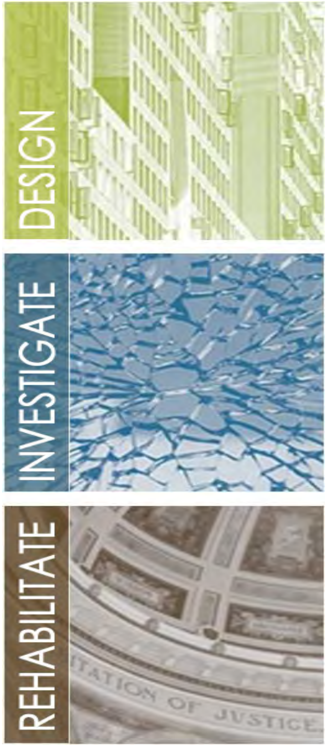

SIMPSON GUMPERTZ & HEGER
Engineering of Structures and Building Enclosures

Use of FRP to Strengthen and Repair Marine Structures

ICRI Spring Convention
March 2016

Presented by:
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Simpson Gumpertz & Heger, Inc.

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)

Pile damage (continued)

Repair and Strengthening

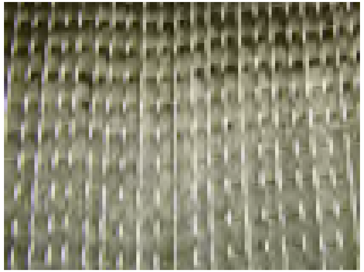
Repairing Damage

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

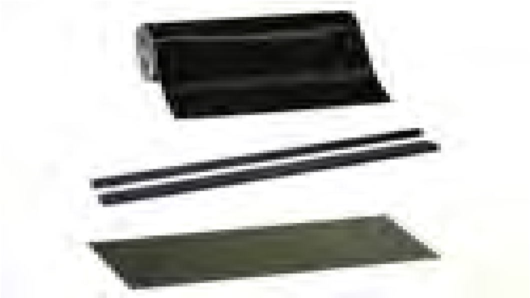
FRP can also add strength!

