A Case Study and Recommendation for Large Diameter FRP Monopile Dolphin Systems

2016 PIANC De Paepe-Willems Award Presentation

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Introduction

Outline

• Case Study
  – Why
  – How

• What Now

• Conclusions

Jamestown-Scotland Ferry
Introduction: Location

- Established 1925
- Operates 24/7
- 1 million vehicles per year
- 4 bi-directional ferry boats
  - 30-70 car capacities
Three part project:

1. Investigate and present alternative replacements
2. Design replacement selected by client
3. Perform construction administrative services (ongoing)
Study: Alternative Dolphins

- Energy absorption
  - Stiffness
  - Strength
- Abrasion resistance
- Installation adaptability
Study: Starting Point

Key Information
1. Vessel impact energy
2. Material Strength
3. Subsurface conditions
4. General Installation

<table>
<thead>
<tr>
<th>Dolphin Position</th>
<th>Slip Velocity (m/s)</th>
<th>Velocity Component (m/s)</th>
<th>Impact Energy (kN-m)</th>
<th>Design Impact Energy (kN-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Cells</td>
<td>2.9</td>
<td>3.8</td>
<td>287</td>
<td>574</td>
</tr>
<tr>
<td>Midpoint</td>
<td>2.4</td>
<td>3.1</td>
<td>194</td>
<td>388</td>
</tr>
<tr>
<td>3/4 Point</td>
<td>1.9</td>
<td>2.4</td>
<td>119</td>
<td>237</td>
</tr>
</tbody>
</table>

1. Energy calc in accordance with PIANC Fender Systems: 2002
2. Factor of Safety (FS) = 2.0
3. Horizontal angle of impact α limited to 30 degrees
Study: Pile Deflection Limit

How much can the dolphin move?
Investigation: Energy Analyses

- Reaction - Deflection
- Rxn-Def Hyperbolic Approx.
- Moment - Deflection

Graphs showing depth vs. reaction and bending moment.
Investigation: Energy Results

Dolphin Force/Deflection Curves for Deep Mudline (EL -10m)

- Design Impact Energy (574 kN-m)
  - Pocahontas impact @ 2.9 m/s with Safety Factor of 2. Expected to occur very rarely.

- Light Impact Energy (119 kN-m)
  - Pocahontas impact @ 1.8 m/s with no Safety Factor. Expected to occur several times per year.

- Timber Cluster Deficiency = 518 kN-m
- Cellular Berthing Fenders (Pair)
- FRP 72" Mono HT_D
- Steel Mono w Donut_D
- FRP 48" Mono CA_D
- FRP 72" Mono HT_D
- Composite Cluster_D

Impact Force on Dolphin (kN) vs Horizontal Deflection of Dolphin at Strike Point (m)
Investigation: Cost Comparison

Lifetime Cost Comparison of Dolphin Systems

(ALL COSTS IN 2016 DOLLARS)

Cumulative System Cost (millions of USD)

Service Life (years)

- Composite Cluster
- 48 inch FRP Monopile
- 72 inch FRP Monopile
- Steel Pile w/ Donut Fender
- Existing Timber

48” FRP Monopile selected
FRP Monopile Summary

Advantages
• Ability to tune stiffness of system to use material efficiently
• Remove need for independent fender system (e.g., donut)
• Reduce pile driving time
  ➔ Lower First Costs
• All polymer system (little to no corrosion)
• Reduced connection hardware and moving parts
  ➔ Lower Maintenance & Lifecycle Costs

Disadvantages
• Few previous installations
• First of its kind system in USA
  ➔ Greater Uncertainty & Inevitable Lessons Learned
Previous Installations
Previous Installations
Design: Strategy

Not too stiff
Not too flexible
Needs to be just right…
Design: Geotechnical Investigation

PMT Pressure vs Radial and Volumetric Strain
Plot to Find Initial Shear Modulus, G₀

\[ y = 639104x^3 - 171924x^2 + 12603x \]

- Volumetric Strain, \( \frac{dV}{V₀} \)
- Radial Strain, \( \frac{dr}{r₀} \)
- Shear Stress
- Poly. (Shear Stress)
Soil Assumptions:
- Virgin vs. Cyclic
- Pseudo-static vs. Dynamic
- Pile Rebound

$p-y$ Curve
Constructed For Input into LPILE Analysis

Soil Resistance, $p$ (kN/cm) vs. Pile Deflection, $y$ (cm)

- Direct Pressuremeter Method (Briaud et al. 1984)
- LPILE Calculated for Stiff Clay, Static
Design: Impact Point

- Mooring Post
- Precast Cap
- HDPE Sleeve
- FRP Pipe Insert
- FRP Shelf
- FRP Pile

4m
Design: Layout

Old vs. New
Design: Phasing of Replacement
Design: Constructability

- Probing
- Void filling
Design: Permitting

- Time Restrictions
- Driving Acoustics
What’s Happening Now

Now: First Phase of Construction

- Install 8 new FRP dolphins, demo 2 existing dolphins
- Contractor Bids
  - Received April 28, 2016
  - $1.7 Million Low Bid (~$210,000 per dolphin, installed)
- In-water Work Begins: September 2016
- Construction Complete: February 2017

Future: Additional Phases

- 10 more new dolphins in Jamestown Terminal
- 18 new dolphins in Surry Terminal
- Total dolphin replacement cost of ~$7.5 Million
  - Expected 10 year repayment period
Conclusions

- FRP monopiles are flexible enough that all impact energy can be absorbed by pile dolphin, making a separate, higher maintenance fender assembly unnecessary for some applications.

- Each new FRP monopile dolphin provides over 10 times the energy absorbing capacity existing 37 timber pile cluster and is more environmentally inert.

- FRP monopiles can be a cost-effective alternative to other steel, composite, and timber systems for midsize ferry vessels.
Thank You

- VDOT Hampton Roads District
  - Capt. Wes Ripley
  - Kristine Martin
  - Aubrey Phillips

- Coauthors/collaborators
  - Pat O’Brien
  - Tom Ripley
  - Cameron Troxel
  - Jeremy Schlussel
  - Bruce English
  - Jeff Basford

- De Paepe-Willems Awards Committee
<table>
<thead>
<tr>
<th>Depth Below Water (m)</th>
<th>Layer Description</th>
<th>N-value (blows per 0.3 m)</th>
<th>Assumed Strength Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 9</td>
<td>Water</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>9 – 15</td>
<td>Silty fine to coarse sand with clay</td>
<td>7 – 30</td>
<td>( \phi = 28^\circ, c = 0 \text{ MPa} )</td>
</tr>
<tr>
<td>15 – 40</td>
<td>Silty clay</td>
<td>14 – 30</td>
<td>( \phi = 0^\circ, c = 0.1 – 0.2 \text{ MPa} )</td>
</tr>
<tr>
<td>40+</td>
<td>Fine to medium sand</td>
<td>30+</td>
<td>( \phi = 36^\circ, c = 0 \text{ MPa} )</td>
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