STEEL DESIGN (1)
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Micropiles - Steel Reinforcement

by Thomas F. Herbst

1. Background

The case 2 applications (table 1) have been part of the original concept of micropiles.

High load bearing capacity was not considered as a central property of the "pali radici" (root piles) as proposed by Lizzi. A small borehole with a centrically positioned rebar was sufficient to enhance the bearing capacity of the soil underneath foundations of historical buildings which had tendencies to settle unduly. Even for settlement prevention only they were considered to be sufficiently strong at this time.

Only after the basic idea of small borehole diameter piles had been accepted interest focussed on increasing load capacity which widened the field of application substantially (table 1).

Gradually the understanding evolved that the combination of a borehole diameter as small as possible, a high percentage of steel reinforcement as the proper bearing element and an adequate grouting technology which is able to transfer the load along the shaft were the principle features of a micropile.

The circular shape of the micropile follows the line of bored piles using drill casings and any kind of rotary and rotary percussion drilling methods. High efficiency hydraulically operated drill rigs with limited dimensions allow to penetrate almost any type of ground and to work from confined spaces.

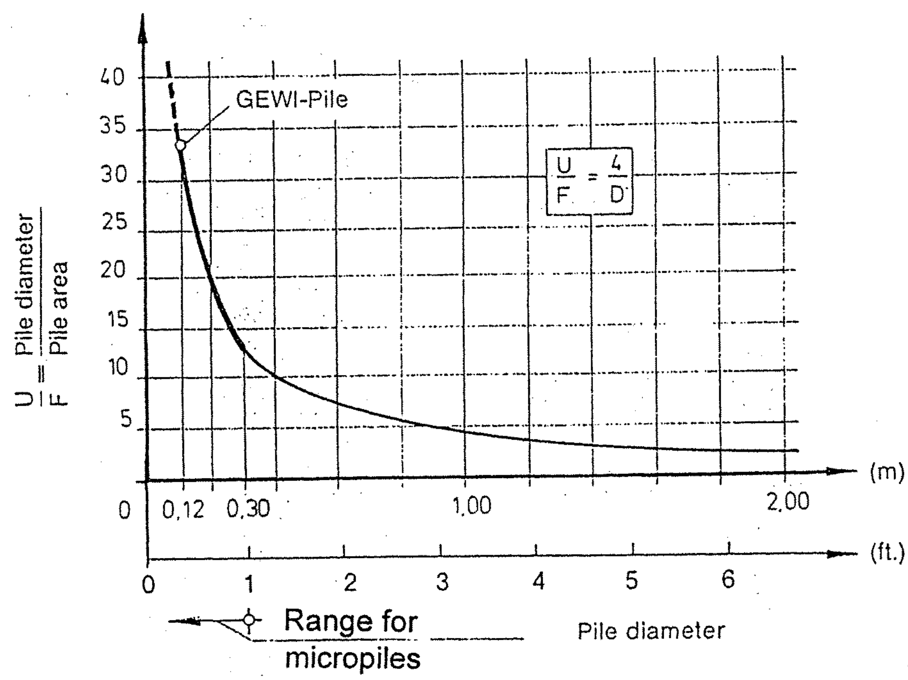

Fig. 1 Ratio Pile Diameter / Pile Area

Fig. 1 shows the influence of the ratio circumference over cross section with decreasing diameter and the typical range of micropiles. The dominance of skin surface along the shaft over an end bearing surface is significant. It coincides with the steep slope section of the curve.

As second property, the slenderness becomes obvious as compared to big diameter piles. For a long time this slenderness has been considered preventive for the implementation of small diameter - high bearing compression piles. However, tests and analytical studies have confirmed that stability problems may only occur in very weak soil with very small bedding values.

2. The reinforcement of micropiles

If small diameters shall be combined with high load bearing capacity, high performance material has to dominate the cross section of a micro pile. Steel reinforcement is the appropriate solution. Fig. 2 shows 3 typical arrangements.

A cage is still more typical for bored piles even if pressure grouting technology is adopted. The ratio between load over diameter is still small.

By far more typical are steel tubes. Though higher in cost they have been adopted frequently for compression piles because they were considered in certain soils to be more resistant against buckling. This, however, depends essentially on the overall bedding resistance of the soil and the thickness of the weak layer and may provide some advantages in certain cases.

If the diameter shall be small, the core has to contain the maximum of steel reinforcement. The typical solution is the central steel core. Its cross-section and steel quality is selected according to the transferable load to the ground and the load requirements. The interfaces are loaded by bond stress. At the steel surface adequate ribs according to the rules for reinforcing steels are required. They prevent debonding and provide the required composite behaviour. Under tension they control the crack width.

The small borehole diameter in the order of 100 to 150 mm permits efficient drilling and pressure grouting. The technology typical for ground anchors is used.

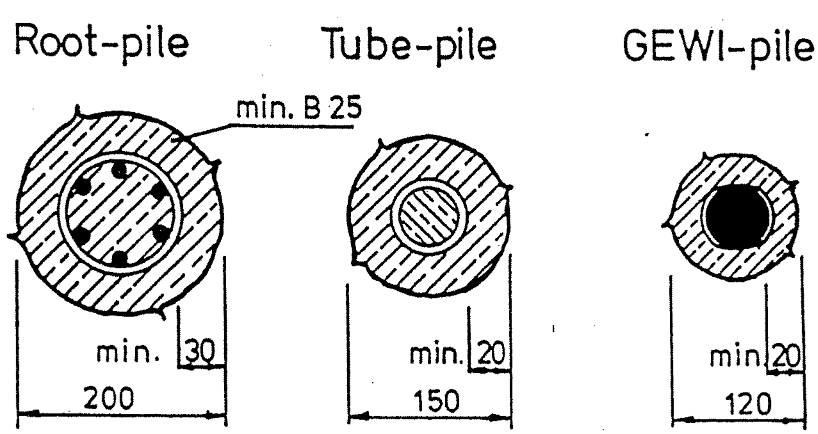

Fig. 2 Different Types of Micropiles

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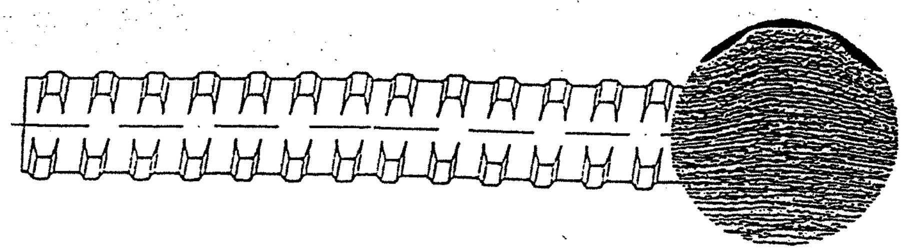
3. Steel properties

The requirements for steel properties have been gradually developed. Basic laws for reinforced concrete have to be observed if a proper composite behaviour between reinforcement and grout shall be reached. The quality of reinforcement steels up to f_y = 560 MPa complies with the commonly accepted strain of grout under compression. Depending on their composition and milling procedure, such steels display a high ductility beyond the yield point (Fig. 3). They are able to produce even plastic hinges in case of heavy overloading.

For the reinforcement with rebars the GEWI-bar has proven to provide optimal properties (Fig. 4)

Its high ribs are arranged to form a continuous coarse thread - which is unsensitive to rough site handling - which can be cut at any location to provide threads for couplings and anchorage elements. Diameters up to # 20 (63,5 mm) provide high bearing capacities.