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



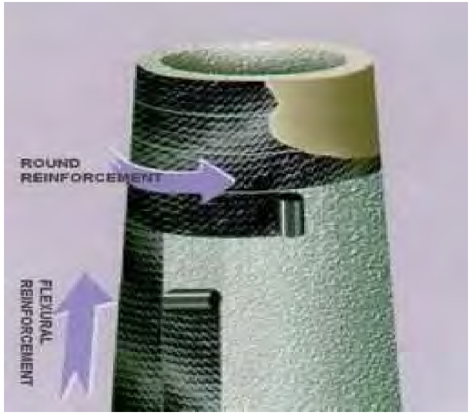
FRP Characteristics

- 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



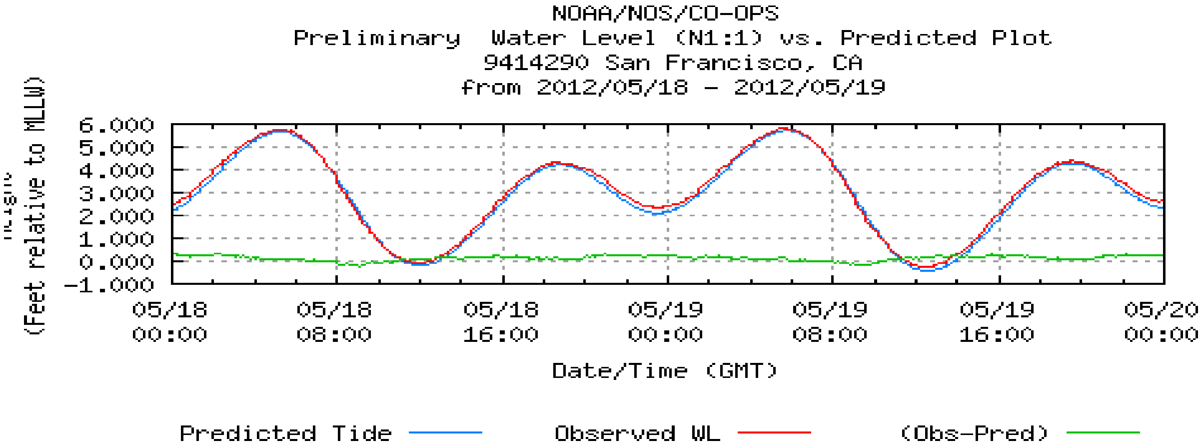
FRP Shape / Laminate

- 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

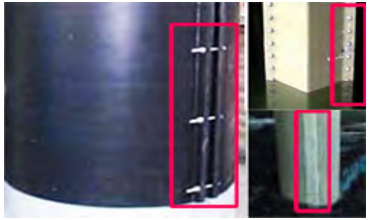
FRP in Marine Applications

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

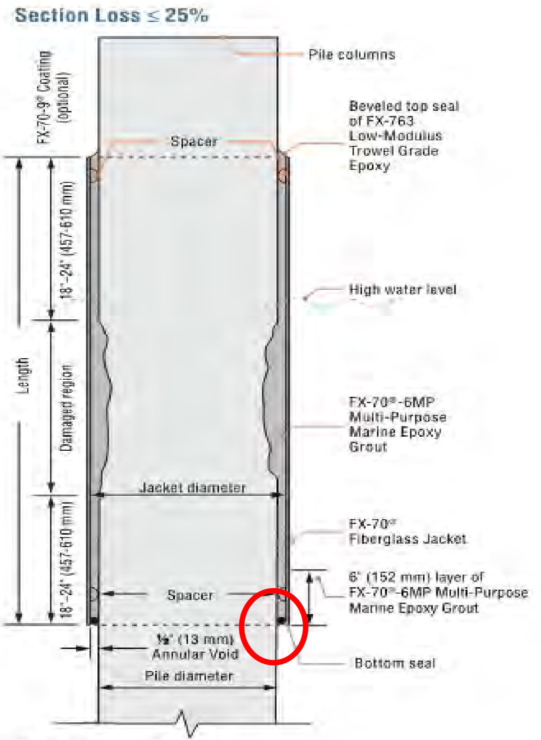
- Samples and Testing
  - Wet lay-up sampled on site
  - Pull test if bond critical
  - Laminates tested prior to installation

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

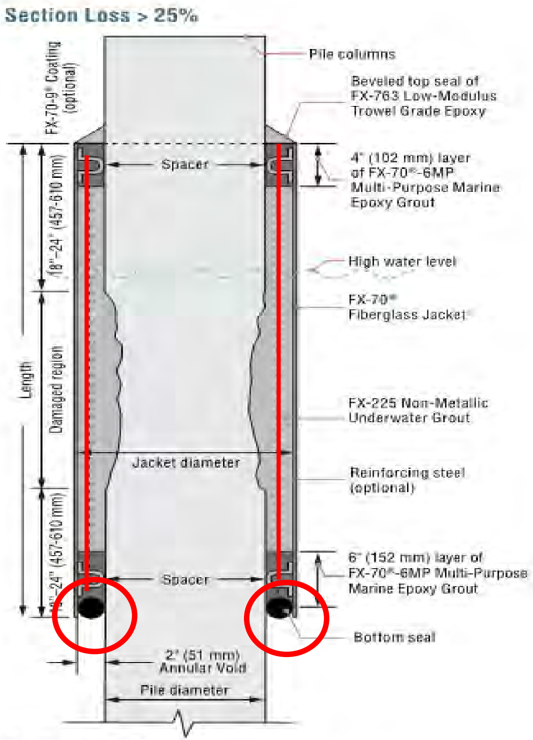



Restore pile cross section



Section Loss ≤ 25%

- FX-70®-6MP Multi-Purpose Marine Epoxy Grout used for bottom seal and repair
- Typical annular void of ½" (13 mm)
- ¾" (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

