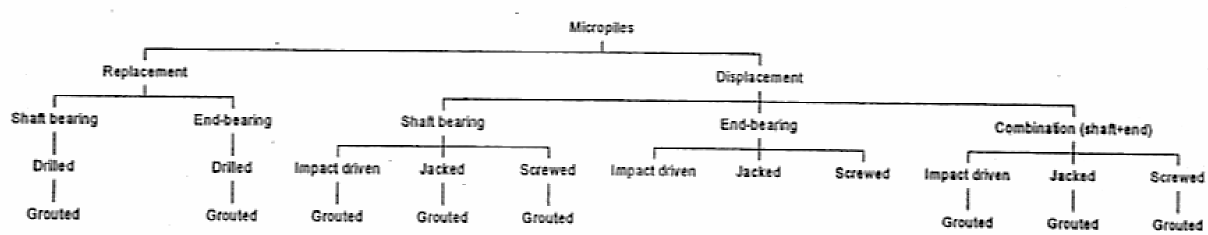


Figure 7. A proposal for a classification of micropiles.

Definition of micropiles should be flexible in order to keep any development available and in order to get more efficient methods with lower costs into common practice. A free competition between different potential methods should be a basic value to the whole branch. A proposal for a definition could be: micropiles are slender, normally under 300 mm of diameter, piles which are applicable under restricted installation headroom. Then micropiles could be *replacement* or *displacement*, *shaft* or *end-bearing*; *steel* or *cast-in-situ*; *drilled*, *impact driven*, *jacked* or *screwed; grouted* or *non-grouted* piles giving to a client or a designer a versatile collection of tools and methods for any soil and construction conditions. Micropiles could be classified for instance according to Fig. 7.

### 6.2 Character of a CSG pile

Shaft resistance of CSG piles approximates to drilled and post-grouted micropiles.

According to the classification of Section 6.1 CSG piles are

- displacement
- shaft bearing, maybe combination of shaft and end-bearing
- impact driven, maybe jacked
- grouted micropiles.

### 6.3 Applications of CSG piles

Typical applications of CSG piles - corresponding other types of micropiles - could be:

- underpinning
- compression pile
- tension pile
- soil anchorage
- soil nailing.

### 6.4 Further research and development

Further research and development is needed due to limited data collected from test sites. Potential items for additional studies are:

- to determine influence of installation method to the roughness of pile shaft
- to determine influence of installation method to compaction of surrounding soil
- to survey long-term loading capacity, especially taking care of relaxation of compacted soil.

## ACKNOWLEDGEMENTS

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## REFERENCES

prEN 12699, CEN/TC288/WG8/ Execution of special geotechnical works: Micropiles

Donald A. Bruce & Ilan Juran: Drilled and Grouted Micropiles: State-of-Practice Review, FHWA-RD-96-016