FRIEDR. ISCHEBECK GmbH, Ennepetal, Germany, founded in 1881, *actual view 2010*
THE DESIGN AND EXECUTION OF DRILLED AND FLUSH-GROUTED TITAN MICROPILES IS GOVERNED IN EUROPEAN UNION (EU) BY NATIONAL TECHNICAL APPROVAL Z-34.14-209 (DIBT)

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From Lizzi’s pioneering vision of “Pali Radice” to type 1 and type 2 Micropiles according to EN 14199 “Micropiles” and national technical approval for Titan drilled Micropiles.
To learn from Nature

Bionik – From Roots to Micropiles Type 1 and 2
Dr. F. Lizzi’s Vision of Pali Radice“ in 1952

4 fundamental Experiences:

- Both Roots and Micropiles can transfer tension or compression loads to the ground.

- Roots and Micropiles increase the cohesion of the ground and form a monolithic, composite foundation material.

- The increased volume of roots through growth or the pressure grouting of micropiles both create confinement of the soil. As a result there is an improvement in shear bond values and smaller displacements of the roots and micropiles.

- A network of roots forms splayed Micropiles, which work like rebar in reinforced concrete or glasfibre – used in reinforced plastic (GRP).
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Anstalt des öffentlichen Rechts

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Allgemeine bauaufsichtliche Zulassung

Zulassungsnummer: Z-34.14-209

Antragsteller: Friedr. Ischebeck GmbH
Loher Str. 31-79
58256 Ennepetal

Zulassungsgegenstand: Verpresspfähle TITAN

Geltungsdauer bis: 30. April 2013

Der oben genannte Zulassungsgegenstand wird hiermit allgemein bauaufsichtlich zugelassen. Diese allgemeine bauaufsichtliche Zulassung umfasst 14 Seiten und acht Blatt Anlagen.
Micropile TITAN – Main Components

- Concrete structure
- Pile Head
- Smooth HD-PE Pipe
- active Zone
- Filtercake (Diaphragma)
- Slip plane
- passive Zone
- Grout Body min. cement stone cover 20 to 50 mm

D ≥ d + 75 mm for gravel
   d + 50 mm for sand
   d + 25 mm for sand-silt
   d + 10 mm for weathered rock, clay

- Consolidated Soil
- Filtercake
- Cement stone
- Steel member
Installation of TITAN Drilled Micropiles
The same procedure for all ground conditions

1. Drilling and flushing with conduit (water, air, grout) up to bore hole depth.

   - w/c ~ 0.7 - 1.0
   - 5 - 20 bar

2. Flushing with grout

   - w/c ~ 0.4 - 0.55
   - 20 - 60 bar

These are just general rules they can vary depending on pile length, ground and site conditions.
Micropile (DIN EN 14199)
Soil Nailing (DIN EN 14490)
Design Diagramm Micropile TITAN 30/11 in sand and gravel

Pull out resistance depends on type of soil, confinement, SPT-value, skin friction qs, drill bit diameters, bonded length

Diagram according Bustamente

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<tr>
<th>Consistency</th>
<th>weich</th>
<th>mitteldicht</th>
<th>dicht</th>
<th>sehr dicht</th>
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<tbody>
<tr>
<td>SPT Wert N=30 cm</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>Spt-Wertstenksun (N)</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>40</td>
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<table>
<thead>
<tr>
<th>Micropile Diameter (mm)</th>
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<tr>
<td>180</td>
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</table>

<table>
<thead>
<tr>
<th>Bonded Length (m)</th>
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<tbody>
<tr>
<td>5 m</td>
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<table>
<thead>
<tr>
<th>Drill bits for TITAN 30/11</th>
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</table>
Load Transfer in Composite Micropiles TITAN for one Homogenous Layer of Soil

Monitoring the Distribution of Load Transfer to the Soil by Extensometers, installed inside the hollow Micropile TITAN
Strain Relation $\beta = \frac{\varepsilon_{m\,\text{micropile}}}{\varepsilon_{s\,\text{steel}}}$ versa Micropile Diameter $D_c [\text{mm}]$
Estimated Displacements of TITAN Drilled Micropiles in Comparison

