CPT Pore Water Pressure Correlations With PDA Rebound to Indentify High Pile Rebound Soils: Case Studies in Florida

By Fauzi Jarushi

Paul Cosentino, Ph.D., P.E.
Edward Kalajian, Ph.D., P.E.
Ryan Krajcik
Project Overview

- Pile Driving Sites throughout Central Florida experience > 1/4 inch rebound during driving: up to 2 inches reported
- Pile Design Capacities & Depths not achieved
- Engineers want to predict this problem during Project Planning and Design Phase
Defining the Problem

Elastic Displacement Following a Hammer Blow

Rebound = $D_{\text{max}} - \text{Set}$
Current Specification

**FDOT Section 455-5.10.3 Practical Refusal**

- 20 blows/inch when hammer at its highest fuel setting
- Less than 1/4 inch rebound per blow
- Stop driving when Engineer determines refusal
Overview of Rebound Sites

High Pile Rebound (HPR) was evaluated at six Central Florida sites:

- Four sites experienced excessive HPR with no or minimal set;
- One site where the pile rebounded, followed by an acceptable permanent set;
- One site where no rebound was noticed.
Research Objective

Develop geotechnical testing processes that allow high pile rebound to be anticipated.

This will avoid:
- damage to piles;
- construction delays;
- pile redesign.
High Pile Rebound History
Summary

- Observed Rebound 0.50 to 1.50 inches;
- High Displacement Piles;
- Rebound Soils: Dense to very dense or Stiff to Hard;
- CPT Pore water pressure >20 tsf (Murrell 2008);
- Soils in the rebound layers typically contained silts and clays;
- Piles were longer than 40 feet;
- Pile driving hammers were single-acting.
Mechanism of Excess Pore Water Pressure during Pile Driving in Saturated Soils

- Bingjian 2011: Excessive pore pressure generated under the tip of the pile was equivalent to 1.25 times effective stress which led to decrease shaft resistance along the pile and tip resistance.

- Eigenbrod (1996): Excess PWP during driving decreased the shaft resistance.

- Robertson et al. (1989): PWP can be extended laterally to a 30-35 pile diameter.

After Eigenbrod (1996)
Jackson et al. (2007) excessive pore pressure developed during the jacking process, reducing the shaft and the tip resistances.

Chen et al. (2001) developed an approach to determine pile movement at the tip and top. The model also included the point and shaft resistances.

Neglected shaft resistance along, pile rebound was large.

Included the effect of shaft resistance, rebound was significantly decreased.
Methodology

Field Tests

- Pile Driving Analyzer (PDA)
- Electrical Cone Penetrometer Testing (CPT)

with pore water measurement $U_2$
Pile Driving Evaluation

- PDA Strain Gage and Accelerometers yield displacement and force versus time.
- Time limited to about 200 milliseconds/blow.
- Evaluated displacement vs. time.
  - Maximum Displacement = DMX
  - Final Displacement = DFN (dSet)
  - pile moves after 200 ms
  - Inspector set (iSet) (blows/ft)
  - PDA Rebound = DMX-iSet
Digital Record of Rebound from PDA Sensors

DMX = max displacement

Rebound = DMX - iSet = 0.89 in

dSet = 0.27 in
iSet = 0.11 in

PDA Recording Time (200 milliseconds)
Site 1: Anderson Street Overpass (Pier 6)

Rebound = 1” followed by no or minimal set

Pile: 24” Prestressed Concrete Piles
Hammer: Delmag D62 single-acting diesel

Foundation were redesigned and replaced with H-Piles
Site 2: SR50 Over SR 436
Rebound = 1” followed by no or minimal set

Pile: 24” Prestressed Concrete Piles
Hammer: Delmag D42 single-acting diesel

Due to refusal (20 blows/in), several piles did not reach design depth
Site 3: I-4/US192 (Ramp CA Pier 6)
Rebound = 1” followed by minimal set

Pile: 24” Prestressed Concrete Piles
Hammer: ICE-20 single-acting diesel
Site 3: I-4/US192 (Ramp CA Pier 7)
Rebound = 0.6” followed by minimal set

Pile: 24” Prestressed Concrete Piles
Hammer: ICE-20 single-acting diesel
Site 3: I-4/US192 (Ramp CA Pier 8)

Rebound = 1.25” followed by no or minimal set;

Pile: 24” Prestressed Concrete Piles
Hammer: ICE-20 single-acting diesel
Site 4: I-4/ Osceola Parkway (Ramp D2)

Rebound = 0.80” followed by minimal set

Pile: 24” Prestressed Concrete Piles
Hammer: ICE-20 single-acting diesel
Site 5: I-4/SR408 Interchange (Ramp B)

Rebound = 0.3 to 0.5” followed by an acceptable set

Pile: 18” Prestressed Concrete Piles
Hammer: D36-32 single-acting diesel
Site 6: I-4/SR417 Interchange

Rebound < 0.25” followed by large undergoing set

Pile: 24” Prestressed Concrete Piles
Hammer: APE D46-42 single-acting diesel
Correlations Between Rebound, inspector Set and CPT Pore Water Pressure
Correlations Between Rebound, inspector Set and Ratio of CPTu pore water pressure and hydrostatic pressure
Conclusions

This study shows the following:

- HPR soils: SC, SM-SC, SM, CL, SP-SM, SP-SC and CH;
- The overburden depth at which HPR occurred was typically greater than 50 ft;
- PWP < 5 tsf Produced rebound of less than 0.25 inches;
- PWP > 5 and < 20 tsf Produced rebound between 0.25 and 0.5 inches followed by an acceptable permanent set;
- PWP > 20 tsf produced rebound larger 0.5 inches followed by unacceptable or minimal permanent set.
Recommendations

The CPTu PWP can be used as a tool to predict HPR problems when driving displacement piles through saturated fine silty sand to sandy silt or clayey sand.

<table>
<thead>
<tr>
<th>CPTu PWP</th>
<th>Potential of High Pile Rebound</th>
<th>Permanent set</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5 tsf</td>
<td>Not expected</td>
<td>Large enough</td>
</tr>
<tr>
<td>&gt; 5 tsf and &lt; 20 tsf</td>
<td>May occur</td>
<td>Acceptable</td>
</tr>
<tr>
<td>&gt; 20 tsf</td>
<td>Will occur</td>
<td>No or Minimal</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENT

The authors gratefully acknowledge the Florida Department of Transportation for their support for this project: Mr. Peter Lai, Dr. David Horhota, MS. Kathy Gray, Mr. Brian Bixler, and Mr. Robert Hipworth.
Thank you

Questions?