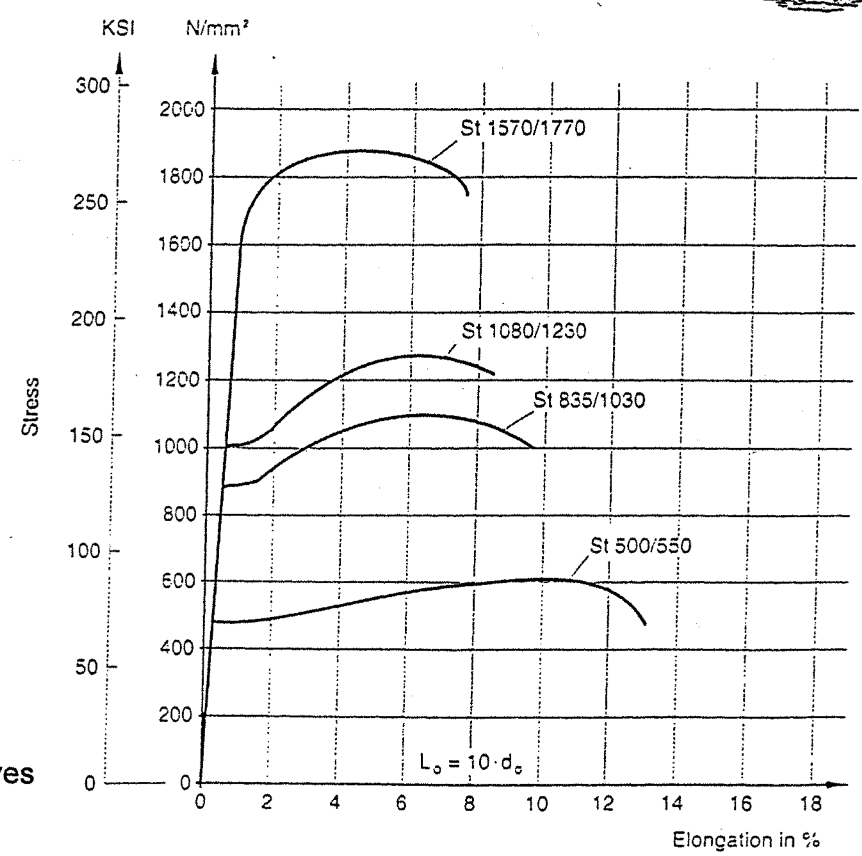


Fig. 3
GEWI-Steel and Stress-Strain Curves for Various Steels

Nominal diameter	Steel grade	Cross sectional area	Ultimate strength	Yield load	Working load	
					tension	compr.
	f_y / f_u	A	$F_u = f_u \cdot A$	$F_y = f_y \cdot A$	$F_y / 1{,}75$	$F_y / 1{,}71$
mm	N/mm²	mm²	kN	kN	kN	kN
32 40 50	500 / 550	804 1257 1963	442 691 1080	402 628 982	230 359 561	235 367 574
63	555 / 700	3167	2217	1758	1004	1028
3 x 40 3 x 50	500 / 550	3770 5890	2074 3239	1885 2945	1077 1683	1102 1722

Fig. 4 Load Capacities of GEWI-Steels

4. Bond behaviour

The composite structural element consisting of reinforcement and grout shall work as uniformly as possible even if the elastic properties of the 2 material are extremely different. Grout with low failure strain under compressive and quasi-brittle behaviour under tension is difficult to combine with the elastic and plastic properties of steel. High bond stresses have to be achieved to force the grout to conforming deformations during steel stressing. For this reason the reinforcement of reinforced concrete consists of ribbed steel. It does not rely on pure adhesion bond but also on shear stresses which are initiated by micro abutments at the ribs. The very high shear bond which results from high ribs as e.g. with GEWI-steel enables the composite behaviour of steel and grout. It should be borne in mind for any reinforcement that debonding should be avoided not only for the reason of load transfer but also for reason of corrosion protection.

5. Corrosion protection

As steel degrades with the time if corrosion can occur any degradation shall be prevented during the design life of a micropile. In reinforced concrete technology to which the grouted-in reinforcement as structural member is closest, the state-of-the-art implies to avoid any corrosion.

Any consideration on the degree of corrosion, pitting of the steel, debonding with reduced load transfer becomes thus obsolete and allows a much higher safety in prediction of life expectancy. This philosophy has equally been adopted for rock and soil anchors and has proven to give great confidence in such highly bearing structural members in the ground.

As long as a grout cover around the reinforcement can be proven to have a minimum thickness and a specified material quality and as long as the bond to the reinforcement can be safely assumed, the micro pile performs according to the experiences collected over decades for reinforced concrete. For compression piles this cover may be sufficient over a long period of time if the strains remain limited to standard reinforcing steel qualities. For tension the crack width criteria of the grout or concrete have to be observed. If it can be proven from exçavated micro piles or laboratory tests that for a certain crack distribution the crack width may be limited to a value of 0.1 mm. Such cracks are not considered to impair the corrosion protection which is created by the alkaline action of the grout cover. Grout forms, in particular during its liquid phase, at the steel surface a layer of highly adhering iron oxides which prevent further dissolving of iron ions during corrosive aggression. The Pourbaix diagram (Fig. 5) provides the theoretical explanation for the resistance of steel to corrosion if it is embedded by material of ph-values between 9 and 13.

If the accepted conditions of grout protection do not exist, additional measures have to be taken.

A protection system which is widely spread in connection with ground anchors is the double corrosion protection (Fig. 6). It does not only provide a double layer of protection against corrosion, it also allows the load transfer to the ground. A corrugated plastic tube with a minimum wall thickness of 1 mm encapsulates a concentrically positioned steel core and a grout with minimum cover thickness of 5 mm. This system is usually prefabricated in a workshop.

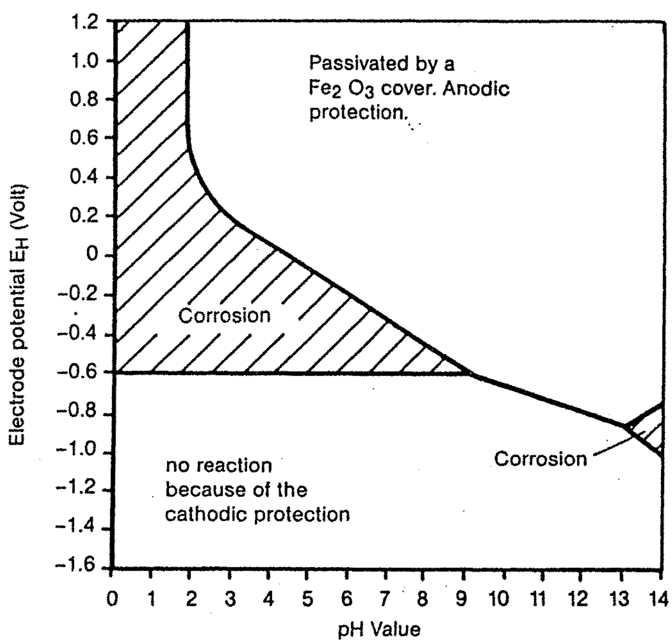


Fig. 5 Pourbaix Diagram

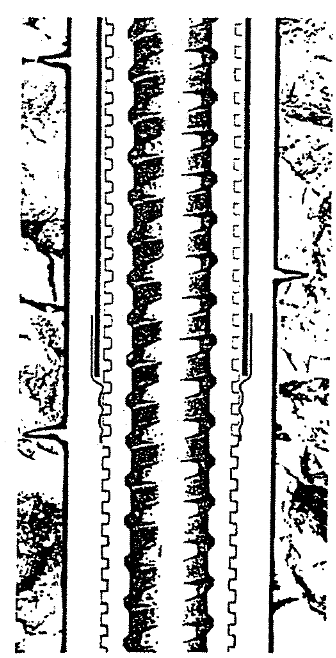


Fig. 6 Double Corrosion Protection System

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6. Ductility and flexibility

Such properties are opposite to static bearing models as commonly adopted for any pile foundation. The recent and expected future seismic events ask, however, for solutions where short lasting horizontal ground displacements may be absorbed or at least tolerated by deep foundations.

