Low Impact Secant-Pile Seawall for protecting SR-A1A along Flagler Beach

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Severe corrosion damage of existing steel sheet pile bulkheads and extensive erosion damage of adjacent sand dune systems necessitated intervention to avoid future collapse of SR A1A along Flagler Beach, especially considering increasingly extreme weather and sea level change. The most recent damage from Hurricane Matthew in 2016, resulted in severe damage and undermining of almost one mile of the state highway (see Figure 1). Several mitigation solutions have been under investigation since 2005, with the final alternative utilizing a secant-pile system scheduled for construction in 2019 (see Figure 2). The secant-pile system will minimize impact on the existing sand dunes and adjacent properties during construction. Additionally, the piles are designed with glass fiber-reinforced polymer rebar which will provide extended maintenance-free service life to minimize future construction activities along the coastal dune system. This presentation will describe the challenges and rationale for selection of the preferred alternative, including LCC analysis and potential improvements for similar future applications.
Outline

- Project Background
- History of Storm Damage
- Wall Feasibility Studies (2005 & 2017 update)
- Secant Pile Walls
- Innovations
- A1A Final Wall Design
- LCC Evaluation
- Future Innovations for Low-Maintenance Coastal Structures
Project Background

FLAGLER BEACH – A1A SEA WALL

LOCATION:
- Flagler Beach, FL --- Hurricane affected beach area

PROJECT PURPOSE:
- Historical erosion issues due to hurricane impacts
- Provide a long term, permanent solution to protect A1A roadway
  - A wall design was needed to protect roadway in the most vulnerable areas
- Governor’s commitment – accelerated acquisition, design, & construction schedule
- Keeping Flagler Beach, Flagler Beach – sand, turtles, A1A alignment
**Project Background**

**FLAGLER BEACH – A1A SEAWALL**

**WALL LOCATION:**
- 4,920 feet of beach along East Flagler Beach
- N. 18th Street to Osprey Dr.
- Segment 3 – high vulnerability area

Wall to be constructed along entire limits of segment 3 above.
A HISTORY OF STORM DAMAGE IN THIS AREA

2004 – 2005 HURRICANES

- Charlie
- Frances
- Ivan
- Jeanne
- Dennis
- Katrina
- Rita
- Wilma

![Map showing storm tracks from 2004 to 2005.](image)
2005 WALL FEASIBILITY STUDY

- Initial Wall Feasibility study prepare looked at 5 options

1. Grouted Anchor Tie-Back
2. Concrete Sheet Pile Bulkhead with Deadman Anchors
3. Curved Face
4. Stepped-Face
5. Combination Stepped and Curved Face
6. Secant Pile Wall
2006 EMERGENCY CONTRACT WALL (Segment 2)

- In response to storm damage and roadway undermining
- Steel Sheet Pile Wall with deadman tie-backs
2011 & 2015 STEEL SHEET PILE EVALUATIONS

- Wall Thickness Evaluation Protocol of A1A Sheet Pile Retaining Wall at Flagler Beach (Report Date: Jan 8, 2016)
- "...If the corrosion progress at the current rate, by the next 3 years many piles will start losing the sacrificial steel and no piles will have any sacrificial steel left by the next 7 years."
- Average Section loss up to 13 mils/year > 2 times SDG 3.1.
OCT 2016 – HURRICANE MATTHEW

- CATEGORY 4: >130 mph winds, storm surge, flooding
Project Background
FLAGLER BEACH – A1A SEAWALL

OCT 2016 – HURRICANE MATTHEW

- Storm Damage
Project Background

FLAGLER BEACH – A1A SEAWALL

OCT 2016 – HURRICANE MATTHEW

- Storm Damage (Segment 2)

2006 Emergency Contract Wall

During the storm

Google Street View after emergency repairs

After the storm
To Determine a wall design in most vulnerable areas of Flagler Beach to prevent future damage

Alternatives Evaluated:

A – ANCHORED SHEET PILE WALL
B – DOUBLE CANTILEVER SHEET PILE WALL
C – SECANT PILE WALL
2017 – WALL FEASIBILITY REPORT UPDATE (Segment 3)

- **Alternative Selected:** **Secant Pile Wall**
  
  - **Corrosion-resistant reinforcing** – Glass Fiber-Reinforced Polymer (GFRP) rebar;
  - **Ease of Construction** -- shallow dense coquina rock difficult to drive sheeting; less equipment;
  - **Speed of Construction** – no predrilling required;
  - **Less Impacts to Community** – less vibration, only one lane closure required to install (no tie backs)
## Update Wall Feasibility Study

