TITAN Injection Pile

An innovation prevails.
Design and construction
Foundations / underpinning
Resisting uplift with TITAN 40/20 injection piles
Arts Centre, Westerhaar, Netherlands

Anchorages
Excavation shoring anchored with TITAN injection piles
Dresden, Germany

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

12 m long soil nails installed from a floating pontoon, with drilling rig mounted on telescopic boom.
This brochure provides basic information about our TITAN injection piles and includes detailed explanations regarding applications. Injection piles are used for many applications in geotechnical engineering:
- As compression piles for foundations
- As tension piles for retaining structures anchored in the ground
- For stabilising slopes
- For cyclic and repeated loadings

The “Design advice” chapter with design examples also provides an overview of the standards to be complied with and the analyses required.

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 injection piles 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.
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).
In the TITAN injection pile, the loadbearing member is a ribbed hollow steel bar that serves as a sacrificial drilling rod, an injection tube and a reinforcing bar (the 3-in-1 principle). In contrast to the method known from DIN 4128, which specifies a casing to prevent the drilled hole from collapsing in, for instance, loose soil or boulders, in the ISCHEBECK system, the drilled hole is prevented from collapsing by a drilling fluid, which renders an additional casing unnecessary. That saves operations in the drilled hole, which in many cases leads to higher productivity during installation than for systems employing a separate casing.

Another advantage is that the drilling operation with the drilling fluid is followed immediately by the dynamic pressure grouting with a cement suspension.

In the absence of a casing, the grout body forms a mechanical interlock with the surrounding soil. This enhanced shear bond means that displacements of the head of the pile are generally only a few millimetres in the case of non-prestressed injection piles, i.e. in a similar order of magnitude to the displacements of prestressed anchors to DIN EN 1537. Therefore, taking into account their loadbearing behaviour, TITAN injection piles represent an equivalent but economic alternative to prestressed permanent anchors.

Depending on the type of application, injection piles are also known as micropiles, anchor piles or soil nails.

**Mechanical interlock between grout body and soil**
2. Range of applications

**Micropile**
- for foundations, underpinning

**Micropile**
- for anchorages

**Soil nail**
- 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

TITAN injection pile as 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

TITAN injection pile as soil nail to DIN EN 14490 for enhancing tensile and shear strength.

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

Further information about applications for TITAN injection piles can be found in the ISCHEBECK application brochures or in the Internet (go to www.ischebeck.com).
TITAN injection pile for tunnels.
- Portal stabilisation
- Soil nails around tunnel portal
- Pipe umbrellas
- Driving with spiles
- IQ Quickset Roofbolts, secured with special resin

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

Monojet
TITAN injection pile used according to the jet-grouting principle with up to 200 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 injection pile 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 made from fine-grained structural steel

Standards
The hollow steel tendon is a steel bar for reinforced concrete injection piles in the meaning of DIN EN 14199 section 6.2.1 and must comply with DIN EN 10080*. 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 $(f_{t,k})_k$, i.e. $R_y/R_t \geq 1.08$
- Elongation at maximum load $\varepsilon_{uk}$, i.e. $A_g \geq 5.0 \%$

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. 100 Joule/cm² (at -20 °C) and therefore much higher than the values of typical structural and prestressing steels, which are 27 and 15 Joule/cm² 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”)

3.1.1 The reinforcing bar function
Hollow steel tendon made from fine-grained structural steel

*Note: DIN EN 10080 has been withdrawn in Germany and replaced by DIN 488.
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

\[
\begin{align*}
A_{\text{solid}} & = 19.60 \, \text{cm}^2 \\
W_{\text{solid}} & = 12.3 \, \text{cm}^3 \\
I_{\text{solid}} & = 30.7 \, \text{cm}^4 \\
A_{\text{hollow}} & = A_{\text{eff}} = 16.15 \, \text{cm}^2 \text{ (see p. 43)} \\
W_{\text{hollow}} & = 22.2 \, \text{cm}^3 \\
I_{\text{hollow}} & = 77.5 \, \text{cm}^4
\end{align*}
\]

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 $f_R = 0.21 - f_R = 0.33$ 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 $45^\circ$ 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 injection pile in detail

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

HD-PE tube for unbonded anchor length

3.2 Sacrificial drill bits

Clay bit
Clay and loam, sandy-cohesive mixed soils without obstructions < 50 S.P.T.¹¹

Cross-cut bit
Dense sand and gravel with obstructions > 50 S.P.T.¹¹

Button bit
Weathered rock², phyllite, slate, mudstone; strength < 70 MPa

Carbide cross-cut bit
Dolomite, granite, sandstone; strength 70–150 MPa

Carbide button bit
Reinforced concrete or rock², 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.

¹¹ 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. Kurosche 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.

![Coupling nut image]

### 3.4 Centraliser
Guaranteeing the 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. \( c = 20 \text{ mm} \) 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.

![Centraliser image]

### 3.5 End plate details
Compensating for angles between 0° and 45°

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 frequently in the form of an end plate fitted to the projecting 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, 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.

A tapered plate can be mounted on the end plate with spherical recess in order to compensate for angles of up to 36°. When anchoring sheet pile walls, angles of up to 45° to the vertical are achieved by using an end plate with spherical recess 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.