All these considerations are presently at their initial state. Micropiles have been identified as foundation elements which may be able to provide solutions to these new requirements. As a matter of fact micropiles are already used for seismic retrofitting. These cases are still restricted to an increase of static load bearing capacity of existing foundation. They are preferred as they can be installed in restricted head rooms.

Future studies shall focus on the ductile and flexible performance of micropiles and shall be used subsequently for new foundations.

The combination of material and cross-sectional properties provides a flexibility which may remain in the elastic range for certain horizontal movements. The lower the moment of inertia of the cross section, the more may a micropile follow the ground movement.

Remains the question, if the design bearing capacity is impaired by a seismic event.

An example (Fig. 7) shall show how a GEWI-pile took over serious plastic deformations without loosing its working load bearing capacity during an unproper testing arrangement.

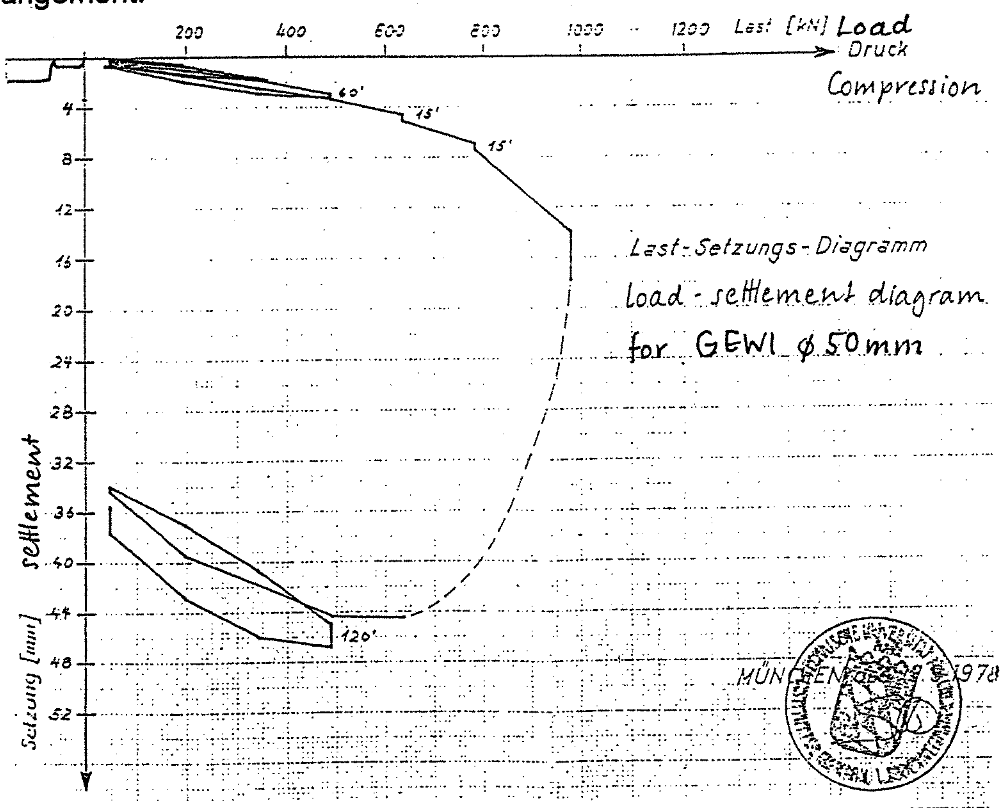
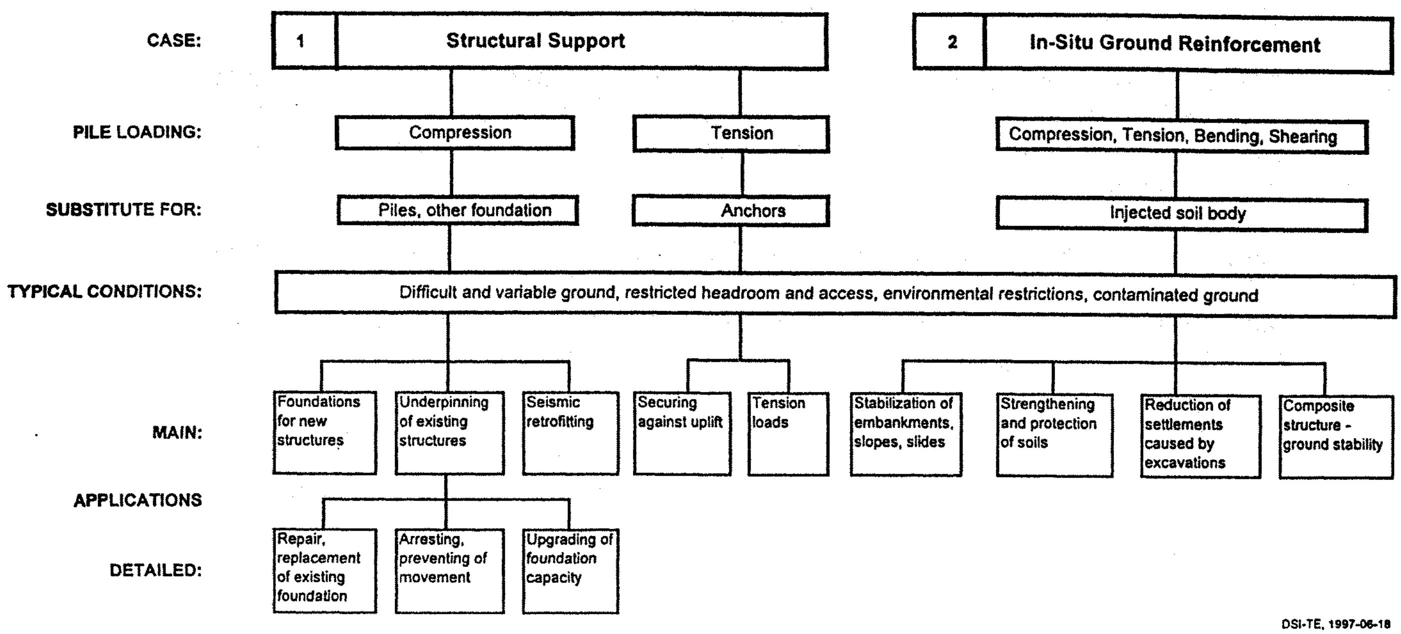


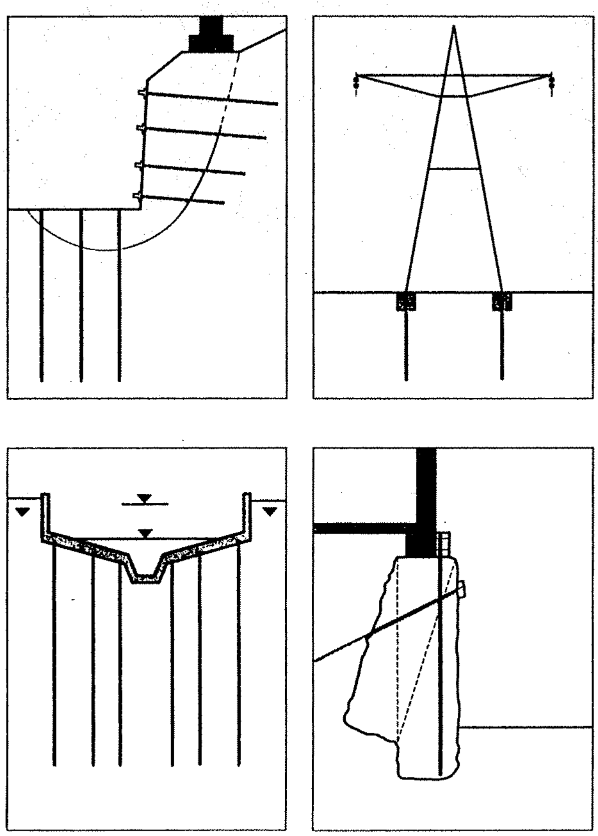
Fig. 7 Pile Test with High Steel Deformation at the Head 6

