Ground Reinforcement in Tension with Micropiles for Securing of Uplift Forces

Thomas F. Herbst
Wessling / Munich, Germany

Introduction

Dominant ground materials for micropiles are soils which may be granular, cohesive or have a mixture of both. The special idea of micropiling is not only the direct load transfer but a soil reinforcement which enhances the mechanical properties. In general compression and shear strength are addressed. Resistance to tensile forces requires new considerations in order to fit them into the model of soil reinforcement.

1. Ground Bodies in Tension

1.1 Model of a Tensioned Soil Body

A calculable tensile strength of soil of whatsoever composition does not exist. Reinforcements only consisting of micropiles can create tensile resistance by their own tensile strength, but not in combination with the soil. The soil around a micropile provides simply its weight. In case of uplift forces the directions of both the weight and the force are vertical. The reinforcements are consequently placed in vertical direction.

The volume of ground influenced by a micropile depends on the bond along the steel shaft, the skin friction along the grouted cylinder and the shear strength of the ground. With increasing depth of the micopile commonly higher shear strength exists which increases the influence area of the micropile. But usually there is a limit where this diameter does not increase further. This is one of the design limits for the spacing of the micropiles if the model of soil reinforcement is chosen. Tests with 4.5 m long micropiles in a test pit which was filled with medium dense sand at the Technical University of Munich showed a ground heaving diameter of 2.50 m.

If compression forces compact the soil around the micropile tensile forces have tendency to losen it. To which degree this phenomenon influences the bearing characteristics and how this model works is unknown so far. It may, however, influence the shear strength which is important in case of dynamic loading with undefined direction of displacement during seismic events.

1.2 Tensile Stresses during Seismic Events

For general application the tensile forces are introduced at the heads of the micropiles and are transferred to the ground along the shaft. In case of earth quakes it can be assumed that at a deep horizontal shear plane opposite tensile forces are transferred to the micropile by the surrounding ground. The length of the micropile below and above this plane should always be sufficient to prevent debonding by this effect. Such a model is already well tested for more rigid materials like rock with joints which would allow displacements without perpendicular reinforcements. In case of soil nailing such design assumptions are basic.

Consequently the tensile strength of a soil body which is reinforced with vertical micropiles may play an important role during earth quakes where high amplitudes combine with low frequencies. Dynamic loading occurs for traffic loads as well, but there only low amplitudes go along with high frequencies over the entire service life of the structure.

Unique tests carried out in full scale at the Technical University of Munich (1) demonstrated the dynamic resistance of micropiles (GEWI-piles) for alternating (cyclic tension and compression) as well as swelling loads (cyclic compression loads). Such tests with only axial loads involved already provide a clue about the resistance to the more complex load pattern at earth quakes.

1.3 Analogies with Composite Construction Materials

The investigation of soil bodies which are reinforced with micropiles working in tension deserves highest interest from a theoretical and practical view. Studies need not start from the beginning as analogies can be drawn from the theory and practice of reinforced concrete. The difference, however, is the much higher compression and shear strength of concrete with much lower deformation but higher brittleness due to the cementitious binding of the aggregates which are originally graded granular soils. This, however, allows the reinforced concrete to be a formed and placed construction material while soil in general remains an in-situ foundation material.

Part of such investigations are fullscale micropile tests for single piles, but in particular for group tests. The latter are extremely expensive and still lack an arrangement and loading philosophy in order to draw the best of informations from the results.

1.4 Classification of a Soil Body with Reinforcements Working in Tension

Single micropiles with sufficient distance to the next one are classified as Case 1 model similar to standard pile design. They work in general in compression and or in tension.

For densly arranged micropiles working in compression, and in shearing as a secondary effect, a Case 2 model has been defined so far (2). Activation of shear stresses in the ground leads to a composite soil - micropile behaviour. Additionally it is enforced by direct loading of the ground with a pile cap beam or slab. This allows to activate bending resistance, if the micropiles are properly arranged.

On the contrary, for densly arranged micropiles which secure against uplift forces, tension loads can only be applied to the pile heads. Composite behaviour is enforced via shear stresses along the micropile. However, vertical tension forces activate only the weight of the soil, so the involved shear stresses do not act like in a bending element.

The question arises now, if Case 2 model has to be subdivided to properly cover the tension case and to better understand the activiation of shear forces.

As the classification serves to establish well defined bearing models for proper analysis methods a further subdivision is recommended like the one proposed in table 1.

	Compression	Bending	Tension	Seismic
Case 1	high	low	high	low to medium
Case 2	high to very high	medium to high	high	high to ?

