A DEEP FOUNDATION COMPARISON:
DRIVEN vs BORED PILES

Professor’s Driven Pile Institute
Logan, UT
June 26, 2013

Presented By:

Billy Camp, PE, D.GE
Technical Principal/Vice President
S&ME, Inc.
Charleston, SC
bcamp@smeinc.com
843-884-0005
COMMON DEEP FOUNDATIONS
(US Practice for Support of Structures)

DRIVEN
- Concrete
  - 10”, 12”, 14”, 18”, 24”, 30” and 36” square PSC
  - 36” to 66” Cylinder
- Steel
  - 10”, 12” and 14” HP (16” and 18” now being rolled)
  - 8” to 36”+ pipe (open or closed)
- Wood
  - 7” to 10” tip diameter, L<65’
- Composite
  - PSC top with HP, W, or Pipe section bottom

BORED
- Drilled Shafts
  - 3’ to 12’
- Micropiles
  - 5” to 12”
- Drilled Displacement
  - 14” to 18”
- Continuous Flight Auger (CFA)
  - 12” to 24”
UNIT RESISTANCE

**DRIVEN**

- Displacement or Low Displacement: Stress Increase – strength increase and stiffer response. ✓

- Disturbance: setup - resistance increase with time. ✓
Driven Pile Time Dependency

![Graph showing the relationship between Qb/Qeod and Time Since Installation (days).]
UNIT RESISTANCE

DRIVEN – Cont.

• Disturbance: relaxation – decreased resistance with time. –

• Disturbance: irrecoverable in some formations (e.g., calcareous sands) –

• Construction method effects rarely a factor. ✓
Driven Piles – Installation Method

[Graph showing capacity vs. time for different piles with different hammers.]

Capacity (mobilized), MN

Time Since End of Installation, hrs
UNIT RESISTANCE

DRILLED SHAFTS

• Excavation reduces stresses – strength decrease and softer response.

• Roughness – small scale (concrete vs steel) and larger scale (irregular surface).
UNIT RESISTANCE

DRILLED SHAFTS – Cont.

• Reduced Disturbance: beneficial in some formations (e.g., calcareous sands) ✓

• Construction method effects can be very important. –
Drilled Shaft – Polymer vs Mineral Slurry

Figure 4 Static Load Deflection Response

From Brown et al 2002
Fundamental Difference

• Point of Manufacture
  – Driven Piles: at steel mill, prestressed yard, or wood yard under factory controlled conditions
    • Uniform, consistent product delivered to the site
    • Highly efficient
  – Drilled Shafts: manufactured on site and in place
    • Complex construction process
    • Significant QA/QC requirements in the field
Driven Pile Manufacturing
Driven Pile Construction Equipment

- Crane
- Hammer & Leads
- Powerpack (hydraulic or air hammer)
- Helper Crane (opt.)
Pile Driving Equipment
Drilled Shaft Manufacturing

- Excavation
- Excavation Stability
- Excavation Cleaning
- Steel Reinforcement Fabrication
- Placement of Reinforcing Cage
- Concrete Delivery
- Concrete Placement
Drilled Shaft Construction Equipment

- Drill Rig
- Helper Crane
- Spoil Handling (loader, skip pan, etc.)
- Casing (opt)
- Slurry Handling (opt)
- Cage Erection Template
- Concrete Truck
- Concrete Pump Truck (opt)
Drilled Shaft Construction Process
Consequently...

- Driven piles are generally less expensive
- General contractors can often self-perform with driven piles
- Drilled shafts usually require a specialty foundation subcontractor
- Since drilled shaft QA/QC is all done in the field, oversight & inspection is more complex but critical
Constructability Issues

Driven Piles

• Length revisions are relatively easy (splicing or cut-off of steel piles, cut-off of PSC piles). ✓
• Minimum penetration requirements (e.g., consideration of scour and liquefaction potential, fixity, uplift) may be hard to meet –

Drilled Shafts

• Length revisions are feasible but take time (cage modifications) –
• Minimum penetration requirements are typically not an issue ✓
# Construction Feedback

## Driven Piles
- Driving resistance
- Transferred hammer energy/hammer performance
- Driving stresses
- Pile integrity
- Capacity

## Drilled Shafts
- Auger cuttings
- Observation of bottom cleanliness (sometimes)
- Concrete volume
- Shaft profile/geometry (possible but not widely done)
**Redundancy & Loading Issues**

**Driven Piles – in general**
- Smaller elements
- Lower capacity
- Lower cost
- More elements used
- Highly redundant

**Drilled Shafts – in general**
- Bigger elements
- Higher capacity
- Higher cost
- Fewer elements used
- Little to no redundancy
Integrity & Reliability Issues