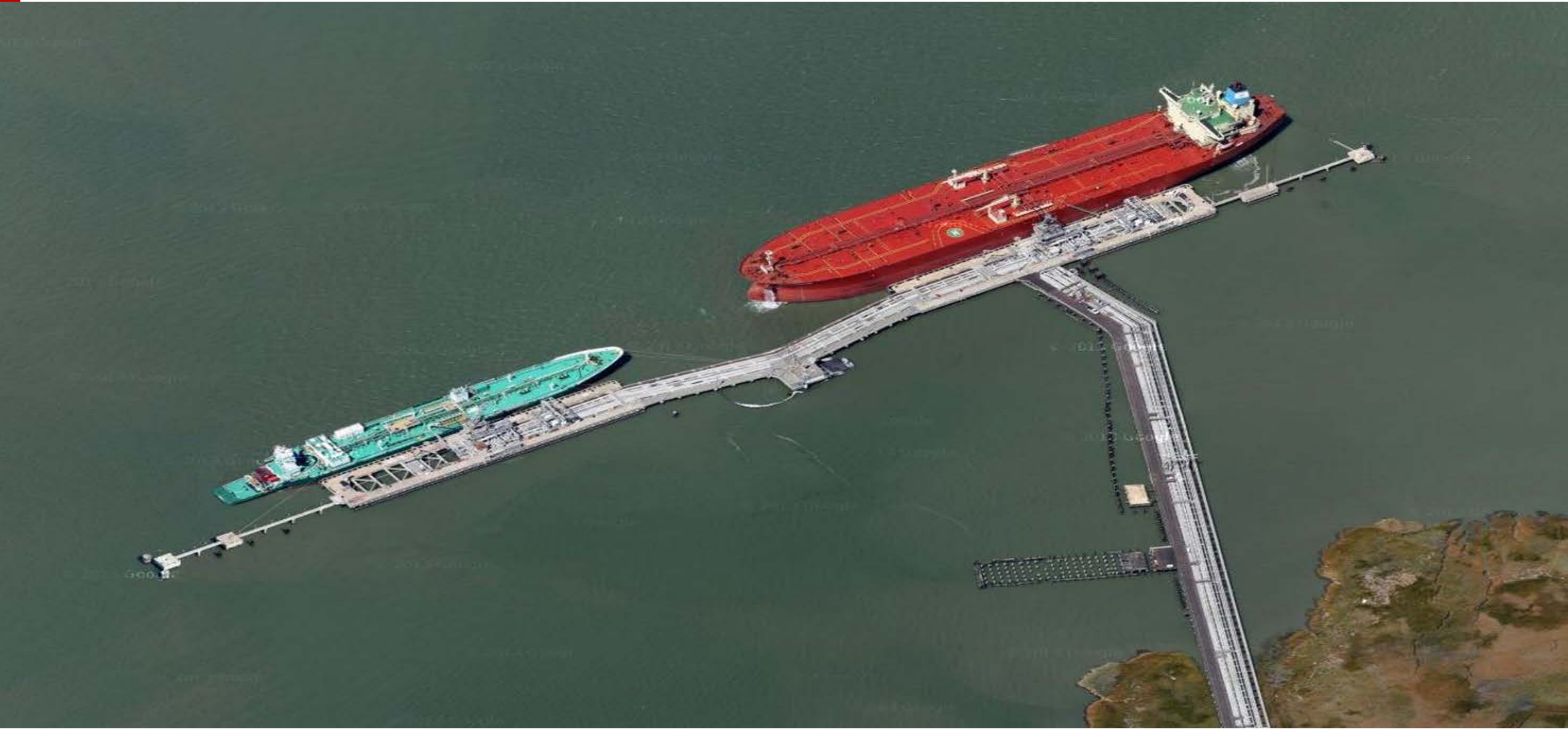
Examples

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

Loading Platform Seismic Upgrade

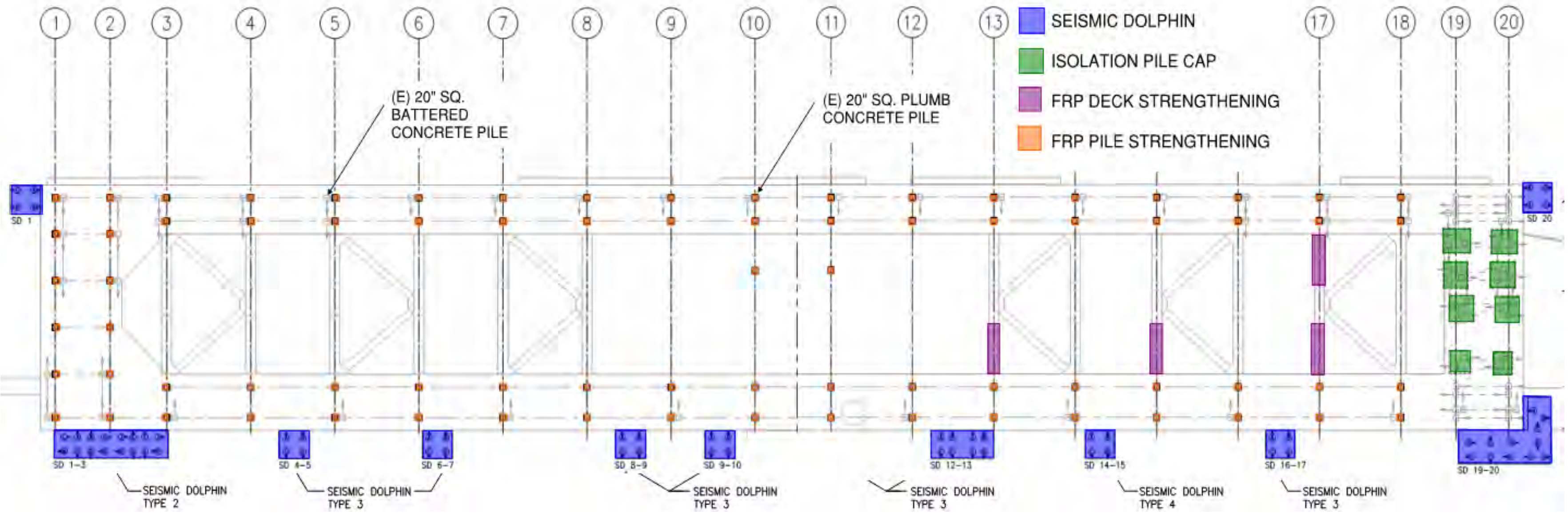


About the Terminal

- 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

ACI 440.2R-08

Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures

Reported by ACI Committee 440

American Concrete Institute®

ICC EVALUATION SERVICE

Most Widely Accepted and Trusted

ICC-ES Evaluation Report **ESR-2103**

Reissued October 1, 2012

This report is subject to renewal November 1, 2014.

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DIVISION: 03 00 00—CONCRETE
Section: 03 01 00—Maintenance of Concrete

DIVISION: 04 00 00—MASONRY
Section: 04 01 20—Maintenance of Unit Masonry

REPORT HOLDER:

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EVALUATION SUBJECT:

CONCRETE AND MASONRY STRENGTHENING USING THE TYFO® FIBRWRAP® FIBER-REINFORCED COMPOSITE SYSTEMS

1.0 EVALUATION SCOPE

Compliance with the following codes:

- 2009 *International Building Code®* (IBC)
- 2009 *International Plumbing Code®* (IPC)
- 1997 *Uniform Building Code™* (UBC)
- 1997 *Uniform Plumbing Code* (UPC)

Properties evaluated:

- Structural
- Fire propagation
- Toxicity
- Fire resistance

2.0 USES

The Tyfo® Fibrwrap Fiber-reinforced Composite Systems are used as alternatives to systems described in the IBC and UBC to strengthen concrete and masonry structural elements. The systems also may be used for weather protection, interior finish, and fire resistance.

3.0 DESCRIPTION

3.1 General:

The Tyfo® Fiberwrap systems are externally bonded fiber reinforced polymer (FRP) systems applied to normal-weight concrete and masonry substrates. The systems consist of carbon, glass, aramid and hybrid fabrics combined with resins which, in combination, create the FRP composite system.

3.2 Materials:

