Analysis of Four Load Tests on Augered Cast-in-Place Piles in the Texas Gulf Coast Soils

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Advantages of ACIP Piles

- Speed of Installation
- High Capacity
- Economic
- Adaptable to Limited Access Areas
- Minimal Vibrations from Installation
- Installation Independent from Soil Conditions
Two Past Areas of Concern

- Soft or loose soil conditions have the potential to result in removal of excessive soils or necking of the pile when using continuous flight auger.
- Perceived lack of quality control because you can’t see what is being installed.
New Trends

- New installation techniques and equipment: robust equipment with automated grout pumping capability

- New quality control and quality assurance techniques
Typical ACIP Pile Installation Rig
Pile Installation

- Drill to required depth
- Begin pumping grout (blow plug)
- Build up grout head around outside of auger
- Withdraw auger at constant rate
- Continue pumping grout until auger tip reaches ground surface
- Pumped volume should be at least 115% to 150% of the theoretical volume
Pile Installation - Completion

- Remove spoils from ground surface
- Clean out and screen top of pile
- Install reinforcing steel or access pipes for sonic integrity logging
- Dip or add grout to establish top of pile grade
Reinforcement Cage Installation
## Applicable Soil Conditions

<table>
<thead>
<tr>
<th>Pile Type</th>
<th>Main Soil Condition</th>
<th>Soil Layer/Pile Diameter Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACIP Pile</strong></td>
<td>Medium dense to very dense sand; soft to hard clay; soft rock</td>
<td>If a loose sand layer is present, diameters should be limited to 24-inch; if the loose sand is more than 20 ft thick the diameter should be limited to 16-inch.</td>
</tr>
<tr>
<td><strong>Partial Displacement ACIP Pile</strong></td>
<td>Loose to dense sand with blow counts less than 50</td>
<td>For any diameter stiff, firm and soft clay layers should not exceed 15 ft, 20 ft and 30 ft thick, respectively.</td>
</tr>
<tr>
<td><strong>Full Displacement ACIP Pile</strong></td>
<td>Loose to medium dense sand with blow counts less than 25</td>
<td>For any diameter stiff, firm and soft clay layers should not exceed 5 ft, 10 and 20 ft thick respectively; dense sand layers should not exceed 10 ft.</td>
</tr>
</tbody>
</table>
# Equipment Specifications

<table>
<thead>
<tr>
<th>Pile Type</th>
<th>Gearbox Torque</th>
<th>Crowd/Gearbox Weight</th>
<th>Drill Rig Horsepower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical ACIP</td>
<td>36,000 ft-lbs</td>
<td>5,000 lbs (wt)</td>
<td>350 hp</td>
</tr>
<tr>
<td>Large/Deep ACIP</td>
<td>88,000 ft-lbs</td>
<td>10,000 lbs (wt)</td>
<td>750 hp</td>
</tr>
<tr>
<td>LHR ACIP</td>
<td>21,000 ft-lbs</td>
<td>3,000 lbs (wt)</td>
<td>200 hp</td>
</tr>
<tr>
<td>Partial Displacement ACIP</td>
<td>150,000 to 180,000 ft-lbs</td>
<td>15 to 20 tons</td>
<td>250 hp</td>
</tr>
<tr>
<td>Full Displacement ACIP</td>
<td>150,000 to 180,000 ft-lbs</td>
<td>15 to 20 tons</td>
<td>250 hp</td>
</tr>
</tbody>
</table>
Design Methods – Summary


- Jardine and Saldivar (1999) observed failure surface away from the pile-soil interface into the native clay – Conservative Design
Mohr-Coulomb Failure Criteria

For Mohr-Coulomb Soil, \( \phi = 0 \) (Vesic, 1972):

- What \( E_u \)?
- What \( u \)?

- Undisturbed?
- Fully Remolded?
- Critical State?
- Other?
O’Neill (2001) – The α method is appropriate for clays using total stress principle. The undrained shear strength, $s_u$, can be easily determined in the lab using UU Triaxial testing.

- TXDOT uses a limiting end bearing resistance of 380 kPa
- Pile tip resistance is neglected in clays.
- At $\Delta = 5\%$ pile dia = 23mm

$Q_T = R_S + R_B$

$R_S = \sum f_{\text{max}} A_S$

$R_B = c N_c A_B = 9 s_u A_B$

The α method, $f_{\text{max}} = \alpha s_u$

$f_{\text{max}} = \text{Peak unit side shear}$

$\alpha = \text{Adhesion factor}$

$s_u = \text{Shear strength (UU, } \phi = 0\text{)}$
The $\beta$ Method, $f_{\text{max}} = \beta \sigma_v'$ ($\beta = K \tan \phi$)
McVay (1994) – The β method is used for sands using effective stress principle including coefficient of lateral earth pressure, K and friction angle φ'.

\[ f_s = p_o' K_s \tan \phi = \beta p_o' \leq 150 \text{ kPa} \]

- \( p_o' \) = average effective vertical stress along the pile
- \( K_s \) = earth pressure coefficient = 1.1
- \( \beta \) = friction factor (0.2 to 1.0)

TXTDOT, limiting side resistance is 100 kPa.

