Corrosion Potential Monitoring for Polymer Composite Wrapping and Galvanic CP System for Reinforced Concrete Marine Piles

David Bailey, Richard Lampo and Vince Hock
U.S. Army Engineer Research and Development Center
Construction Engineering Research Laboratory
<table>
<thead>
<tr>
<th>1. REPORT DATE</th>
<th>FEB 2010</th>
<th>2. REPORT TYPE</th>
<th>3. DATES COVERED</th>
<th>00-00-2010 to 00-00-2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. TITLE AND SUBTITLE</td>
<td>Corrosion Potential Monitoring for Polymer Composite Wrapping and Galvanic CP System for Reinforced Concrete Marine Piles</td>
<td>5a. CONTRACT NUMBER</td>
<td>5b. GRANT NUMBER</td>
<td>5c. PROGRAM ELEMENT NUMBER</td>
</tr>
<tr>
<td>6. AUTHOR(S)</td>
<td></td>
<td>5d. PROJECT NUMBER</td>
<td>5e. TASK NUMBER</td>
<td>5f. WORK UNIT NUMBER</td>
</tr>
<tr>
<td>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</td>
<td>U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory, 2902 Newmark Drive, Champaign, IL, 61822-1076</td>
<td>8. PERFORMING ORGANIZATION REPORT NUMBER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</td>
<td></td>
<td>10. SPONSOR/MONITOR’S ACRONYM(S)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. SPONSOR/MONITOR’S REPORT NUMBER(S)</td>
<td></td>
<td>12. DISTRIBUTION/AVAILABILITY STATEMENT</td>
<td>Approved for public release; distribution unlimited</td>
<td></td>
</tr>
<tr>
<td>15. SUBJECT TERMS</td>
<td></td>
<td>17. LIMITATION OF ABSTRACT</td>
<td>Same as Report (SAR)</td>
<td></td>
</tr>
<tr>
<td>16. SECURITY CLASSIFICATION OF:</td>
<td>a. REPORT unclassified</td>
<td>b. ABSTRACT unclassified</td>
<td>c. THIS PAGE unclassified</td>
<td>18. NUMBER OF PAGES</td>
</tr>
<tr>
<td>19a. NAME OF RESPONSIBLE PERSON</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Abstract:**

Corrosion Potential Monitoring for Polymer Composite Wrapping and Galvanic CP System for Reinforced Concrete Marine Piles

**Subject Terms:**

corrosion, polymer composite, galvanic CP system, reinforced concrete marine piles

**Security Classification:**

Unclassified

**Number of Pages:**

31
Project Sponsors
DoD Corrosion Prevention and Control

• Office of Under Secretary of Defense, Office of Corrosion Policy and Oversight

• Deputy Assistant Secretary of the Army Acquisition Policy and Logistics

• Assistant Chief of Staff for Installation Management

• Headquarters, U.S. Army Installation Management Command
DoD Corrosion Problem

• Piers and wharves
  – Critical facilities
  – $14.5M maintenance costs
  – Reinforced concrete piles

• Aged and deteriorated
  – Rebar corrosion
  – Spalling concrete
Repair Options

- Patching
- Polymeric composite wraps
- Pre-fabricated composite shell with CP
Objective

- Demonstrate and implement innovative technology that provides corrosion protection and impact resistance to reinforced concrete piles in marine environments

- FRP Composite wrap with galvanic CP protection
Demonstration Site
Kawaihae Harbor Dolphin Piers
Demonstration Site

Kawaihae Harbor Dolphin Piers
Pre-Cast Steel Reinforced Concrete Piles

Octagonal - 19 cm face

7 - 13mm Dia. Strands
3 Ga. Spiral, Epoxy Coated
76 mm Clearance Typical
Demonstration Metrics

- FRP composite pile wrapping
  - Field applied, commercially available
  - Underwater installation
  - Splash zone application (2.4 meters)
  - Impact and abrasion resistance

- Galvanic cathodic protection system
  - Integrated anode within wrapped section

- Corrosion potential monitoring
System Design

- Expanded mesh zinc anode
- Composite board compression panels
- Woven glass fiber wrap
  
  - Nominal Thickness: 0.685 mm
  - Tensile Strength: $32.8 \times 10^4$ kN/m$^2$
  - Tensile Load, per ply: 580 kg
  - Comp. Strength: $17.2 \times 10^4$ kN/m$^2$
- Bulk zinc anode
Corrosion Monitoring System

• Silver/silver chloride reference electrodes
  – Three locations per pile
  – Cables protected with PVC conduit

• Remote Monitoring Unit (RMU)
  – Onboard software & data storage backup
  – Instant off, depolarisation measurements
  – PV-powered data transmission

• Shore-side Main Control Unit (MCU)
  – Radio transmission from RMU
  – Data storage
  – Land line accessibility
Dolphin #2 Piles

Monitored Piles:
- Green: No wrap, No CP
- Orange: Wrap, No CP
- Pink: Wrap, bulk CP only
- Blue: Wrap, full CP

Piles with No Monitoring:
- Yellow: Wrap, full CP
- White: No work
System Installation

- Work restricted to low tide
- Interruptions
  - planned
  - Unplanned
- Dive Crew Coordination
Shore Side Preparation