3.2.1 General: All materials must comply with specifications outlined in Appendix B of the Fyfe Co. quality control manual (hereinafter referred to as the QCM), revision 10, dated August 2010.

3.2.2 Fabrics: The SEH, SCH, WEB, and BC fabrics are composed of either carbon or glass fibers. Standard rolls measuring 675 square feet (62.1 m^2) for the SEH fabric, 600 square feet (55.1 m^2) for the SCH fabric, 1562 square feet (145 m^2) for the WEB fabric, or 1,200 square feet (110.4 m^2) for the BC fabric are shipped in boxes, and special roll sizes are available. Material properties vary with fiber designation.

3.2.3 Tyfo® S Epoxy Matrix: The Tyfo S epoxy matrix is an ambient cure epoxy resin mix used to bind the fibers. Components A and B of the matrix are shipped in either 5-gallon (18.9 L) buckets or 55-gallon (208 L) drums and must be mixed at either the jobsite or the facility of the approved fabricator at a volumetric ratio of 100:42 (A:B) for five minutes in a low-speed (400-600 rpm) mixer prior to application. Pot life is three to six hours at 68°F (20°C).

3.2.4 Tyfo SEH-51 (A) Composite: In the primary direction (0°), the glass fiber composite has a minimum ultimate tensile strength of 66 ksi (460 MPa), a minimum tensile modulus of 3,036 ksi (20.9 GPa), and a corresponding elongation of 1.7 to 4 percent. Layer thickness is 0.05 inch (1.30 mm).

3.2.5 Tyfo SCH Composites:

3.2.5.1 Tyfo SCH 41S(1) Composite: In the primary direction (0°), the carbon fiber composite has a minimum ultimate tensile strength of 107 ksi (745 MPa), a minimum tensile modulus of 8,900 ksi (61.5 GPa), and a corresponding elongation of 0.8 to 1.7 percent. Layer thickness is 0.04 inch (1.04 mm).

3.2.5.2 Tyfo SCH-41 Composite: In the primary direction (0°), the carbon fiber composite has a minimum ultimate tensile strength of 121 ksi (834 MPa), a minimum tensile modulus of 11,900 ksi (82 GPa), and a corresponding elongation of 0.8 to 1.7 percent. Layer thickness is 0.04 inch (1 mm).