Design advice for connections in reinforced concrete and for anchoring sheet pile walls can be found in our brochure detailing the standard end plate variations.
One method for all applications
Irrespective of the ground conditions and the particular application, TITAN injection piles are always installed using the same method.

4. Method of installation
4.1 An anchorage in two steps

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.

The method represents the state of the art and is used for diaphragm walls to DIN 4126 and bored piles to DIN 4014 (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, \( w/c = 0.7 \)) and a strength of \( f_{\text{ck}} \geq 35 \text{ N/mm}^2 \) 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.
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. 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 pressure 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 the right 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 section 7.2 of DIN 4128 is always reached.

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 underreaming effect. Injection piles 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, it may be assumed that the pile diameter when installed 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** \( a \geq 20 \text{ mm} \)
Empirical values supplied by Ischebeck (measured on excavated grout bodies)
- \( a = 75 \text{ mm} \) (medium and coarse gravel)
- \( a = 50 \text{ mm} \) (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.
A typical site setup consisting of a grouting unit and a drilling rig mounted on construction plant.
TITAN injection piles with a nominal outside diameter ($D_{\text{nom}}$) of up to 40 mm can be installed with hand-held, pneumatic hammer drills. Any construction plant with a hydraulic rotary percussive drive and drilling attachment can be employed for nominal outside diameters up to $D_{\text{nom}} = 52$ mm.

TITAN injection piles 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 injection piles 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.
5. Plant

### Hand-held pneumatic 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 52 anchors
- Manufacturers: Morath, TEI Rock-drills, etc.

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

#### Suitable drills

<table>
<thead>
<tr>
<th>TITAN 30/...</th>
<th>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 300 HT</th>
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<tr>
<td>TITAN 40/...</td>
<td>Atlas Copco COP 1036, 1038, 1238; SIG PLB 291 A; TAMROCK HL 438; Morath HB 70; Klemm KD 204, KD 511, KD 1011; Krupp HB 11, HB 15, HB 20; Eurodrill HD 1001, HD 1002; TEI TE 300 HT</td>
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<tr>
<td>TITAN 52/...</td>
<td>Morath HB 100; Klemm KD 511, KD 1011, KD 1215; Krupp HB 25, HB 35; Eurodrill HD 2004; TEI TE 500 HT</td>
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<tr>
<td>TITAN 73/...</td>
<td>Krupp HB 35, HB 45, HB 50; Morath HB 100; Klemm KD 1011, KD 1215; Eurodrill HD 2004, HD 4010</td>
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<tr>
<td>TITAN 103/...</td>
<td>Krupp HB 50, HB 60; Klemm KD 1215, KD 1624, KD 1828; Eurodrill HD 4010, HD 5012</td>
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</tbody>
</table>

#### Pressure-grouting plant

<table>
<thead>
<tr>
<th>TITAN 40/...</th>
<th>35 l/min Grouting unit with water regulation, turbo mixer for colloidal mixing, 1 mixing receptacle + 1 reservoir, duplex plunger pump, up to 100 bar Manufacturers: Scheltzke, Obermann, Häny, Morath</th>
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</thead>
<tbody>
<tr>
<td>TITAN 52/...</td>
<td>50 l/min</td>
</tr>
<tr>
<td>TITAN 73/...</td>
<td>70 l/min</td>
</tr>
<tr>
<td>TITAN 103/...</td>
<td>90 l/min</td>
</tr>
<tr>
<td>TITAN 127/...</td>
<td>120 l/min</td>
</tr>
</tbody>
</table>

Drilling rate: 0.31–1.0 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 injection piles.
Flushing heads are available for the most popular drifters which connect the hollow steel tendon and the grouting unit to the drifter.
6. Design advice

6.1 Designing a TITAN injection pile as a micropile

The design of a TITAN injection pile is carried out to different DIN standards depending on the particular application. 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 $R_{M,d}$.

The partial safety factor for calculating $R_{M,d}$ according to EC7 and National Technical Approval Z-34.14-209 is $\gamma_d = 1.15$ ($R_{M,d} = R_{M,k} / \gamma_d$).

**Verification: $E_d < R_{M,d}$**

<table>
<thead>
<tr>
<th>Designation</th>
<th>Unit</th>
<th>TITAN 30/16</th>
<th>TITAN 30/11</th>
<th>TITAN 40/20</th>
<th>TITAN 40/16</th>
<th>TITAN 52/26</th>
<th>TITAN 73/56</th>
<th>TITAN 73/53</th>
<th>TITAN 73/45</th>
<th>TITAN 73/35</th>
<th>TITAN 103/78</th>
<th>TITAN 103/51</th>
<th>TITAN 127/103</th>
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<tr>
<td>Nominal outside diameter $\varnothing$</td>
<td>mm</td>
<td>30</td>
<td>30</td>
<td>40</td>
<td>40</td>
<td>52</td>
<td>73</td>
<td>73</td>
<td>73</td>
<td>103</td>
<td>103</td>
<td>127</td>
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<tr>
<td>Nominal inside diameter $\varnothing$</td>
<td>mm</td>
<td>16</td>
<td>11</td>
<td>20</td>
<td>16</td>
<td>26</td>
<td>56</td>
<td>53</td>
<td>45</td>
<td>35</td>
<td>78</td>
<td>51</td>
<td>103</td>
</tr>
<tr>
<td>Characteristic load-carrying capacity $R_{M,k}$ according to German approval document</td>
<td>kN</td>
<td>155(^2)</td>
<td>225</td>
<td>372</td>
<td>465</td>
<td>620</td>
<td>695(^2)</td>
<td>860</td>
<td>1218</td>
<td>1386</td>
<td>1550</td>
<td>2325</td>
<td>1800(^2)</td>
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<td>Yield Point $F_{0.2,k}$ (mean value)</td>
<td>kN</td>
<td>190</td>
<td>260</td>
<td>425</td>
<td>525</td>
<td>730</td>
<td>830</td>
<td>970</td>
<td>1270</td>
<td>1430</td>
<td>1800</td>
<td>2670</td>
<td>2030</td>
</tr>
</tbody>
</table>

