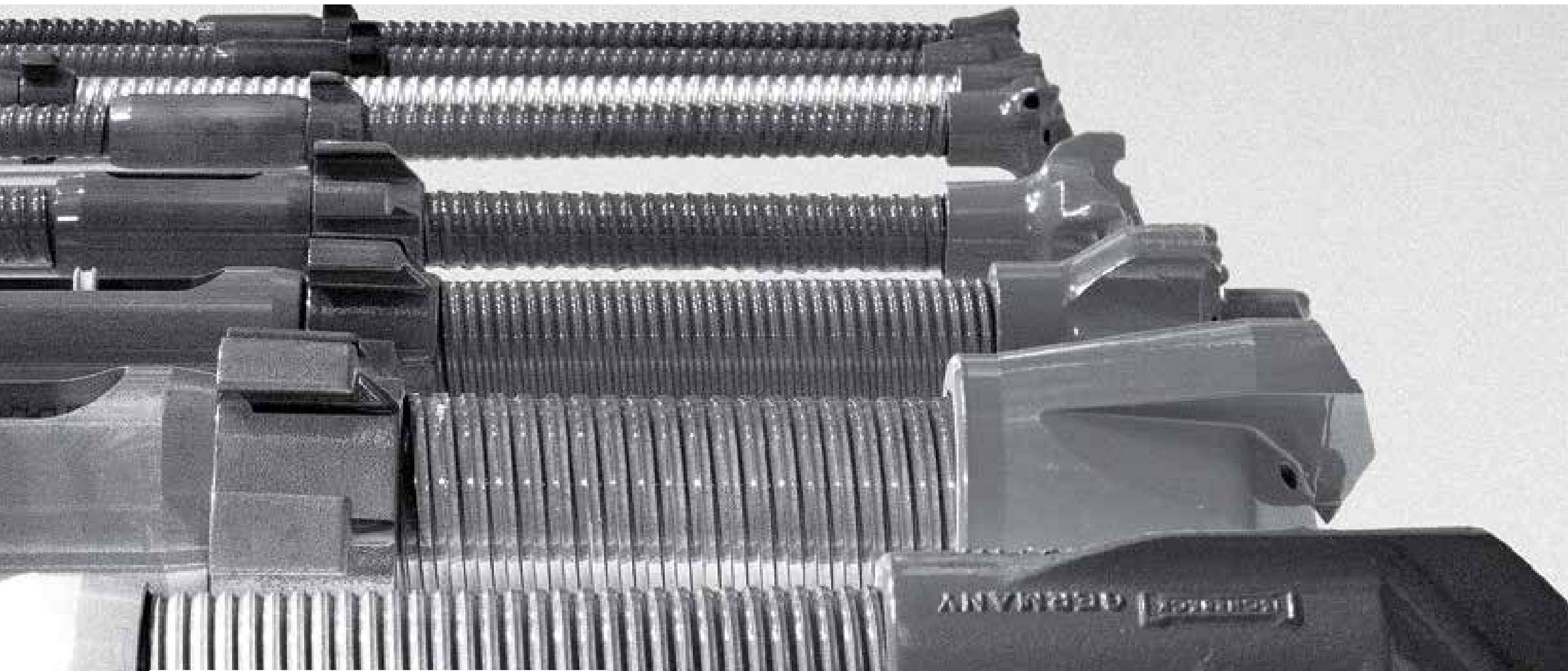
ISCHEBECK TITAN



Foundations / underpinning

Anchorages

Slope stabilisation

TITAN Micropiles

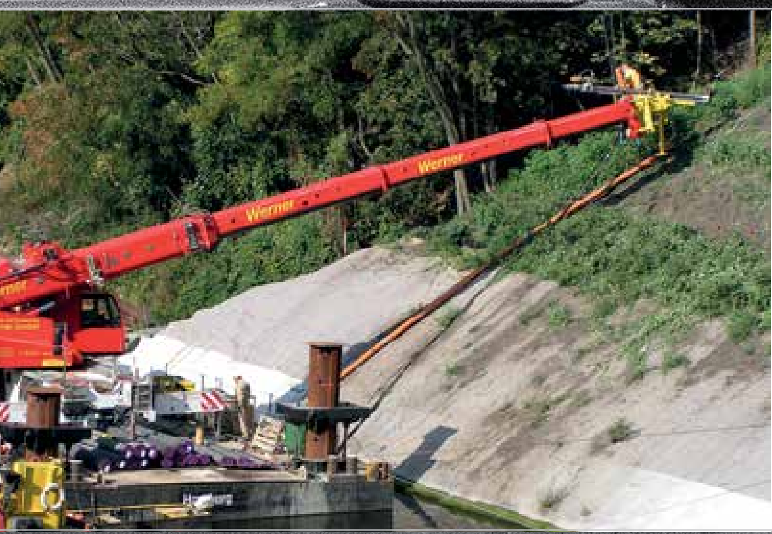
An innovation prevails.

Design and construction

National Technical Approval
Z-34.14-209

Foundations / underpinning
Resisting uplift with TITAN 40/20 micropiles
Arts Centre, Westerhaar, Netherlands

Anchorages
Excavation shoring anchored with TITAN micropiles
Dresden, Germany



Slope stabilisation
Stabilising a slope with TITAN 30/11 micropiles
Teltow Canal, Lot 2, Berlin, Germany

12 m long soil nails installed from a floating pontoon, with drilling rig mounted on telescopic boom.

About this brochure...

This brochure provides basic information about our TITAN micropiles and includes detailed explanations regarding applications. Micropiles are used for many geotechnical engineering applications where it is necessary to transfer tension and/or compression loads into the subsoil:

- Foundations and underpinning
- Anchored retaining structures
- Stabilising slopes and embankments
- Protecting against uplift (also reversed loadings)

The “Design guidance” chapter with design examples provides an overview of the analyses required by the design codes.
The appendix summarises a number of basic tests and provides an overall view of all the system components available in tabular form.

Detailed information on the various potential applications for TITAN micropiles can be found in the ISCHEBECK application brochures and in the Internet (go to www.ischebeck.com), or can be obtained from your ISCHEBECK representative.

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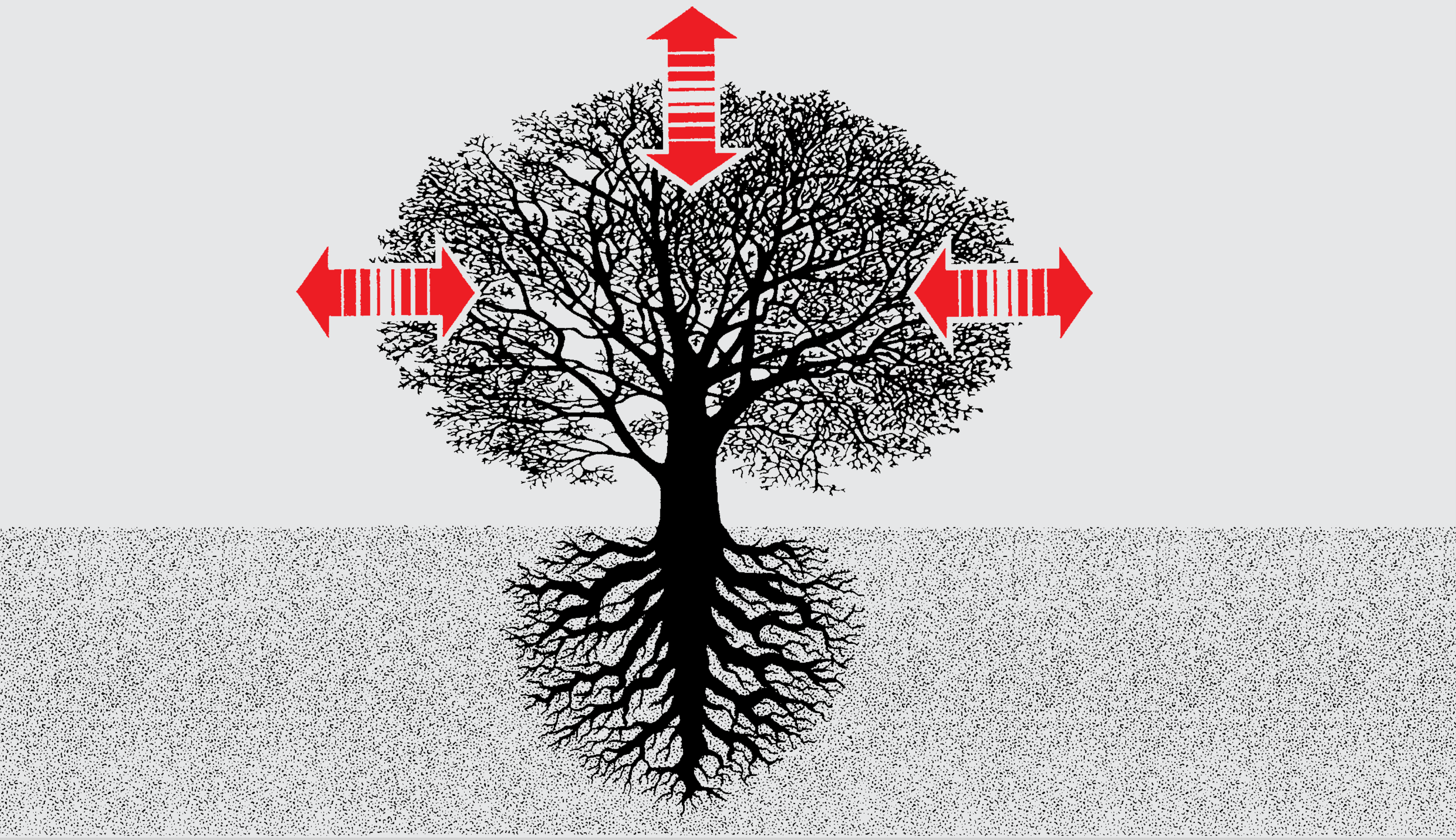
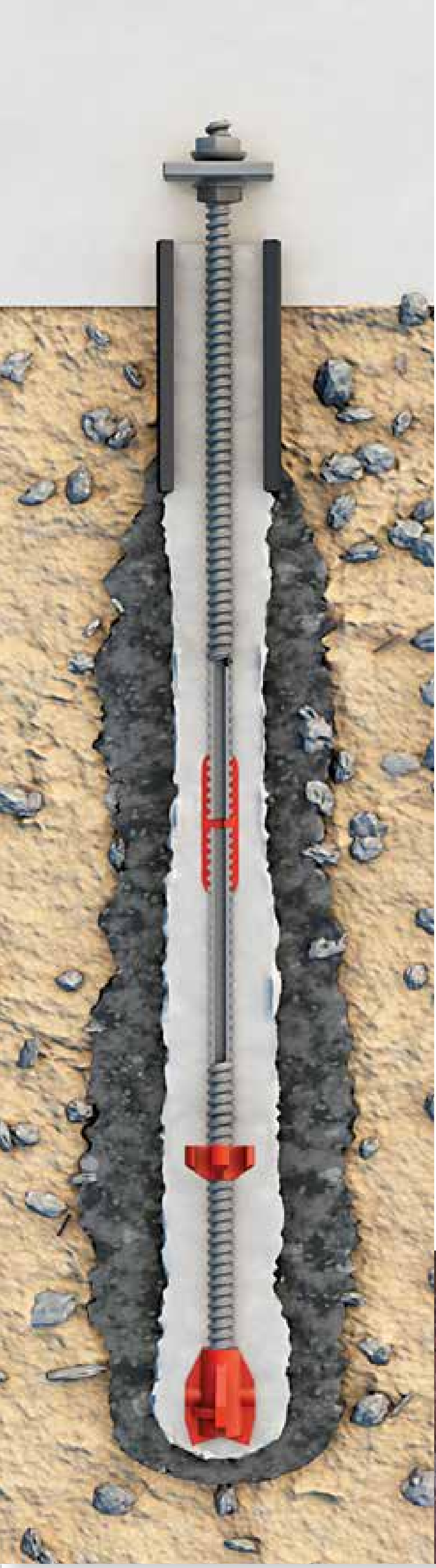
1. Our model

The roots of a tree – a model for us.

It was the image of a mighty tree that guided us. The tree has a network of large and small roots that support it and anchor it in the soil, without the need for a concrete foundation. The roots resist the vertical and horizontal static and dynamic forces, also bending moments and impacts, acting on the tree and transfer them to the ground. So the tree can withstand wind, snow and earthquakes.
The roots interlock with the soil, bond with it to create a monolithic root ball composed of roots and soil, and thus a composite material. How the tree "calculates" the size of the root system it needs for its stability remains largely a mystery to us. But the tree teaches us how to build with the soil, how to use it sparingly, how to improve it and reinforce it. This new way of thinking about foundations was recognised by Dr. F. Lizzi as long ago as 1952. He called his micropiles "root piles" (pali radice).





TITAN micropiles – our system.