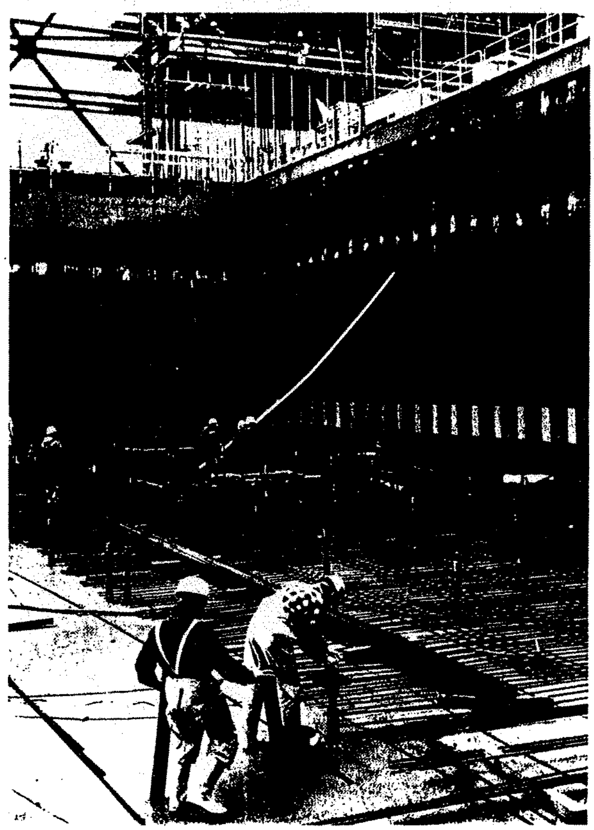
Table 1: FIELDS OF APPLICATION FOR MICROPILES



GEWI-Pile: The Ideal Foundation Element

New: Ø 63,5 mm





Unternehmensgruppe
DYWIDAG

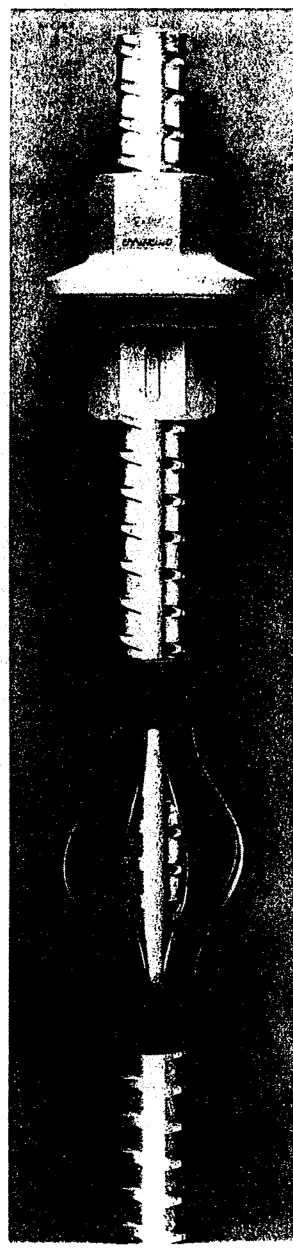
GEWI-Pile: The Future is founded on Tradition

From ancient times on, safe foundations for supporting structures have preoccupied mankind. Already in the bronze age wooden piles were driven into the bottom of waters in order to build on them.

A wide arc stretches between the timber piles of that civilization and the piles of today's technology. Materials and installation procedures have changed, but the basic requirements dictated by the underground are still a challenge.

The GEWI-Pile has set new measures:
A most slender version of drilled micropiles (Fig.1)

Within the given load range, the GEWI-Pile is a most economical and universally usable foundation element.



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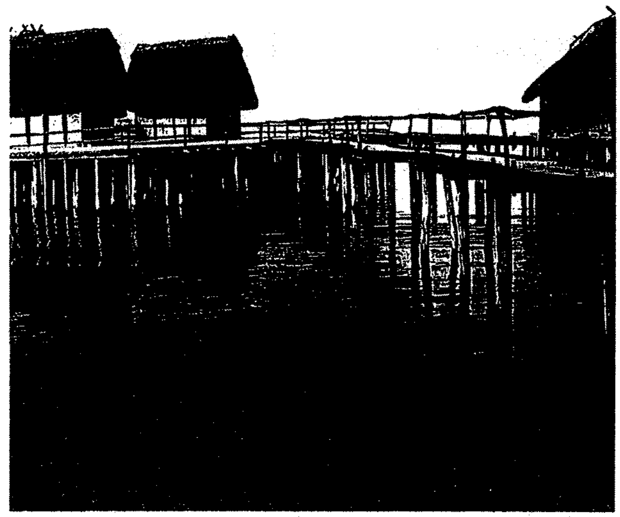

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Content

in Harmony with the Environment

The individual components, design concept and the installation technique for the GEWI-Pile were developed considering their compatibility with the environment (Fig.3).

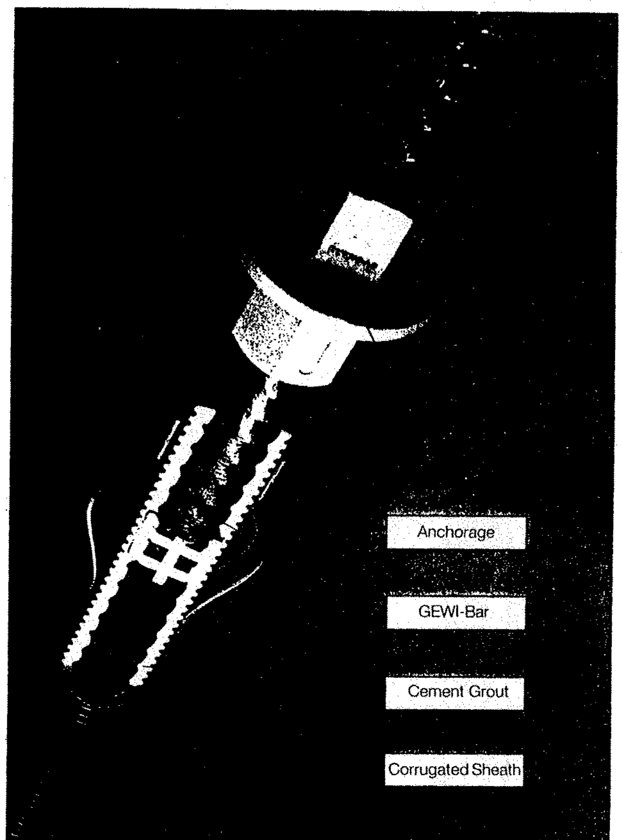
Its design does not use protection materials that set free harmful substances into the water.

In the installed form, its components are insoluble in water and compatible with each other.

Relatively small amount of excavated and installed material does not disturb the environment.

Transportation and disposal of drill cuttings are also minimized.

The installation technique is in compliance with the environment, as only small and quiet drill equipment is required.