\(^1\) In the case of permanent tension loads and a cement grout cover $c < 40$ 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 and 127/103, the values were interpolated in a similar way to the approval.
6. Design advice
6.1 Designing a TITAN injection pile as a micropile

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

Micropiles transfer their loads to the loadbearing soil strata mainly by the means of skin friction. End bearing is normally neglected (with the exception of rock). The pile resistance in the ground (grout/soil friction) is primarily dependent on the surface area $A_s$ of the grout body and the characteristic skin friction $q_{s,k}$ 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 $q_{s,k}$, 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. 5.29 and 5.30 of “EA-Pfähle” (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 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: $a_{\text{min}} = 20 \text{ mm}$
  (for installation with external jetting)

- Average empirical value supplied by Ischebeck for preliminary design purposes:
  Sandy soils: $a \approx 50 \text{ mm}$
  Gravelly soils: $a \approx 75 \text{ mm}$
  (values measured on excavated grout bodies)
Ranges of empirical skin friction values for pressure-grouted injection piles are specified in “EA-Pfähle” (recommendations of the “micropiles” working group of the German geotechnical association). These can be read off in relation to the results of cone penetration tests (C.P.T.) according to DIN 4094-1. They specify ranges of empirical values for the characteristic skin friction $q_{sk}$ for pressure-grouted injection piles ($D_s < 0.30 \text{ m}$).

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

<table>
<thead>
<tr>
<th>Resistance</th>
<th>Symbol</th>
<th>Design situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS-P</td>
<td>BS-T</td>
<td>BS-A</td>
</tr>
</tbody>
</table>

- **Base resistance**: $\gamma_b = 1.10$  
- **Shaft resistance (compression)**: $\gamma_s = 1.10$  
- **Total/combined resistance (compression)**: $\gamma_t = 1.10$  
- **Shaft resistance (tension)**: $\gamma_{s,t} = 1.15$  

**Pile resistances based on empirical values**

<table>
<thead>
<tr>
<th>Resistance</th>
<th>Symbol</th>
<th>Design situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS-P</td>
<td>BS-T</td>
<td>BS-A</td>
</tr>
</tbody>
</table>

- **Compression piles**: $\gamma_{b}, \gamma_{s}, \gamma_{t} = 1.40$  
- **Tension piles** (in exceptional circumstances only): $\gamma_{s,t} = 1.50$  
- **Pull-out resistance**: $\gamma_a = 1.40$  
- **Soil nails or rock bolts**: $\gamma_a = 1.40$  
- **Grout bodies of injection piles**: $\gamma_a = 1.10$  
- **Flexible reinforcing elements**: $\gamma_a = 1.40$

**EA-Pfähle Tab. 5.29 in non-cohesive soils**

<table>
<thead>
<tr>
<th>Average end bearing $q_e$ in C.P.T. in MN/m²</th>
<th>Ultimate skin friction $q_{sk}$ in kN/m² *</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5</td>
<td>135-175</td>
</tr>
<tr>
<td>15</td>
<td>215-280</td>
</tr>
<tr>
<td>$\geq 25$</td>
<td>255-315</td>
</tr>
</tbody>
</table>

**EA-Pfähle Tab. 5.30 in cohesive soils**

<table>
<thead>
<tr>
<th>Shear strength $c_{uk}$ of undrained soil in kN/m²</th>
<th>Ultimate skin friction $q_{sk}$ in kN/m² *</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>55-65</td>
</tr>
<tr>
<td>150</td>
<td>95-105</td>
</tr>
<tr>
<td>$\geq 250$</td>
<td>115-125</td>
</tr>
</tbody>
</table>

* Intermediate values may be obtained by linear interpolation.
6. Design advice
6.1 Designing a TITAN injection pile as a micropile

6.1.3 Verification of buckling (compression piles)

According to EC7 and DIN EN 14199, injection piles loaded in compression must be checked for buckling when the undrained shear strength \( c_{u,k} \) is < 15 kN/m² in soft cohesive soils.

According to the approvals issued by the DIBt, buckling has to be checked for \( c_{u,k} < 10 \) kN/m² without assuming lateral support from the ground (to DIN 18800, see approval) and for \( 10 \) kN/m² \( \leq c_{u,k} < 30 \) kN/m² with lateral support. Design methods (in German) can be found in...