DIN EN 14199 distinguishes between cast-in-place systems (micropiles with a continuous reinforcement cage) and composite piles (micropiles with a continuous tendon). An approval for the whole system is required for composite piles. The publication Recommendations on Piling (EA-Pfähle) divides composite piles into monobar piles and tubular grouted piles in which the tendon is installed directly with a sacrificial drill bit and a cement suspension as drilling and flushing fluid (= system: ISCHEBECK TITAN).
The tendon used in TITAN micropiles is a steel tube with a profiled outer surface based on DIN 488. It functions as sacrificial drilling rod, injection pipe and reinforcing bar (3-in-1). In contrast to the earlier method known from DIN 4128, where a casing is used to prevent the drilled hole from collapsing in, for instance, loose soil or boulders, the ISCHEBECK TITAN system uses a drilling fluid (cement suspension) to stabilise the drilled hole in accordance with DIN EN 14199 and DIN 18301 "Drilling works". That renders an additional casing unnecessary and saves operations in the drilled hole, which in many cases leads to higher productivity during installation compared with systems employing a separate casing.
Another advantage of direct drilling and simultaneous flushing/grouting with a cement suspension (dynamic grouting) compared with a casing is the mechanical interlock between the grout body and the soil. This enhanced shear bond results in higher load-carrying capacities and less settlement. Displacement at the head of the pile is generally in the order of magnitude of a few millimetres. Therefore, taking into account their loadbearing behaviour, TITAN micropiles represent an equivalent but economic alternative to prestressed permanent anchors according to DIN EN 1537.
The TITAN micropile is a tubular grouted pile. However, depending on the application, they are also known as injection piles, composite piles, anchor piles or soil nails.

TITAN micropiles comply with DIN EN 14199 (+ DIN SPEC 18539)* and in Germany their use is regulated by National Technical Approval Z-34.14-209 issued by the German Institute of Building Technology (DIBt).

Mechanical interlock between grout body and soil

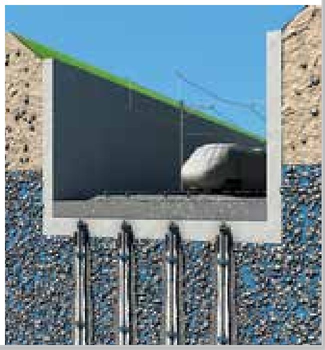
* In the following, references to DIN EN 14199 shall be deemed to include the supplementary national provisions contained in DIN SPEC 18539.

2. Range of applications

Micropile
for foundations, underpinning

TITAN micropile to DIN EN 14199 for foundations, underpinning. For transferring tension and compression loads to loadbearing soil strata deeper in the ground.

- New structures
- Change of use in older buildings
- Following damage (e.g. undermining etc.)
- Securing against uplift



Micropile
for anchorages

TITAN micropile to DIN EN 14199 for tying back structures. For transferring tension loads to loadbearing soil strata deeper in the ground.

- Excavations
- Anchorages for sheet pile walls
- Anchorages for retaining walls
- Temporary and permanent
- An alternative to prestressed anchors

Soil nail

TITAN micropile as soil nail to DIN EN 14490 for reinforcing soils so that tensile forces can be accommodated, which would otherwise be impossible.

- Stabilising slopes
- Stabilising embankments
- Reinforced soil
- Fixing protective netting

> Further information about applications for TITAN micropiles can be found in the ISCHEBECK application brochures or in the Internet (go to www.ischebeck.com).

Tunnelling

TITAN micropile for tunnels.

- Tunnel floor stabilisation
- Soil nailing around tunnel entrances
- Soil nailing around tunnel portals
- Pipe umbrellas
- Self-drilling spiles
- Self-drilling anchors
- IQ Quickset Roofbolts, secured with special resin

Special applications

- Drill Drain
  TITAN micropile as horizontal drain with a special, permeable grout body for reliable, specific drainage of slope seepage water

- Monojet
  TITAN micropile used according to the jet-grouting principle with up to 240 bar.

- Geothermal projects
  TITAN Geothermal Energy Pile as a combined loadbearing and geothermal element

Advantages for design
- Approved system
- Quick, dependable planning
- Diverse applications – even with difficult boundary conditions
- Suitable for use in all soil types

Advantages for construction
- Standard method irrespective of type of application
- Suitable for use on cramped sites
- Fast progress on site
- Unaffected by changing soil conditions
- No additional plant necessary

Advantages for clients
- No ongoing costs for monitoring tests
- Permanent corrosion protection
- Highly reliable installation method
- No major intervention in existing works
- Economic system

3. The TITAN micropile in detail

3.1 Loadbearing element with three functions

- Direct drilling without casing
- Fewer operations on site = more efficient working
- Highly reliable installation method

Hollow steel tendon as
- Reinforcing bar
- Injection tube
- Drilling rod

3.1.1 The reinforcing bar function

Hollow steel tendon made from fine-grained structural steel

Standards

According to DIN EN 14199, section 6.2.2, steel tendons must comply with EN 10080*. For selfdrilling systems, drawn seamless tubes to EN 10210 can be used. Eurocode 2 (DIN EN 1992) and DIN 488 divide steel reinforcing bars into three or two classes respectively. Class B bars must have the following properties:

- Yield stress $f_{y,k}$: 400-600 N/mm²
- Yield stress ratio $(f_t/f_y)_{k,}$ i.e. $R_m/R_e \geq 1.08$
- Elongation at maximum load $\varepsilon_{uk,}$ i.e. $A_{gt} \geq 5.0$ %

Fine-grained structural steel S 460 NH to DIN EN 10210**

An element made from fine-grained structural steel can carry a higher load than one made from a normal structural steel with the same dimensions. Therefore, a tougher, more ductile steel with a high notched impact strength is used for the reinforcing bar. The notched impact strength of this steel is approx. W ≥ 40 Joule (at -20°C) and therefore much higher than the values of typical structural and prestressing steels, which are 27 and 15 Joule respectively (at -20°C). That minimises the risk of damage during rotary percussive drilling. Once installed by means of rotary percussive drilling, all the demands placed on reinforcing steel are fulfilled. Furthermore, the fine-grain structural steel is not sensitive to stress corrosion cracking.

Ductility – no sudden failure of the material

The high ductility of the steel means that it reacts with a highly uniform strain in the event of an overload. The load remains constant. In practice, a potential overload therefore initially causes deformations before the component fails. Sudden failure is therefore ruled out.

Permanent protection against corrosion

The grout cover, i.e. the grout body, around the hollow steel tendon provides permanent protection against corrosion (see p. 32).
The following additional measures can be employed to improve the corrosion protection for special applications:

- Hot-dip galvanising
- Duplex coating
- Stainless steel
  (see 6.3, "Verification of durability")

* Note: In Germany EN 10080 is not part of building legislation and therefore, according to DIN SPEC 18539, DIN 488 still applies for reinforcing steel.
** DIN EN 10210: Hot finished structural hollow sections of non-alloy and fine grain steels

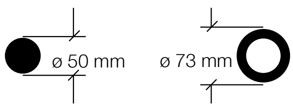
3.1.2 The injection tube function
Hollow instead of solid steel tendon

No additional casing = less work
The hollow steel tendon is driven to the required depth by means of rotary percussive drilling. The drilling fluid injected via the drill bit automatically stabilises the drilled hole. An additional casing is unnecessary, there is no need to insert a separate steel tendon or extract a casing.

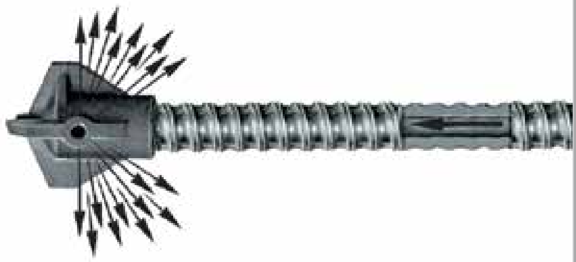
Reliable filling = no multi-stage grouting
The hollow steel tendon is used to fill the drilled hole starting at its deepest point, i.e. from the bottom up. That guarantees that the drilled hole is inevitably completely filled, including all fissures and crevices. No additional injection hoses are needed. Multi-stage grouting is unnecessary.

Additional advantage: better structural cross-section
A hollow tendon is better than a solid tendon with the same cross-sectional area because of its better structural behaviour in terms of buckling, circumference (bond area) and bending stiffness. The result is a higher buckling and flexural stability for the same amount of steel (cost of material) and the same tensile and compressive forces.

Example: comparison of 50 mm dia. solid bar and TITAN 73/53



$A_{solid} \approx 19.60$ cm²	$A_{hollow} = A_{eff} \approx 16.15$ cm² (see p. 43)
$W_{solid} \approx 12.3$ cm³	$W_{hollow} \approx 22.2$ cm³
$I_{solid} \approx 30.7$ cm⁴	$I_{hollow} \approx 77.5$ cm⁴



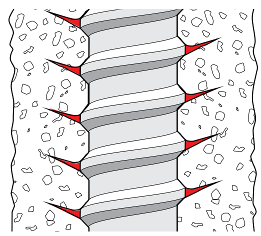
3.1.3 The drilling rod function
Hollow steel tendon with TITAN thread*

Continuous thread for flexible usage
The hollow steel tendons can be readily cut to any length to suit cramped site conditions or a limited overhead clearance. The continuous thread guarantees that a thread is available at every point for coupling, prestressing, etc.

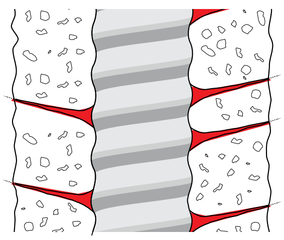
Self-locking thread
The self-locking pitch saves two counternuts per coupling nut.

Optimum shear bond with minimum crack widths in grout body
The shear bond, the most effective, most reliable type of bond, is essentially dependent on the geometry of the ribs. Here, the relative rib area f_R serves as a parameter for the quality of the bond. The relative rib area of the TITAN thread is very high; it lies close to the optimum value of $f_R = 0.14$ - $f_R = 0.25$ and is therefore many times higher than the relative rib area of ribbed reinforcing bars ($f_R = 0.056$). In addition to the good bond, the rib surfaces at an angle of 45° reduce the splitting forces. The crack widths at maximum load lie below the 0.1 mm stipulated for verification of permanent corrosion protection. Such a crack width cannot be achieved by drilling rods with rope threads, e.g. R32 or R38 (to ISO 10208 and ISO 1720).

TITAN thread*
Damaging microcracks do not penetrate the grout body



rope thread
A few cracks penetrating the grout body

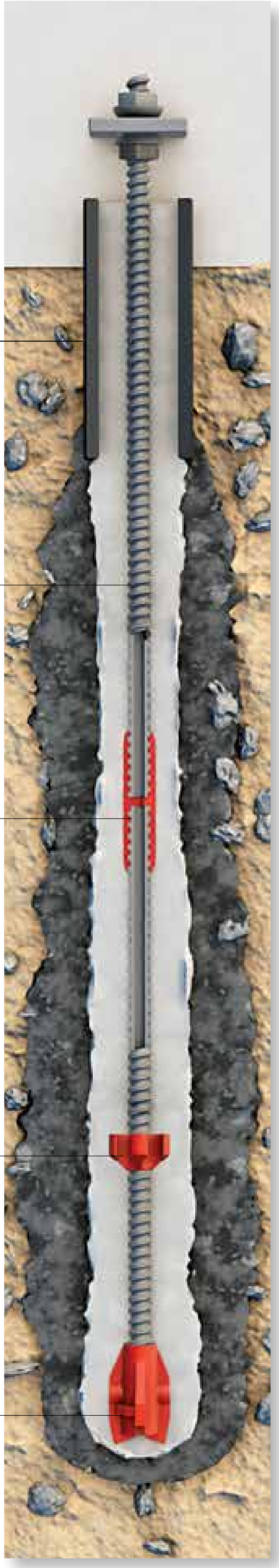


The special TITAN thread guarantees an excellent shear bond and minimises the risk of longitudinal cracks in the grout body.

*The form and structure of the thread complies with Eurocode 2, DIN 488, DIN EN 10080 and ASTM-A 615.

3. The TITAN micropile in detail

- Suitable drill bits available for all soil types
- Unforeseen changes in the ground conditions do not normallyrequire a change of method



3.2 Sacrificial drill bits

Clay bit
Clay and loam, sandy-cohesive mixed soils without obstructions < 50 S.P.T.[1)]

Cross-cut bit
Dense sand and gravel with obstructions > 50 S.P.T.[1)]

Button bit
Weathered rock[2)], phyllite, slate, mudstone; strength < 70 MPa

Carbide-Y-Cross Drill bit
Dolomite, granite, sandstone; strength 70–150 MPa

Carbide button bit
Reinforced concrete or rock[2)], predrilling; strength > 70 MPa

Carbide shouldered bit:
For drilled holes with a stable direction in the case of faults in the ground

- All drill bits include venturi flushing outlets.
- Illustrations of drill bits are typical only; forms and colours may differ from those shown here.

[1)] S.P.T. = standard penetration test
[2)] The compressive strength of rock lies well below that of the rock material itself because of the faults that are present in almost every situation. The rule of thumb is: the compressive strength of rock can be assumed to be 10–20% of that of the rock material itself. (source: Prof. Dr. Kurosch Thuro, Chair of Engineering Geology, Munich TU).

3.3 Coupling nut

Connection without counternuts

The coupling nut can accommodate both repeated loadings and dynamic load changes – made possible by the central stop (steel ring with seals). Tightening against the central stop also achieves an optimum transfer of the blow energy during drilling.
An additional tightening nut as used in other systems is not required.

3.4 Centraliser

Guaranteeing the minimum grout cover

The centraliser fitted ahead of each coupling nut (every 3 m at least, according to approval) is carried into the hole as it is drilled. The dimensions of the centraliser are such that it guarantees a consistent grout cover of min. c = 20 mm around the tendon and that the tendon remains in the centre of the drilled hole. The drill bit increases the diameter of the drilled hole (see p. 14) and this helps to guarantee the grout cover specified in the approval. The shape of the centraliser is optimised for transporting drilling debris out of the drilled hole. Furthermore, the centraliser helps to maintain the direction during drilling. Centralisers are fitted with the tapered side pointing towards the bottom of the hole.