**Driven Piles**
- Delivered free of defects
- May be damaged during or infrequently, after installation
- Damage is typically easily detectable – *A Driven Pile is a Tested Pile*
- Repair generally consists of adding a new pile

**Drilled Shafts**
- Defects may occur during construction
- Damage after construction is possible but rare
- Defects are not easily quantified
- Repair is generally very complex
Driven Pile Damage

• Handling

Fix – replace with new pile
Driven Pile Damage

• Driving

Pipe pile toe damaged when trying to penetrate limestone – identified during installation via dynamic testing

*Fix – spud through caprock, switch hammers*

Crack in PSC pile between mudline and water surface – identified during installation via dynamic testing

*Fix – underwater patching w epoxy grout, switch hammers*
Driven Pile Damage

• Post-Installation

Pipe group damaged due to ground movement – confirmed via low strain dynamic testing

Fix – drive H-piles in between broken piles
Low Strain Integrity Testing

PDPI
June 26, 2013 – Logan, UT
Sample PIT Data

PIT Record from a 98-ft long production pile stored on-site (supported on blocks).

PIT Record from a pile laying on the ground with a break at 46 ft.
If unbroken, no velocity increase before 98 ft, which is the pile toe location.
Drilled Shaft Defects

Slide from Dr. Dan Brown
Crosshole Sonic Logging

\[ E = \rho V^2 \]

\[ F'_{c} \approx \text{Constant} \times E^2 \]
Defect or Anomaly

• Drilled Shaft Case History – DOT Project
  – 4.5 ft diameter, 28 ft long shaft (approx 16 cy vol)
  – Dry Method (but Wet)
  – No problems reported on construction logs
Delayed velocity and low energy
Defect: Segregation caused by free-fall placement of concrete through 10 ft of water (as noted by inspector)
Defect or Anomaly

Low Energy/Loss of Signal
Anomaly: Minor segregation/channelization due to bleed water – inconsequential with respect to shaft performance
Detectable by CSL?

Example 4 of Shaft Defects due to the Loss of Workability (Caltrans)
Integrity & Reliability Summary

- Pile problems easily identified via testing
- Repair generally possibly via replacement/supplementation
- Shaft problems often hard to quantify
- Remedy of shaft problems may be very difficult
Vibration Misconception

• *Construction Activities* generate vibrations
• Pile driving often inappropriately penalized because of its consistent auditory alert
• Structures and soil are much more tolerant of vibrations than people
Vibration Criteria

Slide from Ed Hajduk

Upper blue line is most commonly used
Human Perception Thresholds

Formation of hairline cracks in plaster and drywall joints

Approx PPV that will induce 0.01% strain in a very loose sand (Vs of 500 fps)
### Range of Common Residential Criteria and Observed Side Effects

<table>
<thead>
<tr>
<th>Vibration Intensity</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 ips (1.27 cm/s) (12.7 mm/s)</td>
<td>Bureau of Mines recommended guideline for plaster-on-lath construction near surface mines (long-term, large-scale blasting operations, low-frequency vibrations (RI 8507)).</td>
</tr>
<tr>
<td>0.75 ips (1.91 cm/s) (19.1 mm/s)</td>
<td>Bureau of Mines recommended guideline for sheetrock construction near surface mines (RI 8507).</td>
</tr>
<tr>
<td>1.0 ips (2.54 cm/s) (25.4 mm/s)</td>
<td>OSM regulatory limits for residences near surface mine operations at distances of 301-5000 ft. (long-term, large-scale blasting).</td>
</tr>
<tr>
<td>2.0 ips (5.08 cm/s) (50.8 mm/s)</td>
<td>Widely accepted limit for residences near construction blasting and quarry blasting (BuMin Bulletin 656, BuMin RI 8507, various codes, specifications and regulations). Also allowed by OSM for frequencies above 30 Hz.</td>
</tr>
<tr>
<td>5.4 ips (13.7 cm/s) (137 mm/s)</td>
<td>Minor damage to the average house subjected to quarry blasting vibrations (BuMin Bulletin 656).</td>
</tr>
<tr>
<td>9 ips (22.9 cm/s) (229 mm/s)</td>
<td>About 90% probability of minor damage from construction or quarry blasting. Structural damage to some houses. Depends on vibration source, character of vibrations and the house.</td>
</tr>
<tr>
<td>20 ips (50.8 cm/s) (508 mm/s)</td>
<td>For close-in construction blasting, minor damage to nearly all houses, structural damage to some. A few may escape damage entirely. For low-frequency vibrations of long duration, major damage to most houses.</td>
</tr>
</tbody>
</table>

(from Oriard, 1999)
Largest Vibration-Related Claims in Charleston, SC

St. Philips Church: Extraction of drilled shaft temporary casing with vibratory hammer

French Huguenot Church: Pavement demolition with large track-hoe
Driven Piles vs Drilled Shaft
Foundation Selection Case Histories
Indian Inlet River Replacement Bridge
Design Build

Scour concerns – no foundations in inlet

Larger main pier footings = longer span length (expensive)

Two DB teams: winning team used all driven piles, other team used drilled shafts
Indian Inlet River – Cont.