Table 1 Efficiency of bearing behaviour of micropiles

This shall be an invitation for future research which opens huge perspectives for soils with micropile reinforcement, in particular for the new field of seismic retrofit.

2. Construction Methods for Uplift Securing of Bottom Slabs for Excavations below Ground Water Table

The following considerations shall not deal with the equally important lateral watertight retaining walls and their joints to the bottom slab which may vary according to the ground and water conditions as well as structural and construction requirements but only with the horizontal sealing membrane and the underlying soil body.

Usually three technical details have to be solved in a satisfactory manner and combined in such a way that an easy and well controllable construction method evolves:

- Drilling, placing and grouting of the micropile,
- Design and fixation of the anchorage of the micropile which guarantees a watertight connection to the concrete bottom slab,
- Construction of a watertight bottom slab which is able to distribute the punctual loads of the micropiles inside the slab.

2.1 Solutions with Ground Water Lowering

If lowering of the ground water level below the excavation level is possible the advantages of a ground reinforcement in tension with micropilies cannot be demonstrated a clearly as if the water can only be removed after the bottom slab and retaining walls are safely completed and anchored with the ground.

A variety of solutions for the sealing membranes and soil reinforcement is available in this case; mostly it is a watertight reinforced concrete slab in which the micropiles and tendons are anchored. Classical construction components are used. Quality control is easily possible.

A real challenge occurs if the ground water can only be pumped after a watertight and properly anchored box has been constructed. In historical order two methods are described which are already used or are starting to be used

2.2 Solution Maintaining the Free Ground Water Level during Micropiling and Concreting after Excavation of the Soil

Drilling, placing and grouting of the vertical micropiles and casting of the concrete bottom slab have to be executed under water (Fig. 1). The working platform may be a floating pontoon if the excavation is wide, or a bridge which travels along mostly parallel retaining walls for limited spacing. If floating pontoons are used special experience in water or off-shore work is advisable.

For drilling (driving), placing and grouting of the micropiles the platform has to be held in place and must not move. Micropiles which use a casing for rotary drilling for installation allow a controlled placing and grouting of appropriate steel reinforcements like GEWI-steel of different diameters with and without double corrosion protection. In many cases

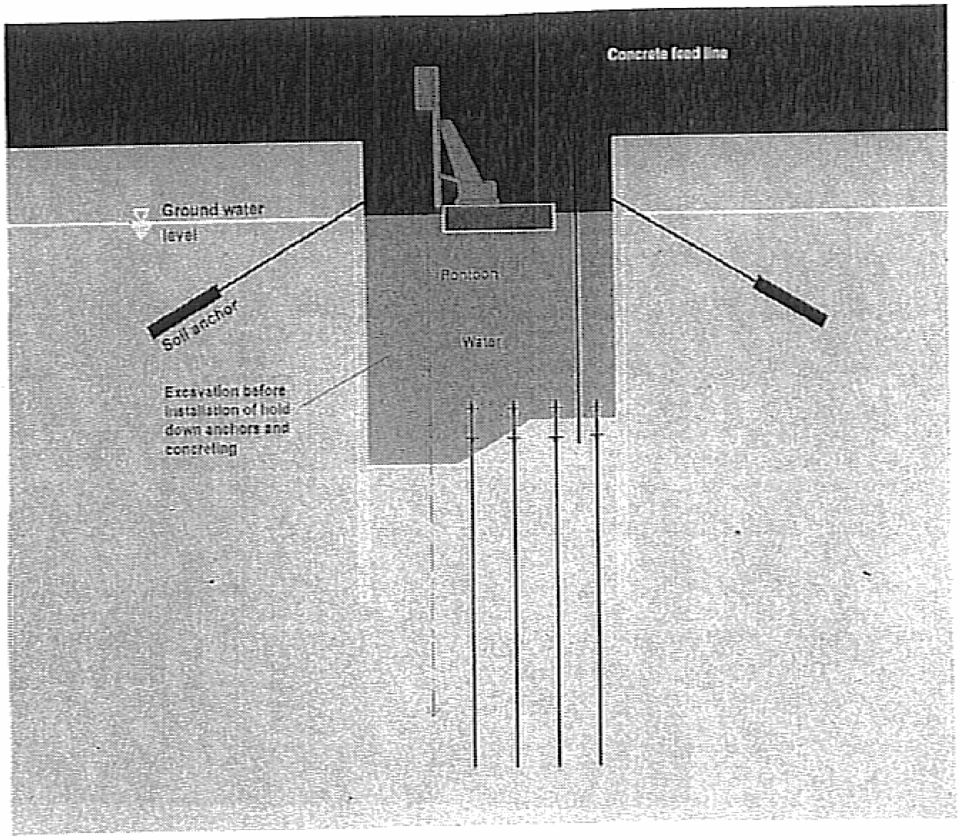

Fig. 1 Underwater concrete slab with micropiles for tension reinforcement

the diameter of the head anchorage passes even through the casing. Then the micropiles are ready for the connection to the concrete slab if the drilling depth has been properly observed during placing. If the level of the anchorages shall remain adaptable they are screwed on after placing of the micropiles. Depending on the depth under water the anchorage may be attached by divers or some automatic devices. This method can be applied in most cases, but has its advantages at deep, wide and large excavations with high ground water level and for varying ground conditions. Commonly these works are executed by a general contractor where the micropile works are subcontracted.