3.2.5.3 Tyfo SCH-41 2X Composite: In the primary direction (0°), the carbon fiber composite has a minimum ultimate tensile strength of 121 ksi (834 MPa), a minimum

Composite Material Properties

COMPOSITE GROSS LAMINATE PROPERTIES			
PROPERTY	ASTM METHOD	TYPICAL TEST VALUE[1]	SUGGESTED DESIGN VALUE[2]
Ultimate tensile strength in primary fiber direction, psi	D-3039	142,000 psi (979 MPa) (5.7 kip/in. width)	101,000 psi (696 MPa) (4.04 kip/in. width)
Elongation at break	D-3039	1.2%	1.0%
Tensile Modulus, psi	D-3039	12.35×10^6 psi (85.1 GPa)	8.90×10^6 psi (61.3 GPa)
Ultimate tensile strength 90 degrees to primary fiber, psi	D-3039	0	0
Nominal Laminate Thickness	D-1777	0.04 in. (1.0mm)	0.04 in. (1.0mm)

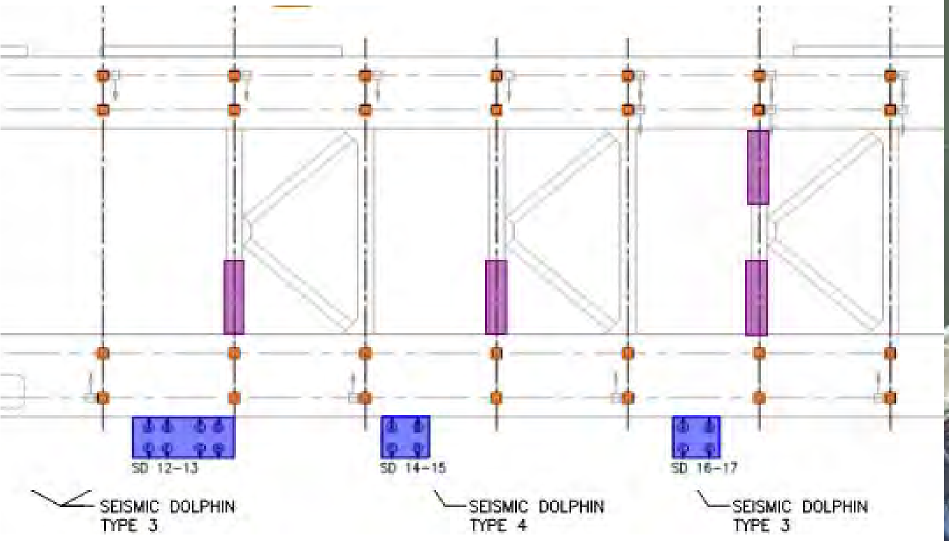
[1] Typical values based on samples prepared at room temperature in ambient air. Samples were not exposed to water.
[2] Gross laminate design properties based on ACI 440 suggested guidelines will vary slightly. Contact Fyfe Co. LLC engineers to confirm project specification values and design methodology.

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

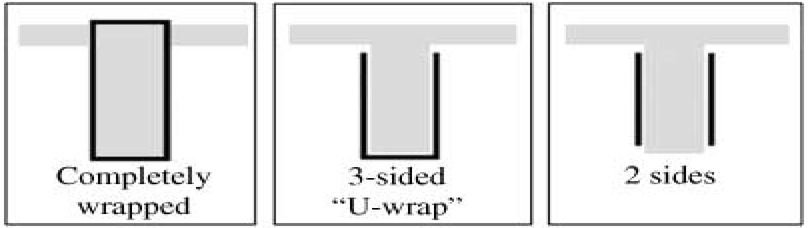
Fully wrapped

– Loss of Interlock at 0.4%

$$\varepsilon_{fe} = 0.75\varepsilon_{fu} \leq 0.004$$

– Higher strength reduction

(Ψf = 0.95 vs. 0.85)