Recommendation R9 of “EAU 2004” (Recommendations of the Committee for Waterfront Structures, Harbours and Waterways) contains the following undrained shear strength values \( c_{u,k} \) for cohesive soils that are to be considered as critical:

- Silt/clay, soft \( c_{u,k} = 5 \) - 60 kN/m²
- Silt/clay, stiff \( c_{u,k} = 20\text{-}150 \) kN/m²
- Silt/clay, semi-stiff \( c_{u,k} = 50\text{-}300 \) kN/m²
- Organic silt/clay, very soft \( c_{u,k} = 2 < 15 \) kN/m²
- Mud/digestive sludge, very soft \( c_{u,k} = < 6 \) kN/m²

Guidance values for relationships between the consistency and the shear strength of the undrained soil for cohesive soils (“EA-Pfähle” Tab. 3.3):

<table>
<thead>
<tr>
<th>Consistency</th>
<th>Shear strength of undrained soil ( c_{u,k} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 ... 0.75</td>
<td>15 ... 50 kN/m²</td>
</tr>
<tr>
<td>0.75 ... 1.00</td>
<td>50 ... 100 kN/m²</td>
</tr>
<tr>
<td>&gt; 1.00</td>
<td>firm to stiff, stiff &gt; 100 kN/m²</td>
</tr>
</tbody>
</table>

The undrained shear strength can be calculated from CPT 10 and CPT 15 tests (DIN 4094-1:2002, annex D, D.4).

\[
c_u = \frac{(q_c - \sigma_o)}{N_k}
\]

where:
- \( c_u \): undrained shear strength
- \( q_c \): cone resistance
- \( \sigma_o \): total overburden pressure
- \( N_k \): cone factor

Further details can be found in “EAU” and “EA-Pfähle”.

---

Relevant standards:
- EC7
- DIN EN 14199

---
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 ($c_{uk} < 30 \text{ kN/m}^2$), 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 $c_{uk}$ value according to the acknowledged buckling analyses of Ofner/Wimmer or Vogt or DIN 18800.

The drawing shows an 18 m long TITAN 73/53 compression pile (max. $E_d = 748 \text{ kN}$) that is in the form of a 6 m long TITAN 103/78 in the area of the soft clay strata with $c_{uk} = 20 \text{ kN/m}^2$. The TITAN 103/78 is designed according to the buckling analysis of Ofner/Wimmer.
6.1 Designing a TITAN injection pile as a micropile

6.1.4 Verification of serviceability
Estimating the total deformation

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. 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 injection pile is a composite component.
- Strain stiffness of steel tendon (see technical data)
- Strain stiffness of grout body can be calculated with a modulus of elasticity $E_{\text{cement}} = 17000 \, \text{N/mm}^2$.

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

$$(E A)_{\text{sum}} = (E A)_{\text{steel}} + (E A)_{\text{cement}}$$

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

$$\varepsilon_{\text{sum}} = \frac{E}{(E A)_{\text{sum}}}$$

<table>
<thead>
<tr>
<th>Designation</th>
<th>Unit</th>
<th>TITAN 30/16</th>
<th>TITAN 30/11</th>
<th>TITAN 40/20</th>
<th>TITAN 40/16</th>
<th>TITAN 52/26</th>
<th>TITAN 73/56</th>
<th>TITAN 73/53</th>
<th>TITAN 73/45</th>
<th>TITAN 73/35</th>
<th>TITAN 103/78</th>
<th>TITAN 103/51</th>
<th>TITAN 127/103</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside diameter $D_o$ *</td>
<td>mm</td>
<td>29</td>
<td>29</td>
<td>40,5</td>
<td>40,5</td>
<td>50,3</td>
<td>72,4</td>
<td>72,4</td>
<td>72,4</td>
<td>72,4</td>
<td>101</td>
<td>101</td>
<td>126,8</td>
</tr>
<tr>
<td>Effective cross-sectional area $A_{\text{eff}}$</td>
<td>mm</td>
<td>340</td>
<td>415</td>
<td>730</td>
<td>900</td>
<td>1250</td>
<td>1360</td>
<td>1615</td>
<td>2239</td>
<td>2714</td>
<td>3140</td>
<td>5680</td>
<td>3475</td>
</tr>
<tr>
<td>Strain stiffness $E \cdot A$ *</td>
<td>$10^6 , \text{kN}$</td>
<td>63</td>
<td>83</td>
<td>135</td>
<td>167</td>
<td>231</td>
<td>251</td>
<td>299</td>
<td>414</td>
<td>502</td>
<td>580</td>
<td>1022</td>
<td>640</td>
</tr>
</tbody>
</table>

*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 \( \Delta \) depending on load.

