MICROPILES: HISTORY

- Early 1950’s in Italy – Conceived to underpin historic structures and monuments damaged in WW II.
- 1952 - Palo Radice (Root Pile) patented by Fondedile (Dr. Fernando Lizzi).

Figure 1-2. Classical Arrangement of Root Piles for Underpinning. (FHWA NHI-05-039)
MICROPILES: HISTORY

• 1970 – Fondedile Corp. established in US.

• 1972 – First use of Root Piles in US (Illinois).

• 1980 to 90 – Decline and Closure of Fondedile in US.

• Early 1980’s - Big “Push” by East Coast Contractors.

Figure 1-3. Typical Network of Reticulated Micropiles. (FHWA NHI-05-039)
MICROPILES: HISTORY

- 1989 – Loma Prieta & Start of Micropile Seismic Retrofits on West Coast.
MICROPILES: HISTORY

- 1997 – International Workshop on Micropiles (IWM) Founded
- 2002 – ADSC develops FHWA/NHI Course
- 2005 – International Society of Micropiles (ISM) Founded

Dulles Town Center Underpinning
(Photograph courtesy of Dennis Triplett LLC)
14.528 DRILLED DEEP FOUNDATIONS
Micropile Design and Construction

DEEP FOUNDATION CLASSIFICATIONS

Figure 8.1. FHWA NHI-05-042
Design and Construction of Driven Pile Foundations Volume I.
# Deep Foundations: Micropiles (A.K.A. Mini, Pin)

## Table 8-1. FHWA NHI-05-042 (from NAVFAC DM7.02).

<table>
<thead>
<tr>
<th>Pile Type</th>
<th>Micropiles</th>
<th>Typical Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Lengths</td>
<td>12 m - 25 m (40 - 100 ft)</td>
<td></td>
</tr>
<tr>
<td>Material Specifications</td>
<td>ASTM C150 - for Portland cement.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASTM C595 - for blended hydraulic cement.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASTM A615 - for reinforcing steel.</td>
<td></td>
</tr>
<tr>
<td>Typical Axial Design Loads</td>
<td>300 kN - 1100 kN (70 - 250 kips)</td>
<td></td>
</tr>
<tr>
<td>Disadvantages</td>
<td>• Cost</td>
<td></td>
</tr>
<tr>
<td>Advantages</td>
<td>• Low noise and vibrations.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Small amount of spoil.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Excellent for sites with low headroom and restricted access.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Applicability to soil containing rubble and boulders, karstic areas.</td>
<td></td>
</tr>
<tr>
<td>Remarks</td>
<td>• Can be used for any soil, rock or fill condition.</td>
<td></td>
</tr>
</tbody>
</table>

**FHWA NHI-05-039**
Typ. < 12 inch dia.
A micropile is a small-diameter (typically less than 12 in.), drilled and grouted non-displacement pile that is typically reinforced.
MICROPILE APPLICATIONS

- Restricted access or is located in a remote area
- Required support system needs to be in close proximity to existing structures
- Supplemental Existing Structure Support (e.g. Settlement)
- Difficult ground conditions (e.g., karstic areas, uncontrolled fills, boulders)
- Pile driving would result in soil liquefaction (dubious)
- Vibration and/or noise needs to be minimized
- Hazardous or contaminated spoil material will be generated during construction
- Adaptation of support system to existing structure is required
- Scour

After FHWA NHI-05-039
Figure 3-5. Micropiles for Foundation Support of Transportation Applications. (FHWA NHI-05-039)


MICROPILE LIMITATIONS

- Buckling (Seismic and Liquefaction).
  - High Slenderness Ratio
- Lateral Capacity
- Limited experience in their use for slope stabilization
- Requires good QC / QA
- Cost.
  - Not cost effective vs. conventional piling systems in open headroom conditions
  - High lineal cost relative to conventional piling systems
  - Requires specialized equipment

After FHWA NHI-05-039 & ADSC
FHWA CLASSIFICATION SYSTEM

Based on two (2) Criteria

1. Philosophy of Behavior (Design)

2. Method of Grouting (Construction)

Figure 2-1. CASE 1 Micropiles. (FHWA NHI-05-039)
CASE 1: Micropile loaded directly and micropile reinforcement resists the majority of the applied load.

- Primary resistance provided by steel reinforcement and side resistance over bond zone.
- >90% of ALL North America Projects are CASE 1.

