MICROPILES SUBJECT TO LATERAL LOADING

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Las Vegas, NV
April 3-4, 2008

Outline

- When are micropiles subject to lateral load?
- How do we analyze them?
- Load testing
- Case histories
Where are micropiles subject to lateral load?

- Building foundations (earthquake, wind)
- Basement wall foundations
- Retaining wall foundations
- Excavation support
- Tower and stack foundations
- Machine foundations
- Slope stabilization

Why not use another foundation system?

- Other solutions such as caissons or piles are not necessarily better
- Micropiles are installed within tight areas
- Micropiles can be inclined
- Advancing through difficult formations and obstructions
Building foundations

Issues for analysis

- Analysis almost identical to other foundations
- Micropile characteristics
- Fixity of micropile head
- Soil properties
- Pile cap resistance
- Tolerable displacement
- Bending capacity of micropile
- Are batter piles necessary?
Micropile characteristics

- Reinforcement type (casing, bar, etc)
- Inertia and Section Modulus (I, S) of Micropile section
- Grout can be taken into account for composite section modulus
- Consider cracking of grout
- Joints
- Installation (annular space?)

Typical casing

<table>
<thead>
<tr>
<th>THREADED SINGLE CASING</th>
<th>O.D.</th>
<th>WALL</th>
<th>WALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-7/8</td>
<td>.280-500</td>
<td>7</td>
<td>.362-590</td>
</tr>
<tr>
<td>3-1/2</td>
<td>.368-500</td>
<td>7-5/8</td>
<td>.430-500</td>
</tr>
<tr>
<td>4</td>
<td>.330-500</td>
<td>8-5/8</td>
<td>.500</td>
</tr>
<tr>
<td>4-1/8</td>
<td>.430-531</td>
<td>9-5/8</td>
<td>.545</td>
</tr>
<tr>
<td>5</td>
<td>.361-500</td>
<td>10-3/4</td>
<td>.363-545</td>
</tr>
<tr>
<td>5-1/2</td>
<td>.361-500</td>
<td>11-3/4</td>
<td>.545</td>
</tr>
<tr>
<td>6-5/8</td>
<td>.280-500</td>
<td>12-3/4</td>
<td>.500</td>
</tr>
</tbody>
</table>

Star Iron Works manufactures single or multi-use casing with flush tapered threads. Multiple wall thickness available.
Fixity of Micropile Head:
- In caissons, often assumed as 0 to 50%
- In micropiles it should be higher than caissons under equal conditions
- 50% fixity often assumed. 100% fixity could be justified; however, …
- Fixity not only function of connection type. It also depends on superstructure. Ask Structural Engineer.
- Need further research
Fixity of Micropile Head:

- For single micropiles supporting unbraced structures (power pole, cantilever retaining wall, etc), use Free Head condition.
- For single micropiles or small groups supporting framed structures, can achieve 50 to 100%. Ask Structural Engineer.

Quick check on fixity
Quick check on fixity

- Say 7-inch OD casing, t=0.5 inch, Fy = 80 ksi
- Say F’c = 4 ksi concrete
- At yield, My = 1,240 in-kip (no reduction)
- To develop this capacity in the connection, need about 15 to 16 inch embedment
- For ductility, say 20 inch embedment
- Need to add pile cap steel to prevent splitting of concrete

Soil properties

- Soil properties needed depend on analysis method used
- Typically, for sands, need friction angle, unit weight, lateral reaction modulus
- For clays, need undrained strength or cohesion, unit weight, and lateral reaction modulus or ε₅₀
- Results not too sensitive to soil properties
- If lateral response is critical, run load test
Pile cap resistance

- Often significant. Previous studies in caissons report cap resistance as 50 percent or more of overall lateral resistance of foundation system
- Should be considered in many cases
- Do not include if pile cap likely to be exposed (scour, future construction, etc)

Tolerable lateral displacement

- Depends on project requirements
- Often 0.5 to 1 inch
- Really important to establish reasonable deflection tolerances
- Watch for P-Delta effect
P-Δ Effect:

Lateral deflection

Eccentricity

Additional bending

Additional deflection

Available Tools

- Similar analysis procedures as for caissons or piles
- May use Charts and/or simplified procedures (NAVFAC, etc) for simple checks
- Prefer numerical analysis to account for P-Δ effects, changes in section, 3-D effects, pile top fixity
- Lpile, Group, COM624, FLPier, Finite Element, Finite Differences
P-y Curves

\[ P = \sigma \times B \]

B = pile diam.

Pult

Es (lb/in²)

P (lb/in)

y (ln)
Example

Medium Sand
Micropile:
7-inch casing
t = 0.5 inch
Fy = 80 ksi
Free Head

Example

First 5-10 ft critical
Acceptable deflection under 10 kip (~3/4 inch)
20 kip is close to ultimate
For fixed head, deflection <1 inch under 20 kip
Example

Max Moment ~ 400 in-kip at ~5ft
Section Modulus of Casing
S = 15.5 in³
Maximum Stress = 400 in-kip / 15.5 = 26 ksi (0.32 F_y)
OK

Usually, deflection controls for free head condition. Moment often controls for fixed head condition.