**Example:**
Given: TITAN 52/26, L = 15 m long, SWL = 400 kN (90.000 lbf); Dc = 200 mm,
E x A = 231 x 10³ kN Axial Stiffness of Steel Member

with Displacement of Steel Member only:

\[
\Delta L_{steel} = \frac{F \times L}{E \times A}
\]

\[
= \frac{400 \, kN \times 15 \, m}{231 \times 10^3 \, kN} = 7,7 \, mm
\]

\[
\Delta L_{steel} = 26 \, mm
\]

with Displacement of Micropile, free unbonded length:

\[
\Delta L_{MP} = \beta \times \Delta L_{steel}
\]

\[
\beta = \frac{\varepsilon_{MP}}{\varepsilon_{steel}}
\]

Read by folie 12: \( \beta \approx 0,5 \) for \( D_c = 200 \, mm \)

\[
\Delta L_{MP} = 13 \, mm \ (1/2")
\]

with Measured Displacement of Micropile in the Ground University of Siegen, Prof. Herrmann, A. Scholl, 2008)

\[
\Delta L = 4,57 \times e^{0,0013 \times F}
\]

\[
\Delta L = 4,57 \times 2,718^{0,0013 \times 400}
\]

\[
\Delta L = 7,7 \, mm
\]

with Displacement of Strand Anchor, 3 strands 15,7 mm Ø (0,6”), 6 m free length

without prestressing

\[
\Delta L_{strand} = \frac{400 \times 6000}{195 \times 3 \times 150} = 27,3 \, mm
\]

with prestressing to 80 %

\[
\Delta L_{strand} = 27,3 \, mm \times (1 - 0,8) = 5,5 \, mm
\]

Conclusion: Displacements of Micropiles - without prestressing (passive Anchors) and - without designed free length can be compared with displacement of prestressed strand anchors.
Verification Tests with Micropiles  TITAN 89/67

Grundbauingenieure Steinfeld und Partner, Hamburg, 28.10.1985
Nearly horizontal, 15° inclination
Medium Dense Sand, Point Resistance $q_c$ 6MPa

Micropile No. 1

<table>
<thead>
<tr>
<th>Horizontal Diameter [cm]</th>
<th>Vertical Diameter [cm]</th>
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<tbody>
<tr>
<td>1.00</td>
<td>20</td>
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<tr>
<td>1.00</td>
<td>24</td>
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<td>1.00</td>
<td>25</td>
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<td>27</td>
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<tr>
<td>1.00</td>
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6.00 m (20')
Exhumed Micropile TITAN 40/16 - Grout Body Diameter depends on S.P.T. or C.P.T. Test
Tests on TITAN Micropiles 40/16 were included in FRENCH NATIONAL RESEARCH PROJECT (FOREVER). This was to improve design of single and splayed micropiles.

Several tests were carried out in St-REMY-LES-CHEVREUSE in 1998. The micropiles were installed within the loose, fine and dry sand of Fontainebleau.

TITAN Micropiles 40/16, length 5 m, drill bit 70 mm, flushing grout w/c=0,9, grout pressure 8 – 20 bar.

Results:

1. Skin friction $qs = 74 \text{kN/m}^2$
   
   Micropiles TITAN fulfil the requirements of the French DTU 13.2 micropieux Typ IV (IRS or postgrouted)

2. Load transfer in compression was 7% by end bearing, 93% by friction

3. Micropile Diameter $D=113 \text{ mm}$
   
   Drill bit $d = 70 \text{ mm}$, $D = (1,5 \div 1,8) \times d$

4. No visible cracks observed within the grout body

5. Steel tendon centred within the grout body

6. Successful Dynamic integrity testing using the French method SIMBAT which was confirmed by CEBTP
An exhumed grout body of a TITAN 103/78

installed in very fine, loose sand, 40 m below water table, S.P.T. approx. 3, $q_c = 15$ MPa

1. Neat (full strength) grout = Ordinary Portland cement, quality B25, unconfined compressive strength $> 25$ N/mm²
2. Filter cake (Membrane) = concentration of cement, stabilised the annulus, brighter and darker rings show different W/C- mixture
3. Very good shear bond
4. TITAN 103/78 centered in the micropile, almost constant grout cover (C $> 50$ mm) $> 2”$
Verification Test with TITAN 103/78 Micropiles - Lochau (Halle) April 2005, Prof. Dr. Wichter