Figure 2-3. CASE 1 Micropile Arrangements. (FHWA NHI-05-039)
CASE 2: Networks of reticulated micropiles as components of a reinforced soil mass which is used to provide stabilization and support.

- Lightly reinforced.
- Structural loads to entire soil mass.
- Design methods “Iffy”.

Figure 2-2. CASE 2 Micropile Arrangements. (FHWA NHI-05-039)
FHWA Classification System

Method of Grouting (Construction)

Type A: Neat cement or sand-cement cement grout placed under gravity.

Type B: Neat cement grout injected into drill hole under pressure (72-145 psi), while withdrawing temporary drill casing or auger.

Type C: Two-Step Process.
- Neat cement grout under gravity (Type A).
- After 15-25 minute, Sleeved grout pie w/o packer (>145 psi).

Figure 2-5. Grouting Methods. (FHWA NHI-05-039)
**Type D: Two-Step Process**
- Neat cement grout placed under gravity (Type A & C) or pressurized (Type B)
- Full Hardening of grout (15-25 minutes)
- Pressure grouted through sleeved grout pile (260-1160 psi)

*Figure 2-5. Grouting Methods.*
(FHWA NHI-05-039)
**AASHTO Classification System**

**Method of Installation**

**Type E:** Hollow Bar Drilling with Grout Injection.
- “Injection Bore Bars”
- “Self Drilling”

Figure courtesy of Geosystems LP (after FHWA and AASHTO).

Revised 9/2012
AASHTO Classification System

Method of Installation

Type E: Hollow Bar Drilling with Grout Injection.

- TITAN IBO Example
TYPE E MICROPILES

EXHUMED TITAN IBO MICROPILES

Figures courtesy of Con-Tech Systems Ltd.
FHWA Classification System Method of Grouting (Construction)

Table 2-1. Details of Micropile Classification Based on Type of Grouting (after Pearlman and Wolosick, 1992). (FHWA NHI-05-039)
MICROPILE APPLICATIONS: TRANSPORTATION

Table 3-1. Relationship Between Micropile Application, Design Behavior and Construction Type (modified after FHWA, 1997).

(FHWA NHI-05-039)

<table>
<thead>
<tr>
<th>Application</th>
<th>Structural Support</th>
<th>In-Situ Earth Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underpinning of Existing Foundations</td>
<td>Slope Stabilization and Earth Retention</td>
<td>Ground Stabilization and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Earth Retention</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ground Stabilization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Settlement Reduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Structural Stability</td>
</tr>
</tbody>
</table>

| Design Behavior                          | CASE 1                                                 | CASE 1 and CASE 2          |
| Construction Type                        | CASE 2 with minor CASE 1                               | CASE 2                     |
| Frequency of Use                          | Probably 95 percent of total world applications        | 0 to 5 percent              |
MICROPILE APPLICATIONS: TRANSPORTATION

Figure 3-3. Protection of an Existing Diaphragm Wall with a Secant Micropile Screen using Anti-acid Mortar (after Bachy, 1992). (FHWA NHI-05-039)

Figure 3-13. Slope Stabilization at FH-7 Project in Mendocino National Forest, California. (FHWA NHI-05-039)
MICROPILE CONSTRUCTION: DRILLING

Figure 4-1. Typical Micropile Construction Sequence Using Casing.
(FHWA NHI-05-039)
MICROPILE CONSTRUCTION: DRILLING

- Rotary only
- Drifter, Rotation/Percussion
- Double Head Systems
- Sonic Head

Figures Courtesy of ADSC.
MICROPILE CONSTRUCTION
OVERBURDEN DRILLING

Table 4-1. Overburden Drilling Methods (after Bruce, 1989). (FHWA NHI-05-039)

