# Execution of Micropiles
# A Synopsis

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## 1. General

Definition is needed what shall be understood by execution of micropiles as it may range from the entire works related to micropiles as defined by the European Standard (Execution of Geotechnical Works). In this paper execution of micropiles shall comprise

- drilling or driving to form a hole for the installation of the bearing member,
- installation of the reinforcement,
- grouting,
- pile head connection to the superstructure.

## 2. Synopsis of Related Deep Foundation Elements

The development of deep foundations in the 20$^{th}$ century shows that the use of ground with weak bearing properties has become a central task for industrial development, construction of commercial space and housing.

Pile driving was known for wooden piles for a long time. The change to prefabricated piles with different materials allowed higher bearing capacities and started a new technology, comprising excavation procedures, shaft dimensions and bearing capacities. Bored reinforced concrete piles followed later and opened the range of high bearing shafts with big diameters. An opposite development was followed up by decreasing the borehole diameter but maintaining relatively high bearing capacities as well. The similar execution methods for ground anchors and micropiles started only after the high load bearing capacity by skin friction of pressure grouted boreholes with small diameters was detected and the fear of buckling of grouted-in bars under compression has decreased and been limited to very weak soils.

From Tab. 1 the similarities between ground anchors and micropiles can be recognized. Basicly the same technology is addressed and knowledge and publications relating to ground anchors can largely be adopted for micropiles. If rules for the execution of micropiles are established those for ground anchors should be borne in mind.

## 3. Method and Sequence of Execution of Micropiles

The big variety of drilling and driving methods and the differences in installation and grouting allow for many micropile systems. Many of them exhibit special advantages for certain conditions.

Table 2 is the attempt to cover all those features in one survey. This may help the designer to decide on the possibilities of application and establish acceptance criteria.

If rotary percussion drilling mostly with casing is used, almost any soil can be penetrated, other drilling and driving methods specialize on certain ground conditions and borehole depths. Ground water conditions have to be considered as well. Artesian water needs special measure to prevent soil losening. The sequence of operations for drilling or driving, installation and grouting varies with the different micropile systems. Not all types of reinforcement are appropriate for the various drilling and grouting methods. Selfdrilling micropiles e.g. require tubes.

The type of grouting may depend on the sequence of the installation and the chosen reinforcement as well. High bearing capacities require special types of grouting tubes and valves, if no foot enlargements are chosen. The bond may be enhanced if water flushing during drilling is replaced by cement slurry with high W/C ratio. With increased pressure and hydraulic widening of the borehole, transition to jet-grouting technology is reached. The mainly vertical and subvertical position of the borehole sometimes allows gravity filling only for low capacity applications and granular soils. In any case the gravity pressure of the grout until setting improves the bond at the lower end of the micropile and adds safety.

A large amount of publications covers the execution of micropiles or their components and is referenced in Tab.2. Literature on ground anchors adds lots more of available experiences.

## 4. Anchorages for Micropiles

Surprisingly the topic of anchorages between micropiles and superstructure has not yet been addressed extensively in literature, is, however, of equal importance for safe load transfer.
To the favourable features of micropiles belong the availability of tested anchorage components and easiness of their mounting or custom designed weld-on parts. In addition mere bond anchorage can be chosen if sufficient bond length is available.

For the design some requirements should always be born in mind:

- The load induced stresses flare outat the anchorage element or along the bond length
- Splitting forces due to load transfer have to be balanced by spiral reinforcement in foundations with small dimensions or are taken over by material strength for larger dimensions.
- The load direction determines the position of the anchorage element and spiral reinforcement. Alternating forces are possible.
- Anchorages shall be free of slip.
- For bond anchorages the design resistance of the interface along the steel reinforcement and the borehole as well have to be investigated. Tests frequently yield more favourable results.
- Shear cones may theoretically occur at the tension side of a bonded-in reinforcement. Bond interruption may be considered if required.

A particular challange are old brick and stone foundations to which the micropile reinforcement has to be bonded. A roughened drill hole wall is advisable for safe load transfer and reasonably short bond length. In common the interface borehole – old structure is the weakest link. Sufficient distance to the edge of the existing, non-reinforced structure has to be observed to avoid splitting. In special cases bond connection may be supported by an abutment which is created by a borehole enlargement underneath the old foundation. If the connecting concrete structure is built after installation of the micropiles reinforcement according to the rules can be provided.

The anchorage of micropiles in jet-grouted horizontal diaphragms needs the proof that load transfer requirements are compatible with the jet-grout qualitiy and available bond length which may be extended by additional anchorage cylinders. Extraction tests have to be performed.

Screw-on anchorages for threaded bars or tubes usually have to be locked to avoid slip and cracks in the concrete. Frequently they are subject of investigation tests for general approval. Hydraulic wrenches are fitted to the anchorage components for easy operation.

For standard tubes which are incorporated into micropiles weld-on anchorages are common. It has to be distinguished between weldings for fixation and for load transfer. Compression anchor plates usually need a fixation welding only. This can easily be done at site conditions. For bearing weldings all provisions and requirements have to be observed in order to accomplish a complete and safe load transfer to the superstructure. In particular, easy access has to be provided.