3.5 End plate

Compensating for angles between 0° and 45°


1


2


3


4

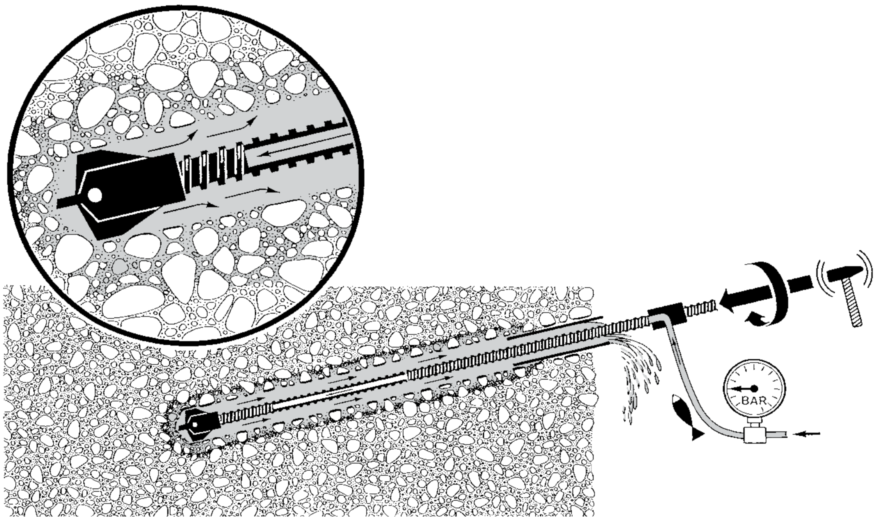
Various end plate details are available to suit different applications. The heads of piles are generally embedded in reinforced concrete (capping beam, foundation, ground slab) or sprayed concrete (soil nailing) or connected to a steel structure (sheet pile wall, waling).
In reinforced concrete, the head of the pile is an end plate fitted to the often protruding end of the tendon with two spherical collar nuts. This type of detail must be checked for bearing pressure, punching shear and bending of the plate.
In sprayed concrete, generally an end plate with a spherical recess is used in conjunction with one spherical collar nut. Angles of up to 5° can be compensated for with this type of detail (picture 1 and 2).
An angle adapter plate can be mounted on the end plate with spherical recess, in order to compensate for angles of up to 36° (picture 3). When anchoring sheet pile walls, angles of up to 45° to the vertical are achieved by using a plate for steel ball in conjunction with a steel ball. It is also possible to achieve movement in the horizontal direction depending on the angle in the vertical plane (picture 4).
Design guidance for connections in reinforced concrete and for anchoring sheet pile walls can be found in our brochure detailing the standard end plate variations.

4. Method of installation

4.1 An anchorage in two steps

One method for all applications
Irrespective of the ground conditions and the particular application, TITAN micropiles are always installed using the same method.

- Standard method for all types of soil
- Standard method for all types of application, e.g. for pile foundations, anchor piles or soil nails
- No multi-stage grouting

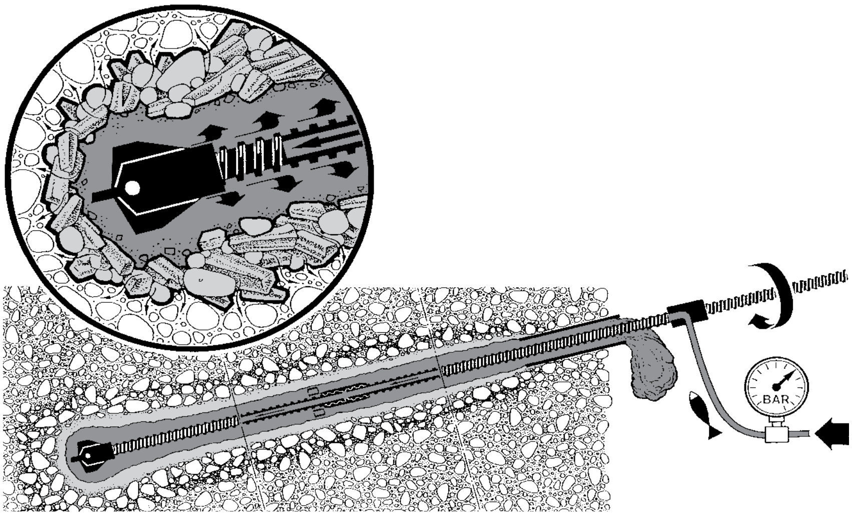


Step 1: Direct drilling
Rotary percussive drilling with a flushing medium

Rotary percussive drilling in conjunction with a cement suspension displaces and improves the soil in the same way as a displacement pile. During the drilling procedure, the water is filtered off from the cement suspension to leave behind a filter cake that stabilises the drilled hole. This filter cake can also be called the initial injection that improves the shear bond between the grout body and the soil. The cement forms a mechanical interlock with the microstructure of the soil. In contrast to the down-the-hole (DTH) hammer technique with air flushing or a cased hole, the side of the hole is not loosened or relieved.
Stabilising the drilled hole with flushing fluid represents the state of the art and is used for diaphragm walls to DIN EN 1538 and bored piles to DIN EN 1536 (but in this case with cement suspension instead of bentonite!). There are also similarities with stabilising with sprayed concrete: the side of the drilled hole is immediately closed with cement.

The flushing medium
A cement suspension with a water-cement (w/c) ratio of 0.4–0.7 (e.g. 70 l water per four 25 kg bags of cement, w/c = 0.7) is used as a flushing and drilling fluid. The use of thinner cement suspensions, water or air can be considered as the flushing medium depending on the particular application.

Drilling rate and cleaning out the hole
The quality of the grout body and the bond are improved by lowering the drilling rate (approx. 1 m/min) and cleaning out the hole more often. Cleaning out means repeatedly extracting and reinserting the drilling rod while continuing to rotate it and also continuing to flush out the hole. This method of working rinses the drilled hole clean and forces drilling debris out of the top of the hole. As a check, the flushing medium flowing out of the top of the hole can be passed through a sieve. There should be no interruption to this flow out of the hole. If there is an interruption, or the medium disappears down the drilled hole, flushing should continue without drilling, possibly with a thicker cement mix, until the cement suspension starts to flow out of the top of the hole again.



Step 2: Dynamic pressure grouting
with grout suspension

Dynamic pressure grouting is the name given to injecting grout and rotating the tendon simultaneously. The cement suspension used for pressure grouting has a w/c ratio of 0.4–0.5 and a strength of $f_{c,k} \geq 35$ N/mm². This stiff mix displaces the flushing medium that supports the side of the drill hole, forcing it out of the top of the hole. Dynamic pres-
sure grouting can be likened to a poker vibrator in concrete and results in a dense grout body around the tendon.
If the first step (drilling) is carried out using a grout suspension with a w/c ratio of 0.4–0.5, then according to the approval, dynamic grouting (step 2) is not required.

Injection pressure
A rising injection pressure towards the end of the pressure-grouting phase indicates a well-installed pile. The increase in the injection pressure, despite the fact that the top of the drilled hole is open, is explained by the fact that the plugs of rapid-hardening cement ratio that are pushing up the drilled hole become wedged between the rotating hollow steel tendon and the surrounding soil, either creating a natural blockage (packer) or according to Darcy's law describing fluid flow through porous media. With increasing injection pressure, sufficient skin friction develops. Therefore, the final injection pressure must be recorded in every installation log.
Multi-stage grouting is unnecessary because the injection pressure of 5 bar specified in DIN SPEC 18539, section A 8.8.1.1, is always reached.

Controlled underreaming and dowelling effect of injected material due to radial jets

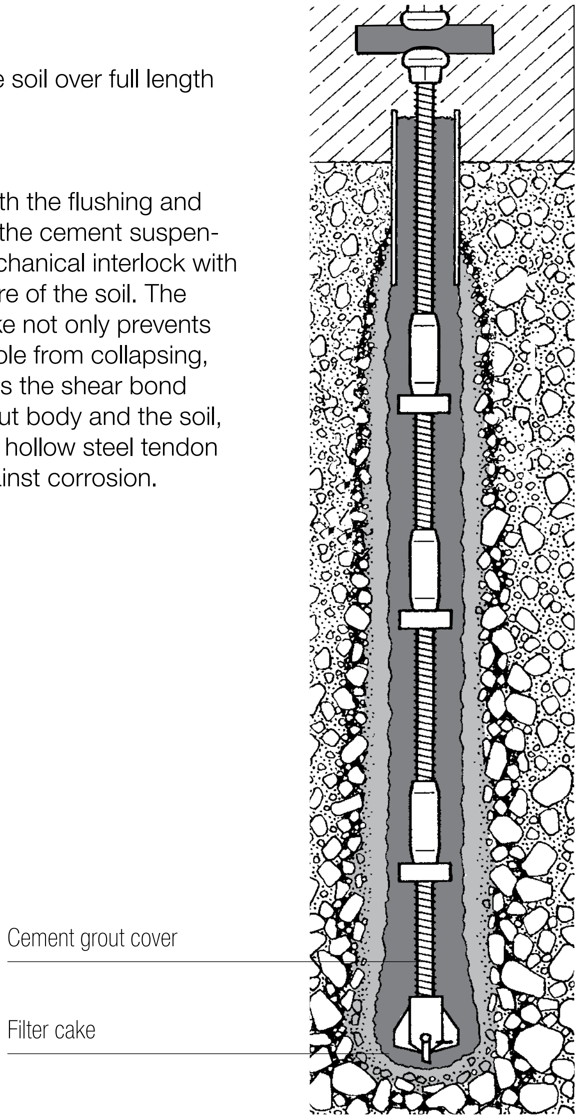
All drill bits have lateral venturi openings which leads to a sort of dowelling effect between the injected material and the surrounding soil, and which can be exploited to create a controlled under-reaming effect. Micropiles excavated for inspection purposes have revealed that the radial jets cut into the soil even at low pressures in a similar way to "jet grouting" and "compaction grouting" (profiled surface to grout body with a diameter up to twice that of the drill bit).

4. Method of installation

4.2 Result

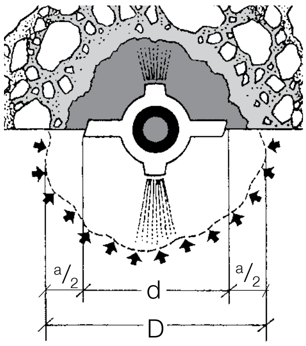
Grout body
Interlock with the soil over full length

During drilling with the flushing and drilling medium, the cement suspension forms a mechanical interlock with the microstructure of the soil. The ensuing filter cake not only prevents the side of the hole from collapsing, but also improves the shear bond between the grout body and the soil, and protects the hollow steel tendon permanently against corrosion.



Widening of drilled hole

The drilling process with the radial jets creates an annulus for the grout body which has a larger diameter than that of the drill bit. According to DIN SPEC 18539, section 3.3, it may be assumed that the pile diameter when installing with external jetting is at least equal to the maximum diameter of the drill bit or the installation plant (drill bit diameter in this case) plus 20 mm.



$D = d + a$
Widening value a ≥ 20 mm
Empirical values supplied by Ischebeck (measured on excavated grout bodies)
a = 75 mm (medium and coarse gravel)
a = 50 mm (sand and sandy gravel)

The mechanical interlock between the hollow steel tendon, cement grout cover, filter cake and the soil. The grout body broken away for inspection purposes shows the hollow steel tendon and coupling nut within – permanently protected against corrosion.

5. Plant

A typical site setup consisting of a grouting unit and a drilling rig mounted on construction plant.

TITAN micropiles with a nominal outside diameter (D_{steel}) of up to 40 mm (TITAN 40) can be installed with hand-held, hammer drills. Any construction plant with a hydraulic rotary percussive drive and drilling attachment can be employed for nominal outside diameters up to D_{steel} = 52 mm (TITAN 52).

TITAN micropiles have a continuous thread and can therefore be cut and joined at any point. The use of small, lightweight drilling equipment makes it possible to install TITAN micropiles even on sites with cramped conditions (e.g. basements, enclosed yards, factories between machinery) or sites with difficult access (e.g. beneath bridges, riverbanks, steep slopes, mountainous areas).

The space required for a mini excavator with drilling attachment is less than that required for a drilling rig mounted on crawler tracks (6 m of levelled ground in front of installation area).

In some circumstances, lightweight drilling equipment can be delivered to inaccessible sites, e.g. mountainous districts, by helicopter.

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5. Plant

Hand-held hammer drill
- Suitable for installing the smaller TITAN 30 and TITAN 40 anchors.

- **Drilling attachment for mounting on any construction plant with hydraulic drive**
- Suitable for installing the small to medium-sized TITAN 30, TITAN 40 and TITAN 73 anchors
- Manufacturers: Morath, TEI Rock-drills, Klemm etc.

Anchor drilling rigs
- Universal crawler track-mounted units for installing all TITAN anchors
- Manufacturers: Klemm, Hütte-Casa-grande, Morath etc.