With a load of 360 kN, a total deformation of 7.3 mm was observed, calculated from the formula for the trend line

\[
\Delta = 4.5754 \cdot e^{0.0013 \cdot F} = 4.5754 \cdot e^{0.0013 \cdot 360 \text{kN}}
\]

\( \Delta = 7.3 \text{ mm} \)

90 % of all measured values lie within these bounds (upper bound 13 mm – lower bound 3 mm)

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 Abnahmever suchen” (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. Design advice

6.2 Design examples

6.2.1 Example of pile foundation: compression pile

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

Verification of load-carrying capacity:
\[ E_d \leq R_{M,d} \]
\[ R_{M,d} = R_{M,k} / \gamma_M \]
\[ R_{M,d} = 860 \text{ kN} / 1.15 = 748 \text{ kN} \text{ (where } \gamma_M = 1.15) \]
\( \rightarrow \) Satisfactory

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

Shaft resistance (compression):
\( \gamma_s = 1.10 \)
(to DIN 1054:2010-12 Tab. A.2.3)

Given:
Loading tests carried out on two piles: \( \xi_1 = 1.25 \)
Subsoil: down to 4 m: fill (inadequate loadbearing capacity)
below 4 m depth: gravel/sand \( q_c = 15 \text{ MN/m}^2 \)
(end-bearing pressure)
Drill bit: Cross-cut drill bit \( d = 175 \text{ mm} \)
Widening value: DIN SPEC 18539: \( a = 20 \text{ mm} \)
(alternative Ischebeck empirical value: \( a = 50 \text{ mm} \))
Projection \( \hat{U} = 0.50 \text{ m} \)

Skin friction:
“EA-Pfähle” (Tab. 5.29) \( q_{s1,k} = 215 \text{ kN/m}^2 \)
Must be confirmed by loading tests:
selected: 2 (correlation factor \( \xi_1 \), see p. 23)

\( P_p = 712 \text{ kN} \cdot 1.10 \cdot 1.25 = 979 \text{ kN}^* \)
*(Larger steel cross-sections may need to be selected for loading tests.)

Bonded length \( l_b \)

\[ l_b = \frac{E_d}{\pi \cdot (D + a) \cdot \frac{C_{st,1}}{\gamma_s \cdot \xi_1}} = \frac{712 \text{ kN}}{\pi \cdot (0.175 \text{ m} + 0.02 \text{ m}) \cdot \frac{215 \text{ kN/m}^2}{1.10 \cdot 1.25}} = 7.43 \text{ m} \]

Total length of pile \( L_{sum} \)

\[ L_{sum} = l_b + \hat{U} + l_{free} \]
\[ L_{sum} = 7.43 \text{ m} + 0.50 \text{ m} + 4.0 \text{ m} = 11.93 \text{ m} \]
Selected: \( L_{sum} = 12.00 \text{ m} \)
6.2.2 Example of pile foundation (estimate of pile head displacement)
Steel/grout body displacement only

Pile length: \( L_{\text{sum}} = 12.00 \text{ m} \)
Action: \( E_k = 500 \text{ kN} \)

**TITAN 73/53 (S)**
Nominal outside diameter: \( D_{\text{steel}} = 73 \text{ mm} \)
Effective cross-section: \( A_{\text{eff}} = 1615 \text{ mm}^2 \)
Strain stiffness: \( (EA)_{\text{steel}} = 299000 \text{ kN} \)

**Grout body (Z)**
Pile diameter: \( D = 180 \text{ mm} \)
Cross-section, grout body
\[
A_{\text{cement}} = \left( \pi \cdot \left( D^2 - D_{\text{steel}}^2 \right) \right) / 4
\]
\[
A_{\text{cement}} = (\pi \cdot (180^2 \text{ mm}^2 - 73^2 \text{ mm}^2)) / 4
= 21262 \text{ mm}^2
\]
(The cement within the hollow steel tendon is neglected.)

Modulus of elasticity, grout body
\( E_{\text{cement}} = 17000 \text{ N/mm}^2 = 17 \text{ kN/mm}^2 \)
Strain stiffness, grout body
\( (EA)_{\text{cement}} = E_{\text{cement}} \cdot A_{\text{cement}} \)
\( (EA)_{\text{cement}} = 17 \text{ kN/mm}^2 \cdot 21262 \text{ mm}^2 \)
\( = 361454 \text{ kN} \)

Total strain stiffness
\( (EA)_{\text{sum}} = (EA)_{\text{steel}} + (EA)_{\text{cement}} \)
\( (EA)_{\text{sum}} = 361454 \text{ kN} + 299000 \text{ kN} \)
\( = 660454 \text{ kN} \)

Calculation of deformation/displacement at head of pile
\[
\varepsilon_{l,\text{sum}} = \frac{E_k}{(EA)_{\text{sum}}} \]
\[
\varepsilon_{l,\text{sum}} = \frac{500 \text{ kN}}{660454 \text{ kN}} = 0.08 \% \]
\[
f = \varepsilon_{l,\text{sum}} \cdot L_{\text{sum}} \]
\[
f = 0.08\% \cdot 12.00 \text{ m} = 0.9 \text{ mm} \]
6. Design advice
6.2 Design examples

6.2.3 Example of piled foundation: 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:
$E_d \leq R_{M,d}$

$R_{M,d} = \frac{R_{M,k}}{\gamma_M}$

$R_{M,k} = 465$ kN / 1.15 = 404 kN (where $\gamma_M = 1.15$)