Special Considerations for Micropiles

- Remember: Joints!!
- Better specify “no joints” in first 5 to 10 ft
- Remember: Annular space!!
- Better specify grouting outside casing
- Buckling usually not an issue, but should be checked in soft soils
Load Testing

- Predict capacity using Lpile, FL Pier, etc
- Instrument pile if possible (inclinometer)
- Test Free Head Condition. Follow ASTM D3966
- Using the same numerical model, back-calculate soil properties
- Check for problems and inconsistencies using numerical model and test data
- Predict deflection for expected boundary condition in structure (fixed head, 50% fixity, etc)
Load Testing

Load Testing

Test Pile 1 Results
L-Pile calibration for Free-End condition
L-Pile calibration 50% Fixity

Design Load: 10 Kips
Test Load: 20 Kips

Remarks: Lateral Load Test - TP-1
0.43" Thick Wall 80 ksi Steel
4000 psi Grout
2 - 15 ft. long #18 75 ksi Williamsform Bars

SCHNABEL ENGINEERING
Length: 39 ft Date Installed: 7/11/2002 Date Tested: 7/16/2002
ASSOCIATES

SCHNABEL ENGINEERING

Contract No.: DATE

Load (kips) vs. Displacement (in.) chart
Is Lateral Load Response a Problem?

- Verify boundary conditions in analysis (fixity)
- Verify soil properties used for analysis
- Verify units used
- Neglecting pile cap?
- Check through load test (two for the price of one!!)
- Use larger casing
- Use double casing in first 5-10 ft
- Increase number of micropiles
- Introduce batter micropiles
- Use drilled shafts

Crystal Bridges Museum of American Art
Site Location

Crystal Bridges
CRYSTAL BRIDGES

Micropiles under wall
Lateral Load Test
Lateral Load Test

Evidence of lateral deflection
Strain Gauges

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Four Point Bending Test Data (at Threaded Joints)

<table>
<thead>
<tr>
<th>Casing</th>
<th>Maximum Moment (Kip-in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7” – ½” wall (N80)</td>
<td>1120</td>
</tr>
<tr>
<td>7” – ½” wall (N80)</td>
<td>1200</td>
</tr>
<tr>
<td>9 5/8” – ½” wall w/ 7”-½” wall inside (N80)</td>
<td>3000</td>
</tr>
</tbody>
</table>

Typical Comparison

<table>
<thead>
<tr>
<th>Soil f (kN/m³)</th>
<th>Above Ground Water</th>
<th>Below Ground Water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Loose</td>
<td>Medium</td>
</tr>
<tr>
<td>HP 10 x 42, Ei = 17,477 kN·m²</td>
<td>14.2</td>
<td>27.5</td>
</tr>
<tr>
<td>HP 12 x 53, Ei = 32,707 kN·m²</td>
<td>18.3</td>
<td>35.3</td>
</tr>
<tr>
<td>HP 14 x 89, Ei = 75,235 kN·m²</td>
<td>25.5</td>
<td>49.3</td>
</tr>
<tr>
<td>MP 129.7 mm, 9.17 mm wall, Ei = 1,905 kN·m²</td>
<td>5.9</td>
<td>11.3</td>
</tr>
<tr>
<td>MP 177.8 mm, 12.65 mm wall, Ei = 5,237 kN·m²</td>
<td>8.7</td>
<td>17.0</td>
</tr>
<tr>
<td>MP 244.5 mm, 11.99 mm wall, Ei = 15,396 kN·m²</td>
<td>13.5</td>
<td>26.1</td>
</tr>
</tbody>
</table>

Lateral loads (kN) in free-head condition required for 0.25-inch deflection
Buckling Potential

![Graph showing buckling potential with different bars and a check buckling capacity line.]

Cadden and Gómez, 2002

**LPile**

- Use for single micropiles
- Nonlinear soil response modeled through P-y curves
- Linear or nonlinear pile response
- Define free head, fixed head, or rotation magnitude
- Multiple load combinations and boundary conditions
- Group effects not considered. Need to do manually
FLPier

- Best for pile group analysis
- Nonlinear soil response modeled through P-y curves
- Linear or nonlinear pile response
- Define rotational stiffness of superstructure
- May introduce batter
- Very powerful

Slope stabilization
Micropile Installation

Bridge and tower foundations

Courtesy: Fundaciones Franki C.A.
Excavation support

Union Station
Washington, DC

Micropiles for Temporary Excavation Support at Ramp Area

Fixity

Fixed Head?  Free Head?
Ellis Island seawall repair

Concrete Stub Wall on Timber Relieving Platform
Ellis Island seawall repair

1. Fill Voids Underneath Seawall with Concrete
2. Placement of Filter Zone Behind Seawall
3. Installation of Steel Sheet Pile in Front of Seawall
4. Seawall Underpinning with Micropiles