## 5. Recent Examples of Execution

It is worthwhile to shortly report on two more recent executions of large amounts of micropiles:

### 5.1 Underwater installation of GEWI-Piles for the big excavations of the „Central Construction Area" in Berlin (see U-64 in Tab.2).

About 6500 GEWI-Piles were installed at 15 –18 m under open water level. Due to the great depth little diver assistance was allowed. The contractor who was experienced in marine construction sites chose installation from precisely guided pontoons which were docked-on along a main pontoon. Standard rotary drilling with Ø168 mm casing, cement slurry flushing and type III grouting was executed from the individual units. The boreholes were located by D-GPS measurement. Whilst the execution followed standard methods the management of the works was an outstanding organisational task.

### 5.2 Uplift securing of the excavation for a lock in Northern Germany

The contractor chose a jet-grouted horizontal diaphragm as water stop for the excavation. A large scale application of 1700 SOILJET-GEWI Piles secures it against uplift pressure. The proprietory micropile system uses in combination with the diaphragm the jet-grouting technology for the drilling of the borehole and the bond enhancement with the surrounding ground. The diameter is increased by forming a jet-grouted column or spiral shaped ribs (Fig. 2) depending on the ground properties. The borehole is filled with pure cement grout and the GEWI-Bar is installed subsequently. The reinforcement connects directly to the diaphragm. The bearing capacity of the bond had to be proven by test

**Tab. 1 Linear Construction Elements for Deep Foundations**

| | Bored and driven piles | Ground anchors | Micropiles |
|---|---|---|---|
| **Historical development** | Bored reinforced concrete piles since the beginning of the 20th century | Soil anchors BAUER 1958 | Root piles Lizzi 1952 |
| **Bearing** | Compression<br>Bending<br>Shearing<br>(tension) | Tension | Compression<br>Tension |
| **Diameter of boring** | >300mm | 100 – 250 mm | 100 – 300 mm |
| **Excavation** | Auger<br>Grab<br>Impact driving<br>Vibrating | Rotary and percussion<br>Driving of casing | Rotary and percussion<br>Driving of (lost)casing |
| **Bearing section** | Reinforced concrete column | Tendon | Bar, tube, steel profile, reinforced concrete |
| **Load transfer to ground** | End bearing and<br>limited shaft bearing | Shaft bearing | Shaft bearing and<br>very limited end bearing (compression) |
| **In-situ manufacture** | Casting of reinforced concrete | High pressure grouting | Gravity and high pressure grouting |
| **Drilling equipment** | Large, heavy | Small, versatile, partially light weight | Small, versatile, partially light weight |
| **Working space** | Large, heavy load bearing platform and access | Restricted platform | Restricted platform + headroom possible |

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# Tab. 2 Method and Sequence of Execution for Micropiles

| Drilling (piling) method | Drilling | Driving | Installation of reinforcment | | | Grouting | | | Ground* | Literature |
|---|---|---|---|---|---|---|---|---|---|---|
| | sequ. | sequ. | sequ. | type | splice | sequ. | type | W/C | | |
| Continuous flight auger with solid and hollow stem | 1 | | 3 | b/t/c/p | no | 2 | I,II | fixed | cohesive,dry | S-59, S-66, S-67, S-103, S-123, S-271 |
| Cased** drilling with (air)/water flushing | 1 | | 2 | b/t | sp.c. | 3 | II to IV | f | any | |
| Cased driving | | 1 | 1 and 2 | b | sp.c. | 3 | II to IV | f | loose | U-39, U-67, U-74, U-83, U-93, U-127, U-131, U-141, U-153, U-157, " |
| Uncased drilling with air<br>water<br>mud | 1 | | 2 | b/t | sp.c. | 3 | II to IV | f | rock<br>cohesive<br>granular | |
| Drilling with cement slurry | 1 | | 2 | b/t | sp.c. | 1 | II | variable | soils | |
| Jet-grouted borehole | 1 | | 2 | b | (sp.c.) | 1 | jet -grouting | v | granular,fine | |
| Selfdrilling micropile | 1 | | 1 | t | yes | 1 and 2 | II to IV | v | any | |
| Driven pile | - | 1 | 1 | t/p/(b) | yes | - | - | - | soft+bedrock | |
| Driven and grouted pile | - | 1 | 1 | t/p/(b) | yes | 1 | I | f | soft+bedrock | |

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**No.** = sequence of execution, same **no.** = simultaneous operation
* = preferred ground conditions
* * = drill casing or lost casing forming part of the micopile
b = bar, t = tube, c = cage, p = steel profile, ( ) = limited
W/C = water–cement ratio, sp.c. = special conditions
drilling: rotary or percussion or both combined
driving: impact or vibration or jacking (special systems)

Type of grouting:
- I gravity filling
- II gravity and low pressure
- III pressure on top >1MPa
- IV pressure through valves, repeated, >1MPa