2.3 Solution where Works are Executed from an Excavation Platform above Ground Water Level

Rotary drilling efficiency has substantially increased by more powerful drill rigs with higher masts and with high pressure water flushing. This makes a solution competitive where the underwater concrete slab may be replaced by a jet-grouted horizontal diaphragm (Fig. 2). Quite obviously the soil must be appropriate for jet-grouting technology. A strict quality control for jet-grouting allows in general water tight diaphragms.

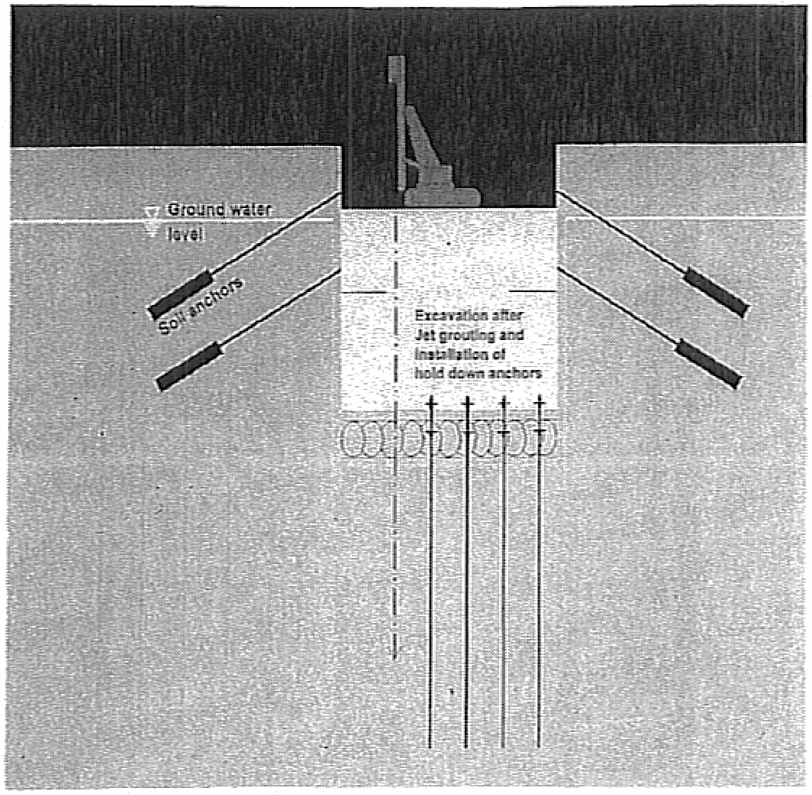

Fig. 2 Jet-grouted horizontal diaphragm with micropiles for tension reinforcement

With the same drill rigs, often with the same drilling tools cement slurry stabilized boreholes for the micropiles can be drilled either in continuing the boreholes for the jet-grouted diaphragm or as separate boreholes after completing the jet- grouting.

A special challenge is the anchorage of the reinforcement of the micropile to the diaphragm. The strength of the jet-grouted material is limited due to its production procedure. The highest strength can be achieved in the center around the drillhole. For the load transfer sufficient bond i.e. shear strength of the jetted grout is required.

Fortunately the jet-grouting procedure allows to shape a grouted body which is adapted to the load transfer requirements of the micropiles. A vaulted shape allows for arching of the compression stresses between the micropiles and an increased bond length (Fig.3).

The upper surface of the diaphragm is very pointed and irregular with such a design. The level for the structural concrete bottom slab has to be designed at a safe distance above the jet-grouted diaphragm. The structural concrete has to be anchored to the micropiles as well. If their reinforcement consists of GEWI-steels with continuous coarse threads an anchorage can easily be screwed on in dry condition after excavation and pumping of the ground water.

Bond enhancing devices which only slightly increase the diameter of a drill hole may be used to increase the load transfer to the grout body.The strength of the cement grout which contacts the anchorage determines the possible load transfer. The GEWI-steel with its high coarse thread ribs displays already favorable bond properties. They may, however, even be improved in case of the double corrosion protection where the load is transferred along the corrugated sheathing. Special steel helices may provide the highest possible bond.

