Pile Driving and Barotrauma Effects

AASHTO – SOC
Louisville, KY

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California Division
Transportation Needs

- Capacity
- Strength
- Constructability
Constructability

- “Biddable” & “Buildable”
- 100% Complete PS&E
- Defined Scope of Work
- Defined Work Area
  - ESA’s-Environmental Sensitive Area’s
- Avoid Dictating Contractors Operations
- Allow Contractors Innovation to Meet Specs/Plans
- Minimize Change Orders & Claims
  - May Effect Dollars and/or Time
Pile Types

- Large Diameter Steel
- Timber Piles
- Small Diameter Ø & “H” Piles
- Concrete Piles
Hammer Types

Hydraulic Hammer

Diesel Hammer

Drop Hammer

Vibratory Hammer
Project Developer’s Reality?

Environmental Requirements

Project by 
Project by
Project by
Project Developer

Scope, Schedule, Budget

Consistent 
Project by 
Consistent 
Programmatic

Impact Assessment and 
Mitigation Methodology

Timely 
Timely

Responsible 
Responsible

Protective 
Protective

Economical 
Economical

Biddable 
Biddable

Buildable 
Buildable

Predictable 
Predictable

Quality 
Quality
Regulator’s Reality?

Watch-Dog Groups
(3rd Party Law Suites)

“Best Available Data”

Regulator

Project Proponents
(History/Agendas)

Conservative

Responsible

Protective

Concern

Continued Existence

Uncertainty

Comfort Level
Regulatory Requirements

- Endangered Species Act (Section 7)
- Other Federal and State Laws
Endangered Species Act

- Take
- Harm
- Harassment
New Benicia Bridge – Construction

- Footing Plan
  - Pier Wall
  - 8’ Diameter CIDH Piling with Steel Casing

- Benicia
- Carquinez Strait
The Birds Descend

Construction Halted Immediately!!!!

Photo by Bud Abbott
Case Studies - Bridges

- SFOBB – CA
- Richmond-San Rafael – CA
- Woodrow Wilson – MD
San Francisco-Oakland Bay Bridge East Span (SFOBB)

- Mitigation Plan in Design
- Noise Target Value
  - 180 dB re1µPa peak at 10 m
Richmond-San Rafael Bridge

- Seismic Retrofit
- Most of Piles Driven Prior to Issue Identification
- Some Delay and Cost Increase
- Differing Site Conditions
Woodrow Wilson Bridge

- Identified During Construction
- Noise Level - 208 dB re 1µPa peak
Majority of Energy Dissipation Through Soil Resistance

- Young Bay Mud
- Merritt/Posey Sands: Dense To Very Dense Sand With Clay Layers

Airborne Noise Compression Waves

Water

Very Stiff Clays With Dense Sand Layers

Pile Tip Elevation

Dense To Very Dense Sand With Clay Layers
## Typical Underwater Sounds

<table>
<thead>
<tr>
<th>Source</th>
<th>Sound Level dB (re 1 μPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 kg high explosive (100m)</td>
<td>240</td>
</tr>
<tr>
<td>Beluga Whale Echolocation call (1m)</td>
<td>220</td>
</tr>
<tr>
<td>Airgun Array (100m)</td>
<td>200</td>
</tr>
<tr>
<td>Large Ship (100m)</td>
<td>180</td>
</tr>
<tr>
<td>Fin Whale Call (100m)</td>
<td>160</td>
</tr>
<tr>
<td>Beluga Whale Threshold (1 kHz)</td>
<td>140</td>
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<tr>
<td>Ambient, Moderate Waves</td>
<td>120</td>
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<tr>
<td>Seal Threshold (1 kHz)</td>
<td>100</td>
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<tr>
<td>Ambient, Glassy &amp; Calm</td>
<td>80</td>
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<tr>
<td>Beluga Whale Threshold (30kHz)</td>
<td>60</td>
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<tr>
<td>Beluga Whale Threshold (1 kHz)</td>
<td>40</td>
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<tr>
<td>Ambient, Glassy &amp; Calm</td>
<td>20</td>
</tr>
<tr>
<td>Beluga Whale Threshold (30kHz)</td>
<td>0</td>
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</tbody>
</table>
Sound Pressure Wave Forms & Impacts to Fish
(Not To Scale)

Explosions
Pile Driving
Continuous
Boyle’s Law

Under conditions of constant temperature and quantity, there is an inverse relationship between the volume and pressure for an ideal gas.

\[ p_1v_1 = p_2v_2 \]
Organ Systems Affected by Barotrauma

Swimbladder

Heart
Baroeffects

- Barotrauma
  - Physical Injury
    - Swim Bladder Rupture
    - Rectified Diffusion
- Baroeffects
  - Behavior Altered
    - Swim Patterns Affected

