Special use of micropiles and permanent anchors

Helmut Schwarz¹, Klaus Dietz², Horst Köster³, Thomas Groß⁴, Stump Spezialtiefbau GmbH

Abstract: Micropiles and permanent anchors are important elements in geotechnical engineering. To use them successfully under difficult site and soil conditions it is necessary to improve the normal systems in due compliance with project specific specialist measures. Necessary improvements for difficult site and soil conditions are explained by three examples. The first shows the production of micropiles und permanent anchors in tidal-zone and the improvement of the load surfer zone to guarantee the load bearing capacity through a jetting foot. In the second example it is described how to protect permanent anchors against lime-attacking carbon dioxide in the groundwater in rock. At least the concept for the post-foundation under organic soil conditions of the Berlin State Library “Unter den Linden” is explained.

1. Introduction
Micropiles and permanent anchors are important elements to provide more safety in specialist underground works. Based on over 30 years of experience the scope of application is continuously extended. With the following three examples we show how permanent anchors and micropiles can be manufactured successfully even in an
adverse subsoil environment, in due compliance with project specific specialist measures and a consistent quality assurance system.

2. Prestressed tension piles in harbor construction

2.1 Project
The former AG Weser shipyard premises at Bremen are converted into a harbor and industrial park. Therefore, the existing quay-side installations must be strengthened and stabilized to facilitate deeper excavations. In one section, the so-called Pier II (FIG. 2), the existing sheet piling can still be used and only has to be secured additionally by providing a permanent anchor in the tidal zone. In the area of Pier I, a completely new sheeting is foreseen, with a micropile keeping the beam tie in place (FIG. 1).

![Diagram of rehabilitation of AG Weser premises, Pier I](image)

**FIG. 1:** Rehabilitation of AG Weser premises, Pier I

2.2 Foundation soil and boundary conditions
Owing to numerous structural changes on the premises the subsoil in the project area is covered all over by fill material. This fill area with its brick remains and concrete...
fittings reaches down to approx. – 7 m. The other sand-gravel fill layers further below had been placed to be used as foundation area. These are followed by a loose gravel-sand mix layer with clay and silt depositions between – 8 to - 10 m above MSL. The loose gravel-sand mix layer necessitated additional measures, in the form of a jetted foot, for the 900 kN pile working load to be safely lowered into the ground. Owing to the fact that the anchor starting points at Pier II were located in the tidal range area, anchor setting and tensioning work could only be carried out under low-water conditions.

FIG. 2: Rehabilitation of AG Weser premises, Pier II

2.3 Specialist measures and quality assurance
The load bearing capacity of both piles and anchors was guaranteed through a jetted foot. Initially, a drilling was sunk in the twin-rotary-drive drilling method (overburden drilling) at Ø 160 mm. Upon reaching the final depth of ca 27 m the last 3 m of the fixed length were enlarged by using the jetting method. Following this, the piping was carried to the final depth again and the St 52 Ø 90 mm steel load bearing element inserted, which in turn was followed by the step-by-step grouting of the 12 m fixed length. All anchors were submitted to an acceptance test and tensioned to
1200 kN. All tension bars were found in compliance with the admissible deformation values.

In addition to safeguarding the load bearing capacity of the piles, bore manufacture proved equally difficult. In the area of Pier I, where the pile ended in the beam tie, a traveling cradle was used which could be moved on the quay wall (FIG. 3).

![Drilling operations at the top end, from traveling cradle (Pier I).](image)

FIG. 3: Drilling operations at the top end, from traveling cradle (Pier I).

![Drilling operations in tidal zone, from pontoon (Pier II).](image)

FIG. 4: Drilling operations in tidal zone, from pontoon (Pier II)
At Pier II, no additional load was admissible for the sheeting during construction work, so that the traveling cradle could not be used in this instance. For this reason, operations were carried out from the water side via a pontoon (FIG. 4). Owing to the tidal effects (ca. 3 m range of tide) the drill pipes had to be adjusted continuously during drilling. Owing to the fact that the drilling team carried out their work with utmost care, drill pipe twist-offs only occurred in exceptional cases.

3. Permanent anchors in aggressive foundation rock

3.1 Project
DB AG (German Federal Railways) construct a new railway line between Cologne and Frankfurt for high-speed trains. Several special structures must be erected as part of this project some of which have to be secured by means of anchors. In one particular case a retaining wall had to be provided to secure a side-hill cut. A buttress-type bored cut-off with back anchoring to the beam tie (FIG. 5) was selected instead of the angular retaining wall initially foreseen. A total of 431 permanent anchors with working loads of up to 1,130 kN and up to 45 m long had to be manufactured. In the case of approx. 290 permanent anchors the anchoring length reached below groundwater level. Specialist measures were required since the free carbon dioxide contained in the groundwater was aggressive to concrete.

FIG. 5: Cross-section of Hombach retaining wall, new Cologne – Rhine/Main railway line
3.2 Foundation soil and boundary conditions
An approx. 1.5 m thick hillside loam layer is found below an approx. 1 m thick capping. Below this, we find a layer of decomposed to weathered rock and, finally, moderately weathered Devonian rock consisting mainly of clay, silt and sandstone as well as sand and slate. Depending on the more or less open seams and fault zones this rock material of the Rhenish Slate Mountain Range normally constitutes a moderately permeable water-bearing horizon. Based on the foundation soil report the mean permeability was assumed to be \( k_f \approx 10^{-7} \) m/s. Owing to the lime-attacking carbon dioxide contained in the groundwater at an approx. 20 to 100 mg/l ratio, the groundwater must be classified as being slightly to strongly aggressive to concrete, according to DIN 4030.