- Skanska: voided 36” sq. PSC piles
- Self-performed
- Higher resistance factor
- Faster
- Less expensive
Main Piers
Boeing 787 Second Assembly Line
Eave Height = 101’

610’ Continuous Truss

16” Thick Floor Slab

460’ Clear Span

Utility Tunnel

Foundation Alternates in Bid Documents

24” Pipe Piles - 2, 3, 4 and 5 pile groups

HP 14 x73 – 2, 4, 5, and 7 pile groups

Lowest Cost Foundation

4’ & 5’ dia. Drilled Shafts

• compressive load ≤ 2300 kips

• uplift ≤ 547 kips

• lateral load ≤ 350 kips
SC 802 – Bridge over Broad Creek
Beaufort, SC

• New bridge adjacent to existing bridge (c. 80s)
• Existing bridge on driven H-Piles and PSC piles
• New bridge design requirements
  – Much larger seismic hazard
• New bridge foundations
  – Driven PSC piles on approaches
  – Drilled shafts at higher bents
Existing Bridge
PARTIAL BRIDGE PLAN

COLLINS ENGINEERS
BEAUFORT COUNTY SOUTH CAROLINA

PDPI
June 26, 2013 – Logan, UT
An existing bridge foundation is shown for information only. Actual conditions of bridge may vary from what is shown from existing bridge plans.

Limits of Subsurface Plan shown on this sheet is based on as assumed 12" F-lng pit depth, or shallower information from the US but it is not a driving record.

It is not anticipated that the contractor will be satisfied with existing bridge foundation during installation of proposed SHP and piles.

Contractor may request design as needed dates from previous construction of bridge and will be responsible for any measures necessary to work around or remove such debris.
Power Plant Expansion

- Major expansion of existing power plant
- All original structure supported on 3’ or 4’ diameter drilled shafts (due to karst concern)
Units 3 & 4
2007 & 2009
$1.4 billion

Unit 2
1983

Unit 1
1995
Sample Profile

G

P-5  P-39  P-6  P-7  P-38  B-104  P-37  P-8  P-36  B-346  B-103  B-249  B-341

PLEISTOCENE SEDIMENTS

Santee Limestone

Black Mingo Formation
Sample Profile

The image contains a detailed geological profile with various stratigraphic units labeled. The profile includes sections marked as 'Pleistocene Sediments,' 'Santee Limestone,' and 'Black Mingo Formation.' The diagram is labeled with various points and depths, indicating the geological layers and their positions along the profile. The profile is oriented with elevation (feet MSL) on the y-axis and approximate distance along the profile (feet) on the x-axis.
Coring Comparison

Previous Methods

Triple-Tube Coring
Coring Comparison – Cont.

**Triple-Tube Coring**

**Previous Methods**
Foundation Design – Part 1

• 3’ or 4’ Diameter Drilled Shafts
• Rock Sockets: $fs=12\text{ksf}$
• 300 ton Design Load
Drilled Shaft Lateral Response

Moment

Shear

Loose Sand/Soft Clay

Santee Limestone
Change Since Units 1 & 2 Design

• New Design Event in Building Code
  – Prior Codes: 10% prob of exceedance in 50 yrs
  – IBC: 2% prob of exceedance in 50 yrs (w 2/3 factor)
Seismic Hazard Differences

Pineville Response Spectra

2/3 of 2% Probability Event

10% Probability Event
Foundation Alternatives

- Larger Shafts
- Ground Improvement
- Driven Piles
  - “Flexible”
  - Reduced Liquefaction Potential
Driven Pile Model

Displacement Piles:
Reduced Liquefaction Potential due to Densification

Santee Limestone
Foundation Design – Part 2

- Driven Piles Bearing on the Santee Limestone
- 14-in. square PSC Piles: 100 Ton Design Load
- 12-in. square PSC Piles: 70 Ton Design Load
- Savings of $6 to $8 million on Unit 3
- Savings of 1 to 2 months on Unit 3
Construction

• 20,000+ PSC piles driven
• 30 piles per rig per day
• PSC Pile Manufacturers: Tekna & Palmetto Pile Driving
• Foundation Costs > $100 million
Summary

Driven Piles
• Simplicity
• Cost
• Reliability

Drilled Shafts
• Capacity
• Geologic Versatility
Thanks for Listening

Billy Camp, PE, D.GE
Technical Principal/Vice President
S&ME, Inc.
Charleston, SC
bcamp@smeinc.com
843-884-0005