<table>
<thead>
<tr>
<th>Drilling Method</th>
<th>Principle</th>
<th>Common Diameters and Depths</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Single-tube advancement</td>
<td>Casing with “lost point” percussed without flush</td>
<td>50-100 mm to 30 m (2-4 in. to 100 ft)</td>
<td>Obstructions or very dense soil problematic.</td>
</tr>
<tr>
<td>a) Drive drilling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) External flush</td>
<td>Casing, with shoe, rotated with strong water flush</td>
<td>100-250 mm to 60 m (4-10 in. to 200 ft)</td>
<td>Needs high torque head and powerful flush pump.</td>
</tr>
<tr>
<td>2 Rotary duplex</td>
<td>Simultaneous rotation and advancement of casing plus internal rod, carrying flush. Rod may have down-the-hole hammer</td>
<td>100-220 mm to 70 m (4-8.75 in. to 230 ft)</td>
<td>Used only in very sensitive soils/site conditions. Needs positive flush return. Needs high torques. (Internal flushing only)</td>
</tr>
<tr>
<td>3 Rotary percussive concentric duplex</td>
<td>As 2, except casing and rods percussed as well as rotated.</td>
<td>89-175 mm to 40 m (3.5-7 in. to 130 ft)</td>
<td>Useful in obstructed/rocky conditions. Needs powerful top rotary percussive hammer.</td>
</tr>
<tr>
<td>4 Rotary percussive eccentric duplex</td>
<td>As 2, except eccentric bit on rod cuts oversized hole to ease casing advance.</td>
<td>89-200 mm to 60 m (3.5-8 in. to 200 ft)</td>
<td>Expensive and difficult system used for difficult overburden. Rod can be percussive at top, or may have down-the-hole hammer above bit.</td>
</tr>
<tr>
<td>5 “Double head” duplex</td>
<td>As 2 or 3, except casing and rods may rotate in opposite directions.</td>
<td>100-150 mm to 60 m (4-6 in. to 200 ft)</td>
<td>Powerful, new system for fast, straight drilling in very difficult ground. Need significant hydraulic power. Casing can be percussed by top hammer. Rod may be percussed by top hammer or may have down-the-hole hammer above bit.</td>
</tr>
<tr>
<td>6 Hollow-stem auger</td>
<td>Auger rotated to depth to permit subsequent introduction of grout and/or reinforcement through stem.</td>
<td>100-400 mm to 30 m (4-16 in. to 100 ft)</td>
<td>Obstructions problematic; care must be exercised in cohesionless soils. Prevents application of higher grout pressures.</td>
</tr>
<tr>
<td>7 Sonic</td>
<td>Casing is excited by a variable frequency, variable amplitude, sonic head</td>
<td>100 to 300 mm to 100 m (4-12 in. to 330 ft)</td>
<td>No or minimal flush needed. Full length sample of soil recovered for each hole.</td>
</tr>
</tbody>
</table>

Note: Drive drilling, being purely a percussive method, is not described in the text as it has no application in micropile construction.
MICROPILE CONSTRUCTION: GROUTING

- High strength and stability (i.e., bleed), but must also be pumpable (Typical w/c ratios in the range of 0.40 to 0.50 by weight).
- Grouts are produced with potable water, to reduce the danger of reinforcement corrosion.
- Type I/II cement conforming to ASTM C150/AASHTO M85 is most commonly used.
- Neat cement-water grout mixes are most commonly used.
- Design compressive strengths of 28 to 35 MPa (4,000 to 5,000 psi) can be attained with properly produced neat cement grouts.
- If admixtures and/or additives are used, it is essential that they are chemically compatible. This is best achieved by using only one chemical supplier, and not by “mixing and matching”.

Figure 4-9. Effect of Water Content on Grout Compressive Strength and Flow Properties (after Littlejohn and Bruce, 1977). (FHWA NHI-05-039)
MICROPILE CONSTRUCTION: GROUTING
Micropile Construction: Drilling

Figures Courtesy of ADSC.
MICROPILE DESIGN

Table 5-1. Design Steps for Micropiles used for Structural Foundations. 
(FHWA NHI-05-039)

1. Identify project requirements and evaluate micropile feasibility
2. Review available information and perform subsurface exploration and laboratory testing program
3. Develop all loading combinations
4. Preliminary design of micropiles
   - spacing
   - length
   - cross section
5. Evaluate allowable structural capacity of cased length
6. Evaluate allowable structural capacity of uncased length
7. Compare design loads to structural capacity from Steps 5 and 6 and modify structural section, if necessary
8. Evaluate geotechnical capacity of micropile
    - evaluate suitable ground stratum for bond zone
    - select bond stress and calculate bond length required to resist design load
    - evaluate micropile group capacity for compression and tension (i.e., uplift)
9. Estimate micropile group settlement
10. Design micropile to footing connection at pile cap
11. Develop load testing program
12. Prepare Drawings and Specifications

Other Design Considerations
1. Corrosion Protection**
2. Plunge Length
3. End Bearing Micropiles
4. Downdrag
5. Lateral Loads on Single Vertical Micropiles
6. Lateral Loads on Micropile Groups
7. Buckling
8. Seismic

** Corrosion protection is a critical component of all micropile designs.

Revised 9/2012