Incorporating Set-Up Into Driven Pile Design and Installation

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Set-Up Overview

• Set-up can provide significant contribution to long-term pile capacity

• Benefits include:
  - Smaller hammers
  - Smaller pile sections
  - Shorter piles
  - Higher capacities
  - More-economical installations

• Benefits of characterizing unit shaft set-up profile:
  - Produce depth-variable criteria, multiple allowable loads
  - Evaluate hammers, sections, capacities, & depths
  - Assign reduced capacities to short or damaged piles (may preclude requiring additional piles)
Soil/Pile Set-Up

- Time-dependant capacity increase
- Predominantly related to increased shaft resistance due to dissipation of driving-induced excess porewater pressures
- Related to pile properties (size and type), and soil properties (composition, strength/relative density, and permeability)
- Empirical relationships limited in applicability
- Site-specific test programs most-valuable to characterize set-up
<table>
<thead>
<tr>
<th></th>
<th>Capacity</th>
<th>Initial</th>
<th>Change</th>
<th>Long-Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geotechnical</td>
<td>Relatively Low</td>
<td>Set-Up</td>
<td>Relatively High</td>
<td></td>
</tr>
<tr>
<td>Structural</td>
<td>Relatively Low (Steel Shell Only)</td>
<td>Concrete Fill</td>
<td>Relatively High (Steel &amp; Concrete Composite Section)</td>
<td></td>
</tr>
</tbody>
</table>
## Pile Type – Structural Capacity

### Marquette South Leg

- Structural capacity derived from both steel (expensive) and concrete (inexpensive)

<table>
<thead>
<tr>
<th>Pile Type</th>
<th>Structural Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 x 0.500 A_s=24.35 in^2</td>
<td>16 x 1.350 A_s=62.13 in^2</td>
</tr>
</tbody>
</table>

### Canal Street Viaduct

- Structural capacity derived only from steel (expensive)
Lake Pointe Tower
Lake Pointe Tower

### Combined Pile Loads from All Sources, tons

<table>
<thead>
<tr>
<th>Distance from Z-Axis, feet</th>
<th>Pile Row Number</th>
<th>0.00</th>
<th>1.00</th>
<th>2.00</th>
<th>3.00</th>
<th>4.00</th>
<th>5.00</th>
<th>6.00</th>
<th>7.00</th>
<th>8.00</th>
<th>9.00</th>
<th>10.00</th>
<th>11.00</th>
<th>12.00</th>
<th>13.00</th>
<th>14.00</th>
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<tbody>
<tr>
<td>22.00</td>
<td>1</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
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<td></td>
<td>2</td>
<td>150</td>
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<td>4</td>
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<td>150</td>
<td>150</td>
<td>150</td>
</tr>
</tbody>
</table>

### Color Legend

- **1**: 360 to 315 Tons
- **2**: 375 to 300 Tons
- **3**: 290 to 275 Tons
- **4**: 250 to 250 Tons
- **5**: 200 to 125 Tons
- **6**: 175 to 25 Tons
- **7**: 150 to 175 Tons

*Based on soil compatibility between steel shell and concrete fill.*
<table>
<thead>
<tr>
<th>Soil Description</th>
<th>Blows / Foot N</th>
<th>Unconfined Compressive Strength, tsf</th>
<th>General Soil Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>FILL: Sand</td>
<td>5 to 28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silty clay, trace sand &amp; gravel with silt seams and layers</td>
<td>8 to 13</td>
<td>1.5 - 3.5</td>
<td></td>
</tr>
<tr>
<td>Clayey silt to sandy silt</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silty clay, little to trace sand &amp; gravel</td>
<td>17 - 29</td>
<td>1.75 - 2.75</td>
<td></td>
</tr>
<tr>
<td>Clayey to silty fine sand</td>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clayey silt, trace to little fine sand, with silt &amp; sand seams</td>
<td>19 - 23</td>
<td>1.5 - 2.5</td>
<td></td>
</tr>
<tr>
<td>Clayey fine sand to sandy clay</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clayey silt, little sand, with sand &amp; clay seams</td>
<td>8 - 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very sandy silt, with sand seams</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine to coarse sand, little silt</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very sandy silt, trace clay</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silty clay, trace to little sand &amp; gravel</td>
<td>28 - 61</td>
<td>2.5 - 4.5+</td>
<td></td>
</tr>
<tr>
<td>Sandy silt, little gravel</td>
<td>88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine sand</td>
<td>55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silt, trace sand &amp; clay</td>
<td>109</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Lake Pointe Tower

• Three different closed-end pipe piles considered:
  - 12.75-inch-O.D. x 0.375-inch wall
  - 14-inch-O.D. x 0.500-inch wall
  - 16-inch-O.D. x 0.500-inch wall