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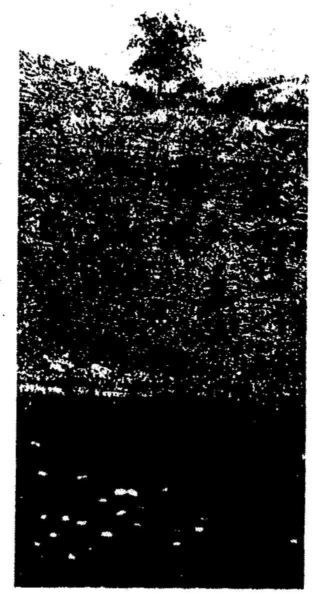

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GEWI-Pile: Strong, but slender -

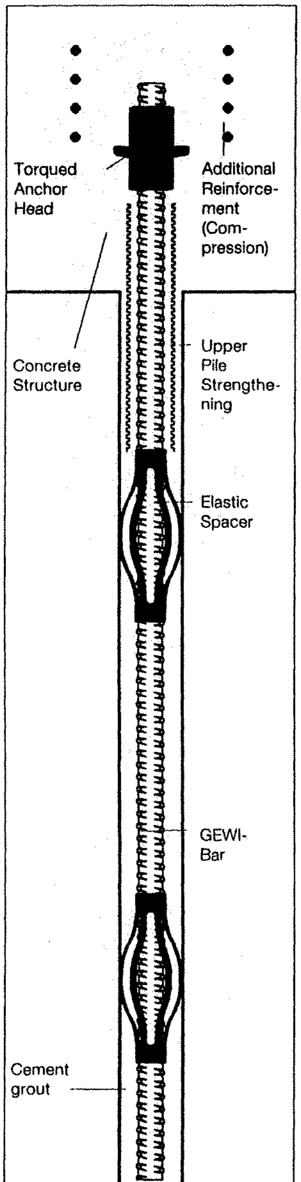
The GEWI-Pile represents the consistent development towards minimizing the diameter, while maintaining a high bearing capacity.

It convinces by its simple design (Fig. 6).

Core of the pile is the GEWI-Bar with hot-rolled continuous thread deformations on both sides, the coarse GEWI-Thread. The grout body encasing the steel provides the Standard Corrosion Protection, enables the force transfer into the rock or soil, as well as stabilization against buckling in weak soil layers.

The GEWI-Pile combines a multitude of advantages:

- The small drill hole diameter (Fig. 8) allows economic drilling methods. Drilling through hard obstacles (Fig. 9) and bonding into rock is easily accomplished.
- The stress strain curve shows high ductility at high strength (Fig 7) required for shear deformations and seismic loads.
- Compression and tensile loads, also alternating loads, can be transferred into the underground by skin friction along the grout body.
- Compared to conventional drilled piles, the GEWI-Pile has a greater elasticity. A combined load transfer by GEWI-Pile and foundation slab may be chosen when the economic conditions so warrant.



GEWI-Pile with Standard Corrosion Protection

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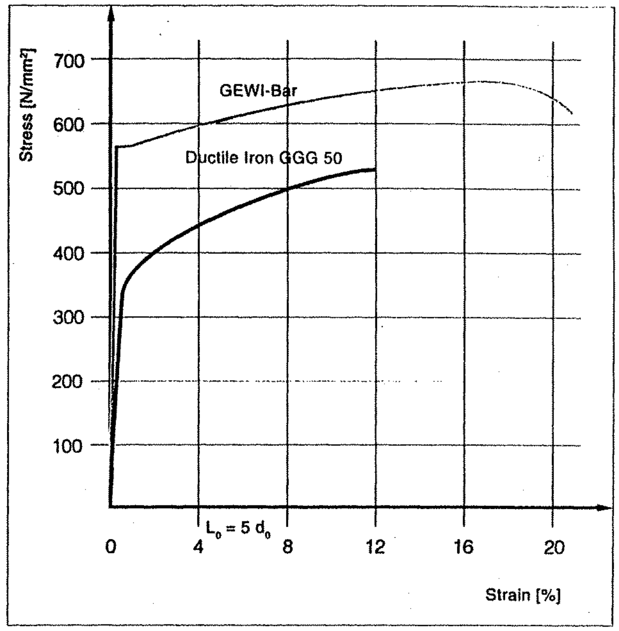

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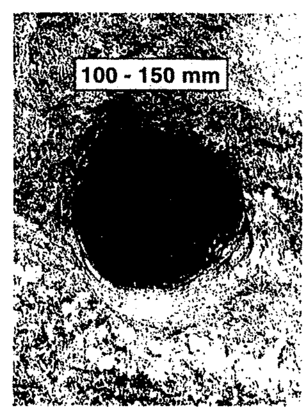
- Continuing settlements of a structure can be stopped by preloaded GEWI-Piles (Fig 15, Page 6).
- The GEWI-Bar, as a centrically located load bearing element, allows the installation of a Double Corrosion Protection system, unique in the pile technology (Fig 21, Page 9).
- The coarse GEWI-Thread guarantees maximum bond between GEWI-Bar and cement grout with uniform bearing behavior.
- The continious coarse GEWI-Thread allows GEWI-Anchorages and GEWI-Splices at any given point.



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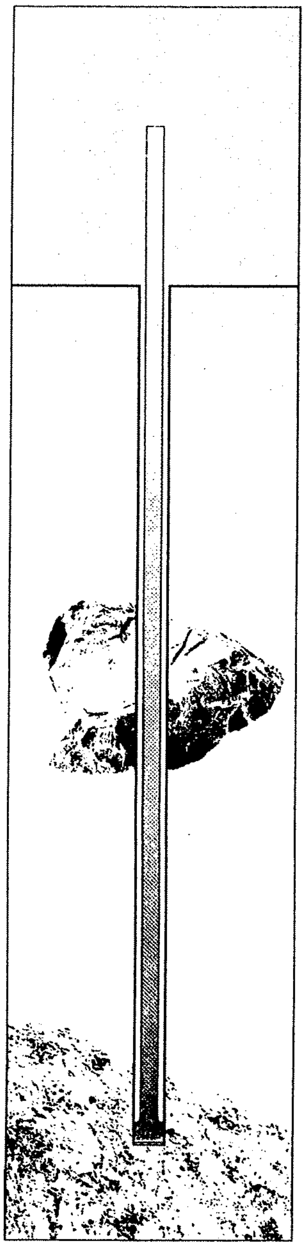
also as a Multibar Pile



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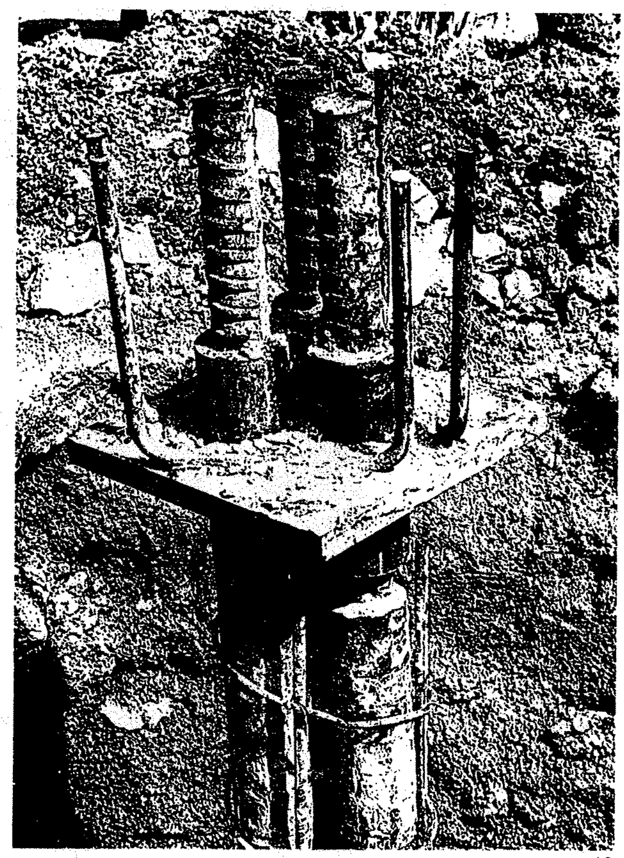
A combination of up to three GEWI-bars permits higher loads, provided they can be transferred into the underground (Fig. 10) (see table on Page 11).