Suitable drills		Pressure-grouting plant	
TITAN 30/...	Atlas Copco COP 1036, 1038, 1238; SIG PLB 291 A; TAMROCK HL 438; Krupp HB 5, HB 11, HB 15, HB 20; Eurodrill HD 1001, HD 1002; Klemm KD 204, KD 511; Morath HB 23; TEI TE 160 HT, TE 260 HT	35 l/min	Grouting unit with water regulation, turbo mixer for colloidal mixing, 1 mixing receptacle + 1 reservoir, double plunger pump, up to 100 bar Manufacturers: Scheltzke, MAT, Obermann, Häny, Morath
TITAN 40/...	Atlas Copco COP 1036, 1038, 1238; SIG PLB 291 A; TAMROCK HL 438; Krupp HB 11, HB 15, HB 20; Eurodrill HD 1001, HD 1002; Klemm KD 204, KD 511, KD 1011; Morath HB 70; TEI TE 260 HT, TE 350	50 l/min	
TITAN 52/...	Krupp HB 25, HB 35; Eurodrill HD 2004; Klemm KD 511, KD 1011, KD 1215; Morath HB 100; TEI TE 560	70 l/min	
TITAN 73/...	Krupp HB 35, HB 45, HB 50; Eurodrill HD 2004, HD 4010; Klemm KD 1011, KD 1215; Morath HB 100; TEI TE 560	90 l/min	
TITAN 103/... TITAN 127/...	Krupp HB 50, HB 60; Eurodrill HD 4010, HD 5012; Klemm KD 1215, KD 1624, KD 1828; TEI TE 1000	120 l/min	

Drilling rate: 0.3–1.0 m/min, approx. 50 r.p.m., flushing pressure 10–15 bar
Note: Compared with drilling holes for explosive charges in rock, reducing the drilling rate and the percussive action to approx. 1/3 is recommended.
We recommend using rotary percussive plant for installing TITAN micropiles.

Typical grouting units

Flushing heads are available for the most popular drifters which connect the hollow steel tendon to the drifter.

6. Design guidance

6.1 Designing a TITAN micropile

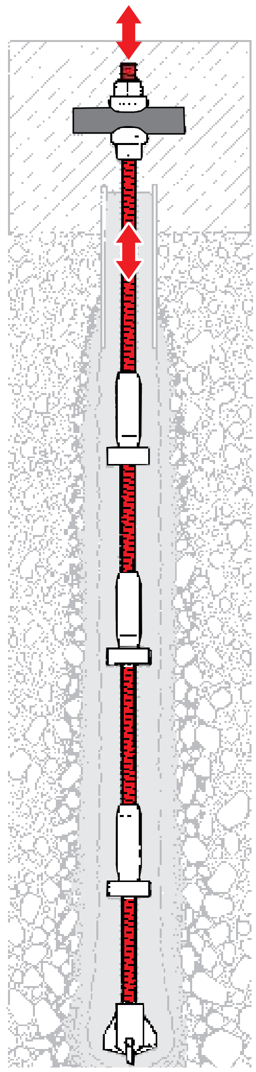
The design of a TITAN micropile is carried out to EN 1997 (EC7). Verification of the following is always necessary irrespective of the type of application:

> 1. Load-carrying capacity
> 2. Grout/soil friction
> 3. Buckling (compression piles)
> 4. Serviceability

6.1.1 Verification of load-carrying capacity

The analysis requires that the design value of the actions E_d is less than the design value of the resistance of the hollow steel tendon R_d.
The partial safety factor for calculating R_d according to EC7 and National Technical Approval Z-34.14-209 is
$\gamma_M = 1.15$ ($R_d = R_k / \gamma_M$).

Verification: $E_d < R_d$



Relevant standards:
- National Technical Approval Z-34.14-209 (resistance)
- EC7 (actions)

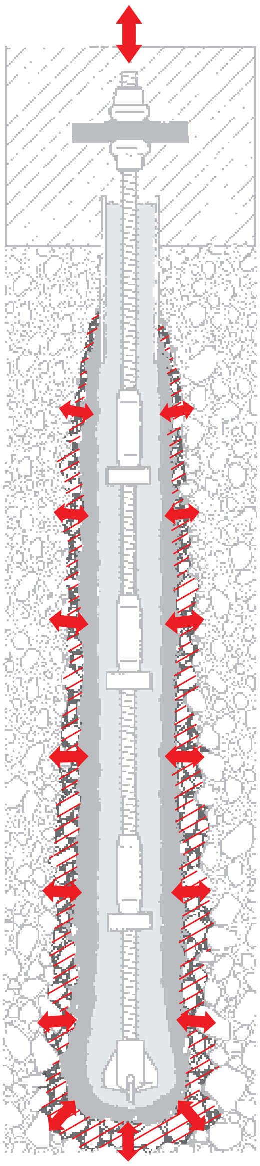
Designation	Unit	TITAN 30/16	TITAN 30/11	TITAN 40/20	TITAN 40/16	TITAN 52/26	TITAN 73/56	TITAN 73/53	TITAN 73/45	TITAN 73/35	TITAN 103/78	TITAN 103/51	TITAN 103/43	TITAN 127/103
Nominal outside diameter Ø	mm	30	30	40	40	52	73	73	73	73	103	103	103	127
Nominal inside diameter Ø	mm	16	11	20	16	26	56	53	45	35	78	51	43	103
Characteristic load-carrying capacity R_k according to German approval document[1]	kN	155[2]	225[3] (250)	372	490	650	695[2]	900	1218	1386	1626	2500	3015[2]	1800[2]
Yield Point $F_{0.2,k}$ (mean value)	kN	190	260	425	525	730	830	970	1270	1430	1800	2670	3398	2030

[1] In the case of permanent tension loads and a cement grout cover c < 45 mm, the load-carrying capacities may need to be reduced according to approval Z-34.14-209.

[2] An approval is not available for these sizes: for TITAN 30/16, 73/56, 103/43 and 127/103, the values were interpolated in a similar way to the approval.
[3] A characteristic load carrying capacity R_k = 250 kN may be used for TITAN 30/11 in temporary installations.

6.1.2 Verification of grout/soil friction
(at interface between grout body and soil)

- DIN EN 14199
- EC7



Micropiles transfer their loads to the loadbearing soil strata by the means of skin friction. End bearing is neglected. The pile resistance in the ground (grout/soil friction) is primarily dependent on the surface area $A_{s,i}$ of the grout body and the characteristic skin friction $q_{s,i,k}$ of the insitu soil.

The bonded length l_b of the pile required to transfer the loads into the soil is calculated from the diameter of the grout body and the skin friction value $q_{s,i,k,}$ which is reduced by the appropriate partial safety factor for the pile resistance according to Tab. A 2.3 of DIN 1054:2010-12.

Unless the true project-specific skin friction values have been determined by way of load tests on preliminary test piles, the skin friction values used in the calculations should be those given in Tabs. 5.31 and 5.32 of "EA-Pfähle" for tubular grouted piles (recommendations of the "micropiles" working group of the German geotechnical association) for tensile and compressive loads according to DIN 1054:2010-12.

It is important to select the correct drill bit first (see "Technical data" brochure) when determining the grout body diameter D required.
The choice of drill bit depends on:

- the drilling relevant prevailing soil type
- the minimum cement grout cover to the hollow steel tendon stipulated in the standard/approval

Depending on the subsoil and the method of installation, the grout body diameter D will be larger than the drill bit diameter by an amount equal to the widening value a:

$$D = d + a$$

Widening of drilled hole a:
- to DIN SPEC 18539: $a_{min} \geq 20$ mm (for installation with external jetting)
- tubular grouted piles (EA-Pfähle) a = 20 mm
- Average empirical value supplied by Ischebeck for preliminary design purposes:
  Sandy soils: a ≈ 50 mm
  Gravelly soils: a ≈ 75 mm
  (values measured on excavated grout bodies)

Verification: $E_d \leq R_d$
with load test

$$\text{Compression: } R_{c,d} = \frac{R_{c,k}}{\gamma_s \cdot \xi_1} = \frac{\pi \cdot D \cdot l_b \cdot q_{s,k}}{\gamma_s \cdot \xi_1} \text{ [kN]}$$

$$\text{Tension: } R_{t,d} = \frac{R_{t,k}}{\gamma_{s,t} \cdot \xi_1 \cdot \eta_M} = \frac{\pi \cdot D \cdot l_b \cdot q_{s,k}}{\gamma_{s,t} \cdot \xi_1 \cdot \eta_M} \text{ [kN]}$$

where:

- Correlation factor ξ_1
  (depends on number n of loading tests planned/ performed according to DIN 1054:2010-12, Tab. A 7.1)

n	1	2	3	4	5
ξ_1	1.35	1.25	1.15	1.05	1.00

- Model factor η_M
  (for tension loads, irrespective of rake of pile according to amendment DIN 1054/A1:2012-08)
  $\eta_M = 1.25$

without load test (with empirical values of skin friction)

$$\text{Compression: } R_{c,d} = \frac{R_{c,k}}{\gamma_s} = \frac{\pi \cdot D \cdot l_b \cdot q_{s,k}}{\gamma_s} \text{ [kN]}$$

$$\text{Tension: } R_{t,d} = \frac{R_{t,k}}{\gamma_{s,t} \cdot \eta_M} = \frac{\pi \cdot D \cdot l_b \cdot q_{s,k}}{\gamma_{s,t} \cdot \eta_M} \text{ [kN]}$$

Ranges of empirical skin friction values for pressure-grouted micropiles (System GEWI) and tubular grouted piles (System ISCHEBECK TITAN) in non-cohesiv and cohesive soils are specified in “EA-Pfähle” (recommendations of the "micropiles" working group of the German geotechnical association).

The data is provided from load tests.
The lower value is the 10 % fractile value, the upper value is the 50 %-fractile value of the statistic analysis.

Partial safety factors γ_R for resistances
(extract from DIN 1054:2010-12, Tab. A 2.3)

Resistance	Symbol	Design situation		
		BS-P	BS-T	BS-A
Pile resistances obtained from static and dynamic pile loading tests				
Base resistance	γ_b	1.10	1.10	1.10
Shaft resistance (compression)	γ_s	1.10	1.10	1.10
Total/combined resistance (compression)	γ_t	1.10	1.10	1.10
Shaft resistance (tension)	$\gamma_{s,t}$	1.15	1.15	1.15
Pile resistances based on empirical values				
Compression piles	$\gamma_b, \gamma_s, \gamma_t$	1.40	1.40	1.40
Tension piles (in exceptional circumstances only)	$\gamma_{s,t}$	1.50	1.50	1.50

Empirical data range for the characteristic skin friction $q_{s,k}$ for tubular grouted piles
EA-Pfähle Tab. 5.31 in non-cohesive soils

Average end bearing q_c in C.P.T. in MN/m²	Ultimate skin friction $q_{s,k}$ in kN/m² * 10 %		50 %
7.5	170	-	210
15	255	-	320
≥ 25	305	-	365

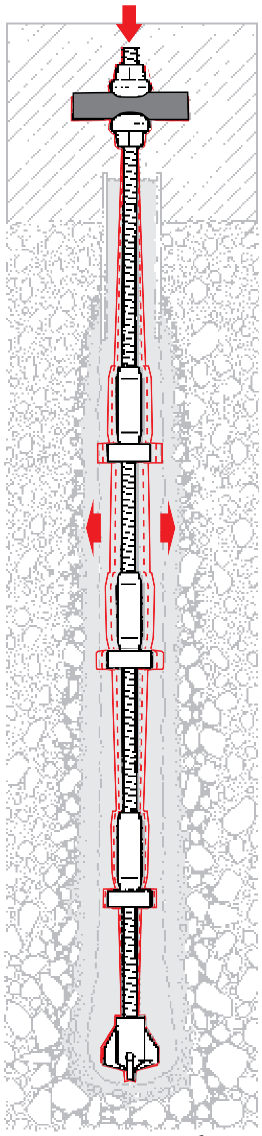
EA-Pfähle Tab. 5.32 in cohesive soils

Shear strength $c_{u,k}$ of undrained soil in kN/m²	Ultimate skin friction $q_{s,k}$ in kN/m² *		
60	70	-	80
150	115	-	125
≥ 250	140	-	150

* Intermediate values may be obtained by linear interpolation.

6.1.3 Verification of buckling (compression piles)

Relevant standards
- EC7
- DIN EN 14199
- Recommendations on Piling (EA-Pfähle)
- EC3



On request we can support you to check buckling according to OFNER/WIMMER for your project.

Generally, the supporting effect of the soil surrounding the shaft of the pile stops compression piles from buckling. However, DIN EN 1997-1 calls for a buckling analysis for slender piles embedded partly in water or thicker strata of very soft cohesive soils with an undrained shear strength $C_{u,k}$ < 10 kN/m².
Studies by, for example, VOGT/VOGT/KELLNER* and OFNER/WIMMER** have shown that under unfavourable boundary conditions, a buckling failure can occur in soil strata offering low lateral support even with $C_{u,k}$ > 10 kN/m².
For micropiles, DIN 1054 refers to Recommendations on Piling, and according to that publication a buckling analysis is not required for non-cohesive or at least firm cohesive soils.
The undrained shear strength can be determined by uniaxial compression tests, UU triaxial compression tests or vane shear tests. Unfortunately, such tests are not included in standard soil investigations, which means that the undrained shear strength is normally obtained from tables or must be correlated with penetration resistances.
Further information on the buckling of micropiles can be found in Recommendations on Piling.