• Test pile program for structure
  - Test piles dynamically monitored at end-of-initial-drive (“EOID”) and beginning-of-restrike (“BOR”)
  - CAPWAPs performed on EOID and BOR data
  - Internally-instrumented static load test
Lake Pointe Tower Test Program

• 7 test piles, 1 statically load tested (16-inch)

• Hammers
  - Installation: Delmag D46-32 single-acting diesel, 107.2 ft-kips (manufacturer’s maximum rated energy)
  - Restrike: GRL APPLE drop hammer, with 20-ton ram, 388 ft-kips maximum energy

• Embedded lengths: 115.8 to 147.3 feet

• EOID penetration resistances: 21 to 69 blows per foot
Lake Pointe Tower - Penetration Resistance vs. Pile Toe Elevation - 16-Inch Piles

Driving Behavior
Lake Pointe Tower - Case-Method Initial Ultimate Capacity vs. Pile Toe Elevation - 16-Inch Piles

CASE-Method Initial-Drive Capacity
EOID CAPWAP Unit Shaft Resistance Profiles
Unit Shaft Set-Up Profile Determination

BOR Unit Shaft Resis.

EOID Unit Shaft Resis.

Unit Shaft Resistance, pounds per square foot

Unit Shaft Resistance, pounds per square foot
Design Unit Shaft Set-Up Profile
Cumulative Shaft Set-Up Profiles
Long-Term Capacity Profile Determination

Case-Method EOID Capacity

Cumulative Set-Up

Estimated Ultimate Capacity, tons

Estimated Ultimate Capacity, tons
Elev. -116: Set-Up is 80% of Long-Term Capacity
Lake Pointe Tower - Required Initial Capacity Profile Determination - 16-Inch Piles - 350 Tons Allowable/700 Tons Ultimate

- Required Long-Term Ultimate Capacity (350 Tons Allowable/700 Tons Ultimate)
- Design Cumulative Shaft Set-Up Profile - 16-Inch Piles
Lake Pointe Tower - Required Initial Capacity Profile Determination -
16-Inch Piles - 300 Tons Allowable/600 Tons Ultimate

- Ultimate Capacity, tons
- Pile Toe Elevation, feet (Milwaukee City Datum)

- Required Long-Term Ultimate Capacity
  (300 Tons Allowable/600 Tons Ultimate)

- Design Cumulative Shaft Set-Up Profile -
  16-Inch Piles

- Required Initial for 600 T (Ultimate) Set-Up
  Pile Toe (Elev. -90)
Lake Pointe Tower - Required Initial Capacity Profile
Determination Example - 16-Inch Piles

Red line: Required Initial Capacity (350 Tons Allowable/700 Tons Ultimate)
Green line: Required Initial Capacity (300 Tons Allowable/600 Tons Ultimate)

Pile Toe Elevation, feet (Milwaukee City Datum) vs. Required Initial Ultimate Capacity, tons
## Depth-Variable Criteria

<table>
<thead>
<tr>
<th>Embedded Depth, feet</th>
<th>Minimum Required Penetration Resistance, blows per foot (bpf)</th>
<th>Hammer Stroke, feet (Highest (#4) Fuel Setting)</th>
</tr>
</thead>
<tbody>
<tr>
<td>From</td>
<td>To</td>
<td>7.0</td>
</tr>
<tr>
<td>90</td>
<td>92</td>
<td>--</td>
</tr>
<tr>
<td>93</td>
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<td>117</td>
<td>119</td>
<td>39</td>
</tr>
<tr>
<td>120</td>
<td>deeper</td>
<td>35</td>
</tr>
</tbody>
</table>
Conclusions

• Set-up can account for significant portion of long-term capacity (up to 80% in case history)

• Accounting for set-up in design offers numerous benefits: smaller hammers, smaller pile sections, shorter piles, higher capacities, and more-economical installations

• Characterizing unit shaft set-up profile allows for depth-variable installation criteria for numerous capacities, and assignment of reduced capacities to short or damaged piles

• EO ID and BOR dynamic monitoring can be used to characterize unit shaft set-up profiles
Conclusions (cont.)

• Estimated initial and long-term capacity profiles can be used to evaluate potential production-pile sections, select allowable loads, estimate installed lengths
Lake Pointe Tower - Estimated Ultimate Capacity vs. Pile Toe Elevation - Northwest Anchor Pile (16-inch)

- Case-Method Initial Capacity
- Cumulative Shaft Set-Up Capacity
- Long-Term Capacity (Initial Plus Cumulative Shaft Set-Up)

Long-Term Capacity Profile
Conclusions (cont.)

• Estimated initial and long-term capacity profiles can be used to evaluate potential production-pile hammers and sections, select allowable loads, estimate installed lengths.

• Approach allows application of separate (different) safety factors to EOID and set-up capacity components.
Long-Term Capacity Profile
Never, ever, anger the backhoe operator.

Any other questions/comments?
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