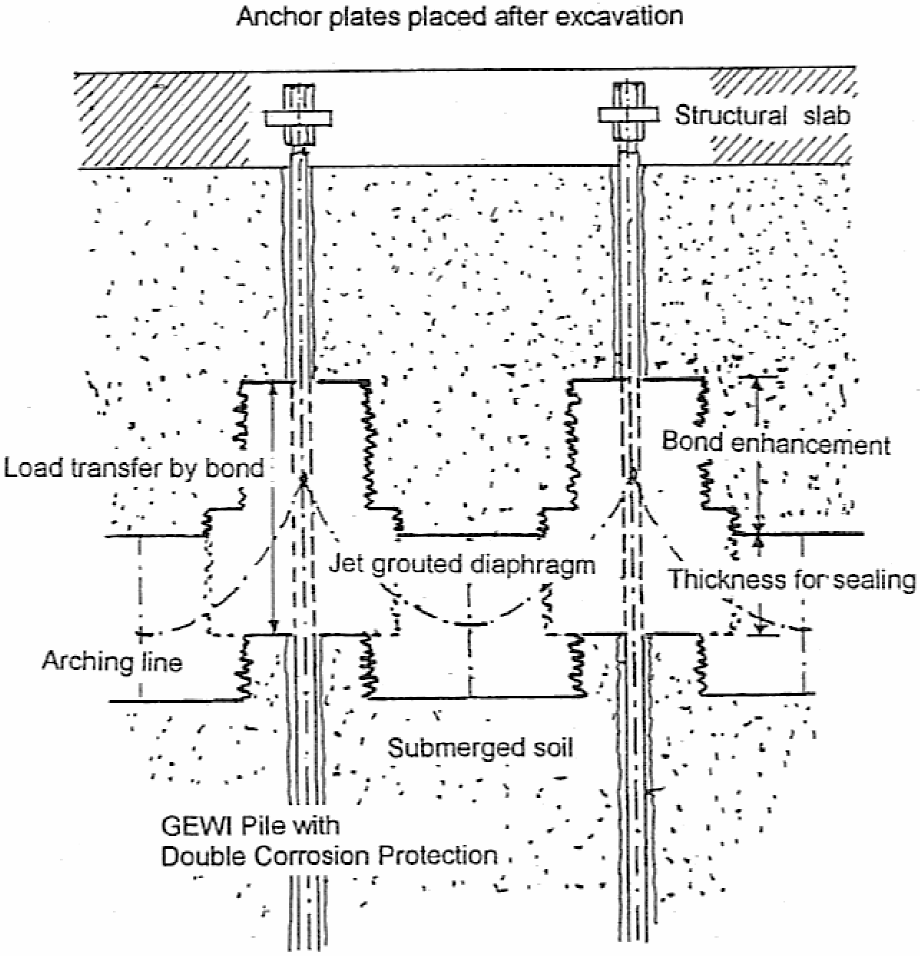

Fig. 3 Schematic detail of jet-grouted diaphragm with anchorage of micropiles

The special advantage of this solution is that all works can be executed in dry conditions i.e. from dry working platforms. No floating equipment is required. Cost advantages are governed by size and depth of the excavation and the ground water level. Its applicability depends, however, on the soil properties. A further advantage of this solution is that diaphragm and micropiles can be quoted by one specialist foundation firm which avoids splitting of responsabilities and operational steps.