$R_{M,d} = 465$ kN / 1.15 = 404 kN

$\Rightarrow$ 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) $c_u = 250$ kN/m²
Drill bit: clay bit $d = 150$ mm
Widening value: DIN SPEC 18539: $a = 20$ mm
Skin friction: $q_{s1,k} = 115$ kN/m²
(assumption from “EA-Pfähle“: Tab. 5.30)

Must be confirmed by load tests: selected: 3 (correlation factor $\xi_1$, see p. 23)

$P_p = 400$ kN \cdot 1.15 \cdot 1.25 \cdot 1.15 = 661$ kN*

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

Bonded length $l_b$

$l_b = \frac{E_d}{\pi \cdot (d + a) \cdot \frac{q_{s1,k} \cdot \xi_1 \cdot \eta_M}{c_u \cdot \gamma_s \cdot \xi_1 \cdot \eta_M}}$

$= \frac{400 \text{ kN}}{\pi \cdot (0.15 \text{ m} + 0.02 \text{ m}) \cdot \frac{115 \text{ kN/m}^2}{1.15 \cdot 1.25 \cdot 1.15}} = 10.77 \text{ m}$

Total length of pile $L_{sum}$

Wall-lower slip plane distance: $l_{wb} = 8.10$ m

$L_{sum} = \frac{l_b}{2} + l_{wb} + \delta = \frac{10.77}{2} + 8.10 \text{ m} + 0.30 \text{ m} = 13.80 \text{ m}$ (selected 14 m)
Anchored shoring to deep excavation
Salt Lake City, Utah, USA
Permanent corrosion protection for TITAN injection piles is guaranteed by:

**Cement grout cover**

Permanent corrosion protection for TITAN injection piles 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 cover called for in the approval, which is in some cases somewhat larger than the minimum cover required by relevant standards:

- min. 20 mm in soils  
  (to DIN 4128 Tab. 1)
- min. 10 mm in rock  
  (to DIN 4128 Tab. 1)
- min. 20 mm for compression piles  
  (to EN 14199)
- min. 30 mm for tension piles  
  (to EN 14199)

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 injection piles 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.

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
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 injection piles against corrosion is dealt with in the approval. Galvanising is a special precaution that can be provided to protect the hollow steel tendon against corrosion. The coating of zinc applied to the steel withstands severe corrosion and represents a durable, economic form of corrosion protection.

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).

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

According to the 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: “Volumes of grout of up to 1.7 times the theoretical void size created upon installing injection piles and pressure-grouted displacement piles will not be remunerated separately. Larger quantities of grout will only be remunerated after prior agreement with the client.”

### Sample calculation for volume of drilled hole

**TITAN 52/26**
- Clay drill bit: \( D = 175 \text{ mm} \)
- Cohesive soil: \( a = 25 \text{ mm (hole widening)} \)
- Diameter of drilled hole: \( D = 17.5 \text{ cm} + 2 \text{ cm} = 19.5 \text{ cm} \)

Theoretical cross-section of grout body:
\[
A = \pi \cdot \left( \frac{D}{2} \right)^2 = \pi \cdot (9.75 \text{ cm})^2 = 299 \text{ cm}^2
\]

Volume of drilled hole per 1 m length of injection pile:
\[
V = A \cdot 1 \text{ m} = 299 \text{ cm}^2 \cdot 100 \text{ cm} = 29900 \text{ cm}^3 = 29.9 \text{ litres}
\]

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

<table>
<thead>
<tr>
<th>D [mm]</th>
<th>Volume of drilled hole [l/m]</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>2.8</td>
<td>3.9</td>
<td>3.4</td>
<td>3.0</td>
<td>2.7</td>
<td>2.5</td>
<td>2.3</td>
<td>2.1</td>
</tr>
<tr>
<td>90</td>
<td>6.4</td>
<td>8.7</td>
<td>7.6</td>
<td>6.8</td>
<td>6.2</td>
<td>5.6</td>
<td>5.2</td>
<td>4.8</td>
</tr>
<tr>
<td>120</td>
<td>11.3</td>
<td>15.4</td>
<td>13.6</td>
<td>12.1</td>
<td>10.9</td>
<td>10.0</td>
<td>9.2</td>
<td>8.5</td>
</tr>
<tr>
<td>150</td>
<td>17.7</td>
<td>24.1</td>
<td>21.2</td>
<td>18.9</td>
<td>17.1</td>
<td>15.6</td>
<td>14.3</td>
<td>13.3</td>
</tr>
<tr>
<td>180</td>
<td>25.4</td>
<td>34.7</td>
<td>30.5</td>
<td>27.3</td>
<td>24.6</td>
<td>22.5</td>
<td>20.6</td>
<td>19.1</td>
</tr>
<tr>
<td>200</td>
<td>31.4</td>
<td>42.8</td>
<td>37.7</td>
<td>33.7</td>
<td>30.4</td>
<td>27.7</td>
<td>25.5</td>
<td>23.6</td>
</tr>
<tr>
<td>220</td>
<td>38.0</td>
<td>51.8</td>
<td>45.6</td>
<td>40.7</td>
<td>36.8</td>
<td>33.5</td>
<td>30.8</td>
<td>28.5</td>
</tr>
<tr>
<td>250</td>
<td>49.1</td>
<td>66.9</td>
<td>58.9</td>
<td>52.6</td>
<td>47.5</td>
<td>43.3</td>
<td>39.8</td>
<td>36.8</td>
</tr>
<tr>
<td>300</td>
<td>70.7</td>
<td>96.4</td>
<td>84.8</td>
<td>75.7</td>
<td>68.4</td>
<td>62.4</td>
<td>57.3</td>
<td>53.0</td>
</tr>
</tbody>
</table>
Deep foundations for 380 kV electricity pylons with TITAN 103/78 bored anchor piles approx. 24 m long
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 injection pile
Installation at an angle of 20° to the horizontal.
Deviation from intended direction: 66 cm for micropile length of 27 m = 2.4%
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 4125, can be measured and checked in a similar way by means of test loads.