$$V_f = \frac{A_{fv} f_{fe} (\sin\alpha + \cos\alpha) d_{fv}}{s_f}$$

U-Shaped or Two sided

- Bond-reduction coefficient

$$\varepsilon_{fe} = \kappa_v \varepsilon_{fu} \leq 0.004$$

- Bond-reduction factors based on:
  - concrete strength

$$k_1 = \left(\frac{f_c'}{4000}\right)^{2/3} \quad \text{in in.-lb units}$$

  - wrapping scheme

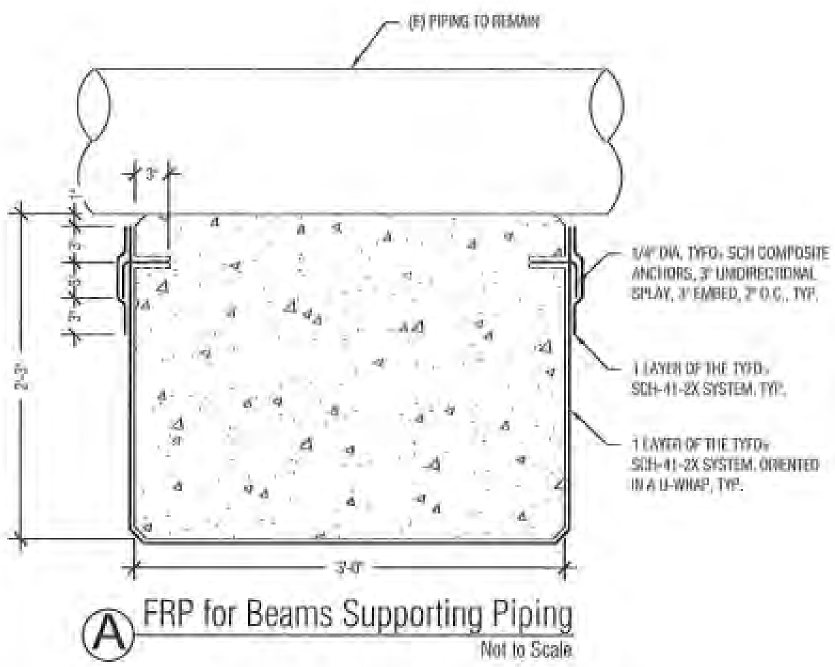
$$k_2 = \begin{cases} \dfrac{d_{fv} - L_e}{d_{fv}} & \text{for U-wraps} \\ \dfrac{d_{fv} - 2L_e}{d_{fv}} & \text{for two sides bonded} \end{cases}$$

  - bond length

$$L_e = \frac{2500}{(n t_f E_f)^{0.58}} \quad \text{in in.-lb units}$$

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

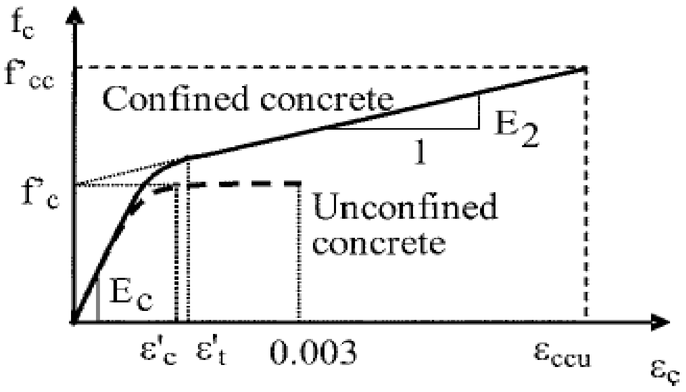
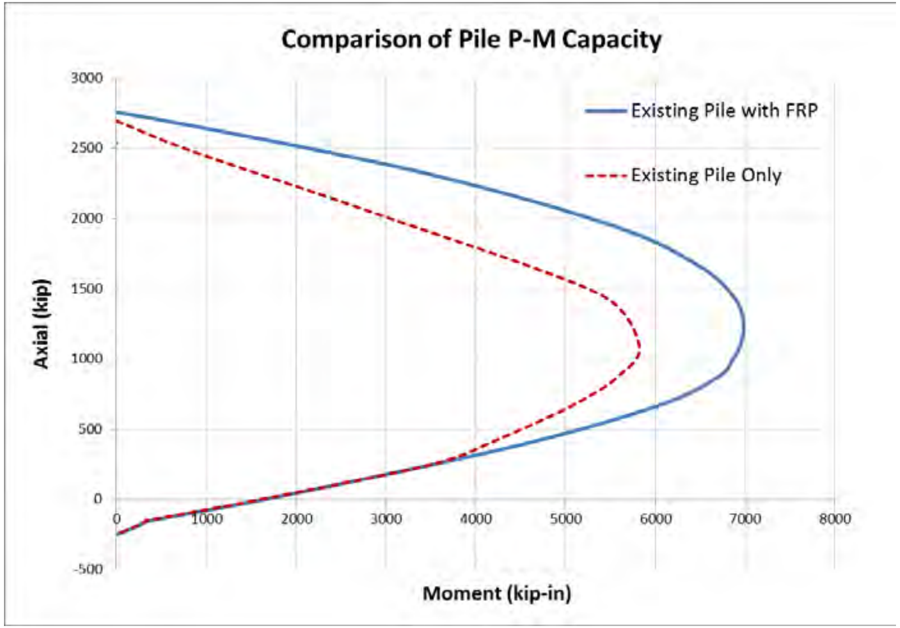
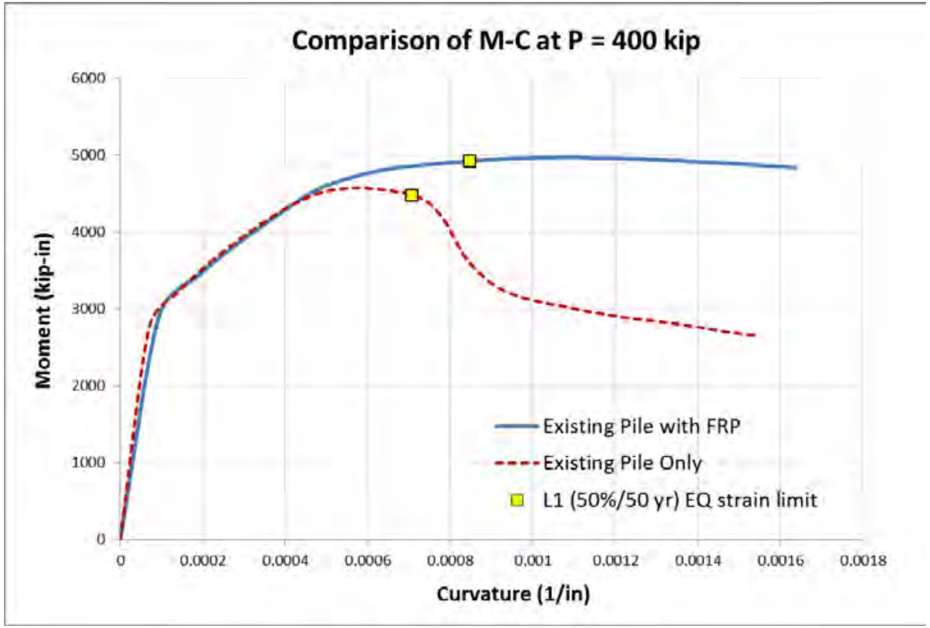