Relationship between consistency, undrained shear strength $C_{u,k}$ and number of blows of various penetrometer tests

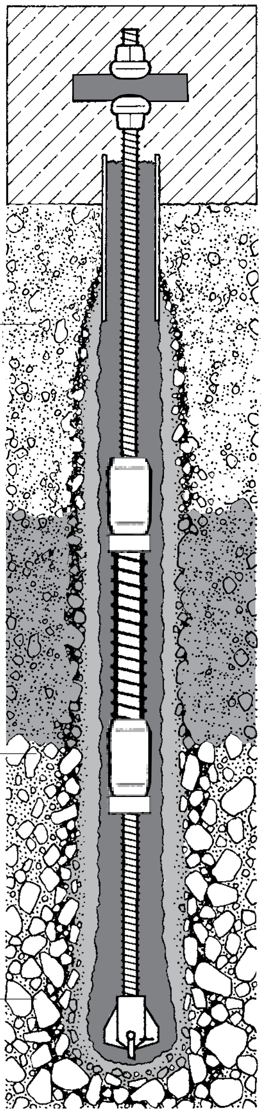
Consis-tency	Undrained shear strength $C_{u,k}$ (kN/m²)	Toe resistance q_s (MN/m²)	No. of blows			
			DPH N_{10}	DPM N_{10}	DPL N_{10}	SPT N_{30}
very soft	< 20	< 2,0	0 - 2	0 - 3	0 - 3	< 2
soft	20 - 60	2,0 - 5,0	2 - 5	3 - 8	3 - 10	2 - 6
firm	60 - 200	5,0 - 8,0	5 - 9	8 - 14	10 - 17	6 - 15
stiff	> 200	8,0 - 15,0	9 - 17	14 - 18	17 - 37	15 - 30
very stiff	> 400	> 15,0	> 17	> 28	> 37	> 30

Table E06.10, Geotechnical Centre; Chair of Foundations, Soil Mechanics, Rock Mechanics & Tunnelling (TU Munich)

*Buckling of slender piles in soft soils, Bautechnik 82 (2005)

**Buckling resistance of micropiles in varying soil layers, Bautechnik 84 (2007)

Note:
When making a decision as to whether to check buckling and which method to use, it should be remembered that no significant cases of damage are known involving stability failures due to undrained shear strengths $C_{u,k}$ > 10 kN/m². The above studies were based on model tests and the methods of analysis derived from those are not generally acknowledged methods.



Combination pile - the solution for subsoils with a risk of buckling

Combination of different sizes

The TITAN system includes the option of creating a combination pile. What this means is that in subsoils with a risk of buckling, the hollow steel tendon can be overdesigned. Strengthening the hollow steel tendon in this area increases the bending strength of the pile without the need for additional, expensive constructional measures, e.g. installing a steel casing. The design of the hollow steel tendon is carried out using the design load of the compression pile and the in situ $c_{u,k}$ value according to the buckling analyses of Ofner/Wimmer or Vogt/Vogt, Kellner or EC3.

The drawing shows a TITAN 73/53 compression pile (max. E_d = 783 kN) that is in the form of a TITAN 103/78 in the area of the soft clay strata with $c_{u,k}$ = 20 kN/m². The TITAN 103/78 is designed according to the buckling analysis of Ofner/Wimmer.

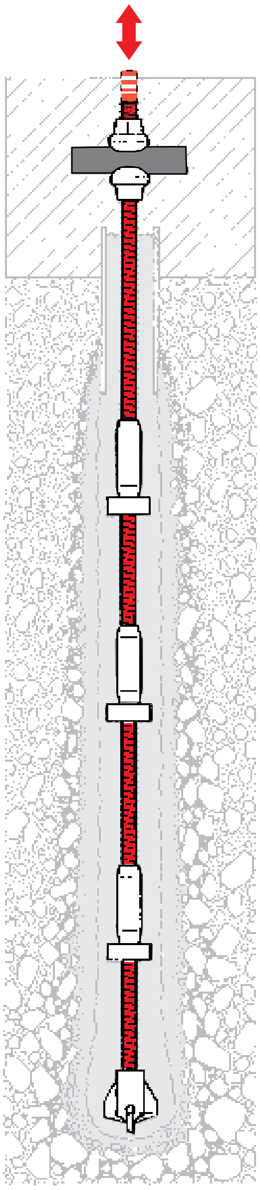
Designation	Unit	TITAN 30/16	TITAN 30/11	TITAN 40/20	TITAN 40/16	TITAN 52/26	TITAN 73/56	TITAN 73/53	TITAN 73/45	TITAN 73/35	TITAN 103/78	TITAN 103/51	TITAN 103/43	TITAN 127/103
Bending stiffness E · I*	10^6 kNmm²	3,7	4,6	15	17	42	125	143	178	195	564	794	838	1163

*These values were determined in tests. It is not possible to calculate the modulus of elasticity, cross-sectional area or moment of inertia from these figures. The values from the German approval are to be used in the case of deformation calculations. For buckling calculations the real bending stiffness should be used.

6.1.4 Verification of serviceability

Estimating the total deformation

Relevant standards
- DIN 18800
- EC7



Deformation calculations are complex and are carried out with the help of elaborate computational methods (e.g. DC-Software) or pile test loads. Extensive soil surveys, which could be used as a basis, are often unavailable.
According to DIN 4128, chapter 9.1:
For individual piles of a total length up to 10 m and without freestanding parts, axial displacements of the pile head of up to 10 mm must be expected under the permissible loading.
Load-deformation diagrams (based on extensive loading tests) make it easier to estimate quickly the displacement at the head of the pile. A simplified design approach enables the remaining displacement of the head of the pile to be estimated.

- The strain stiffnesses of the steel tendon and the grout body are used to determine the remaining deformation because the TITAN micropile is a composite component of steel and cement.
- Strain stiffness of steel tendon (see technical data)
- Strain stiffness of grout body can be calculated according to DIN EN 1992-1 Tab. 3.1, $f_{ck,cyl} = 35$ N/mm² with a modulus of elasticity E_{cm} = 34000 N/mm².

This results in a simplified way of obtaining a total strain stiffness for the micropile, which is:

$$(EA)_{sum} = (EA)_{steel} + (EA)_{cement}$$

and a deformation/displacement at the head of the pile:

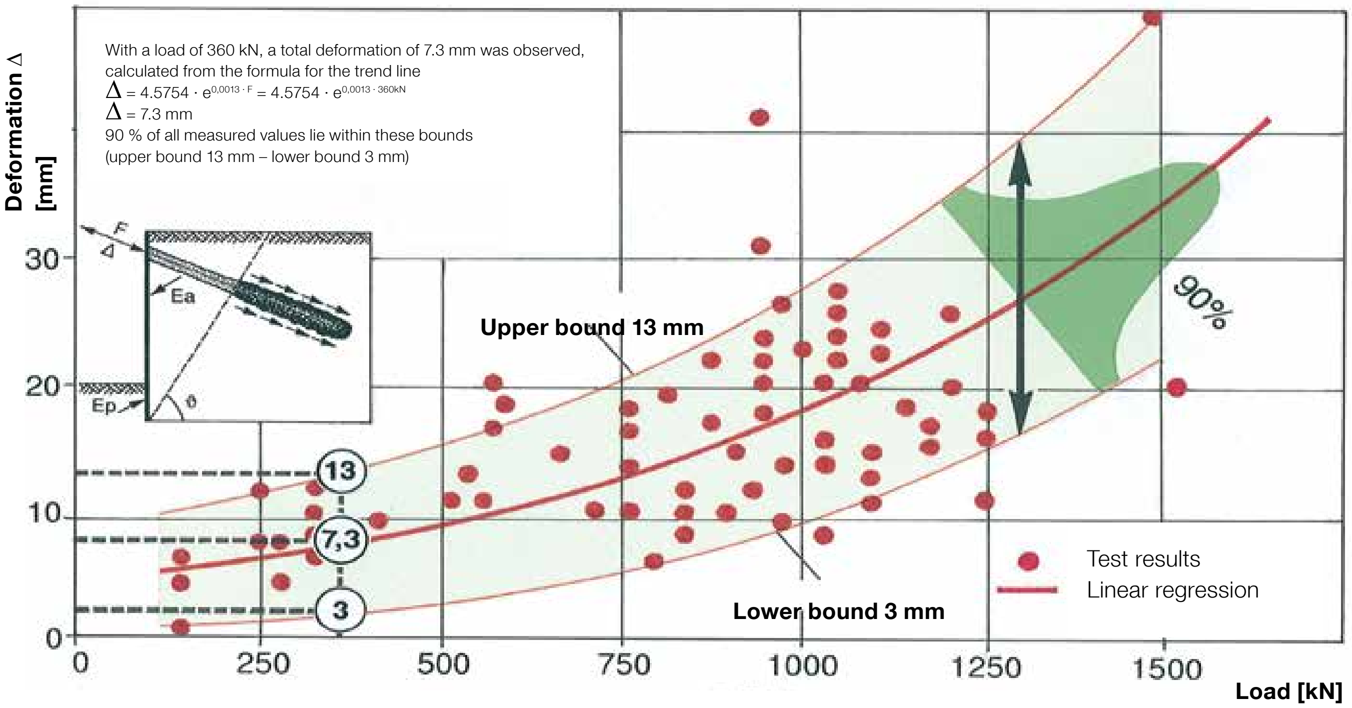
$$\varepsilon_{l,sum} = \frac{E_k}{(EA)_{sum}}$$

Designation	Unit	TITAN 30/16	TITAN 30/11	TITAN 40/20	TITAN 40/16	TITAN 52/26	TITAN 73/56	TITAN 73/53	TITAN 73/45	TITAN 73/35	TITAN 103/78	TITAN 103/51	TITAN 103/43	TITAN 127/103
Outside diameter D_a *	mm	29	29	40,5	40,5	50,3	72,4	72,4	72,4	72,4	101	101	101	126,8
Effective cross-sectional area A_{eff}	mm	340	415	730	900	1250	1360	1615	2239	2714	3140	5680	6023	3475
Strain stiffness E · A*	10³ kN	63	83	135	167	231	251	299	414	502	580	1022	1202	640

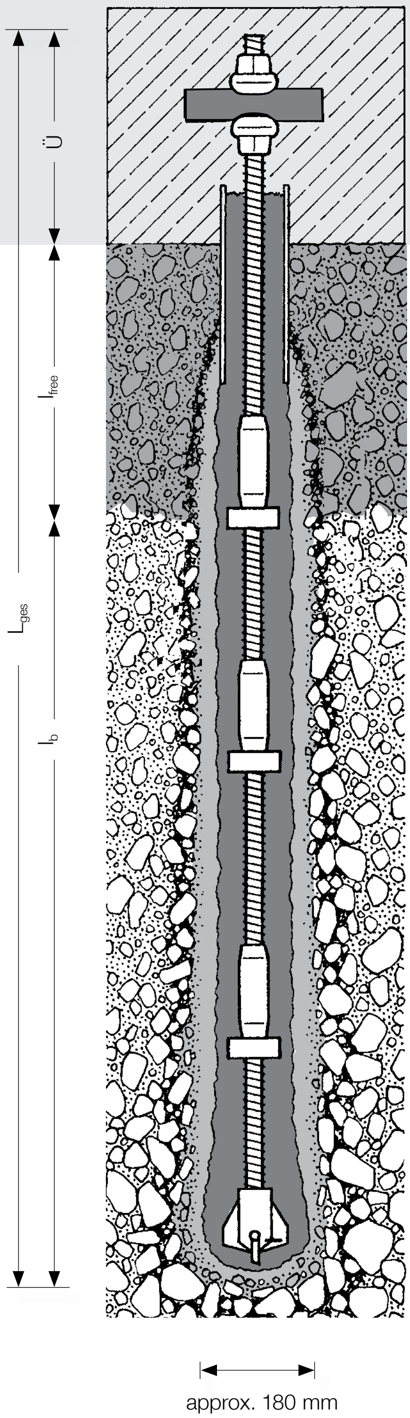
*See annex 2 of the approval

**These values were determined in tests. It is not possible to calculate the modulus of elasticity, cross-sectional area or moment of inertia from these figures.

Load–deformation diagram
Statistical evaluation of 136 tensile tests carried out for suitability and acceptance purposes. The displacement at the head of the pile was measured (total deformation, measured at head of pile). Bonded length in sandy and gravelly soils, loadbearing subsoil at different depths. Deformation Δ depending on load.



Diploma thesis by A. Scholl: “Entwicklung eines Modells zur Verformungsberechnung von Verpresspfählen (schlaffen Ankern) TITAN nach DIN EN 14199, auf der Grundlage von durchgeführten Eignungs- und Abnahmeversuchen” (development of a model for calculating deformations of TITAN injection piles – non-prestressed anchors – to DIN EN 14199 based on tests carried out for suitability and acceptance purposes), 2008, Siegen University, Prof. Dr.-Ing. R. Herrmann



6.2.1 Example of pile foundation: compression pile

Design load (compression):	E_d = 712 kN
Selected:	TITAN 73/53 hollow steel tendon

Verification of load-carrying capacity:
$E_d \leq R_d$
$R_d = R_k / \gamma_M$
R_d = 900 kN / 1.15 = <u>783</u> kN (where γ_M =1.15)
-> Satisfactory

Verification of grout/soil friction:
Calculation of bonded length l_b required using:

Shaft resistance (compression): (to DIN 1054:2010-12 Tab. A.2.3)	γ_s	=	1.10
Given: Loading tests carried out on two piles:	ξ_1	=	1.25
Subsoil: down to 5 m: fill (inadequate loadbearing capacity)	l_0	=	5 m
below 5 m depth: gravel/sand (end-bearing pressure)	q_c	=	15 MN/m²
Drill bit: Cross-cut drill bit	d	=	175 mm
Widening value: DIN SPEC 18539:	a	=	20 mm
Projection	Ü	=	0.50 m
Skin friction: “EA-Pfähle” (Tab. 5.31, tubular grouted pile)	$q_{s1,k}$	=	255 kN/m²

Must be confirmed by loading tests:
selected: 2 (correlation factor ξ_1, see p. 23)

P_P = 712 kN · 1.10 · 1.25 = <u>979</u> kN*

*(Larger steel cross-sections may need to be selected for loading tests.)