Loadbearing function for injection pile measured with extensometer

- Progressive failure in soil up to equilibrium
- Skin friction $q_s$
- Silt with clay belts
- Dense sand
- Pile length $L$
- $q_{s,\text{max}}$
- $l_s$ to DIN 4125
- Effective "unbonded" pile length
- Bonded length $l$
- Completed crack pattern in grout body
7. Appendix
7.1 Proofs and basic tests

7.1.3 Diameter of grout body

The grout bodies around TITAN injection piles 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 injection pile was exposed to reveal the widening of the drilled hole in the sandy subsoil when using a \(\varnothing 175\) 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/m\(^2\))

1. Portland cement, compressive strength \(f_{ck} > 35\) N/mm\(^2\)
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

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 injection piles 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 for 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 injection pile broken away to show completed crack pattern.
7. TENSION

7.1 Proofs and basic tests

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 injection piles 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: \( a_{\text{min}} = 20 \text{ mm} \) (for installation with external jetting)
- average empirical values supplied by Ischebeck for preliminary design purposes (values measured on excavated grout bodies):
  - Sandy soils: \( a \approx 50 \text{ mm} \)
  - Gravelly soils: \( a \approx 75 \text{ mm} \)

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

<table>
<thead>
<tr>
<th>Measured circumference</th>
<th>Radius of grout body</th>
<th>Effective diameter</th>
<th>Widening of drilled hole</th>
<th>Cement grout cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>( u ) [mm]</td>
<td>( r = \frac{u}{2 \cdot \pi} ) [mm]</td>
<td>( d_{\text{eff}} = 2 \times r ) [mm]</td>
<td>( b = d_{\text{eff}} - d_v ) [mm]</td>
<td>( c = \frac{2 \cdot r - d_v}{2} ) [mm]</td>
</tr>
<tr>
<td>550.0</td>
<td>87.54</td>
<td>175.07</td>
<td>45.07</td>
<td>51.04</td>
</tr>
<tr>
<td>550.0</td>
<td>87.54</td>
<td>175.07</td>
<td>45.07</td>
<td>51.04</td>
</tr>
<tr>
<td>546.0</td>
<td>86.90</td>
<td>173.80</td>
<td>43.80</td>
<td>50.40</td>
</tr>
<tr>
<td>Average value</td>
<td>548.7</td>
<td>87.32</td>
<td>174.65</td>
<td>44.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50.82</td>
</tr>
</tbody>
</table>

**TITAN 73/53 injection pile, \( d_v = 73 \text{ mm} \), 73 mm, cross-cut drill bit, \( d_b = \varnothing 130 \text{ mm} \)**

<table>
<thead>
<tr>
<th>Section</th>
<th>( u ) [mm]</th>
<th>( r ) [mm]</th>
<th>( d_{\text{eff}} ) [mm]</th>
<th>( b ) [mm]</th>
<th>( c ) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>466.0</td>
<td>74.17</td>
<td>148.33</td>
<td>38.3</td>
<td>54.17</td>
</tr>
<tr>
<td>2</td>
<td>471.0</td>
<td>74.96</td>
<td>149.92</td>
<td>39.9</td>
<td>54.96</td>
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<tr>
<td>3</td>
<td>472.0</td>
<td>75.12</td>
<td>150.24</td>
<td>40.2</td>
<td>55.12</td>
</tr>
<tr>
<td>4</td>
<td>464.0</td>
<td>73.85</td>
<td>147.70</td>
<td>37.7</td>
<td>53.85</td>
</tr>
<tr>
<td>Average</td>
<td>468.3</td>
<td>74.52</td>
<td>149.05</td>
<td>38.85</td>
<td>54.52</td>
</tr>
</tbody>
</table>

**TITAN 40/16 injection pile \( d_v = 40 \text{ mm} \), clay drill bit, \( d_b = \varnothing 110 \text{ mm} \)**
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
### Relevant standards