Fig. 12.2—Lam and Teng's stress-strain model for FRP-confined concrete (Lam and Teng 2003a).

Benefit of FRP Pile Confinement

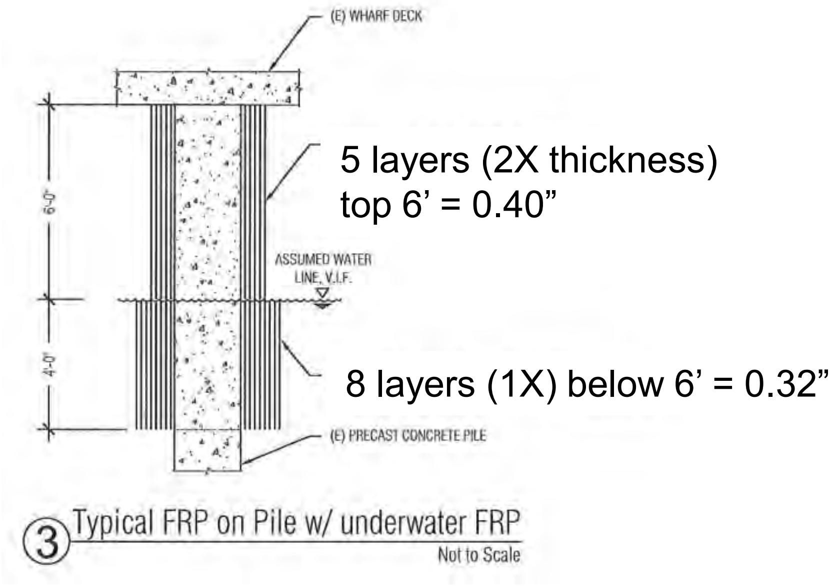
– Increased ductility, flexural capacity





