Use of FRP to Strengthen and Repair Marine Structures

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Presented by:
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Presentation Outline

• The marine environment
  – Typical concrete damage
  – Unique challenges
• Fiber Reinforced Polymers
  – FRP wrap and laminates
  – Use on marine structures
• Pile restoration with FRP
• Example FRP project
  – Deck strengthening (shear)
  – Pile strengthening (flexure)
• Summary
The Marine Environment
Concrete Marine Structures
Deterioration of Marine Concrete

- Humidity, splash zone, wet cycles
- Chlorides, steel corrosion – cracking & spalls
Deck Damage
Pile Damage

- Pop-outs
- Horizontal cracking
- Vertical cracking
Pile damage (continued)
Repair and Strengthening
Repairing Damage

- Conventional spall repair
- Encasement
- Replacement
- **Fiber reinforced materials**
  - Jackets/Laminates
  - Wraps

FRP can also add strength!
Fiber Reinforced Polymer (FRP) Products
Fiber Reinforced Polymer (FRP)

• Fiber and resin composite
  – Typically carbon or glass fibers
  – Woven or stitched fabric

• Specially formulated structural epoxy or resin
  – Saturated on site, or
  – Formed into laminates
FRP Characteristics

- High strength and durability
  - 2-3x stronger than steel
- Light weight
  - Specific weight 100 to 160 pcf
- Low maintenance
- Typically minimal volumetric increase
- Versatile for repairs, protection, and/or strengthening
Two Main Types of Application

FRP Wrap

• Flexible fabric
• Surface preparation
• Onsite saturation with resin – wet lay up
• Layer to design requirements

FRP Shape / Laminate

• Pre-formed fiberglass jacket, or FRP cured laminate
• Suitable on damaged sections
• Void filled with grout
• Optional rebar cage
FRP in Marine Projects
Construction in Marine Environment

- Access – barges, work platforms
- Current – 2 knots +
- ‘In water work’ permit windows
- Tides – approx. 2 cycles per 24 hours
FRP in Marine Applications

• Substrate preparation
  – Depends on existing condition, extent of damage
  – Marine growth easily removed
  – Coat exposed rebar
  – Patch spalls for wet lay-up

• Application
  – Access (divers or platform)
  – Under water epoxy
  – Schedule at low tides
FRP in Marine Applications

• Protection during Curing
  – FRP Wrap – 72hrs, or 4-5 days underwater
  – Protected with plastic film from tides/current
  – Jackets sealed top & bottom

• Samples and Testing
  – Wet lay-up sampled on site
  – Pull test if bond critical
  – Laminates tested prior to installation
Pile Restoration with FRP Jackets

- FRP Laminate
- Various shapes, sizes
- Off-the-shelf or custom
- In place form for grout fill
- Various types of connections
Restore pile cross section

Section Loss ≤ 25%
- FX-70°-6MP Multi-Purpose Marine Epoxy Grout used for bottom seal and repair
- Typical annular void of 1/4 (13 mm)
- 3/8 (19 mm) annular void for H-piles

Section Loss > 25%
- FX-70°-6MP Multi-Purpose Marine Epoxy Grout used for top and bottom seal
- FX-225 Non-Metallic Underwater Grout used for repair
- Typical annular void of 2" (51 mm)

Source: Fox Industries, FX-70
Examples
Pile Restoration with FRP Fabric

- Saturated on site
- Bonds directly to pile, any shape
- Vertical or horizontal
- Customize thickness by layers
Project Example Utilizing FRP Wrap to Strengthen Deck Beams and Piles
About the Terminal

- 2 active Berths – each 450 ft long
- Concrete wharf head
- Transfers crude oil, refined petroleum, gasoline
- Over 200 transfers per year
- Seismic mitigation required to satisfy CBC, Chapter 31F
Seismic Mitigation Concept

- FRP work included in:
  - Strengthening of Deck Elements
  - Strengthening of Existing Plumb Piles
Design Criteria for FRP