Bonded length l_b

$$l_b = \frac{E_d}{\pi \cdot (d + a) \cdot \frac{q_{s1,k}}{\gamma_s \cdot \xi_1}} = \frac{712\ \text{kN}}{\pi \cdot (0.175\ \text{m} + 0.02\ \text{m}) \cdot \frac{255\ \text{kN/m}^2}{1.10 \cdot 1.25}} = \underline{6.27}\ \text{m}$$

Total length of pile L_{sum}

$L_{sum} = l_b + Ü + l_{free}$

L_{sum} = 6.27 m + 0.50 m + 5.0 m = <u>11.77</u> m

Selected: L_{sum} = 12.00 m

6.2.2 Example of pile foundation (estimate of pile head displacement)

Steel/grout body displacement only

Pile length: L_{sum} = 12.00 m
Action: E_k = 500 kN

TITAN 73/53 (S)
Nominal outside diameter: D_{steel} = 73 mm
Effective cross-section: A_{eff} = 1615 mm²
Strain stiffness: $(EA)_{steel}$ = 299000 kN

Grout body (Z)
Pile diameter: D = 180 mm

Cross-section, grout body

$$A_{cement} = (\pi \cdot (D^2 - D_{steel}^2)) / 4$$

$$A_{cement} = (\pi \cdot (180^2\ mm^2 - 73^2\ mm^2)) / 4 = \underline{21262}\ mm^2$$

(The cement within the hollow steel tendon is neglected.)

Modulus of elasticity, grout body

$$E_{cement} = 34000\ N/mm^2 = \underline{34}\ kN/mm^2$$

Strain stiffness, grout body

$$(EA)_{cement} = E_{cement} \cdot A_{cement}$$

$$(EA)_{cement} = 34\ kN/mm^2 \cdot 21262\ mm^2 = \underline{722908}\ kN$$

Total strain stiffness

$$(EA)_{sum} = (EA)_{steel} + (EA)_{cement}$$

$$(EA)_{sum} = 722908\ kN + 299000\ kN = \underline{1021908}\ kN$$

Calculation of deformation/displacement at head of pile

$$\varepsilon_{l,sum} = \frac{E_k}{(EA)_{sum}}$$

$$\varepsilon_{l,sum} = \frac{500\ kN}{1021908\ kN} = \underline{0.05}\ \%$$

$$f = \varepsilon_{l,sum} \cdot L_{sum}$$

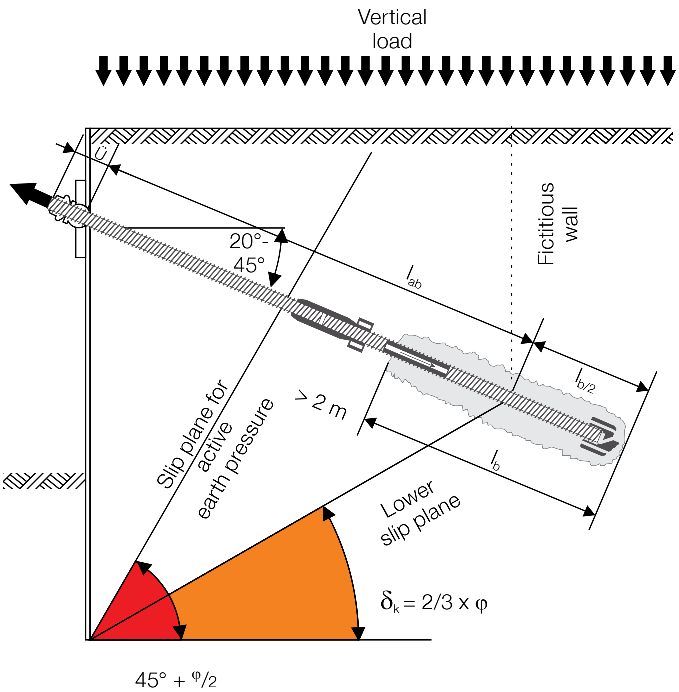
$$f = 0.05\% \cdot 12.00\ m = \underline{6}\ mm$$

Foundation to noise barrier adjacent to Karlsruhe–Freiburg railway line, south-west Germany

Erection of noise barrier directly adjacent to railway tracks, on separate pad foundations with TITAN 40/16

6.2.3 Example of tie back: tension pile
Verification according to “EAU” based on the design model of Kranz, 1940

Design load (tension) $E_d = 400$ kN
Selected: TITAN 40/16 hollow steel tendon



Verification of load-carrying capacity:
$E_d \leq R_d$
$R_d = R_k / \gamma_M$
$R_d = 490$ kN / 1,15 = $\underline{426}$ kN (where γ_M =1,15)
-> Satisfactory

Verification of grout/soil friction:
Calculation of bonded length l_b required using:

Shaft resistance (tension): $\gamma_s = 1.15$
(to DIN 1054:2010-12 Tab. A.2.3)

Model factor $\eta_M = 1.25$

Given:
Load tests carried out
on three piles: $\xi_1 = 1.15$

Subsoil: cohesive soil
(undrained shear strength) $c_{u,k} = 250$ kN/m²

Drill bit: clay bit d = 150 mm

Widening value: DIN SPEC 18539: a = 20 mm

Skin friction: $q_{s1,k} = 140$ kN/m²
(assumption from “EA-Pfähle”: Tab. 5.32
for tubular grouted piles)

Must be confirmed by load tests:
selected: 3 (correlation factor ξ_1, see p. 23)

$$P_P = 400 \text{ kN} \cdot 1.15 \cdot 1.25 \cdot 1.15 = \underline{661} \text{ kN*}$$

* (Larger steel cross-sections may need to be selected for load tests.)

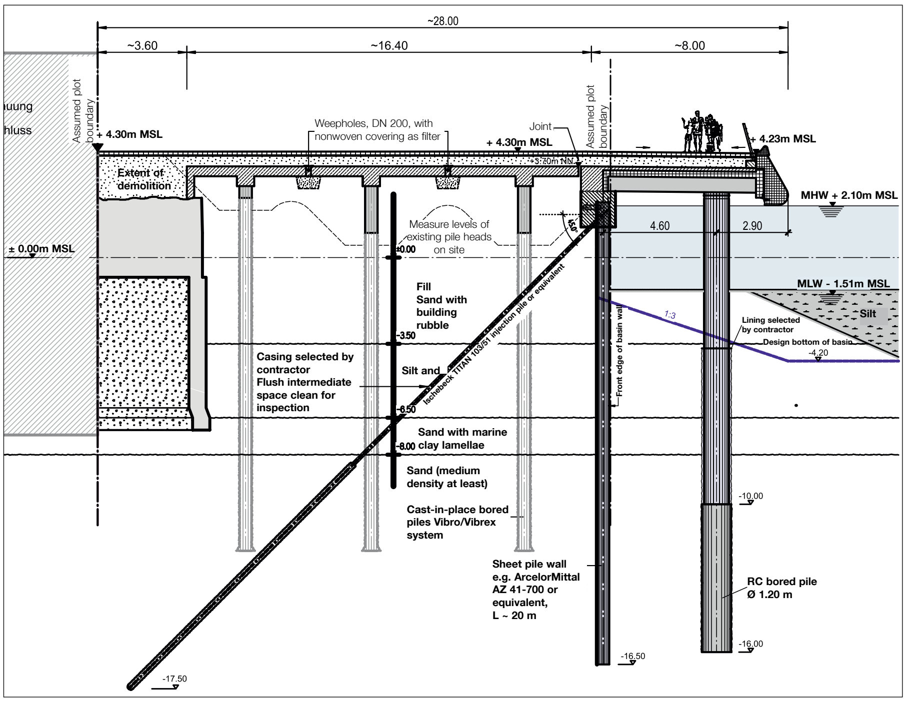
Bonded length l_b

$$l_b = \frac{E_d}{\pi \cdot (d + a) \cdot \frac{q_{s1,k}}{\gamma_s \cdot \xi_1 \cdot \eta_M}} = \frac{400 \text{ kN}}{\pi \cdot (0.15 \text{ m} + 0.02 \text{ m}) \cdot \frac{140 \text{ kN/m}^2}{1.15 \cdot 1.25 \cdot 1.15}} = \underline{8.85} \text{ m}$$

Total length of pile L_{sum}
Wall-lower slip plane distance: $l_{ab} = 8{,}10$ m

$$L_{sum} = \frac{l_b}{2} + l_{ab} + \ddot{U} = \frac{8.85}{2} + 8.10 \text{ m} + 0.30 \text{ m} = \underline{12.83} \text{ m (selected 13 m)}$$

Installing anchors at “Elbtor” Pier, Magdeburger inland port, Hamburg



6. Design guidance

6.3 Verification of durability

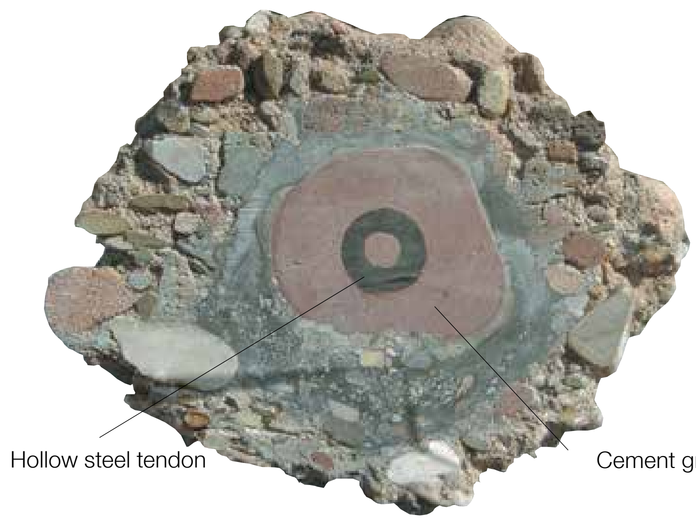
Relevant standards:
- According to approval
- DIN EN 14490 – "Soil nailing", appendix B 3.4.5.1
- DIN 4128
- DIN 1045:1978, section 17.6.2
- DIN 50976
- EN 1537 appendix A

Permanent corrosion protection for TITAN micropiles is guaranteed by:

Cement grout cover
Permanent corrosion protection for TITAN micropiles is achieved with a covering of cement grout. Research findings have shown that the grout body ensures corrosion protection for permanent works, provided the cracks under loading are < 0.1 mm wide (see also DIN EN 14490 "Soil nailing", appendix B 3.4.5.1). The 1983 edition of DIN 4128 also refers to limiting crack widths: "...DIN 1045:1978 section 17.6.2 must be applied to verify that the expected crack width is limited to 'very small'" (section 9.2). It was this that led to the cement grout covers called for in the approval, which are in some cases somewhat larger than the minimum covers required by the relevant standards:
- min. 20 mm for compression piles (to EN 14199 / DIN SPEC 18539)
- min. 30 mm for tension piles (to EN 14199 / DIN SPEC 18539)

Such values can be regarded as standard corrosion protection. A thicker covering of cement grout increases the corrosion protection substantially.

Limiting the width of cracks in the grout body to < 0.1 mm was therefore also a stipulation of the DIBt for issuing the National Technical Approval for TITAN micropiles for temporary and permanent applications **without** additional measures to protect against corrosion. Proof of this has been provided by extensive bond tests with measurement of the crack widths.



The following additional measures can be taken in the case special requirements or more aggressive soils:

Hot-dip galvanising
According to DIN EN 14199 section 7.6 “Corrosion protection of steel elements” and the DIN SPEC 18539 supplements, protecting pressure-grouted micropiles against corrosion is dealt with in the approval. Galvanising is an additional precaution that can be provided to protect the hollow steel tendon against corrosion. The coating of zinc applied to the steel according to DIN EN ISO 1461 with stands severe corrosion and represents a durable, economic form of corrosion protection.

Annotations to corrosion likelihood in soil can be found in DIN EN 12501.

Duplex coating
Hot-dip galvanising to DIN EN ISO 1461 with an additional powder coating (duplex) complying with DIN 55633 (Apr 2009).
This comprises a powder coating for corrosivity category C5-M Medium to DIN EN ISO 12944 part 1 plus corrosion protection according to DIN EN ISO 12944 parts 2 and 5.

Advice for installation: If hollow steel tendons with a duplex coating are used, the clamping and braking device should be fitted with “soft” jaws so that the coating is not damaged.

Stainless steel
TITAN 30/11-INOX and TITAN 40/16-INOX are hollow steel tendons made from stainless steel in accordance with National Technical Approval Z-30.3-6. They comply with the highest class of resistance IV/severe (chlorides, sulphur dioxide, mine water). Even without a covering of cement grout, this grade of steel does not corrode. It is recommended where a consistent cover of cement grout cannot be guaranteed, e.g. when refurbishing old tunnels. A detailed corrosion report prepared by the Federal Institute for Materials Research & Testing (BAM) can be sent on request (ref. No. 1.3/12279).

6. Design guidance

6.4 Calculating the theoretical volume of cement required

The rough calculation of the volume of cement likely to be required assumes that the diameter of the drilled hole is equal to that of the drill bit used plus the widening of the hole (depending on the type of soil, see p. 40). This results in a theoretical cross-section for the grout body, which in turn gives us the theoretical volume of cement required per metre length of micropile. The theoretical volume of cement required is influenced by the water/cement ratio.