The advantages of the GEWI-Multibar Pile are:

- Small drill hole diameter
- Standard Corrosion Protection
- Extremely good bonding
- Screwable due to the coarse GEWI-Thread
- Easy installation and grouting



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GEWI-Pile: Always safe, yet simple -

The coarse GEWI-Thread is the safest, simplest and most versatile solution for anchorages and splices in construction.

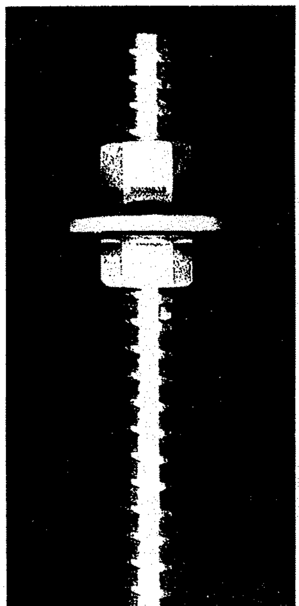
It acts immediately, can be disconnected, as well as preloaded and works in both directions of the bar.

The GEWI-Bar with the continuous coarse GEWI-Thread offers further advantages to the user:

- Its coarse thread is rugged and remains threadable even when dirty or damaged.
- It can be threaded quickly and over the entire length.
- Generous tolerances in the drill hole depth are easily compensated by a correct positioning of the GEWI-Anchorage which is always possible.
- It can easily be held in position by using a wrench at the flat side of the bar. Grout tubes and instrumentation wires can be also located there.

The following GEWI-Anchorages for tensile and compression loads are offered:

- The end anchorage with a torqued anchor head (Fig. 12)
- The plate anchorage with a torqued anchor plate, e.g. for flat concrete slabs (Fig. 13)
- Threaded anchorage with anchor plates for steel structures and precast concrete elements (Fig. 23, Page 10)
- Anchorage for the preloaded GEWI-Pile (Fig.15)



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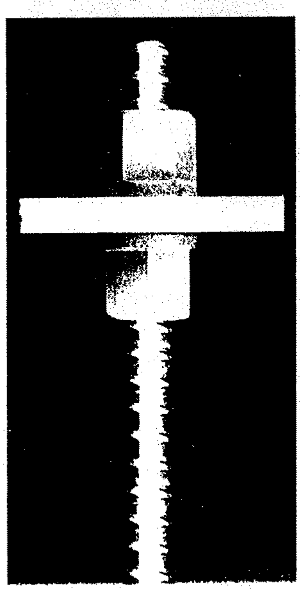

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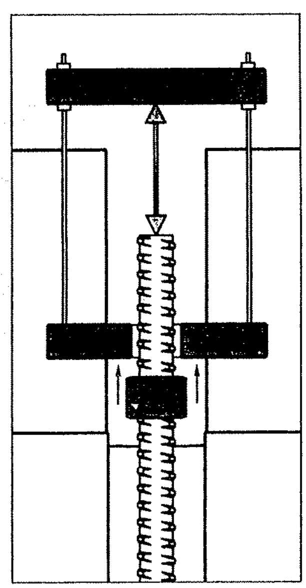

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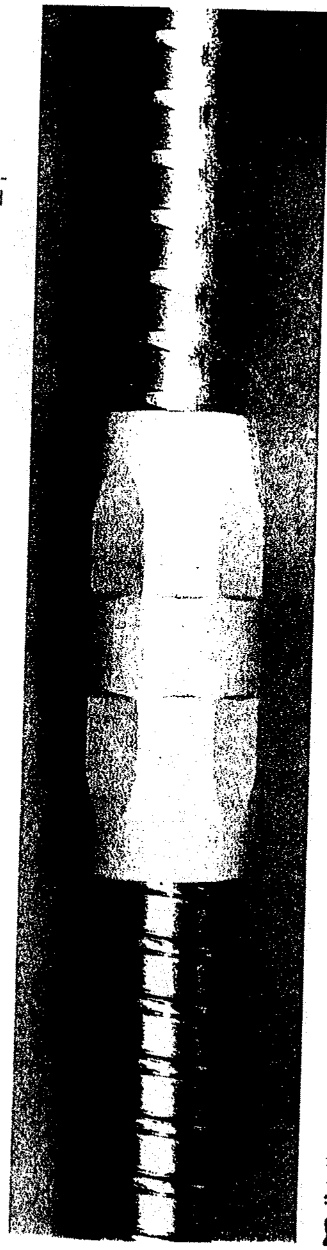
The threadable GEWI-Coupler Splice (Fig. 16), allowing splicing at any point, offers the following advantages:

- Installation of GEWI-Piles under restricted heights, such as for foundation rehabilitations in basements and underneath bridges (Fig. 17 and 18)
- Short transport lengths, for instance in case of container or truck shipments
- Unlimited extension of the GEWI-Bar, for example, at anchoring the cross beam for pile tests (Fig. 23, Page 10)
- Dismantling of sections needed only during installation



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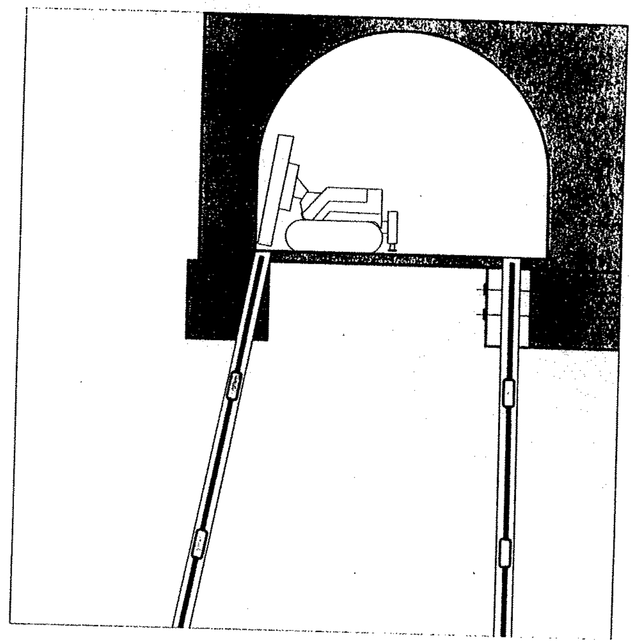

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GEWI-Pile: Strength in any Ground -

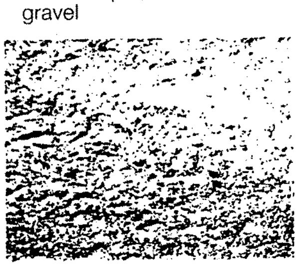
The GEWI-Pile
is a foundation element for any underground:

- **Cohesive Soiles:**

  For example,
  clays, silts (up to an undrained shear strength of $Cu \geq 10\ kN/m^2$
  for sufficient lateral support

- **Noncohesive Soils:**

  For example, sand and gravel



- **Rock:**

  Ranging from hard clays to granite, with open or closed joints and fissures.

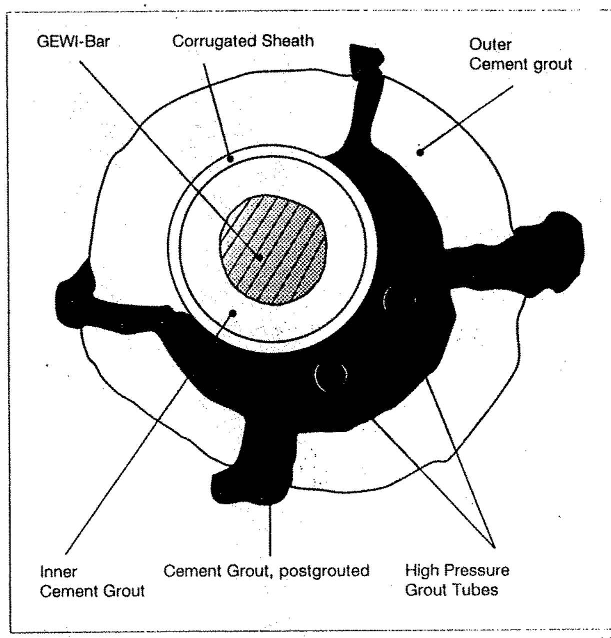
Installation of GEWI-Piles makes, depending upon underground condition, use of different grouting-techniques necessary.