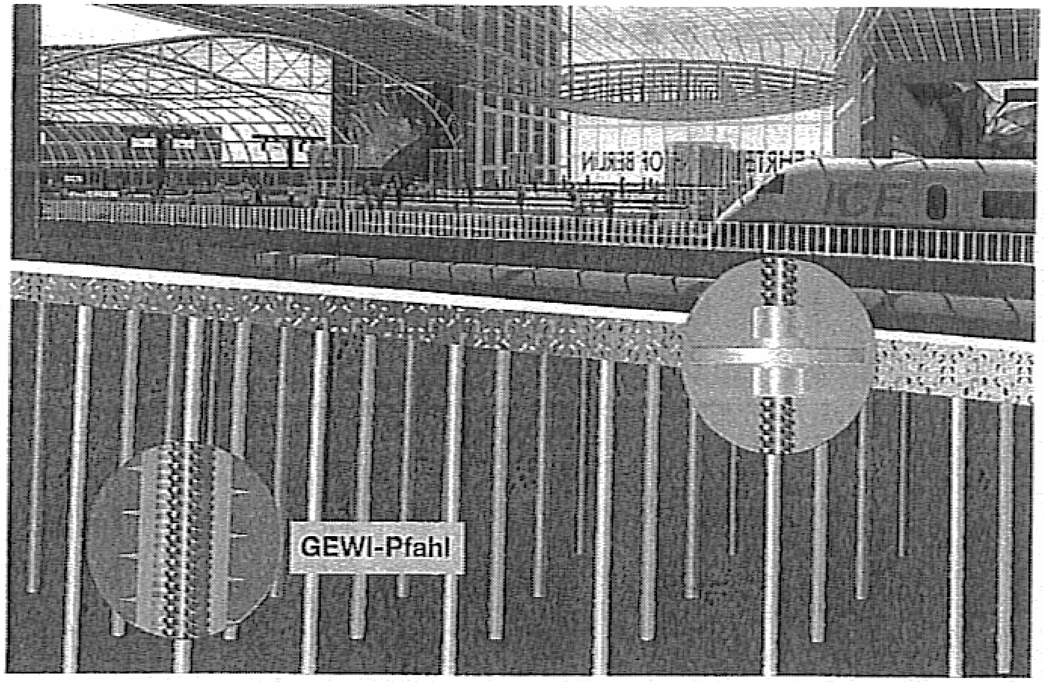

Fig. 4 Future central railway station of Berlin (Lehrter Bahnhof):
Uplift securing with GEWI-Pile

3. The Deep Excavations for the New Underground Traffic Lines and Tunnels in the Central District of Berlin

3.1 Development, Ground Condition and Site

The new government district is located near the former Berlin Wall which had separated the City for almost three decades. Now the traffic lines for railways, metro and road tunnels had to be rearranged and bundled to pass underneath the Spree River and the future central station which allows interchange between the different transport facilities (Fig. 4).

The construction ground of Berlin consists of glacial deposits like medium coarse sands and intermittent layers of clay. The ground water level averages around 2 – 3 m below surface only. It is the ground water which is the biggest challenge for underground works in Berlin and it determines the special construction methods. As the sites are located in the center of the City ground water lowering is strictly prohibited for environmental reasons and because of damage to adjacent buildings. To avoid traffic congestion excavated soil had to be shipped away along canals connecting with the Spree River and the lake district around Berlin. Bulk material had to be shipped as well. Due to its huge extension the new „Central Traffic Area" is divided into several construction sites. They consist of connecting deep and very wide excavations.

3.2 Construction Method

Dry and open excavation pits were required as the works for the excavation were let independently from the upgoing structural works. This allowed the owner to begin these works long before the final design for the superstructure was ready.

The aforementioned conditions have strongly restricted the possibilities of construction methods.

The excavation pits had to be confined by watertight and stiff retaining walls which were held in place by only one single row of ground anchors with anchor heads above water level. Mainly slurry trench concrete walls were chosen, as boulders were expected to be encountered at a certain depth.

For up to 19 m excavation depth a water pressure of up to 17 m head had to be retained. At the time of design experience on a large scale existed only with non-reinforced underwater concrete slabs which were held down by tension piles(Fig. 5). A considerable depth of the ground below these slabs had to be engaged for balancing the uplift forces with the submerged mass weight. For economical reasons the concrete slab was placed without reinforcement as an only temporary membrane until the final reinforced watertight construction slab could be cast.

The spacing of the piles was determined by the possible load distribution for an assumed arching. For a 1.5 m thick concrete slab the maximum spacing of the piles was limited to 3.0 m. This included all tolerances of effective thickness for placing of the slab (e.g. surface roughness of excavation level, minor qualitity of concrete at the interfaces etc.). Such a spacing was ideal for the use of micropiles.

Fig. 5 Free ground water level with floating equipment for dredging and micropile installation (rear) at central site (Lehrter Bahnhof)

3.3 The Micropiles

For the most central site of the „Central Construction Area“ the contractor chose GEWI-Piles steel grade S 555/700 with ∅ 63.5 mm (Fig. 6). The GEWI-steel has a continuous, hot rolled-on, coarse thread which is insensitive to rugged site treatment. It has high bond properties and can be used for screw-on connections at any length (3). Where the GEWI-Piles were designed for permanent uplift securing they were manufactured with double corrosion protection. With a design load of 1004 kN they were spaced at 2.72 m. Their length varied between 17.50 and 26.50 m, the greater lengths being coupled with threaded couplers for reason of road transport.

The special feature of the GEWI-Pile is the availability of a double corrosion protection for permanent piles especially working in tension. Its principle is taken from ground anchors with threaded prestressing steel Dywidag. In a factory the GEWI-Steel ∅ 63.5 mm was centrically placed inside a rugged corrugated plastic sheath, the annular space was then grouted with cementitious grout. After hardening the piles were transported to the site.