- Light plastic clay (cohesive soil)
- Near horizontal, 20° inclination
- Deviation $\frac{0.66 m}{27 m} = 2.5 \% < 4 \%$
- Required by EN 14199 “Micropiles”, Annexe B
- Max. length limited to 33 m (110’)
- Deviation 0.66 m
Exhumed Micropile TITAN 30/11

Claquage

Global Postgrouting through the drill-bit within 2 to 3 hours after initial pressure grouting increases the Pull-Out-Resistance in non-compacted sand e.g. by Stretching the Grout Body to form a Trumpet.
A testmachine with grout body 180 - 220 mm $\phi$, 1200 mm long reinforced with TITAN 103/51, SWL 1000 kN

Position of Coupler

University of Munich
Institute for Building material and Construction
Prof. Zilch – Prof. Schießl
Model of micropile under axial loading acc. to Goto

Showing both:
the tension stiffening effect and crack width limitation.

\[
\frac{\text{Young's modulus } E_s \text{ of steel}}{\text{Young's modulus } E_c \text{ of concrete}} = \frac{210}{30} \approx 7
\]

related rib factor
\[ f_R = \frac{a}{c} \]
\[ f_R = 0.21 \text{ to } 0.33 \text{ for micropiles TITAN} \]
\[ f_R = 0.056 \text{ for rebar} \]
Shear Load transfer at interface steel /. cementstone of micropiles depends on the deformations

This figure confirms, that shear load transfer is improved by using deformed bars. The development of rebar’s over the past 100 years has led to an increase in the use of deformed bars rather than smooth bars in micropiles.
Technical Development of the Shearbond of Micropiles

Projected rib factor
\[ f_R = 0.56 \times \frac{a}{c} = 0.074 \]
characteristic load-carrying capacity
230 N/mm²
(to Z-32.1-2)

Projected rib factor
\[ f_R = \frac{a}{c} = 0.13 \]
characteristic load-carrying capacity
\(~ 500\ N/mm²\)
(to Z-34.14-209)

The related rib-factor \( f_R = \frac{a}{c} \), which is known for deformed rebars, determines the ranking list in shear load transfer.
e.g. \( f_R = 0.13 \) for a hollow TITAN 30/11 - This figure is better than that of a GEWI rebar with \( f_R = 0.074 \)
Significant differences in shear bond

TITAN 30/11
reinforcing steel thread
(thread to DIN 488 / ASTM-A 615)

TITAN R 32/15
drilling thread
(R-Thread to ISO 10208)

relation of cross section \( \frac{A_c}{A} \geq 0,85 \)

\( A_c \) = cross section of cement
(without steelbar)

\( A \) = total cross section of the micropile

for steel quality \( f_y \leq 500 \text{ N/mm}^2 \)

all cracks (fissures) are smaller \( \leq 0,1 \text{ mm} \)

Splitting force in cement is

3 x bigger \( \left(3 \sim \frac{tg \ 45^\circ}{tg \ 17^\circ}\right)\)

thus the cement stone cover must be

3 x bigger for R-threads than for TITAN threads.

Cracks \leq 0,2 – 0,3 mm [Wichter, Hosp]

Cracks reaching the surface can cause dangerous axial cracks and damage corosions protection!
Conclusion:

R-thread does not comply with the requirements of international reinforcing steel standard. (ASTM A 615, EN 10080, DIN 488)

Additional corrosion protection – e.g. galvanising, sacrificial losses – need to be considered.

However galvanising of sacrificial losses are not allowed in Germany (DIBt) and some other countries.

Therefore R-thread finds acceptance only for temporary tunnelling applications or less than 7 – 50 years life time, depending on ground conditions. [ETA-08/0277 MAI]
Bond Test (Pull Out Test)

Pull out tests were carried out according to RILEM/CEB/FIP Recommendation RC 6. For the tests, two types of grout were used, C25/25 and C35/45.

TITAN drilled micropiles can be designed same as rebar. No limitation in bonded length due to the stiff shearbond.

