Bakers Haulover Cut Bridge: Seawall-Bulkhead Rehabilitation and New GFRP-RC Solutions

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1. Defining the problem… Are Composites the solution?
2. Existing BHC Seawall System(s)
3. New BHC Seawall-Bulkhead Design
4. Construction & Lessons Learned
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6. New Solutions – SEACON, GFRP-PC
7. Improving of Creep-Rupture limits
8. Where do we go from here?
What is the Problem?

Need for New Solutions for Corrosion Durability and Sustainability

Avoiding corrosion “concrete cancer”

- GFRP or SS rebar
- CFRP or HSSS prestressing strand

i. Cost-Benefit Analysis Justification, LCA/LCC;

ii. Durability = Long Service Life;

iii. Challenges & Mitigating Risks

- Acquisition Cost
- New material systems;
- Limited suppliers/competition;
- Unfamiliar design criteria;
- Unfamiliar construction practices.
Are Composites the Solution?

Service Life Enhancement thru Durability:

FDOT Research Efforts

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<tr>
<th>Year</th>
<th>Title</th>
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<tr>
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Are Composites the Solution?
Seawall-Bulkhead Development in Florida for the Built-Environment...

(Photographs courtesy of the Burgert Bros.)

Davis Islands, PCA Concrete Piles Pub., pg.70 (1951)
Seawall-Bulkhead Development in Florida

Reinforced Concrete: since 1920’s
Prestressed Concrete:
• Soldier Piles in the 1950’s
• Sheet Piles in the 1970’s ...better,

...but still Reinforced
Concrete CIP cap!
Seawall-Bulkhead Development in Florida

Prestressed Concrete (Miami-Dade):
• Soldier Piles in the 1950’s & 60’s
• Still using RC panels in between...

...similar durability challenges
Seawall-Bulkhead Development in Florida

CFRP Prestressing, since 2014...best?

i. Design criteria for prestressing – **Fiber Reinforced Polymer Guidelines (FRPG)** – Chapter 3;

ii. Developmental **Index D22440** (Nov. 2014)
   - (Halls River Bridge demonstration project);

iii. FDOT **FY2017-18 Design Standards** (Nov. 2016)
   - Index 22440 series (now **Index 455-100 series FY10-20**);
   - CFRP prestressing strands & GFRP stirrups;
   - Stainless Steel prestressed/reinforced alternative.
Existing BHC Bulkhead System(s) at BHC Project

Pile & Panel (north wall) Prestressed Sheet Pile (south wall):
...both in severely corroded condition

North Wall

Soldier Pile & Panel System (original 1948):
Extensive corrosion damage in splash zone

South Wall

Prestressed Sheet Pile System (rebuilt 1970's):
Extensive corrosion damage in splash zone

Bridge site looking Southwest (courtesy: BPA Consulting Eng.)

Adjacent properties to Southwest with one section recently repaired (2014 county approval)
New Seawall-Bulkhead System at BHC

Selected Alternative: ...Steel Sheet Piles with GFRP-RC facia
New Seawall-Bulkhead System at BHC

Selected Alternative: ...Steel Sheet Piles with GFRP-RC facia

Bakers Haulover Cut - GFRP Rebar Cost Comparison

- BHC Rehab 2016
- HRB Bid 2016
- FDOT Expo 2017
- RS Means 2016
- Mateen 2014 (>40KLF)
- Hughes Bros. 2014
- Black (FDOT)
- Low-Chromium (FDOT)
- Stainless (FDOT)
New Challenges

SLR, Extreme Weather, Sustainability, Increased Durability Expectations

Photos from Hurricane Matthew (2016)
New Challenges

SLR, Extreme Weather, Sustainability, Increased Durability Expectations

(a) Hurricane Damage along A1A (2008)
(b) Hurricane Sandy damage along A1A in Fort Lauderdale (Photo: Susan Stocker, Sun Sentinel, 2012).
(c) Hurricane Matthew damage along A1A Flagler Beach, (2016)
(d) Brickell Ave under water during Hurricane Irma (2017)
New Solutions

Reviving an old system with new material
- Post and Panel with FRP-RC/PC

2 new FDOT projects in design:
1. SE 23rd Ave Bridge Replacement
2. US 41 over North Creek replacement
3. Possibly… Barracuda Blvd. over Indian River North

FIGURE 6. US 41 over North Creek, existing combination bridge end bent and abutment bulkhead – Plan View showing: (blue) RC sheet piles, (yellow) precast master piles, & (pink) tie-back.
New Solutions

SEACON...

