Vibration Analysis During Pile Driving

(ALDOT Research Project 930-839R)

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Project Location

Ground Vibrations

Three Measures of Vibration

- Displacement
- Velocity
- Acceleration

Acceleration used in Earthquake Design
Velocity used in Construction Vibrations

- Peak Particle Velocity (PPV)
- Inches per Second (in/sec)

# Vibration Perception/Damage

## Effects of Continuous Vibrations

<table>
<thead>
<tr>
<th>Vibration Level (Peak Particle Velocity)</th>
<th>Human Reaction</th>
<th>Building Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.08 in/sec</td>
<td>Vibration readily perceptible</td>
<td>Upper level for ruins and ancient monuments</td>
</tr>
<tr>
<td>0.1 in/sec</td>
<td>Vibrations begin to annoy people</td>
<td>Virtually no risk of “architectural” damage to normal buildings</td>
</tr>
<tr>
<td>0.2 in/sec</td>
<td>Vibrations annoying to people in buildings</td>
<td>Threshold of “architectural” damage to normal dwelling- houses with plaster wall and ceilings</td>
</tr>
<tr>
<td>0.4-0.6 in/sec</td>
<td>Vibrations considered unpleasant</td>
<td>“Architectural” damage and possible minor structural damage</td>
</tr>
</tbody>
</table>

# Vibration Limits

<table>
<thead>
<tr>
<th>Organization/Jurisdiction</th>
<th>Comments</th>
<th>PPV (in/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Association of State Highway and Transportation Officials (AASHTO 1990)</td>
<td>Historic sites or other critical locations</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Residential buildings, plastered walls</td>
<td>0.2-0.3</td>
</tr>
<tr>
<td></td>
<td>Residential buildings in good repair with gypsum board walls</td>
<td>0.4-0.5</td>
</tr>
<tr>
<td></td>
<td>Engineered structures, without plaster</td>
<td>1.0-1.5</td>
</tr>
<tr>
<td>Federal Transit Administration (FTA 2006)</td>
<td>Buildings extremely susceptible to vibration damage</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>Non-engineered timber and masonry</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Engineered concrete and masonry</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Reinforced-concrete, steel or timber</td>
<td>0.5</td>
</tr>
</tbody>
</table>
## Vibration Limits

<table>
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<tr>
<th>Organization/Jurisdiction</th>
<th>Comments</th>
<th>PPV (in/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>California Department of Transportation (Caltrans 2002)</td>
<td>Upper level for possible damage</td>
<td>0.4-0.6</td>
</tr>
<tr>
<td></td>
<td>Threshold for damage to plaster</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>Ruins and ancient monuments</td>
<td>0.08</td>
</tr>
<tr>
<td>Florida DOT (FDOT 2010)</td>
<td>All construction</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Fresh concrete</td>
<td>1.5</td>
</tr>
<tr>
<td>Iowa DOT (Iowa DOT n.d.)</td>
<td>Project specific specification</td>
<td>0.2</td>
</tr>
<tr>
<td>Louisiana Department of Transportation and Development (Tao and Zhang 2012)</td>
<td>General scenario</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Historic structures or loose sandy soil</td>
<td>0.1</td>
</tr>
<tr>
<td>New Hampshire DOT (NHDOT 2010)</td>
<td>Modern Homes</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Older Homes</td>
<td>0.50</td>
</tr>
</tbody>
</table>
Project Location

Soil Conditions

Water Table at 3 ft.

Approximately 600 ft.
- Soils were similar

<table>
<thead>
<tr>
<th>Depth (ft.)</th>
<th>Basic Material</th>
<th>Average Blow Count (N)</th>
<th>Consistency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-23.5</td>
<td>Sand</td>
<td>12</td>
<td>Loose to Medium</td>
</tr>
<tr>
<td>23.5-89.5</td>
<td>Sand</td>
<td>31</td>
<td>Medium to Dense</td>
</tr>
<tr>
<td>89.5-108.5</td>
<td>Clay</td>
<td>28</td>
<td>Stiff to Very Stiff</td>
</tr>
<tr>
<td>108.5-115</td>
<td>Sand</td>
<td>27</td>
<td>Medium</td>
</tr>
</tbody>
</table>

## Piles

The image shows a pile cross-section with dimensions labeled. Below is a table summarizing the cross-sections, materials, and lengths:

<table>
<thead>
<tr>
<th>Cross Section</th>
<th>Material</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>36” Square</td>
<td>Precast Concrete</td>
<td>89 ft</td>
</tr>
<tr>
<td>HP14x117</td>
<td>Steel</td>
<td>106 ft</td>
</tr>
<tr>
<td>HP12x53</td>
<td>Steel</td>
<td>70 ft</td>
</tr>
</tbody>
</table>