3.3 Specialist measures and quality assurance
Pursuant to DIN 4125, 5.1.3 permanent anchors may be installed in rock of a highly aggressive nature only in those cases where the load bearing capacity of the anchors is safeguarded permanently through implementation of adequate specialist measures, e.g. bore hole improvement through grouting to DIN 4093, so that the grout box is protected against aggressive water attack. The decisive point is such that a destabilization of the hardened cement paste surface is only imminent where the water flowing in the open seams and fault zones gets into contact with the grout box. A destabilization of the hardened cement paste surface is not to be expected in such areas of the grout box as are free of any open seams or faults. Initially, suitability tests were undertaken to find out whether and to which degree it had been possible to successfully grout the solid rock.

For this purpose water permeability tests with a pressure of maximum 1.5 bar were carried out in the fixed anchor length after the bore holes had been sunk (FIG. 6). The quality criterion determined for installation of a permanent anchor was a flow of less than 3 l/min, under a pressure of 1 bar, throughout the entire 6 m grouting section. The water permeability tests were recorded automatically and evaluated by computer. When the water permeability criterion was exceeded, pre-injection to the load application section was effected using cement slurry. Depending on the injection material applied the water-cement ratio ranged between 1.0 and 0.45. CEM 42.5R was used, with an admixture of 20 % fly ash. The average grouting quantity used on the test anchors was in excess of 500 kg. The following day the grouted section was drilled open and another water permeability test carried out. Where the result was positive, the anchor could be installed, otherwise pre-grouting had to be repeated. Each work phase was recorded in a quality assurance plan and countersigned by the construction supervisor.
FIG. 6: Drilling operations using magazine drill

During execution it became apparent that the permeability of the weathered solid rock significantly exceeded the values given in the foundation soil report. As a result, a total of some 840 water permeability tests had to be carried out, in some cases up to seven times in one and the same bore. This led to major disturbances in the works progress. Even during construction execution each individual working step was recorded and countersigned, from permeability tests via pre-improvement and installation all the way up to the tensioning operations (FIG. 7). Manufacture of the permanent anchors involved a period of 8 months.
4. Micropiles in soils with organic admixtures

4.1 Project
Die “Unter den Linden” Berlin State Library is the main building of Germany’s largest universal library of science. The building was erected between 1903 and 1904 and represents the most spacious historic building complex in Berlin. For building substance securing purposes and implementation of a new concept of use extensive post-foundation works had to be carried out on the building which is listed for preservation as a historical site. In addition to 8,000 m³ of subsoil stabilization using the jet-grouting method and 2,000 m³ of soil stabilization by means of ultra-fine cement injections a total of 50,000 lineal meters of micropiles were manufactured, with working loads of 860 kN and maximum lengths of 32 m.

4.2 Foundation soil and boundary conditions
The building complex with a floor area of 106 m x 170 m is founded in the Berlin ‘Urstromtal’ in the area of the river Spree lowlands. The foundation soil investigations have revealed a soft organic soil “Mudde” channel running in north-west direction underneath the building complex up to the well-yard. This channel is characterized by alternating layers of sand and peat. The sediments include digested
sludge and non-cohesive soil material with considerable organic admixtures and are therefore to be considered as non-load bearing. The medium-dense layers of sand found further down are used as load bearing layers for building load transfer purposes (FIG. 8). Owing to the extremely varying foundation soil conditions three different foundation alternatives have been applied in the erection of the State Library:

1. Shallow foundation by means of strip footing
2. Deep foundation with ca 30 cm diameter pinewood piles
3. Deep foundation on timber caissons with rubble and concrete fill

In the course of construction works carried out near by in the seventies and eighties the groundwater level which in this area reaches approx. 31 m above MSL was periodically lowered. As a result, the pile caps of the wooden pile foundation were exposed to constant changes from dampness to drying out, with the supply of oxygen. The resultant rotting had meanwhile reached a stage where the original cross-section was found to be damaged to 70 % on the average, in some areas
however, to up to 95 %. It was determined that under these circumstances the foundation needed complete rehabilitation. The rehabilitation concept was based on relocation of the vertical loads from the existing defective wooden piles to new micropiles.

To protect the existing foundation situation against negative effects, one pile row each was arranged on both sides of the old beam ties (FIG. 9). Based on a special proposal submitted by Stump Spezialtiefbau GmbH “Stump” micropiles with GEWI steel load bearing elements Ø 63,5 mm and tube piles system Stump Ø 80 mm were used. The unfavorable foundation soil conditions were accounted for by a wider pile shaft diameter of 240 mm. A secure bond between foundation soil and a dense pile concrete was achieved by an intensive, phased grouting of the pile shaft. The test loads applied confirmed the required 800 kN load transfer with double safety.

![FIG. 9: Rehabilitation measures – Through-girders and insertion girders in connection with pipe piles or “Stump” GEWI-micropiles](image)

The drillings for the piles foreseen inside the building had to be carried out using special drilling gear, as the room height was only 2.30 m in most cases (FIG. 10).
FIG. 10: Drilling operations for pile manufacture

To check the foundation soil situation and identify drilling obstacles, all relevant drilling data such as feeding and feed pressure were continuously recorded during drilling. In view of the fact that a carefully executed injection was equally decisive for the durability of the foundation work, each injection operation was recorded in every detail via a pressure-quantity recording device.

The drillings for insertion and/or through-girders in the existing foundations were carried out as core drillings with particular care. Installation of the girders was followed by special mortar grouting to ensure an optimal frictional connection (FIG. 11).
FIG. 11: Tube piles System Stump and insertion girders prior to floor slab concreting

5. Summary

The examples given above have shown that a reliable manufacturing of anchors and micropiles is possible even under adverse environmental and subsoil conditions. This however, requires that project specific specialist measures are monitored based on a target-orientated quality assurance system.