The subcontractor chose the classical placing method: Drill rigs were placed on pontoons which were docked to a floating bridge. It was positioned with assistance of GPS with cm-accuracy.

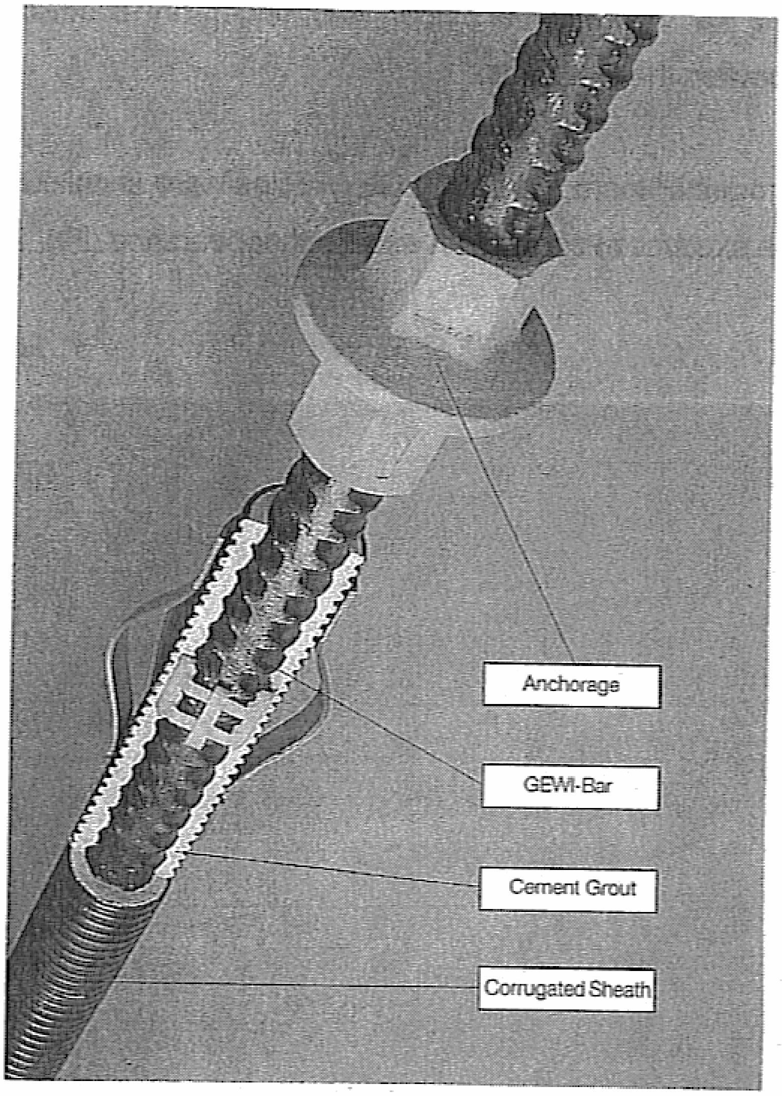

Fig. 6 GEWI-Pile with Double Corrosion Protection

The classical rotary drilling with water and suspension flushing was even able to penetrate boulders which were occasionally encountered at a certain depth. The casing allowed an easy and accurate placing and controlled pressure grouting (Type B) of the micropile over its entire length. From pontoon level to micropile foot an average length of 40 m was available. For underwater conditions a grout excess hydrostatic pressure of 3.2 bars existed there. As this pressure lasted over a fair time until the end of the grouting operation for the micropiles its lower portion got even without additonal pressure from the grouting pump a bond increasing water filtration of the grout.

The structural design requested a second reinforced watertight concrete slab on top of the other one. It had to be connected to the lower underwater concrete slab and the micropile once the water had been pumped out from the excavation. For this purpose the permanent micropiles had an overlength of around 1.20 m over the lower slab which was subsequently equipped with another anchor plate. Thus the steel shaft of the micropile was anchored to the upper slab under dry conditions and served as additional pin between the two slabs.

Altogether more than 6500 GEWI-Piles were installed for the central site. After pumping the excavation showed an excellent appearance (Fig. 7).