In cohesive and noncohesive soils, the grout is normally injected through the casing.

When used in cohesive soils, the GEWI-Pile can be equipped with a postgrouting system (Fig. 20).

Postgrouting increases the load transfer to the ground by bursting the primary grout at the locations of the high pressure grout valves (Fig. 19).

The space saving GEWI-Postgrouting System allows repeated postgrouting.



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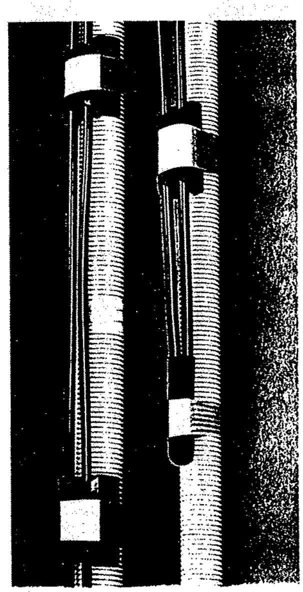

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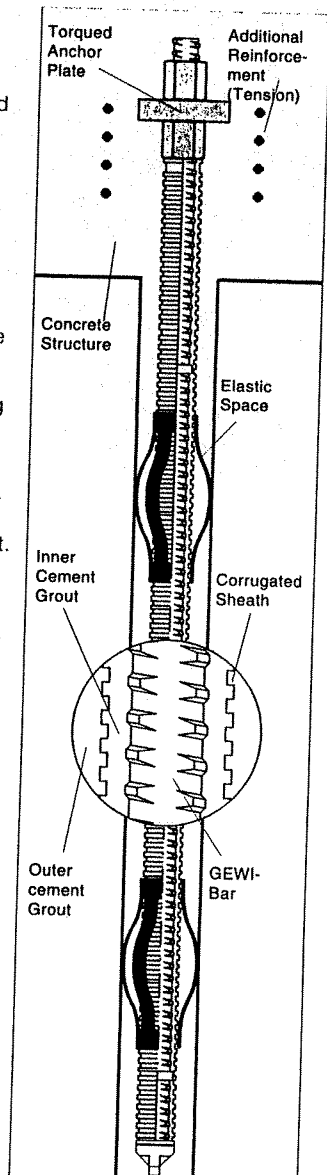
and permanently protected.

The Standard Corrosion Protection

The GEWI-Bar at the core of the pile is normally surrounded by a cement grout layer at least 20 mm thick. The high ph-value of the cement grout increases the steel with an alcaline medium which passivates the steel surface.

The Standard Corrosion Protection is permanent for compressive loads. Because of the high thread deformations, the grout body remains homogeneous. Problems of debonding do not occur.

Under tensile loads, the threaded-deformations cause a uniform distribution of very fine hair cracks in the cement grout. The crack width is further limited by the low elongation of the GEWI-Bar. Further, the GEWI-Bar resists corrosion because of the optimum surface to cross section ratio. For permanent applications, Double Corrosion Protection should be used beyond an acceptable crack width.



GEWI-Pile with Double Corrosion Protection

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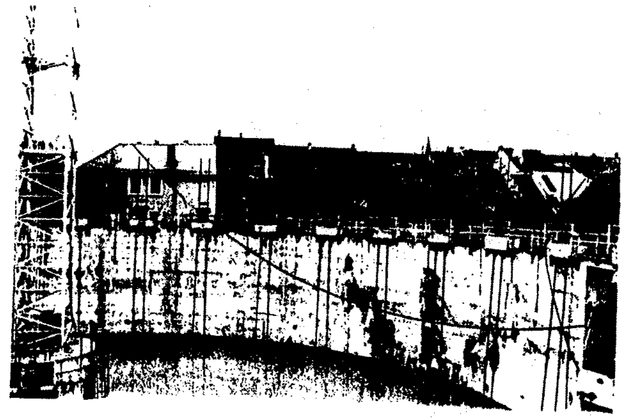

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The Double Corrosion Protection

The centrically located GEWI-Bar allows the installation of a corrugated sheathing which, besides the cement grout, functions as an additional barrier against corrosion. The inner cement grout is shop preferably injected.

The Double Corrosion Protected GEWI-Pile is installed easily as the GEWI-Pile with Standard Corrosion Protection.

The pile load is transferred into the underground over the full length easily through the ribs in the corrugated sheath and the outer cement grout.

In the pile technology necessity of the Double Corrosion Protection of the GEWI-Pile should be specifically stressed in:

- Piles driven in agressive media, such as seawater, water leaking from dump sites (Fig. 20)
- Tensile piles with permanent applications

The concept of the Double Corrosion Protection is also used when the force transfer into the ground needs to be discontinued by means of a smooth sheath, as, e.g. at pile tests or for a high pile elasticity.

GEWI-Pile: Three times Safety by -

For the owner, the design engineer and the contractor the safety issue is of top priority.

The GEWI-Pile is a proven foundation element which satisfies the highest safety requirements.

1. The Design

- The GEWI-Bar is a finished ready to install element
- Simplicity and ruggedness of its few components
- Proven installation methods with controlled pressure, quantity, flowability and strength of the grout
- Defined safety criteria for load bearing components and force transfer (see table Page 11)
- Uniform distribution of the structure load through a multitude of individual foundation elements

2. The Quality Control

All load bearing components are subject to a systematic quality assurance system.

This quality control includes all components affecting the internal safety.

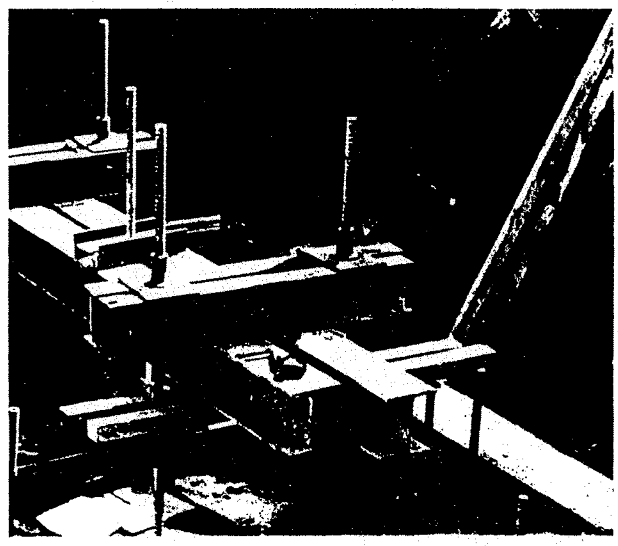
- GEWI-Bar
- Anchorages and splice Components
- Shop applied Double Corrosion Protection
- Grout

3. The Pile Test

It tests the external load bearing capacity, the transfer of the pile load to the surrounding ground. The amount of testing and the procedures are defined in the relevant specifications. A pile test is required when no comparative results are available.

The simple and economic test structure is the big advantage of the GEWI-Pile.