Sustainable concrete using seawater, salt-contaminated aggregates, and non-corrosive reinforcement

Seawater Immersion at 60°C

Graph showing compressive strength (ksi) vs. age (days)

Graph labels:
- Compressive Strength (ksi)
- Age (days)

Graph data points:
- Seawater Immersion at 60°C

Graph materials:
- GFRP
- XM-28
- 304L
- 22-05
- 23-04
(a) & (b) CFRP strand failed during tensioning; (c) cracking following strands release.

(a) GFRP strand prototype cross section; (b) compared to a CFRP alternative.

(a) GFRP-PC sheet pile concept (b) CFRP-PC sheet pile design for Halls River Bridge

(a) & (b) Tensioning apparatus for CFRP; versus (c) standard steel HSCS chucks, for GFRP.
New Solutions

• Affordable higher modulus GFRP \( \geq 65 \) GPa (9,000+ ksi)
• Adhoc continuous stirrups;
• STIC 2018 Incentive Project
  – Basalt-FRP Rebar Standardization

“Develop standard (guide) design specification, and standard material and construction specifications for basalt fiber-reinforced polymer (BFRP) bars for the internal reinforcement of structural concrete”
Why Improve Creep-Rupture Limits?
Enhance AASHTO Specifications and Extend Bridge Service Life

ACI 440.3R B.8 GFRP Creep Rupture Accelerated Testing

1. ACI 440.1R limits the allowable sustained stress for traditional GFRP;
2. Creep rupture limit recently improved $C_C = 0.2$ to 0.3 in AASHTO BDGS-2;
3. ASTM D7957 GFRP rebar of ECR glass fiber in vinyl ester shows improved creep rupture limit.

![Graph showing creep rupture data]

- [831 MPa Creep Rupture Strength] (ECR/VF at 5G-50GPa Modulus)
  $y = -0.9671x + 85.735$
  $R^2 = 0.766$
- [598 MPa Creep Rupture Strength] (ECR/VF at 4G-5GPa Modulus)
  $y = -2.4987x + 82.452$
  $R^2 = 0.9909$
- [507 MPa Creep Rupture Strength] (ECR/VF at 3G-4GPa Modulus)
  $y = -1.3777x + 64.911$
  $R^2 = 0.6161$

![Time to Rupture (hr) vs. Sustained / Ultimate Strength (%) graph]

- 15 yr
- 100 yr

- 1000000
- 100000

Time to Rupture (hr)
Why Improve Endurance Limits?

Validate With Bridge Service Life

Bridge Core Extraction of 15+ Year GFRP Rebar Samples

1. Negligible impact in mechanical properties and chemical composition of GFRP fiber and matrix SEM/EDX (300x image fiber, Ca, Si, Al, C, O)
2. GFRP rebar durability in corrosive environments better than predicted by accelerated test methods $0.85 C_E$
Where do we go from here?

Recommend Endurance Limits to Meet AASHTO LRFD Bridge Design Specification Reliability Requirements

1. Design Limit Refinements
2. Durability Model Refinements
3. GFRP Service Life Design for Tidal and Submerged Concrete Structures
4. Life-Cycle Cost Guidance

Proposal to improve endurance limits for 125-year service life and also develop a simple short duration QA verification test method.

Micro-Exposure Zones proposed under NCHRP Project 12-108 for Service Life Design
QUESTIONS ??

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