Gill & Vent Bleeding
Assumed Fisheries Bioacoustic Impact Zones

- Temporary Threshold Shift
- Permanent Threshold Shift
- Delayed Mortality Shift
- Immediate Mortality
- Pile
New Benicia-Martinez Bridge Project
Harmful Sound Levels

- Noise Thresholds:
  - Benicia and SFOBB: 180 dB re 1μPa
  - Woodrow Wilson Bridge: 208 dB re 1μPa
  - Yakima Bridge: 218 dB re 1μPa

- Comparable Sound Levels:
  - Ambient/Calm: 60 dB re 1μPa
  - Large Ship @ 100m: 100 dB re 1μPa
Project Impacts

- Delays
  - Benicia - 6 months
  - Extra Project Requirements

- Costs
  - Benicia - $135 Million
  - Average = $10,000/pile
Considered Mitigation Measures

- Avoidance of Migration Times
- Scare Charges
- Strobes
- Electric Seine
Preferred Mitigation Measures

- Driving During Slack Current
- Cofferdams
- Air Bubble Curtains (ABC)
Why Steel Shell Piles?

- Superior Structural Properties Max Effect/Min Material ...Cost Effective Solution
  - Material Properties (Tough, Predictable Behavior)
- Minimum Footprint
- Ease of Construction (Drive-ability)
- Scour Protection
- Armor (Fendering, Corrosion Protection)

No Structural Alternative!
Driving Windows

- Species Present
- Currents

![Graph showing tidal patterns and time of high and low tides.](image)
Cofferdams

- Use Air for Attenuation
- Most Effective – 15-35+ dB Reduction
- Depth Limitations
- Costs
Air Bubble Curtains (ABCs)

- Confined
- Isolation Casing
  - 25-30 dB Reduction
- Gunderboom®
Air Bubble Curtains (ABCs)

- Un-Confined
  - Bubble Rings
    - Single and Multi-level
  - Bubble Tree
- 5-30 dB Reduction
Keys to Successful Operation

- Proper Installation
- Warm Up – 10 minutes
- Monitor Air Pressure Delivery
- Monitor Sound Levels
Conclusions

- Identify Impact to Fish
- Define Sound Pressure Limits
- Improve Mitigation Measures
- Share Information Between States, Contractors, and Countries
Lessons Learned:

- Understand Ramifications of Permit Terms & Conditions
- Meaningful and Measurable Values
- Develop and Follow Monitoring Protocol with Specific Objectives and Controls
- Obtain Incidental Take Authorization to Avoid Unanticipated Work Stoppages
- Avoid Jeopardy; Avoid and Minimize Incidental Take to the Extent Practicable
Federal Highway Administration

2005 Environmental Excellence Award

For Excellence in Ecosystems, Habitat and Wildlife:

Fisheries-Hydroacoustics Mitigation for San Francisco Bay Bridges/
Bioacoustics Workgroup

California Department of Transportation
Federal Highway Administration, California Division
NOAA Fisheries, Southwest Region
Mardi C. Hastings, Ph.D.
Arthur N. Popper, Ph.D.
Illingworth & Rodkin, Inc.
Jones and Stokes, Inc.

Unanticipated impacts to aquatic species from marine pile driving operations for the new east span of the San Francisco-Oakland Bay Bridge led Caltrans and its Federal partners to develop innovative response strategies. With the assistance of expert consultants, Caltrans studied impacts to aquatic species during a pile installation demonstration for the project. Underwater sound pressure waves were monitored, impacts to fish were observed, and the effectiveness of innovative mitigation technologies was evaluated. Caltrans, the FHWA and NOAA Fisheries collaborated to streamline the environmental process through rapid response and emergency consultations on this cutting-edge issue. A highly effective bubble curtain system was developed, that substantially attenuated pile-driving noise, significantly reducing impacts to fish species. The successful results from this and other Bay Area projects led to the formation of the multi-agency Bioacoustic Workgroup. Composed of agency representatives supported by a panel of scientific experts, the Workgroup developed a report that establishes the current national scientific framework and common understanding of hydroacoustic effects on fish. The report also includes recommendations to guide the analysis of pile driving, and suggests further scientific research that will support the development of final protective guidelines for managing and minimizing the effects of pile driving on fish.

Mary E. Peters
Federal Highway Administrator

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Sarah Skeen, FHWA
"Plan for the future, because that is where you are going to spend the rest of your life."

Be determined in achieving your goals...
Always listen to good advice...