Improving Installation

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



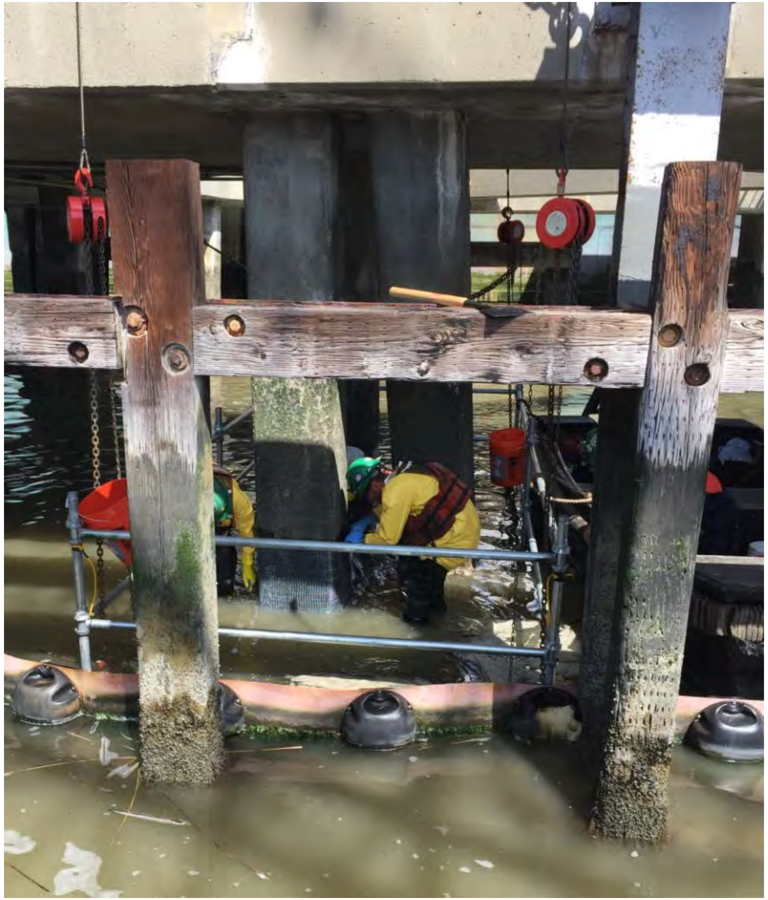
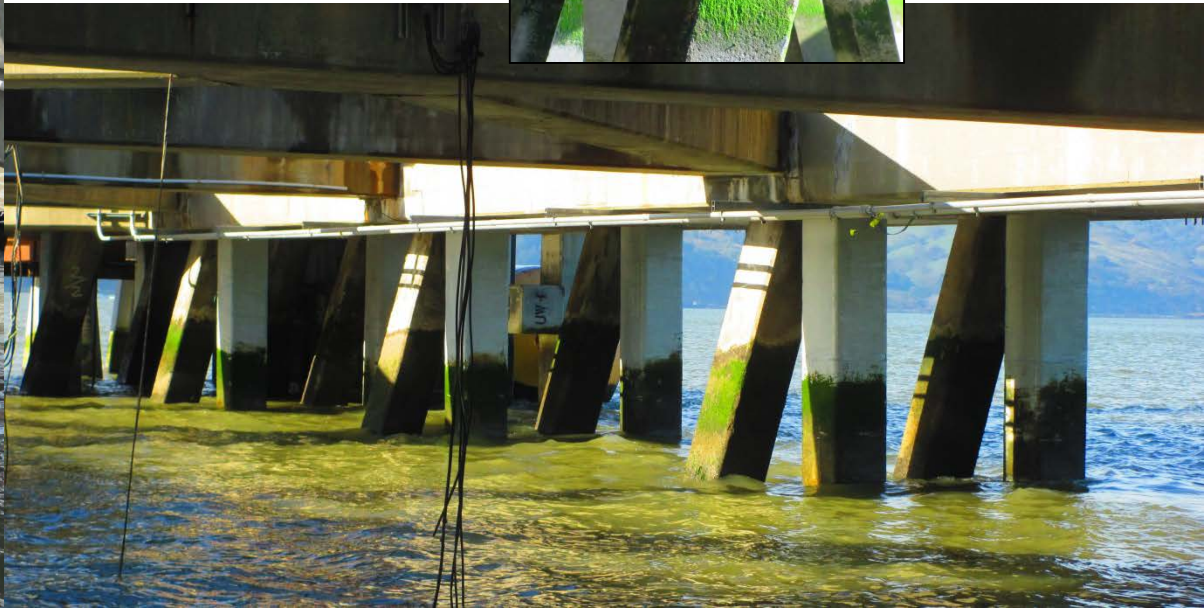


Photo: CS Marine Constructors, Inc.

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

References & Additional Information

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.densona.com
- SikaWrap (Sika Corporation)
  - http://www.sika.com
- Quakewrap / PileMedic
  - http://www.quakewrap.com / http://www.pilemedic.com

Thank You – Questions?

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