A Seawall Constructed with GFRP Bars as Structural Reinforcing

The system was designed to help preserve the character of the local environment and reduce life-cycle costs

by Christian C. Steputat, Steven Nolan, Lowry Denty, Paul A. Kaminski, and Antonio Nanni

In 2016, the seaside community of Flagler Beach, FL, was one of the many communities severely impacted and battered by Hurricane Matthew. To help mitigate the effects of future storms, a secant-pile seawall is being constructed east of State Road A1A (SR A1A) at Flagler/Beverly Beach in the northeastern section of Flagler County, FL. When completed, the new barrier will extend 1.5 km (almost 5000 ft).

To ensure that the protective system remains resilient for decades, the project is being built using concrete reinforced with glass-fiber-reinforced polymer (GFRP) bars. The secant piles have been completed, and the seawall pile cap with vegetative cover is expected to be substantially completed by October 2019.

Background

SR A1A is especially important because it has been designated an evacuation route. Unfortunately, it also passes through areas that are highly vulnerable to hurricane surge flooding. As a result of extensive corrosion of an existing steel sheet pile bulkhead and erosion of an adjacent dune system, almost 1 mile (1.6 km) of the highway collapsed during Hurricane Matthew.

To ensure the restored highway remains in service in the event of a similar future storm, a protection and support system is under construction in the stretch indicated as Segment 3 in Fig. 1. The project consists of a GFRP-reinforced concrete secant-pile seawall/bulkhead designed to provide support for the highway in the event the adjacent sand dunes are lost during a major storm. Figure 2 illustrates the seawall with a reestablished dune that helps to preserve the character of the local environment, including the "Old Florida" feeling of Flagler Beach.

Specifications and Standards

The engineering design specifications and construction standards for this seawall/bulkhead with dune reestablishment comprised information from several documents, including:

- Florida Department of Transportation (FDOT) Structures Manual, January 2018,[1] and subsequent Standards Design Bulletins;
- FDOT Design Manual, January 2018[2];
- American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor (LRFD) Bridge Design Specifications, 8th Edition,[3] and all subsequent interims;
- FDOT Standard Specifications for Road and Bridge Construction, July 2018,[4] Divisions II and III; and
- ACI 440.1R-15, "Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars."[5]

Per FDOT Specifications, Section 346,[4] concrete was to be Class IV without silica fume, and the 28-day compressive strength for the cast-in-place secant-pile seawall cap was specified as 5500 psi (38 MPa). The efficiency and production performance rates of secant-pile installations are highly dependent on the availability and performance of the pile grout.

Fig. 1: The secant-pile seawall/bulkhead project described in this article is located within Segment 3, an area that is considered highly vulnerable to hurricane surge flooding

Per FDOT Specifications, Section 455, Index E,[4] grout needs a minimum standard flow rate of 15 seconds and achieve a minimum compressive strength of 4000 psi (28 MPa). In addition, a cased, continuous-flight auger or equivalent was specified; all pile centers were to be located to an accuracy of 1-1/2 in. (38 mm) in plan; and piles were to be installed using a concrete guide wall that was to be removed after pile installation and prior to cap installation.

The project was designed for an extremely aggressive marine environment, with chlorides at 1320 ppm. This led to a specified minimum resistivity of 300 Ω·cm. The cast-in-place pile cap and auger-cast piles were designed for a minimum cover of 3.0 in. (75 mm), while placement tolerances were per FDOT Specifications, Section 415.[4] The GFRP bars used in this project were required to meet FDOT Specifications, Section 932-3, Table 3-4.[4]

The seawall was designed using strength design with live loads of 220 psf (10.5 kPa) and dead loads of 150 lb/ft^3 (2400 kg/m^3).

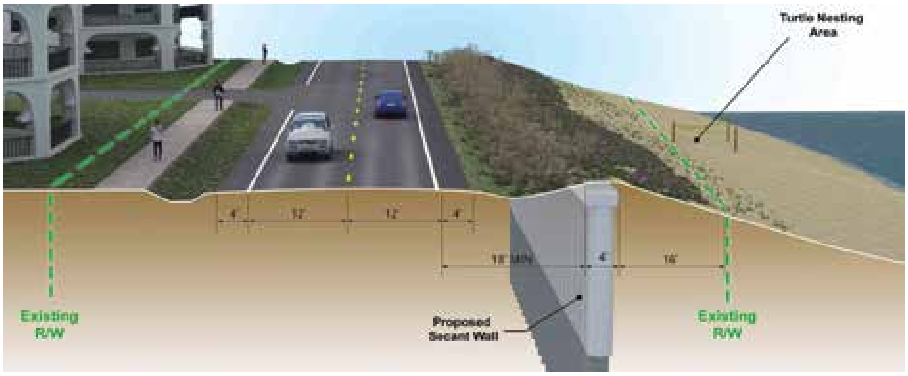

Fig. 2: A schematic rendering of the SR A1A secant-pile seawall/bulkhead project with dune reestablishment and existing right-of-way (r/w) limits