- The GEWI-Bar is extended to the required length using a GEWI-Coupler.
- The test load is introduced through the GEWI-Anchorage.
- During the compression test GEWI-Piles are used to withstand the test load. These piles can be used as normal foundation piles later.
- The arrangement for the tensile test is even simpler still, since the test loads can be transferred directly to the underground.
- Pile tests on GEWI-Piles up to 13 m length have shown settlements of less than 10 mm at full working load (Fig 24)



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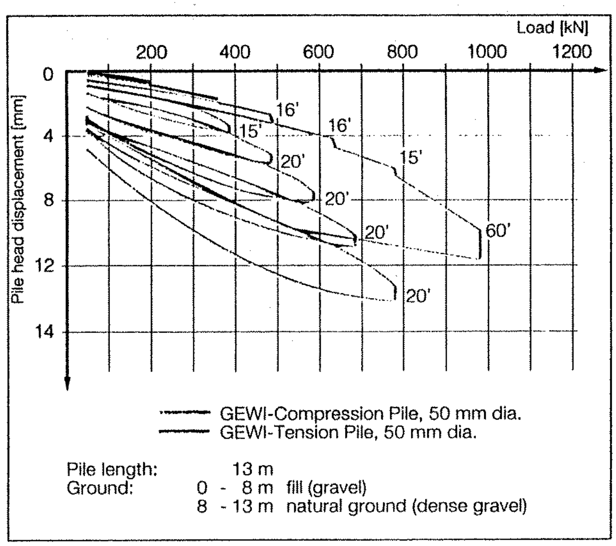

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Design, Quality Control and Pile Testing

Working Load of the GEWI-Pile, Grade St 500/550							
Service Life				Load Case 1 - 3 (acc. German Standard) Compression		Tension	
< 2 years with Standard Corrosion Protection				1	2 and 3	1 to 3	-
≥ 2 years with Standard Corrosion Protection				1	2 and 3	2 and 3	1
≤/> 2 years with Double Corrosion Protection				1	2 and 3	1 to 3	-
	Bar Ø [mm]	Steel Characteristics A [mm²]	$F_Y = A \cdot b_Y$ [kN]	Working Load $F_Y/1,71$ [kN]	$F_Y/1,50$ [kN]	$F_Y/1,75$ [kN]	$F_Y/3,03$ [kN]
GEWI-Pile	32	804	402	235	268	230	133
	40	1257	628	367	419	359	207
	50	1963	982	574	654	561	324
	63,5*	3167	1758	1028	1172	1004	523
GEWI-Multibar Pile	3 x 32	2412	1206	705	804	689	398
	1 x 40 1 x 50	3220	1610	942	1073	920	531
	3 x 40	3770	1885	1102	1257	1077	622
	2 x 50	3927	1963	1148	1309	1122	648
	2 x 40 1 x 50	4477	2238	1309	1492	1279	739
	1 x 40 2 x 50	5184	2592	1516	1728	1481	855
	3 x 50	5890	2945	1722	1963	1683	972

Load Case 1
Permanent loads and regular traffic loads

Load Case 2
Load case 1 plus occasional high traffic loads

Load Case 3
Load case 2 plus extraordinary loads

Example for using the table

Service Life: ≥ 2 years with standard corrosion protection

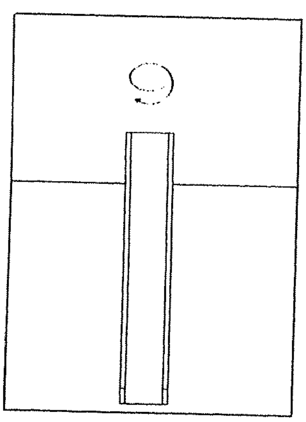
Load Case: Load Case 1, compression

GEWI-Pile: 50 mm dia.

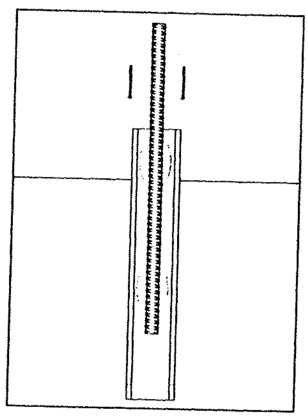
Working Load: 574 kN

* Remark:
bar dia. 63,5 use of grade BSt 555/700

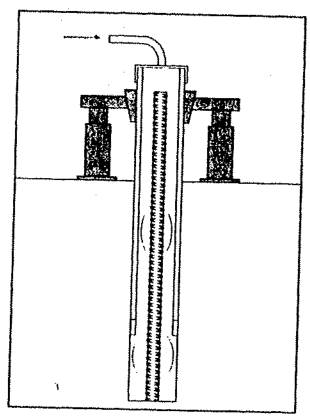
1. Drilling



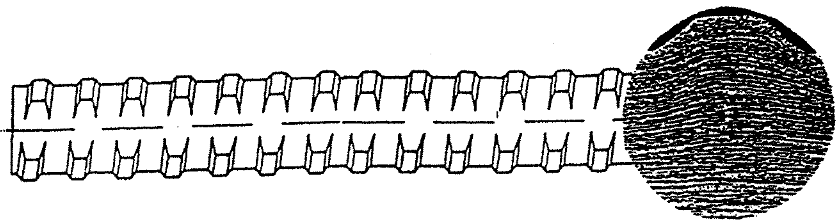
2. Installation



3. Grouting...

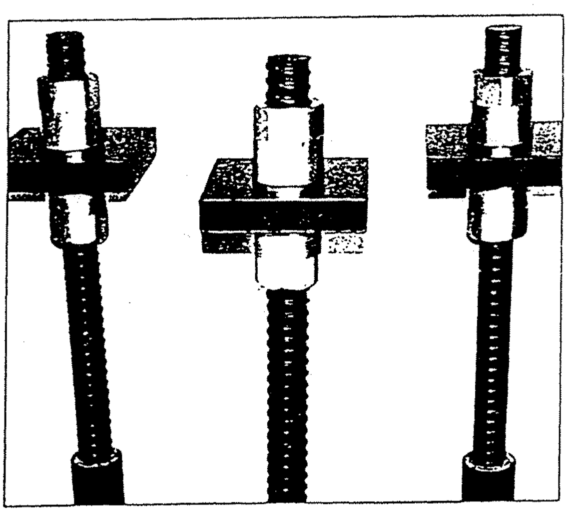


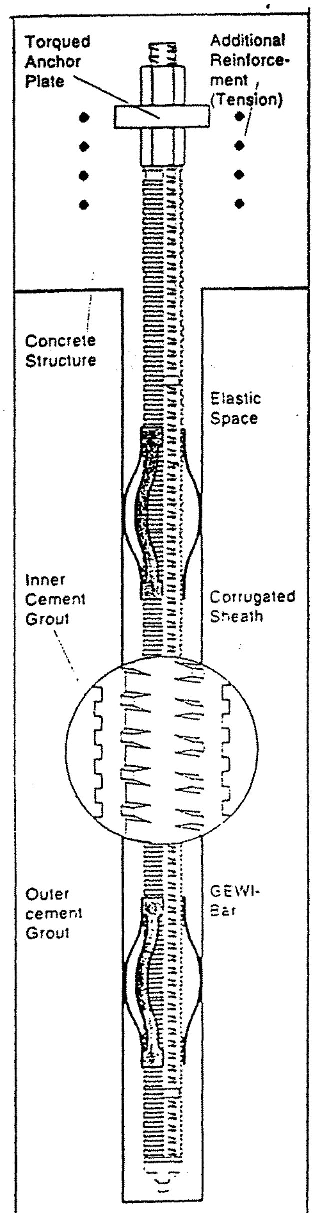
GEWI-Pile: Fast - Economic - Versatile -



Load capacity on GEWI-Piles

Nominal diameter	Steel grade f_Y / f_U	Cross sectional area A	Ultimate strength $F_U = f_U \cdot A$	Yield load $F_Y = f_Y \cdot A$	Working load tension $F_Y / 1{,}75$	Working load compr. $F_Y / 1{,}71$
mm	N/mm²	mm²	kN	kN	kN	kN
32 40 50	500 / 550	804 1257 1963	442 691 1080	402 628 982	230 359 561	235 367 574
63	555 / 700	3167	2217	1758	1004	1028
3 x 40 3 x 50	500 / 550	3770 5890	2074 3239	1865 2945	1077 1683	1102 1722





GEWI-Pile with Double Corrosion Protection

GEWI-Pile: Strong, but slender

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