### 2017 – WALL FEASIBILITY REPORT UPDATE (Segment 3)

**Cost Comparison:**

<table>
<thead>
<tr>
<th>Alt No.</th>
<th>Description</th>
<th>Wall Cost / FT*</th>
<th><strong>Weighted Scores</strong></th>
<th>Total Score</th>
<th>Final Rank</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>50%</td>
<td>25%</td>
<td>5%</td>
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<tr>
<td>1</td>
<td>36&quot; Diameter Secant Pile (steel bars)</td>
<td>$2,123.16</td>
<td>250</td>
<td>86</td>
<td>25</td>
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<td>2</td>
<td>36&quot; Diameter Secant Pile (FRP bars)</td>
<td>$2,308.00</td>
<td>230</td>
<td>86</td>
<td>25</td>
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<tr>
<td>3</td>
<td>Anchored Steel Sheet Pile</td>
<td>$2,146.63</td>
<td>247</td>
<td>125</td>
<td>8</td>
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<tr>
<td>4</td>
<td>Double Cantilever Sheet Pile</td>
<td>$2,790.81</td>
<td>190</td>
<td>94</td>
<td>13</td>
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</table>

The results show that the **36" Diameter Secant Pile (FRP bars)** is the most cost-effective option with a total score of 441 and a final rank of 1. This method is followed by the **Anchored Steel Sheet Pile** with a total score of 406 and a final rank of 3, and the **Double Cantilever Sheet Pile** with the highest cost but the lowest total score of 330 and final rank of 4.
Secant Pile Walls
A bored pile retaining wall consisting of interlocking reinforced concrete piles.
DRILLED SHAFTS vs AUGER CAST PILES

- What’s the difference?

**DRILLED SHAFTS**

- Drill
- Case
- Clean
- Position
- Place

- Caving soils
- Casing (temporary or permanent)

**AUGER CAST PILES**

- Stage 1: Drilling
- Stage 2: Auger withdrawal and simultaneous concrete pouring
- Stage 3: Reinforcement cage insertion
DRILLED SHAFTS vs AUGER CAST PILES

**Advantages and Disadvantages**

**DRILLED SHAFTS**
- Easier to ensure quality of shaft
- Relatively expensive
- Common FDOT method
- Slow install time

**AUGER CAST PILES**
- Harder to ensure quality of shaft
- Less expensive than Drilled Shafts
- FDOT typically only uses for Noise Walls
- Fast installation time
Glass Fiber-Reinforced Polymer (GFRP) Reinforcing Bars
Glass fiber reinforced polymer (GFRP) is an alternative material to the steel rebar.

- Lightweight, no corrosion, superior tensile strength, and high mechanical performance.
- Installation of the GFRP rebar is similar to steel rebar, but with less handling and transporting effort.
Definition

Glass fiber reinforced polymer (GFRP)

SO HOW DOES IT WORK???

FRP Rebar are made of fibers embedded in Polymeric Resin
✓ Fibers provide strength and durability
✓ Resin holds fibers together, transfers load between fibers, and protects from abrasion/environment
Innovation
GLASS FIBER-REINFORCED POLYMER REBAR

STEEL REINFORCING vs GFRP REBAR

- Advantages

STEEL REINFORCING
- Bonds very well to concrete
- Warning before failure
- Can be used in prestressed applications

GFRP REBAR
- Corrosion resistant (less concrete cover required)
- Higher tensile strength compared to traditional steel yield point
- Lightweight and easy to work with
- Moderate fatigue endurance
Innovation
GLASS FIBER-REINFORCED POLYMER REBAR

STEEL REINFORCING vs GFRP REBAR

- Limitations

STEEL REINFORCING
- Corrodes very rapidly in extremely aggressive environments (thicker concrete cover required)
- Heavy and difficult to work with in the field

GFRP REBAR
- Largest ASTM D7957 bar size (for now): #10 Bar. (Now looking at need for #11+)
- Variable surface to concrete bond capacity
- Bends only 60% of straight bar strength
- No yield (warning) before failure
Innovation
G L A S S  F I B E R - R E I N F O R C E D  P O L Y M E R  R E B A R

STEEL REINFORCING vs GFRP REBAR


#8 Steel Rebar: $2.67/ft
#8 GFRP Rebar: $2.25/ft

Steel Bars
GFRP Bars
STEEL REINFORCING vs GFRP REBAR

- Cost Comparison (Published and FDOT Bid Estimates)
SOME FACTS ABOUT DESIGN

- Designed to 100 year scour depth to eliminate need for toe protection
- With traditional steel: 9 ~ #11 bars required \((A_s = 14.0 \text{ in}^2)\)
- With GFRP rebar: 25 ~ #8 bars \((A_f = 19.75 \text{ in}^2)\) deflection governs
- 36” dia. x 36-ft. long Reinforced Auger Cast Piles
- 36” dia. x 18-ft. long Non-Reinforced Auger Cast Piles