The quantities of cement given by the sample calculation or in the table are based on a purely theoretical volume for the drilled hole. More or less significant differences occur in practice, the causes of which can be:

- Infiltration into soil
- Suspension return flows
- Nature and duration of hole stabilisation during drilling
- Flushing/grouting pressure
- Joints in the soil/rock

Remuneration guidance:
DIN 18309:2012-09, German construction contract procedures (VOB) – Part C: General technical specifications in construction contracts (ATV) – Ground treatment by grouting, section 4, classifies quantities as follows:
Filling and grouting quantities up to 1.7 times the theoretical volume of the drilled hole are “associated tasks”. Filling and grouting quantities in excess of that are “special tasks”.
According to the German additional technical contractual conditions (ZTV-W) for sheet pile walls, piles and anchorages, a figure of 1.7 times the calculated theoretical volume of the drilled hole should be used in quotations for work: “Larger quantities of grout will only be remunerated after prior agreement with the client”.

For special applications it can be reasonable to use the following additives:
The use of a ready mixed expanding cement, e.g. CEMEX 15 based on ettringite, is recommended for cohesive soils, e.g. loess, clayey-silty mixed soils. The boundary layer consolidates faster under the expansive pressure.
The use of a ready mixed thixotropic anchor mortar, e.g. WILMIX LAWINA 98, with FLOWCABLE additive, etc. is recommended for drilling overhead.

Sample calculation for volume of drilled hole

TITAN 73/35
Clay drill bit — d = 200 mm
Cohesive soil — a = 20 mm (hole widening)
Diameter of drilled hole — D = 20 cm + 2 cm = 22 cm

Theoretical cross-section of grout body:
$A = \pi \cdot (D/2)^2 = \pi \cdot (11\ \text{cm})^2 = \underline{380}\ \text{cm}^2$

Volume of drilled hole per 1 m length of micropile:
$V = A \cdot 1\ \text{m} = 380\ \text{cm}^2 \cdot 100\ \text{cm} = 38.000\ \text{cm}^3 = 38$ litre

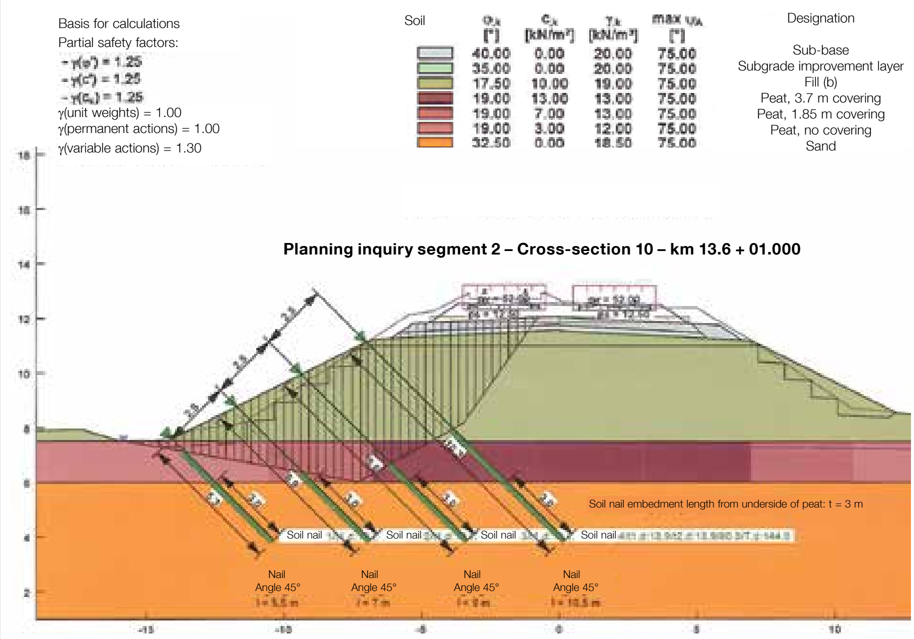
Example for the evaluation of the required quantity of cement
The table below shows how many kg per lin. m of grout body for a certain volume of drilled hole are theoretically needed.
According to the German approval cement to DIN EN 197 and DIN SPEC 18539 have to be used.

required quantity of cement	$Z = \dfrac{V \times \gamma_{Sus}}{1 + W/C}$	[kg]
specific weight of suspension	$\gamma_{Sus} = g_{Sus}/V = \dfrac{W/C + 1}{W/C + 1/3}$	[kg/ltr]
Weight of suspension	$g_{Sus} = W + C$	[kg]
Volume of drilled hole	$V = W + V_C$	[ltr]
Volume of cement	$V_C = C/g_{spec}$	[ltr]
specific weigt of cement	$g_{spec} = 3{,}0$	[kg/ltr]

Volume of drilled hole and quantity of cement depending on w/c ratio

Pile Ø D	Volume of drilled hole V	w/c ratio [-] 0,4	0,5	0,6	0,7	0,8	0,9	1,0
		specific weight of cement suspension γ_{Sus} [kg/ltr] 1,91	1,80	1,71	1,65	1,59	1,54	1,50
[mm]	[l/m]	required quantity of cement C [kg] per lin. m of grout body						
60	2,8	3,9	3,4	3,0	2,7	2,5	2,3	2,1
90	6,4	8,7	7,6	6,8	6,2	5,6	5,2	4,8
120	11,3	15,4	13,6	12,1	10,9	10,0	9,2	8,5
150	17,7	24,1	21,2	18,9	17,1	15,6	14,3	13,3
180	25,4	34,7	30,5	27,3	24,6	22,5	20,6	19,1
200	31,4	42,8	37,7	33,7	30,4	27,7	25,5	23,6
220	38,0	51,8	45,6	40,7	36,8	33,5	30,8	28,5
250	49,1	66,9	58,9	52,6	47,5	43,3	39,8	36,8
300	70,7	96,4	84,8	75,7	68,4	62,4	57,3	53,0

Soil nailing to an embankment for the railway line extension to JadeWeserPort, Wilhelmshaven



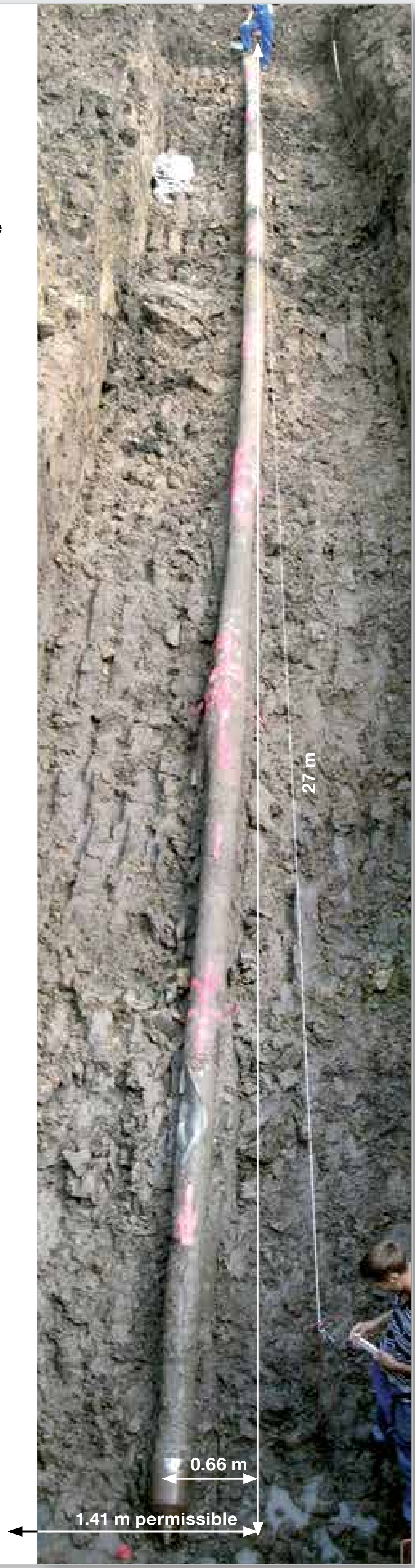
7. Appendix

7.1 Proofs and basic tests

Extensive basic tests have been carried out since the system was first developed. The values obtained from the tests are given on the following pages as verification.

7.1.1 Directional stability

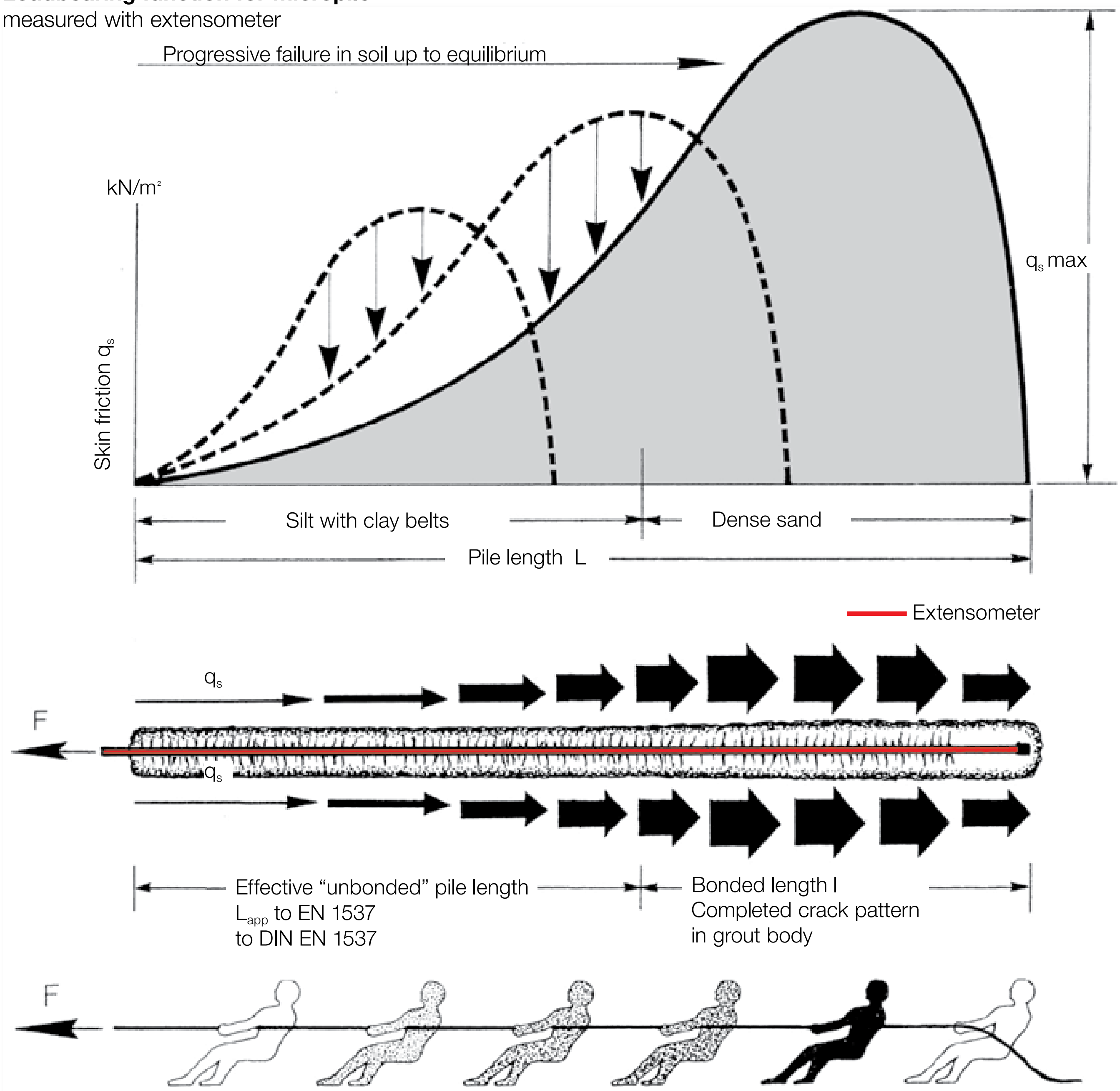
TITAN 103/78 micropile
Installation at an angle of 20° to the horizontal.
Deviation from intended direction: 66 cm for a pile length of 27 m = 2.4% (1.4°).
According to DIN SPEC 18539:2012-02, an installation tolerance of ±7.5 cm at the point of application of the drill and a deviation of 3° in the angle is permissible (which would correspond to 1.41 m here).



7.1.2 Loadbearing function

The elongation of the steel over the total grouted length has been measured in tests. To do this, an extensometer was embedded within the hollow steel tendon.
The test results prove that subsoil with little or no loadbearing capacity is relieved and therefore an effective "unbonded" pile length is formed. This length, like the unbonded steel length of injection piles to DIN EN 1537, can be measured and checked in a similar way by means of test loads.

Loadbearing function for micropile
measured with extensometer



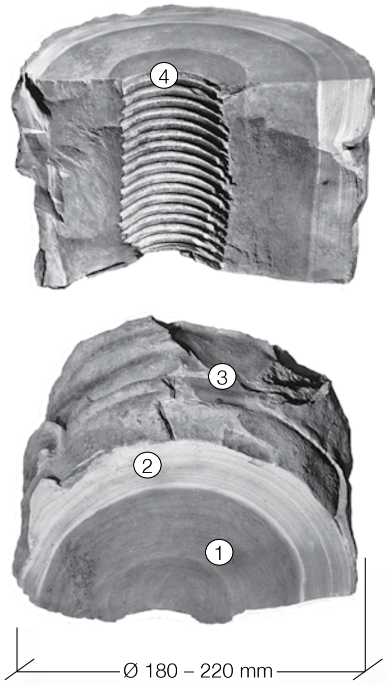
7. Appendix

7.1 Proofs and basic tests

7.1.3 Diameter of grout body

The grout bodies around TITAN micropiles excavated for inspection purposes show quite clearly the good mechanical interlock with the soil, the enlarged diameter compared with that of the drill bit and the consistent covering of cement grout.