Pile Installation

• Concrete Pile:
  – Jetted to ~30 feet
  – Driven to ~79 feet
  – Delmag Model D-62-22 Diesel Hammer (~79,000 ft-lbs of energy)

• Steel H-Piles:
  – Vibrated to ~55 feet for HP 14 and ~15 feet for HP 12
  – Driven to ~96 feet for HP 14 and ~60 feet for HP 12
    ▪ APE Model D30-42 Diesel Hammer (~67,000 ft-lbs of energy)
Vibration Monitoring
Vibration Monitoring Results

- Largest Peak Particle Velocity (PPV) from 36” Concrete Pile (0.82 in/sec)
  - PPV dissipated to 0.15 in/sec at 150 feet
- Vibration levels from steel piles were generally low
  - Increase in vibration level from 100 to 150 feet for H-Piles

<table>
<thead>
<tr>
<th>Vibration Source</th>
<th>50 feet</th>
<th>69 feet</th>
<th>100 feet</th>
<th>150 feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>36” Concrete Pile</td>
<td>0.82</td>
<td>0.54</td>
<td>0.28</td>
<td>0.15</td>
</tr>
<tr>
<td>HP14x117</td>
<td>0.18</td>
<td>-</td>
<td>0.09</td>
<td>0.11</td>
</tr>
<tr>
<td>HP12x53</td>
<td>0.23</td>
<td>-</td>
<td>0.07</td>
<td>0.08</td>
</tr>
</tbody>
</table>

All results are peak particle velocity (PPV) in inches per second (in/sec)
Vibration Monitoring Results

Distance (feet)

PPV (in/sec)

36 inch Concrete Pile

Steel H-Piles
Vibration Monitoring Results

Threshold for damage risk to modern structures

Vibrations annoying to people

Threshold for damage risk to sensitive structures

Vibration Damage

- PPV of 0.82 in/sec from 36” concrete pile could potentially cause damage
  - Vibration measured at 50 feet from pile
- PPV at 150 feet (0.15 in/sec) below potential risk level for architectural damage
Vibration Prediction

• Several methods used to predict vibrations

• Can be based on:
  – Horizontal Distance from Pile
  – Soil Conditions
  – Pile Depth
  – Hammer Energy

• Prediction model based on equation presented by Hendriks (Hendriks 2002)

\[ V = V_0 \left( \frac{D_o}{D} \right)^K \]

where:

\begin{align*}
V & = \text{PPV at distance } D \text{ from the pile} \\
V_0 & = \text{PPV at distance } D_o \text{ from the pile} \\
K & = \text{Vibration attenuation parameter} \\
& \quad \text{(determined experimentally)}
\end{align*}
Vibration Prediction

• Prediction equation based on maximum PPV from 36” Concrete Pile

\[ V = 0.15 \left( \frac{150}{d} \right)^{1.6} \]

Where: \( V = \text{PPV (in/sec)}, \ d = \text{distance from pile (ft)} \)

• Prediction equation based on maximum PPV from HP 12x53

\[ V = 0.23 \left( \frac{50}{d} \right)^{1.6} \]

Where: \( V = \text{PPV (in/sec)}, \ d = \text{distance from pile (ft)} \)
Vibration Prediction

Concrete Pile

$$PPV = 0.15 \left( \frac{150}{d} \right)^{1.6}$$

$$R^2 = 0.988$$

H-Pile

$$PPV = 0.23 \left( \frac{50}{d} \right)^{1.6}$$

$$R^2 = 0.945$$
Conclusions

• Maximum vibrations from 36” concrete pile
  – 0.82 in/sec at 50 feet; 0.275 in/sec at 100 feet; 0.15 in/sec at 150 feet

• Maximum vibrations are potentially damaging at 50 feet

• Vibration levels at 150 feet have little to no risk of damage to adjacent structures

• Vibration Prediction Equations
  – Vibration attenuation parameter (k = 1.6)
  – Equation reported by Hendriks fit data well
  – Equation under predicted vibrations at 150 feet for H-Pile

• Need in Alabama for a comprehensive Construction Vibration Specifications
Questions

References


FDOT. *Standard Specifications for Road and Bridge Construction*. Florida Department of Transportation, 2010.


Iowa DOT. *Special Provisions for Vibration Monitoring (Multiple)*. Iowa Department of Transportation, n.d.