<table>
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<tr>
<th>Description</th>
<th>Value</th>
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<tr>
<td>Full Length Wall Cost</td>
<td>$11,355,377</td>
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<tr>
<td>8% Mobilization</td>
<td>$908,430</td>
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<tr>
<td>5% Contingency</td>
<td>$567,769</td>
</tr>
<tr>
<td>Total Wall Cost</td>
<td>$12,831,576</td>
</tr>
<tr>
<td>Full length wall construction Time</td>
<td>119 days</td>
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<tr>
<td>Mobilization Time</td>
<td>15 days</td>
</tr>
<tr>
<td>Lag Time</td>
<td>30 days</td>
</tr>
<tr>
<td>Work to Calendar Day Factor</td>
<td>1.4</td>
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<tr>
<td>Total Wall Construction Time</td>
<td>229 Calendar Days</td>
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</table>
A1A Wall Design

GLASS FIBER-REINFORCED POLYMER REBAR

Existing R/W

Proposed Secant Wall

Turtle Nesting Area

Existing R/W

4'  12'  12'  4'

18' MIN

16'
Life Cycle Cost Evaluation

**Engineer’s Estimate:**

Traditional steel reinforced auger-cast pile = $191.50 / ft. length pile installed
GFRP-reinforced concrete auger-cast piles = $209.25 / ft. length pile installed

Assuming 75-year life for traditional RC = $2.55 /year/ft.
Assuming 100-year (min.) for GFRP-RC = $2.09 /year/ft. *(not considering reduced maintenance costs and environmental benefits)* > 18% savings!

**Bid Quantities & Unit Cost:**

400-4-11 Class IV Concrete (Wall Cap) = (864 CY)($775/CY) = $669,600  Low Bid $415.00/CY = $358,560
415-10-5 GFRP Reinforcing, #5 = (61892 LF)($1.37/LF) = $84,792  Low Bid $1.45/LF = $89,743
455-112-6 Pile Auger Grouted, 36” Dia. = (51724 LF)($209.25) = $10,823,247  Low Bid $156.50/LF = $8,094,806

**Total Proposal Budget Estimate =** $27,276,946  **Low Bid =** $22,429,705
Other Project Challenges

- **GOVERNOR SCOTT’S COMMITMENT**
  - Condensed Schedule – wall to be under construction within 2 years

- **COORDINATION WITH ARMY CORPS**
  - Future beach renourishment project to the south

- **KEEPING FLAGLER BEACH, FLAGLAR BEACH**
  - SR A1A Alignment – move inland or keep along the beach
  - Minimize Sea Turtle Impacts – start construction outside turtle nesting season
  - Soil Replacement – specific criteria similar to native soil
**Project Delivery**

- **GOVERNOR SCOTT’S CONSTRUCTION COMMITMENT**

- **CONDENSED PRODUCTION SCHEDULE:**
  - Production/Permitting – normally takes 3 years, completed in 11 months;
  - Consultant Acquisition – condensed into 5 weeks with ELOI’s;
  - Extensive Coordination – weekly planning & design meetings;
  - Accelerated Plans Development – submit wall feasibility study then 90% Plans;
  - Accelerated Plans/Calcs Review – interactive reviews.

- **CONDENSED CONSTRUCTION SCHEDULE:**
  - 300 Day Construction Schedule – so construction only occurs in one hurricane season!
  - Contract Incentives & Disincentives to finish on time;
  - Start construction outside of sea turtle nesting season.
Project Status

- **AFTER STORM EMERGENCY REPAIRS INSTALLED:**
  - Project let and completed shortly after Hurricane Matthew
  - Repaired Dune, Placed Revetment / Rip Rap back, Road Pavement

- **A1A SEAWALL:**
  - Design completed (FPID 440557-7)
  - Project has been Let (T5641)
  - Contractor Selected
    - Superior Construction Co.
  - Notice to Proceed January 4, 2019
  - Construction began February 4, 2019
  - Estimated Completion October, 2019
(a) & (b) CFRP strand failure 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

...Future Innovations for Low-Maintenance Coastal Structures...

FIBER-REINFORCED POLYMER REBAR & PRESTRESSING

- STIC 2018 Incentive Project:
  - Basalt-FRP Rebar Standardization
- Adhoc continuous stirrups
- High Modulus FRP rebar

“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”

https://www.fhwa.dot.gov/innovation/stic/incentive_project/
SEACON
Sustainable concrete using seawater, salt-contaminated aggregates, and non-corrosive reinforcement

Subtropical environment (Bicayne Bay)

Tidal zone (Bicayne Bay)

Seawater Immersion @ 60 °C

Early-age compressive strength and percentage difference.

Compressive strength and percentage difference in subtropical environment Coral Gables, FL for 24 months (1 MPa = 145.038 psi).

Source: Khatibmasjedi, M. “Sustainable Concrete Using Seawater and Glass Fiber Reinforced Polymer Bars” (2018)

http://seacon.um-sml.com/
9:00 a.m.
Towards the Experimentally Based Design of an Effective and Eco-friendly Modular Shoreline Protection System for High Energy Tidal Flow
Landolf Rhode-Barbarigos, Ph.D., Marco Rossini, Antonio Nanni, Ph.D., P.E., and Mohammad Ghiasian,

(a) Seahive units for use as scour protection

(b) SUSTAIN wind-wave tank at UM
Questions ???

Engineer of Record:

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