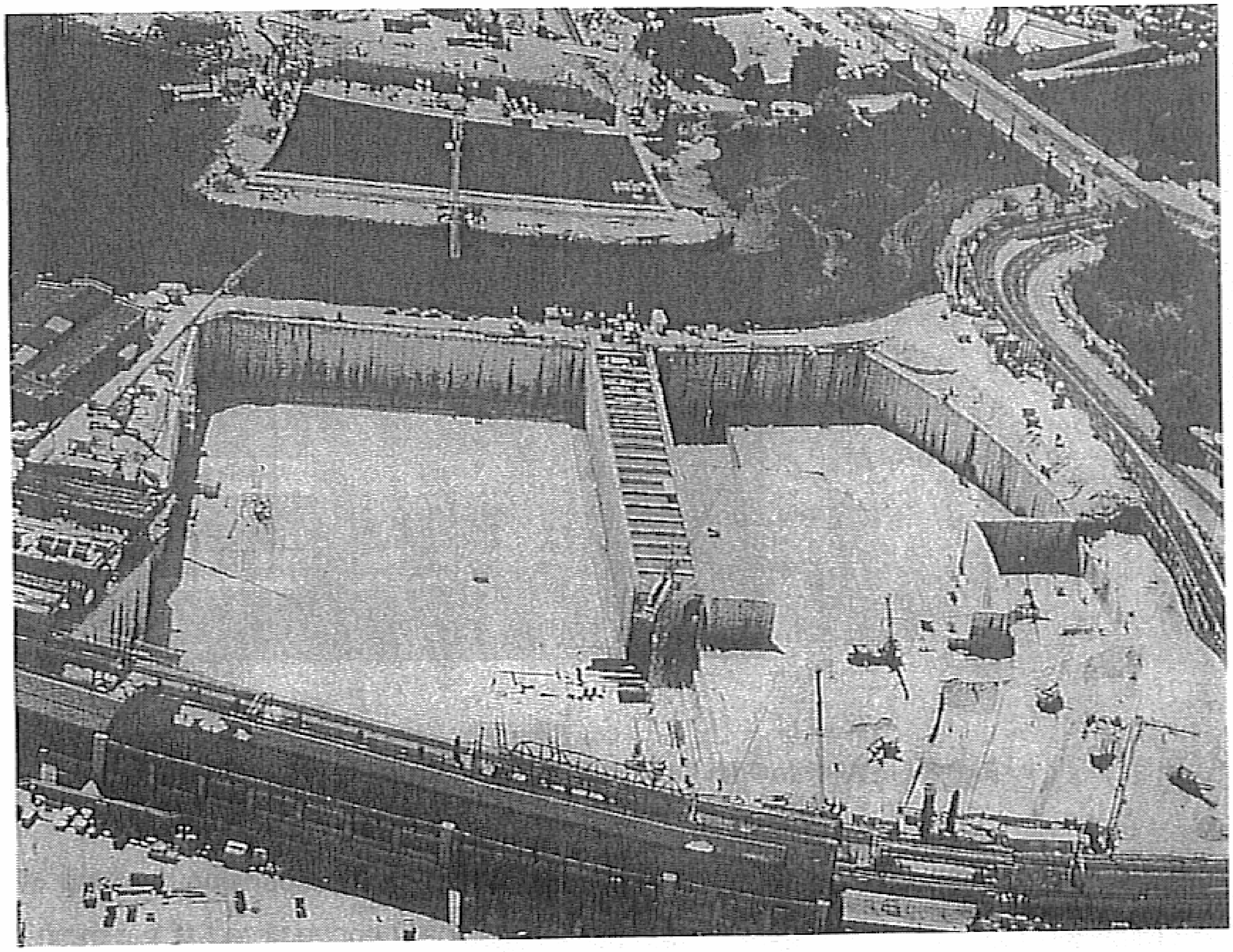

Fig. 7 Free finished excavation pit

3.4 Pile Testing

Pile tests have been performed as performance tests and acceptance tests. Elaborate group tests for 5 piles had to demonstrate adequate performance of the pile which was centered by 4 other piles. The performance tests were carried out in similar ground conditions but at the surface (Fig. 8), acceptance tests were carried out in-situ, i.e. for single piles under water with a special pile testing pontoon. For the group tests no significant difference between center and corner piles could be observed. All piles fulfilled the acceptance criteria of 1550 kN test load.

The possibility of testing a certain percentage of production micropiles provided a high degree of quality control.