Diameter of grout body using the example of the Ericusspitze project, Hamburg: the head of the TITAN 103/78 micropile was exposed to reveal the widening of the drilled hole in the sandy subsoil when using a Ø175 mm cross-cut drill bit.

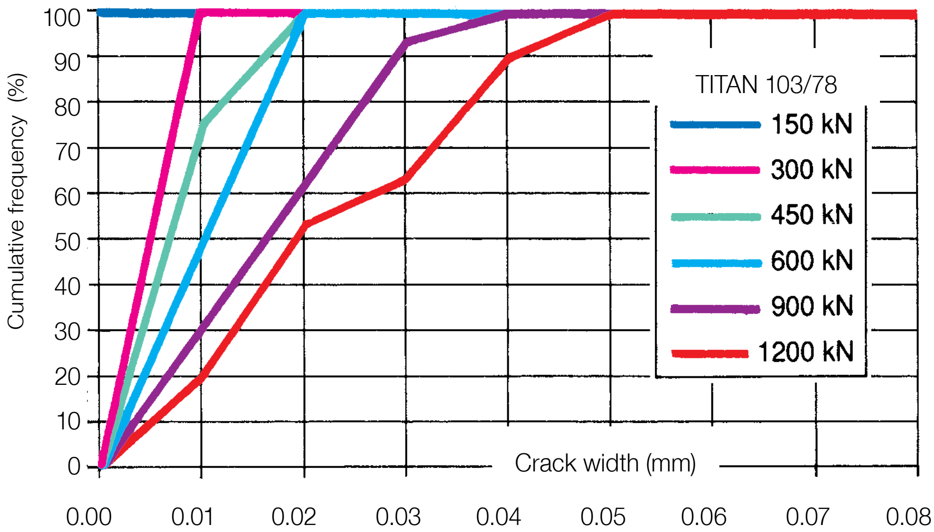


Excavated grout body for TITAN 103/78 pressure-grouted anchor (very fine, loose sand, 40 m below water level, q_c = 15 MN/m²)

1. Portland cement, compressive strength $f_{c,k} \geq 35$ N/mm²
2. Filter cake of filtered-off cement, supporting ring, lighter and darker rings indicate different w/c ratios
3. Mechanical interlock with the soil to create a shear bond
4. Central position of hollow steel tendon, consistent cement grout cover

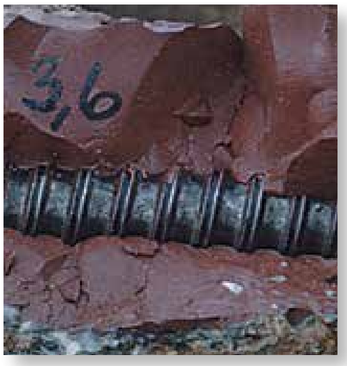
7.1.4 How crack widths affect bond behaviour

Bond tests with measurement of crack widths on excavated TITAN anchor piles/micropiles, Munich TU, Prof. Dr.-Ing. Zilch, Prof. Dr.-Ing. Schießl

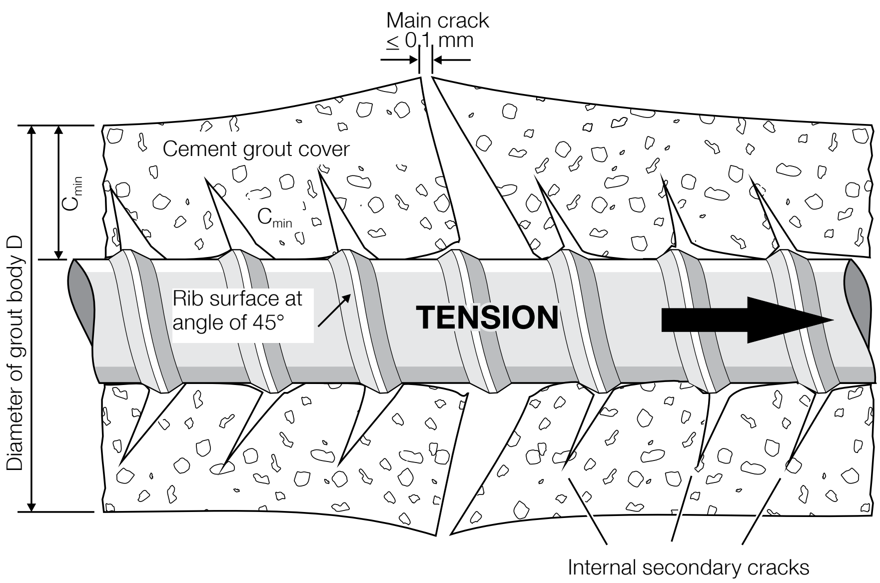


To achieve permanent corrosion protection, it is necessary to limit the crack widths in the grout body to < 0.1 mm (see "Verification of durability", p. 32). Proof of this has been furnished by way of extensive bond tests on TITAN micropiles excavated for inspection purposes, with measurement of crack widths, and by comparative calculations.

The different strains in the steel tendon and the cement are compensated by microcracks starting at every rib. Radial microcracks < 0.1 mm wide are regarded as insignificant in terms of corrosion and bond. The cracked grout body gives rise to a tension-stiffening effect.



Grout body around TITAN 30/11 micropile broken away to show completed crack pattern.

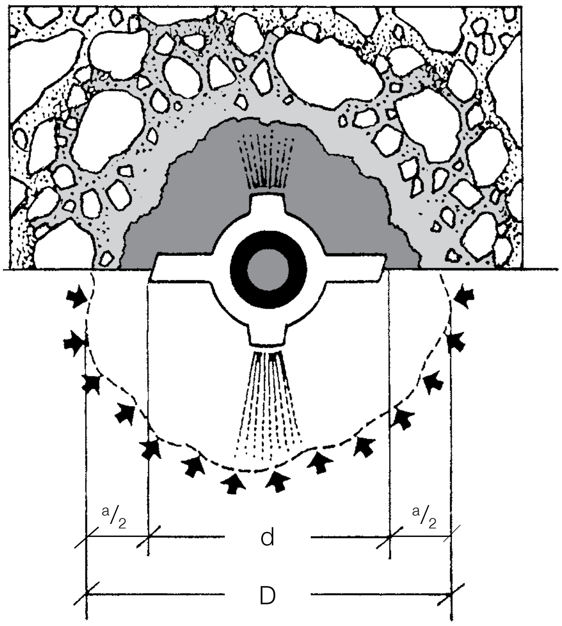


7.1.5 The widening of the drilled hole

The drilling process with radial jets of fluid creates a hole with a larger diameter for the grout body. Based on several test series and the excavation of many TITAN micropiles for inspection purposes, it is possible to assume the following empirical values for the widening of the drilled hole (in cohesive soils):

$D = d + a$

Widening of drilled hole a:
- to DIN SPEC 18539: a_{min} = 20 mm (for installation with external jetting)
- tubular grouted piles to "EA-Pfähle": a = 20 mm
- average empirical values supplied by Ischebeck for preliminary design purposes (values measured on excavated grout bodies):
  Sandy soils: a ≈ 50 mm
  Gravelly soils: a ≈ 75 mm



Verification of widening of drilled hole for the grout body in cohesive soils
Site: Casaramona in Barcelona, Spain, approx. 200 TITAN micropiles excavated

	Measured circumference	**Radius of grout body**	**Effective diameter**	**Widening of drilled hole**	**Cement grout cover**
	u	$r = \frac{u}{2 \cdot \pi}$	$d_{eff} = 2 \times r$	**$b = d_{eff} - d_B$ > 25 mm**	$c = \frac{2 \cdot r - d_v}{2}$
	[mm]	[mm]	[mm]	**[mm]**	[mm]
TITAN 73/53 micropile, d_v = 73 mm, 73 mm, cross-cut drill bit, d_B = Ø 130 mm					
Section 1	550.0	87.54	175.07	**45.07**	51.04
Section 2	550.0	87.54	175.07	**45.07**	51.04
Section 3	546.0	86.90	173.80	**43.80**	50.40
Average value	**548.7**	**87.32**	**174.65**	**44.6**	**50.82**
TITAN 40/16 micropile d_v = 40 mm, clay drill bit, d_B = 110 Ø mm					
Section 4	466.0	74.17	148.33	**38.3**	54.17
Section 5	471.0	74.96	149.92	**39.9**	54.96
Section 6	472.0	75.12	150.24	**40.2**	55.12
Section 7	464.0	73.85	147.70	**37.7**	53.85
Average value	**468.3**	**74.52**	**149.05**	**38.85**	**54.52**

Perimeter beam for Pacific Coast Highway #1, Panamericana, “Devil’s Slide”

Additional anchors for a sheet pile wall, HPA, Port of Hamburg

Drilling underwater

Foundation for a bridge arch using TITAN 40/16 anchor piles
New motorway, Zwardon, Polen

Remainder of embankment stabilised with soil nailing

7. Appendix

7.2 Overview of standards

Relevant standards

Verification	Standard
Load-carrying capacity	National Technical Approval Z 34.14-209
Micropiles / injection piles	DIN EN 14199 DIN SPEC 18539
Soil nailing	DIN EN 14490
Geotechnical verification	EC7, comprising: - DIN EN 1997-1:2009-09 - DIN EN 1997-1 / NA:2010-12 - DIN 1054-2010:12 - DIN 4084 “EA-Pfähle”
Reinforcement (S 460 NH material)	DIN 14199 DIN EN 10210 DIN 488 EC 2
Corrosion protection (cement grout cover)	National Technical Approval Z-34.14-209 DIN EN 14199 DIN EN 14490
Load tests	EC7, comprising: - DIN EN 1997-1:2009-09 - DIN EN 1997-1 / NA:2010-12 - DIN 1054:2010:12 "EA-Pfähle" DIN EN 14199 / EC7 DIN EN 14490 (DIN EN ISO 22477-1) in the future

Technical data

Designation	Unit	TITAN 30/16	TITAN 30/11	TITAN 40/20	TITAN 40/16	TITAN 52/26	TITAN 73/56	TITAN 73/53	TITAN 73/45	TITAN 73/35	TITAN 103/78	TITAN 103/51	TITAN 103/43	TITAN 127/103
Nominal outside diameter D_{steel}	mm	30	30	40	40	52	73	73	73	73	103	103	103	127
Nominal inside diameter D_{steel}	mm	16	11	20	16	26	56	53	45	35	78	51	43	103
Effective cross-section A_{eff}	mm²	340	415	730	900	1250	1360	1615	2239	2714	3140	5680	6025	3475
Ultimate load F_u	kN	245	320	540	660	925	1035	1160	1575	1865	2270	3660	4155	2320[4)]
Characteristic load-carrying capacity R_k according to German approval document[1)]	kN	155[2)]	225[3)] (250)	372	490	650	695[2)]	900	1218	1386	1626	2500	3015[2)]	1800[2)]
$F_{0.2,k}$ force at 0.2 % proportionality limit (mean value)	kN	190	260	425	525	730	830	970	1270	1430	1800	2670	3398	2030
Strain stiffness E · A[5)]	10^3 kN	63	83	135	167	231	251	299	414	502	580	1022	1202	640
Bending stiffness E · I[5)]	10^6 kNmm²	3.7	4.6	15	17	42	125	143	178	195	564	794	838	1163
Weight	kg/m	2.7	3.29	5.8	7.17	9.87	10.75	13.75	17.8	21.0	25.3	44.6	47.3	28.9
Length	m	3	2/3/4	3/4	2/3/4	3	6.25	3	3	3	3	3	3	3
Left-/right-hand thread	-	left	left	left	left	left right	right	right	right	right	right	right	right	right

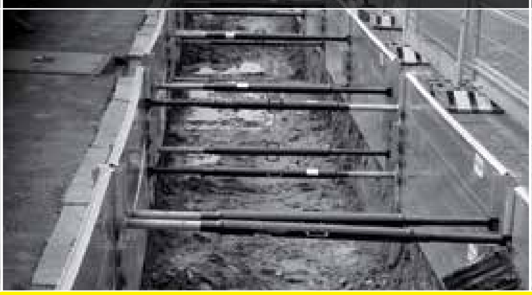
1) The load-carrying capacities must be reduced according to National Technical Approval Z-34.14-209 in the case of permanent tension loads and cement grout cover c < 45 mm.
2) An approval for these sizes is not yet available. The values were interpolated in a similar way to the approval for TITAN 30/16, 73/56, 103/43 and 127/103 micropiles.
3) A characteristic load carrying capacity R_k = 250 kN may be used for TITAN 30/11 in temporary installations.
4) Only applies to hollow steel tendon without coupling nut. The ultimate load is 2048 kN for coupled hollow steel tendons.
5) The values are to be used in the case of deformation calculations. These values were determined in tests. It is not possible to calculate the modulus of elasticity, cross-sectional area or moment of inertia from these figures.

Slope stabilisation alongside Nuremberg-Regensburg railway line

Some 8000 lin. m of hot-dip galvanised TITAN 30/11 were used on this project.

Falsework and Formwork systems

Trench lining systems



Geotechnical solutions

Certified Management-System to DIN EN ISO 9001 / 2008; Registry-No. DE-96-010 DVS ZERT

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