Zinc Mesh Anode / Compression Panels / Electrode Calibration
System Installation

Bulk Zinc Anode Attachment and Surface Cleaning
System Installation

Electrical Continuity & Steel Connections
System Installation

Electrical Continuity & Steel Connections
System Installation

Patching & Securement of Cables
System Installation

Zinc Mesh Anode & Compression Panels
System Installation

Zinc Mesh Anode & Compression Panels
System Installation

Composite Wrap
System Installation
Composite Wrap
System Installation

Electrical Wiring and Monitoring System
System Installation

Electrical Wiring and Monitoring System
System Installation

Electrical Wiring and Monitoring System
System Installation

Commissioning & Performance Monitoring

• Baseline readings of reference electrodes
• Reporting of monthly corrosivity potential data
• 6, 9, 12 and 15 month inspection of RMU / MCU components
• Four-Year evaluation
## Dolphin #3

### Time Zero – Baseline Data

#### Pile #18: Wrap with integrated CP and bulk CP

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Instant On</td>
<td>-0.562</td>
<td>-0.752</td>
<td>-0.433</td>
</tr>
<tr>
<td>Native Potentials</td>
<td>-0.407</td>
<td>-0.444</td>
<td>-0.137</td>
</tr>
</tbody>
</table>

**Current Output**

- **System**: 0.562 amps
- **Bulk Anode**: 0.534 amps
- **Mesh Anode**: 0.270 amps

#### Pile #14 - Wrap with no CP

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Instant On</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Native Potentials</td>
<td>-0.385</td>
<td>-0.508</td>
<td>-0.503</td>
</tr>
</tbody>
</table>

**Current Output**

- **System**: n/a
- **Bulk Anode**: n/a
- **Mesh Anode**: n/a

#### Pile #17: Wrap with bulk CP

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Instant On</td>
<td>-0.349</td>
<td>-0.794</td>
<td>-0.787</td>
</tr>
<tr>
<td>Native Potentials</td>
<td>-0.317</td>
<td>-0.356</td>
<td>-0.370</td>
</tr>
</tbody>
</table>

**Current Output**

- **System**: 0.505 amps
- **Bulk Anode**: n/a
- **Mesh Anode**: n/a

#### Pile #16 - Control, no wrap and no CP

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Instant On</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Native Potentials</td>
<td>-0.629</td>
<td>-0.629</td>
<td>-0.431</td>
</tr>
</tbody>
</table>

**Current Output**

- **System**: n/a
- **Bulk Anode**: n/a
- **Mesh Anode**: n/a
### Dolphin #3
1 Month Data

#### Pile #18: Wrap with integrated CP and bulk CP

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>On</td>
<td>-0.678</td>
<td>-0.878</td>
<td>-0.815</td>
</tr>
<tr>
<td>Instant Off</td>
<td>-0.665</td>
<td>-0.820</td>
<td>-0.761</td>
</tr>
<tr>
<td>IR</td>
<td>0.013</td>
<td>0.058</td>
<td>0.054</td>
</tr>
<tr>
<td>Native Potentials</td>
<td>-0.407</td>
<td>-0.444</td>
<td>-0.137</td>
</tr>
<tr>
<td>Polarisation</td>
<td>0.258</td>
<td>0.376</td>
<td>0.624</td>
</tr>
</tbody>
</table>

**Current Output**
- System: n/a
- Bulk Anode: 0.103 amps
- Mesh Anode: 0.077 amps

#### Pile #14 - Wrap with no CP

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>On</td>
<td>-0.412</td>
<td>-0.484</td>
<td>-0.478</td>
</tr>
<tr>
<td>Instant Off</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>IR</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Native Potentials</td>
<td>-0.395</td>
<td>-0.508</td>
<td>-0.503</td>
</tr>
<tr>
<td>Polarisation</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

**Current Output**
- System: n/a
- Bulk Anode: n/a
- Mesh Anode: n/a

#### Pile #17: Wrap with bulk CP

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>On</td>
<td>-0.638</td>
<td>-0.917</td>
<td>-0.905</td>
</tr>
<tr>
<td>Instant Off</td>
<td>-0.637</td>
<td>-0.909</td>
<td>-0.900</td>
</tr>
<tr>
<td>IR</td>
<td>0.001</td>
<td>0.008</td>
<td>0.005</td>
</tr>
<tr>
<td>Native Potentials</td>
<td>-0.317</td>
<td>-0.368</td>
<td>-0.370</td>
</tr>
<tr>
<td>Polarisation</td>
<td>0.320</td>
<td>0.543</td>
<td>0.530</td>
</tr>
</tbody>
</table>

**Current Output**
- System: n/a
- Bulk Anode: 0.110 amps
- Mesh Anode: n/a

#### Pile #16 - Control, no wrap and no CP

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>On</td>
<td>-0.395</td>
<td>-0.430</td>
<td>-0.478</td>
</tr>
<tr>
<td>Instant Off</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>IR</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Native Potentials</td>
<td>-0.629</td>
<td>-0.629</td>
<td>-0.431</td>
</tr>
<tr>
<td>Polarisation</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

**Current Output**
- System: n/a
- Bulk Anode: n/a
- Mesh Anode: n/a
Conclusions

• An innovative polymer composite pile wrapping system with integrated CP was demonstrated on two structures

• Initial data collection indicates proper operation of CP system

• Data acquisition has posed some preliminary problems. System currently undergoing upgrade