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### Composite Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM Method</th>
<th>Typical Test Value</th>
<th>Suggested Design Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile strength in primary fiber direction, psi</td>
<td>D-3039</td>
<td>142,000 psi (979 MPa)</td>
<td>101,000 psi (696 MPa)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5.7 kip/in. width)</td>
<td>(4.04 kip/in. width)</td>
</tr>
<tr>
<td>Elongation at break</td>
<td>D-3039</td>
<td>1.2%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Tensile Modulus, psi</td>
<td>D-3039</td>
<td>$12.35 \times 10^6$ psi</td>
<td>$8.90 \times 10^6$ psi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(85.1 GPa)</td>
<td>(61.3 GPa)</td>
</tr>
<tr>
<td>Ultimate tensile strength 90 degrees to primary fiber, psi</td>
<td>D-3039</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nominal Laminate Thickness</td>
<td>D-1777</td>
<td>0.04 in. (1.0mm)</td>
<td>0.04 in. (1.0mm)</td>
</tr>
</tbody>
</table>

1. Typical values based on samples prepared at room temperature in ambient air. Samples were not exposed to water.
2. Gross laminate design properties based on ACI 440 suggested guidelines will vary slightly. Contact Fyfe Co. LLC engineers to confirm project specification values and design methodology.

Underwater epoxy (101 ksi) vs. same fiber fabric with standard epoxy (121 ksi)
FRP for Marine Deck Beams
FRP Objectives for Existing Deck Beams

- Localized shear strengthening
- Minimize impact to pipelines and conduit
FRP Solutions for Deck Beams

Fully wrapped
- Loss of Interlock at 0.4%
  \[ \varepsilon_{fe} = 0.75 \varepsilon_{fu} \leq 0.004 \]
- Higher strength reduction
  \( \Psi f = 0.95 \text{ vs. } 0.85 \)

U-Shaped or Two sided
- Bond-reduction coefficient
  \[ \varepsilon_{fe} = \kappa \varepsilon_{fu} \leq 0.004 \]
- Bond-reduction factors based on:
  - concrete strength
  \[ k_1 = \left( \frac{f_c'}{4000} \right)^{2/3} \text{ in.-lb units} \]
  - wrapping scheme
  \[ k_2 = \begin{cases} \frac{d_{fv} - L_e}{d_{fv}} & \text{for U-wraps} \\ \frac{d_{fv} - 2L_e}{d_{fv}} & \text{for two sides bonded} \end{cases} \]
  - bond length
  \[ L_e = \frac{2500}{(n t_f E_f)^{0.58}} \text{ in.-lb units} \]
Strengthening of Deck Beams

- 1 layer
- U-shaped in all areas
- Design using ACI 440.2R-08
- Composite anchors at top edge
- 60 kip added shear strength
Beams wrapped with FRP
FRP for Concrete Piles
FRP Objectives for Existing Piles

- All existing plumb piles:
  - Increase confinement
  - Higher P-M capacity
  - Horizontal fiber orientation

- Existing Build-ups:
  - Strengthen splice
  - Longitudinal (vertical) fibers
Benefit of FRP Pile Confinement

- Increased ductility, flexural capacity

Comparison of Pile P-M Capacity

Comparison of M-C at P = 400 kip

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Improving Installation

- Minimized depth of installation
- Movable work platform
- Eliminated need for divers

5 layers (2X thickness)  
top 6’ = 0.40”

8 layers (1X) below 6’ = 0.32”

Photo: CS Marine Constructors, Inc.
FRP wrap installed on piles

Tension pull test samples
Summary

• FRP = high strength, light-weight alternative
• Used to repair and strengthen marine structures
  – Repair damage
  – Confinement
  – Axial, flexural, and shear capacity increase
• Unique challenges in marine environment
  – Corrosion, access, tides, underwater applications
• Several FRP options available
• Tailored to suit project needs
Seismic Strengthening Example Project:

- Fibrwrap Construction Inc.
  - http://www.fibrwrapconstruction.com
- Fyfe Co LLC
  - http://www.fyfeco.com/
- CS Marine Constructors, Inc.
  - http://www.csmarine.com
- Carbon Wrap Solutions (DowAksa):
  - http://www.carbonwrapsolutions.com
- Fox Industries (Simpson Strong-Tie)
  - http://www.foxind.com/
- Five Star Products
  - http://www.fivestarproducts.com/
- Harbor Technologies
  - http://harbortech.us
- MasterBrace (BASF)
  - http://master-builders-solutions.basf.us
- Sea Shield (Denso North America)
  - http://www.densonacom
- SikaWrap (Sika Corporation)
  - http://www.sika.com
- Quakewrap / PileMedic
  - http://www.quakewrap.com /
  http://www.pilemedic.com
Thank You – Questions?

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