Literature:
- S = 1st IWM Seattle 1997 -page of proceedings
- U = 2nd IWM Ube 1999 -page of "
- T = 3rd IWM Turku 2000 -page of "

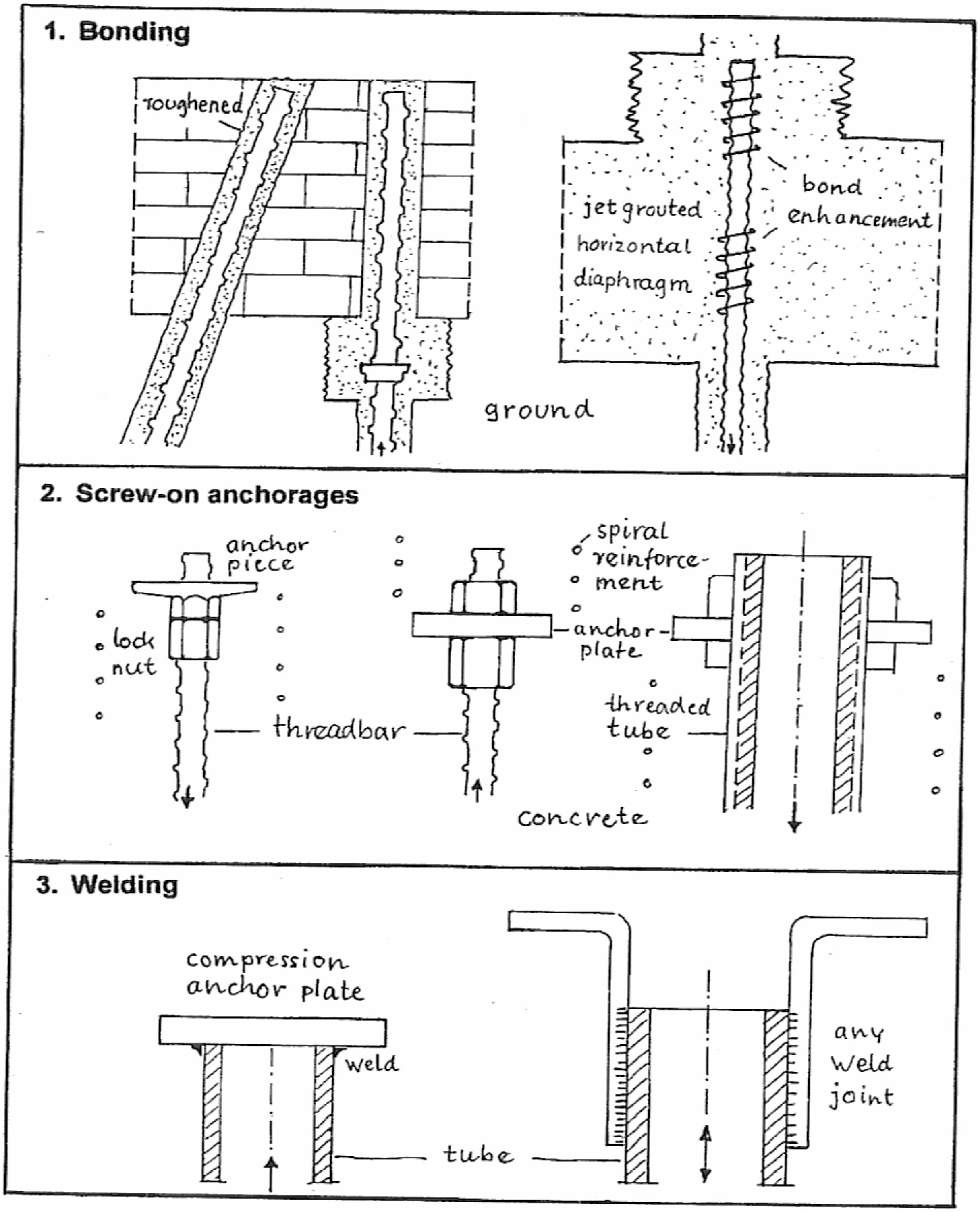


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**Fig. 1 Examples of Anchorages of Micropiles**

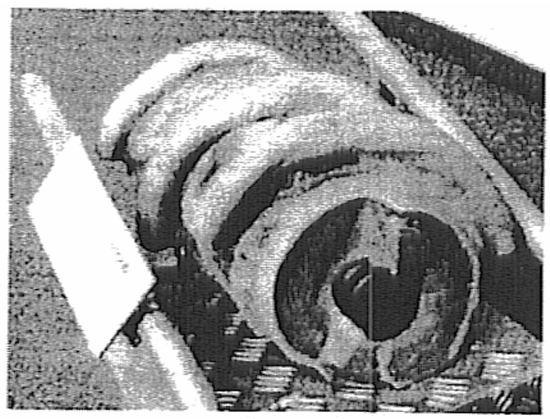

Fig. 2 Jet-grouted Micropile Type Soiljet Gewi Pile

(Courtesy Insond)