<table>
<thead>
<tr>
<th>Verification</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load-carrying capacity</td>
<td>National Technical Approval Z 34.14-209</td>
</tr>
</tbody>
</table>
| Micropiles / injection piles | DIN EN 14199  
DIN SPEC 18539 |
| Soil nails                  | DIN EN 14490  
DIN 4084 |
| Geotechnical verification   | EC7, comprising:  
- DIN EN 1997-1:2009-09  
- DIN EN 1997-1 / NA:2010-12  
- DIN 1054-2010:12  
“EA-Pfähle” |
| Reinforcement (S 460 NH material) | DIN 14199  
EN 10210  
DIN 488  
EC 2 |
| Corrosion protection (cement grout cover) | National Technical Approval Z-34.14-209  
DIN EN 14199  
DIN EN 14490 |
| Execution of tests          | EC7, comprising:  
- DIN EN 1997-1:2009-09  
- DIN EN 1997-1 / NA:2010-12  
- DIN 1054:2010:12  
DIN EN ISO 22477-1 |
| Testing requirements        | DIN EN 14199  
DIN EN 14490  
DIN EN 1537 / DIN SPEC 18537 |
| Scope of testing (number)   | DIN EN 14199 / EC7  
DIN EN 14490  
DIN EN ISO 22477-1 |
7. Appendix
7.3 Technical data

Technical data

<table>
<thead>
<tr>
<th>Designation</th>
<th>Unit</th>
<th>TITAN 30/16</th>
<th>TITAN 30/11</th>
<th>TITAN 40/20</th>
<th>TITAN 40/16</th>
<th>TITAN 52/26</th>
<th>TITAN 73/56</th>
<th>TITAN 73/33</th>
<th>TITAN 73/45</th>
<th>TITAN 73/35</th>
<th>TITAN 103/78</th>
<th>TITAN 103/51</th>
<th>TITAN 127/103</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal outside diameter D_{steel}</td>
<td>mm</td>
<td>30</td>
<td>30</td>
<td>40</td>
<td>40</td>
<td>52</td>
<td>73</td>
<td>73</td>
<td>73</td>
<td>73</td>
<td>103</td>
<td>103</td>
<td>127</td>
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<tr>
<td>Nominal inside diameter D_{hole}</td>
<td>mm</td>
<td>16</td>
<td>11</td>
<td>20</td>
<td>16</td>
<td>26</td>
<td>56</td>
<td>53</td>
<td>45</td>
<td>35</td>
<td>78</td>
<td>51</td>
<td>103</td>
</tr>
<tr>
<td>Effective cross-section A_{eff}</td>
<td>mm²</td>
<td>340</td>
<td>415</td>
<td>730</td>
<td>900</td>
<td>1250</td>
<td>1360</td>
<td>1615</td>
<td>2239</td>
<td>2714</td>
<td>3140</td>
<td>5680</td>
<td>3475</td>
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<tr>
<td>Ultimate load F_u</td>
<td>kN</td>
<td>245</td>
<td>320</td>
<td>540</td>
<td>660</td>
<td>925</td>
<td>1035</td>
<td>1160</td>
<td>1575</td>
<td>1865</td>
<td>2270</td>
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<td>2320</td>
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<tr>
<td>Characteristic load-carrying capacity R_{M,k} according to German approval document ¹)</td>
<td>kN</td>
<td>155²)</td>
<td>225</td>
<td>372</td>
<td>465</td>
<td>620</td>
<td>860</td>
<td>1218</td>
<td>1386</td>
<td>1550</td>
<td>2325</td>
<td>1800²)</td>
<td></td>
</tr>
<tr>
<td>F_{0.2,k} force at 0.2 % proportionality limit (mean value)</td>
<td>kN</td>
<td>190</td>
<td>260</td>
<td>425</td>
<td>425</td>
<td>525</td>
<td>730</td>
<td>830</td>
<td>970</td>
<td>1270</td>
<td>1430</td>
<td>1800</td>
<td>2670</td>
</tr>
<tr>
<td>Strain stiffness E · A³)</td>
<td>10⁶ kN</td>
<td>63</td>
<td>83</td>
<td>135</td>
<td>167</td>
<td>231</td>
<td>251</td>
<td>299</td>
<td>414</td>
<td>502</td>
<td>580</td>
<td>1022</td>
<td>640</td>
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<tr>
<td>Bending stiffness E · I³)</td>
<td>10⁸ kNmm²</td>
<td>3.7</td>
<td>4.6</td>
<td>15</td>
<td>17</td>
<td>42</td>
<td>125</td>
<td>143</td>
<td>178</td>
<td>195</td>
<td>564</td>
<td>794</td>
<td>1163</td>
</tr>
<tr>
<td>Weight</td>
<td>kg/m</td>
<td>2.7</td>
<td>3.29</td>
<td>5.8</td>
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<td>9.87</td>
<td>10.75</td>
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<td>28.9</td>
</tr>
<tr>
<td>Length</td>
<td>m</td>
<td>3</td>
<td>2/3/4</td>
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<td>2/3/4</td>
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<td>3</td>
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<td>3</td>
<td>3</td>
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<tr>
<td>Left-/right-hand thread</td>
<td>-</td>
<td>left</td>
<td>left</td>
<td>left</td>
<td>left</td>
<td>right</td>
<td>right</td>
<td>right</td>
<td>right</td>
<td>right</td>
<td>right</td>
<td>right</td>
<td>right</td>
</tr>
</tbody>
</table>

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 < 40 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 and 127/103 injection piles.

³) 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.

⁴) Only applies to hollow steel tendon without coupling nut. The ultimate load is 2048 kN for coupled hollow steel tendons.
Slope stabilisation alongside Nuremberg-Regensburg railway line

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