GFRP Laboratory Testing

The evaluation of GFRP reinforcing bars was conducted at the Civil, Architectural, and Environmental Engineering Advanced Structures and Materials Laboratory (SML) at the University of Miami, Coral Gables, FL. The laboratory maintains a quality assurance and quality control system (QA/QC) in compliance with the requirements of ISO 17025-2017,[6] accredited under the International Accreditation Services (IAS), and is a qualified testing laboratory for FDOT projects. Table 1 shows test results for the GFRP No. 8 bars tested in 2019 on February 26 (Lot 1), April 16 (Lot 2), and March 18 (Lot 3).

GFRP Cages and Pile Caps

The seawall's auger-cast concrete secant piles are 36 in. (910 mm) in diameter. Primary and secondary piles are 36 and 20 ft (11 and 6 m) in length, respectively. Primary piles are reinforced with 25 No. 8 GFRP bars; secondary piles are reinforced with only a single, centrally placed No. 8 GFRP bar. The design called for a pile overlap of 4 in. (102 mm) and a 4 ft (1.2 m) wide, 18 in. (457 mm) deep pile cap over the full length of the secant-pile seawall (1.5 km). GFRP reinforcing cages for the primary piles are shown in Fig. 3.

GFRP constructability

The project's specialized drill rig was assembled on Flagler Beach starting on

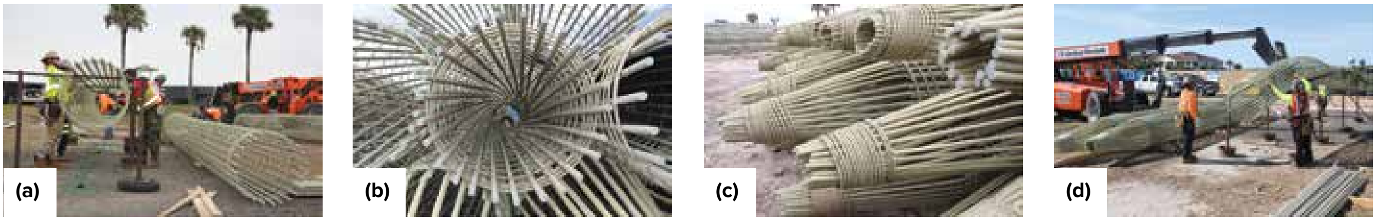

Fig. 3: The seawall was constructed using GFRP cages: (a) cage assembly was completed in the field; (b) a conventional bar layout was used in the upper sections of a cage; (c) a special pile-toe assembly was used in the lower section of each cage; and (d) assembled cages were moved from the assembly stands using a telescopic forklift

Table 1:

GFRP bars were shown to exceed the FDOT Specifications[4]

Test prefix	Standard test method	Laboratory test descriptions	Laboratory test results				FDOT Section 932-3, Table 3-4 requirements[4]
			Lot 1	Lot 2	Lot 3	Mean	
DSC	ASTM E2160[7]	Degree of cure, %	98	100	100	99.3	≥ 95
	ASTM D3418[8]	Glass transition temperature, °F	225	275	256	252	≥ 212
FC	ASTM D2584[9]	Fiber content (by weight), g	84	84	84	84	≥ 70
MAS	ASTM D570[10]	Moisture absorption (short term), %	0.17	0.18	0.12	0.16	≤ 0.25
MXA	ASTM D792[11]	Measured cross-sectional area for No. 8 bar, in.^{2}	0.818	0.825	0.803	0.815	> 0.738 < 0.913
TNS	ASTM D7205/D7205M[12]	Guaranteed tensile load, kip	111.4	93.6	104.3	103.1	> 66.8
		Tensile modulus of elasticity, ksi	8280	7980	7600	7950	≥ 6500

Notes: °C = (°F − 32) / 1.8; 1 g = 0.04 oz.; 1 in.^{2} = 645 mm^2; 1 kip = 4.4 kN; 1 ksi = 6.9 MPa

February 25, 2019. Over the following 4.5-month period, 1847 piles were installed.

The secant piles were located using a guide wall—a plain concrete template cast in a trench. Pile locations were set in the template using removeable, preassembled steel formwork (Fig. 4). In addition to helping define the verticality and top elevation of the secant piles, the template served as a removable form that exposed the upper reaches of the piles and allowed them to extend into the subsequently placed seawall/bulkhead pile cap.

Secant-pile installation

The secant-pile construction sequence involved drilling and placing secondary piles (piles reinforced with only a single GFRP bar) on Day 1 and Day 2 of a 3-day rotating cycle. On Day 3, primary piles (those reinforced with 25 No. 8 GFRP bars, spiral hoops, toe-assembly, and ties) were drilled and placed. This placement sequence resulted in an interlocked and relatively homogeneous deep foundation wall-type system (shown in Fig. 5). Additionally, due to the fact that primary piles (piles with the full reinforcing GFRP bar cages) are cut into the secondary piles (those with only a single, central GFRP bar), all the reinforcing GFRP cages are provided with full cover.