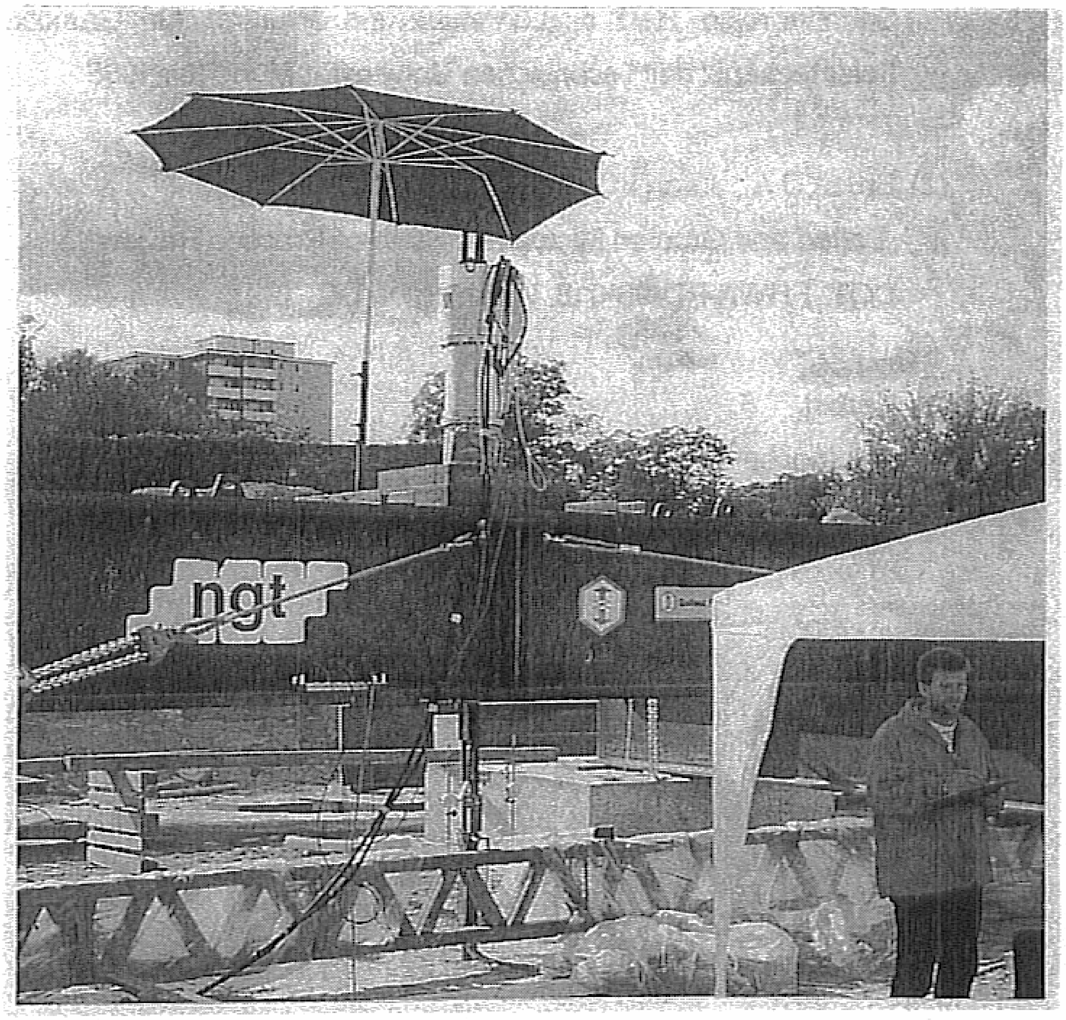

Fig. 8 Pile group test near excavation

Conclusion

The use of densly spaced micropiles for securing of uplift forces is widespread in Germany. The GEWI-Pile with its wide load range and the long life guarantee provided by the Double Corrosion Protection has helped to give confidence into this construction method.

Extended quality control possibilities allow high design safety.

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Appendix to 1.3

Typical Features of Reinforced Concrete, Reinforced Rock and Reinforced Soil

	REINFORCED CONCRETE	REINFORCED ROCK	REINFORCED SOIL
Bulk material	Concrete	Rock mass	Soil body
	Manufactured and cast	In – situ	In – situ
	Formwork	No confining means	None or retaining structure
	Designed and controlled quality	Given quality, joints randomly distributed	Great range of properties, ground water influence
	Standard Quality Control	Site investigation required	Site investigation required
Mechanical Properties	High compressive strength	Mostly high compressive strength	Low compressive strength
	High shear strength	High shear strength except joints	Low shear strength
	Tensile strength sufficient for self bearing	Rare and low tensile strength	None
	High Modulus of Elasticity	Medium to high Modulus of Elasticity	Low Modulus of Elasticity
Reinforcement	Deformed bars, cages	Deformed bars, tubes, profiles	Deformed bars, tubes, profiles
	Any direction	Straight boreholes with feasible directions	Straight boreholes with feasible directions
	Changing cross sections	Important cross sectional areas	Important cross sectional areas
	Placed before casting of concrete	Grouting technology	Grouting technology

Herbst, 26.09.1999