No limitation in bonded length, as known with strand anchors. Deformations of TITAN bars fulfill requirements of ASTM A 615.
Load transfer by the grout cover

Calculation Model for Circular Forces $R$ caused by Shear Bond and Squeezing

TITAN DRILLED MICROPILES in Tension

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<thead>
<tr>
<th>Cementstone Cover C [mm]</th>
<th>Type</th>
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<tbody>
<tr>
<td></td>
<td>40/20</td>
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<td>35</td>
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TITAN DRILLED MICROPILES in Compression

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<th>Cementstone Cover C [mm]</th>
<th>Type</th>
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<td></td>
<td>40/20</td>
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<td>30</td>
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acc. Z - 34.14-209

Necessary Length $0 - 1$ for Load Transfer $F$ from Tendon to Grout Body

Circular Forces $R$ in Grout Body, caused by...
- Squeezing (Difference in Poisson figure)
- Shear Bond

Circular Force $R$ has to be balanced:
By the cross section of cementstone cover $C$ and the tension stress of cementstone e.g. $f_t = 3$ N/mm²
Stress/Strain Diagram for typical Anchor Steels

- Prestressed Strand, 0.6" high yield St. 1570/1770
- Threadbar® Prestressing Steel Grade 126 St.900/1000
- Risk of stress-strain corrosion above 800 N/mm²
- Yield Limit of steel and cement
- Total Elongation Agt %
- Ductility: Reserves for Overloading
- Useable section up to yield
A typical stress-strain diagram of cold formed steel tendons shows the **Bauschinger Effect**.

**Bauschinger Effect** means, that the stress–strain graph line is curved, not linear as it should be, according to Hooke and therefore the yield stress is reduced.
Fatigue (Wöhler-Diagram) of coupled steel-tendons under cyclic loading, such as changing from compression to tension.

Fatigue by cyclic loading is reduced using a TITAN micropile with a coupler without counter nuts. The coupler is double locked by a self locking thread (friction angle < tg 6°) and additional Prestressed by the torque of the drill hammer during connection.

Load-Displacement-Curves for a Coupler TITAN 103/78

Loading with ± 1000 kN within 3 seconds of changing from compression to tension.
Fatigue (Wöhler)-Diagram for micropiles TITAN 103/78
Oscillating Stress versa Number of Load Cycles

Legend:
1 One Point of Wöhler-Line really tested with 2 x 10^6 cycles and 70 N/mm²
2 $\Delta \sigma_D$ Permanent stress for 5 x 10^6 cycles
3 $\Delta \sigma_L$ Final resistance

Example for application of Wöhler-Diagram
Low cycle fatigue in case of seismic events according ISO-DIS 15835-2

Question:
How many cycles are allowed for cyclic loading of ± 1000 kN without damage or reduction in resistance?

$2 \times \sigma_R = \frac{2 \times 1000 \, kN}{3140 \, mm^2} = 637 \, N/mm^2$

According to Wöhler diagram (green line)

$N = \frac{70^3}{637^3} \times 2 \times 10^6$ cycles
$N_{max} = 2655$ cycles $< 3000$ cycles, which was verified by tests.

Further Applications:
Foundation of wind-turbines,
Foundation for noise-barriers along high speed rail-lines.
Bridge foundation

The micro system achieved near uniform resistance and displacements in inhomogenous ground conditions.
Retaining Wall

Permanent Tiebacks (passive anchors), without prestressing.
Cutted slopes in road construction

A steep cut slope constructed using soil nails (micropiles), with a soft face, environment friendly
Track widening for high speed railways

Soil nailed slope with both a soft facing and a hard structural sprayed concrete finish
Foundation for transmission pylons, communication towers and gantries

Drilled TITAN micropiles, are used due to the high axial stiffness and small displacement required without prestressing. The same installation method can be used for schemes with varied ground conditions, which improves the logistics of the project.
Underpinning existing bridge foundations

One of the first applications, because of the extreme stiff axial load transfer of micropiles.
Deep excavation – Anchored sheetpile walls and anti-buoyancy anchors
Back to the roots

New HILTI electric powered drill-hammer - weight ab. 23 kg (50 lbs), 2,2 kw – for hand installation of TITAN drilled micropiles in mining and limited space.
Thank you for your kind attention!

Thank you for your kind attention!