GFRP cage installation

The lightweight, flexible GFRP reinforcing cages in the primary piles allowed for smooth and rapid installation (Fig. 6). Due to the relatively loose nature of the Flagler Beach "beach sand," the piles were installed using the cased auger-cast method. The secant-pile and pile-cap installations were also closely monitored and timed. Based on current estimates, in comparison with similar projects comprising steel reinforcing bar cages, the GFRP cages resulted in bar placement time savings of 32 to 52% throughout the typical observation time of an extended workweek. More time savings were noted toward the end of each week.

Figure 7 shows the installed secant piles, continuous pile-cap construction, and dune reestablishment over the constructed secant-pile seawall. The reestablished dune will minimize the environmental and aesthetic impacts of the protective structure.

Summary and Discussion

The SR A1A seawall project comprises GFRP reinforcing bars in its 1847 secant piles and continuous cap. The GFRP bars have a high tensile strength (about twice the strength of steel bars), low weight (about one quarter the weight of steel bars), and are noncorrosive. As a result of these features, the cage installations were smooth and rapid, and maintenance and repair costs over the life cycle of the seawall are expected to be minimal. While periodic restoration of the dune may be needed to minimize the potential for scouring of the seawall, the durable materials in the wall will provide an extended time window for restoration activities.

Fig. 4: Construction of the guide wall, a concrete template that was used to align and locate the seawall's secant piles and provide positional restraint and the required verticality of the piles. The guide wall was removed prior to construction of the pile cap

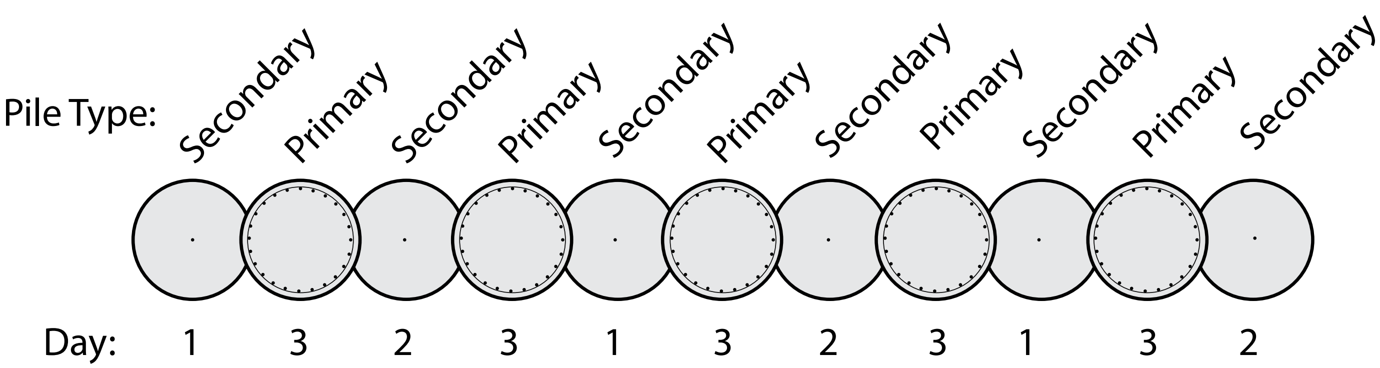

Fig. 5: The piles were placed in a sequence that ensured that the primary piles could be drilled into and interlocked with the secondary piles

Fig. 6: A specialized drill rig was used to install the secant piles using the cased auger-cast method. The installation sequence comprised: (a) drilling; (b) soil removal and grouting; (c) GFRP cage lifting; (d) cage alignment; (e) cage insertion into the grout; and (f) final cage positioning

As the interest in and use of GFRP reinforcement for concrete structures increases further, all stakeholders are working on different fronts to make the technology more effective and efficient, while maintaining low cost and durability as the essential attributes.

Acknowledgments

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Selected for reader interest by the editors.

(a) (b) (c)

Fig. 7: After secant piles were installed: (a) the concrete guide wall was removed; (b) formwork and GFRP reinforcing bars were placed for the pile cap; and (c) a dune was constructed over the wall after the pile-cap concrete was placed and cured, and the pile-cap formwork was removed

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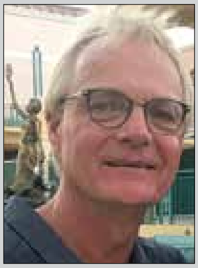

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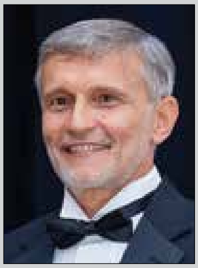

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