According to FHWA Method, \( \beta \) varies with depth.

\[ \beta = 1.5 - 0.135z^{0.5} \quad 0.2 \leq \beta \leq 1.2 \]
Local Practice - Texas Gulf Coast

- ACIP piles are designed as “Friction Piles”
- Beaumont Formation: Overconsolidated, high plasticity clays and lightly OC sand

Project Soil Properties
- Undrained shear strength- 50 kPa to 280 kPa
- Plasticity Indices = 15 to 44
- SPT N$_{60}$ = 10 to 55 per 305 mm penetration
Geology of Texas Gulf Coast
Four Load Tests on 460-mm Diameter ACIP Piles in Houston, Texas

- 33-Story Residential Tower at 1200 Post Oak Boulevard: Uniform soil profile including fat clays and lean clays – 23m long piles (75 ft)
  Load Test # 1 and # 2
- 30-Story Residential Tower – Dominion Post Oak at 2323 McCue Street: Mixed soil profile including clays and sands – 21m and 26m long piles (70 ft & 85 ft)
  Load Test # 3 and # 4
Boring Logs Showing Site Soils
Full-Scale Pile Load Tests

- Full-scale load tests are routinely conducted to verify the design load as part of foundation design before construction of ACIP production piles.

- Static axial compression load tests on piles are conducted according to ASTM D 1143-94.

**Quick Test**: each load step at 5% of design load maintained for 5-minute, loaded up to design load or capacity of the reaction frame, and unloaded after failure or 25 mm settlement limit
Load Test Setup
Instrumentation
A Happy Camper
LOAD TEST NO. 1

CLAY PROFILE - LOAD TEST #1

Pile Dia = 460 mm
Length = 22.99 m
Quilt = 2870 kN
LOAD TEST NO. 2

Axial Load, KN

Pile Head Movement, mm

CLAY PROFILE - LOAD TEST # 2

Pile Dia = 460 mm
Length = 22.90 m
Quilt = 3050 kN
LOAD TEST NO. 3

MIXED SOIL PROFILE - LOAD TEST #3

Pile Dia = 450 mm
Length = 25.90 m
Q = 3100 kN

Axial Load, KN

Pile Head Movement, mm

Load Test Results
Elastic Compression
Deviation Offset
LOAD TEST NO. 4

MIXED SOIL PROFILE - LOAD TEST # 4
Pile Dia = 460 mm
Length = 21.30 m
Quit = 2590 kN
Ultimate pile capacity was determined for each from load-displacement curve based on Davisson offset limit \((QL/AE + 0.15 + D/120)\).

An end bearing resistance of 60 kN was deducted from the ultimate capacity to determine the side resistance. Load transfer to the soil occurs through the effective pile length. TxDOT limiting tip bearing = 380 kPa
Comparison with FHWA Method:
The $\beta$ value varied from 0.5 to 1.1

Table 1. Measured and predicted ultimate pile capacities with the calculated $\alpha$ values.

<table>
<thead>
<tr>
<th>Pile ID</th>
<th>Pile Diameter (mm)</th>
<th>Pile Length (m)</th>
<th>Ultimate Test Capacity $Q_t$ (kN)</th>
<th>Calculated $\alpha$ values</th>
<th>FHWA $Q_t$ (kN)</th>
<th>$[Q_t]_M/ [Q_t]_P$</th>
<th>$[Q_t]_M/ [Q_s]_P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>460</td>
<td>22.90</td>
<td>2940</td>
<td>0.79</td>
<td>2040</td>
<td>1.44</td>
<td>1.45</td>
</tr>
<tr>
<td>2</td>
<td>460</td>
<td>22.90</td>
<td>3070</td>
<td>0.84</td>
<td>2040</td>
<td>1.50</td>
<td>1.52</td>
</tr>
<tr>
<td>3</td>
<td>460</td>
<td>25.9</td>
<td>3110*</td>
<td>0.75</td>
<td>2225</td>
<td>1.40</td>
<td>1.40</td>
</tr>
<tr>
<td>4</td>
<td>460</td>
<td>21.30</td>
<td>2620</td>
<td>0.72</td>
<td>2020</td>
<td>1.30</td>
<td>1.31</td>
</tr>
</tbody>
</table>

*Test stopped at design ultimate pile capacity and 88% of maximum capacity of the reaction frame.

$[Q_t]_M$ = Measured ultimate pile capacity from load-displacement plot.
$[Q_t]_P$ = Predicted ultimate pile capacity using the $\alpha$ method and the $\beta$ method.
Conclusions

- Side resistance of ACIP Piles in Beaumont Clays is being predicted conservatively.
- Based on the data, the $\alpha$ value ranged from 0.72 to 0.84 with an average of 0.78.
- No appreciable change in the $\beta$ value in sands was observed.
- An $\alpha$ value of 0.75 may be used for design of ACIP in Beaumont Clays.
- Cost of load tests justifies the saving in foundation costs due to the higher pile capacity measured in the load tests.