Sustainable cities and communities through GFRP secant-pile seawall innovation, sustainability, fortification and hurricane storm surge protection

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Abstract. In this ever changing technologically evolving world, in order to create a more sustainable built environment, it is essential to adhere to established core elements and improve or re-invent them for all of humanity, and from a Civil Engineering perspective this includes enhancing and better designing our current and future Infrastructure. A Global Education is essential to promote new, advanced materials, that are not yet mainstream, so we concur that the path towards Sustainable Cities and Communities (SDG 11), achieving relevant Targets 11.1, 11.2, 11.3, 11.6 and 11.7, is indeed only possible, if other relevant SDG’s are also met. This research effort is not only discussing Sustainable Cities and Communities (SDG 11), but also addressing Industry, Innovation and Infrastructure (SDG 9), through the use of GFRP Resilient Infrastructure project that were recently (2019) installed, in Florida, U.S.A., to start long-term, environmentally friendly, LCA/LCC long-term saving, protection of the Shorelines from Hurricanes and Sea Level Rise [ Relevant SDG Targets 9.1 and 9.4 will also be discussed]. Climate Action [ Relevant SDG Targets 13.1 and 13.3] and Quality Education [ relevant SDG Targets 4.3, 4.4 and 4.7] which are instrumental to the success of this project are considered. Part of the discussions will address the distinctions in Sustainability, i.e. Stability, Resilience, Durability and Robustness among others. In order to illustrate the interaction of the SDG’s, a Secant-Pile/Bulkhead Shore-Protection project that is buried within a dune-system and is in harmony with the surrounding coastal environment was chosen. Constructability issues will be discussed and illustrated, and data measurements provided to showcase the efficiency of this system, resulting in GFRP assembly time savings of 32% to 52%, lightweight installations and ease of constructability. An indication will be provided how the construction sector (i.e. sustainable built environment) can contribute towards Sustainable Cities and Communities (SDG11) of the future, along with the challenges that are associated with new materials and methods that yet have to find a broader foothold.

1. Introduction to a GFRP Secant Pile Seawall - Sustainable Cities and Communities

A non-intrusive structurally GFRP reinforced secant-pile seawall with continuous GFRP pile-cap was recently completed in 2019, in Flagler Beach, Florida, USA. The advantages of this in-place constructed secant-pile seawall is multifaceted and includes an increased wall stiffness when compared to similar sheet-pile wall sections, induces significantly less noise pollution during construction installation, as verified by vibration monitoring and other specialized testing equipment, makes relatively difficult ground condition installations possible and is comprised of a drastically increased construction.
alignment flexibility. The disadvantage of the installed secant-pile seawall is an incrementally increased initial cost when compared directly to an alternate typical sheet-pile wall installation. The introduced GFRP provides an increased service life, works well in marine environments, and typically requires less maintenance over the projected lifespan of the secant-pile seawall system. At this time, it is estimated that more than $59 Trillion US-Dollars will be required to further build, retrofit, repair, and enhance the global transportation infrastructure, which makes the use of GFRP a logical alternative to be considered to conventional means of construction. Initially developed in the mid 1930’s, GFRP is becoming a key element in the building industry, due to its inherent property and material characteristics, including a very high strength to weight ratio, considerably lower material weight, which results in faster installation (labour time savings) and significantly lower shipping costs. Furthermore, GFRP is resistant to salt-water, chemicals, salts, and others. Additionally, the ability to mold complex shapes and forms, its low maintenance and no loss of laminate properties after 30 years makes it even more attractive as an alternative building material for the future. As part of creating sustainable cities, the development of resilient societies and economies is essential. This typically centers around a substantial investment in essential public transportation infrastructure, the establishment of green public spaces, and adequate planning and incorporation of new technologies into our communities. It is a fact, that more than 50% of our global population will live in cities by the year 2050, while our cities are on the forefront of coping with the COVID-19 pandemic and its lasting impacts. Change is imminent to life in our cities.

2. Hurricane Impact on Flagler Beach, Florida, USA
In 2016 the seaside community of Flagler Beach, FL, USA, was severely impacted and battered by Hurricane Matthew, resulting in the erosion of the dune system and collapse of almost 1.6 km (1 mile) of the Highway-System, designated as an Evacuation-Route that is located in Evacuation Zone-A. This resulted in a decision to fortify and protect the highway system and provide innovative, sustainable, yet resilient storm surge protection. Figure 1 and Figure 2, as illustrated below, show the resulting destructive effort of Hurricane Matthew in 2016, that Flagler Beach, Florida, USA endured.

![Figure 1: Hurricane Matthew caused Dune and Roadway Erosion, in Flagler Beach, FL](image1)

![Figure 2: Space-View of Hurricane](image2)

3. Industry, Innovation and Infrastructure
The need to drastically improve our industry and infrastructure, through innovation is clear and herein it recognizes the importance of research and innovation for finding lasting solutions to social, economic and environmental challenges. This Secant-Pile Seawall is one of these innovations. It is clear, that further Research and Development (R&D) and innovation and sustainable transport will also play a critical role. Equally important is the use of innovative construction materials and methods. The use of Glass Fiber Reinforced Polymer (GFRP) bars to structurally reinforce this Secant-Pile Seawall System clearly demonstrates this. To ensure that the 2016 Hurricane Matthew destroyed and now restored highway remains in service in the event of a similar future Hurricane, a buried Secant-Pile protection and support system was constructed and completed in September of 2019, and was already tested, when 2019 Hurricane Dorian remained approximately 161 km (100 miles) offshore paralleling the Eastern-Coastline. Although, remaining at sea, a maximum of almost 4 m (13 feet) of vertical erosion was measured near the 2019 re-built seawall/bulkhead. It appears that the resilient GFRP seawall was almost fully tested and will remain to protect the shoreline.
4. Secant-Pile Seawall Materials and Methods

Sustainable Cities, Towns and Suburbs are essential for American’s, European’s and the Global Population’s quality of life and wellbeing. It is therefore important to consider stability, robustness, vulnerability, resilience and sustainability among others, in the design of this buried Secant-Pile Seawall, as well as for the community benefit. Investigations sponsored by GFRP Manufacturers are demonstrating the durability of this technology in existing structures that have been in service for more than 20 years. Durability can best be described herein as: \[
\text{Resilience} = \{\text{Durability} + \text{Sustainability}\}.
\]

It is this unique Secant-Pile GFRP Seawall/Bulkhead that is its first of a kind, constructed in Flagler Beach, Florida, USA that if deemed successful will more than likely be implemented in many Coastal Areas and not just Florida, to protect our Shorelines from Hurricanes, Storm-Surges, Sea Level Rise and other adverse conditions. The facts are that in only 4.5 Months almost 1.6 km (1 mile) of GFRP Secant-Pile Seawall/Bulkhead was constructed with an implemented dune re-nourishment program, as depicted further in Figure 3 below.

![Figure 3: 2019 Secant-Pile/Bulkhead buried Seawall installation with 1847 Secant-Piles and Pile-Cap, at Flagler Beach, Florida, USA.](image)

This unique project involved the installation of approximately 305,000 m (1,000,000 LF) of GFRP bars that are corrosion resistant and are expected to significantly reduce the Life Cycle Costs for this project. 1847 GFRP Secant-Piles that are 1 m (3 ft) in diameter and extending to an installation depth of approximately 12.2 m (40 ft) were installed, during utilization of expedited construction methods, enabling the project to proceed smoothly and with minimum impact to the environment. Currently a Life Cycle Analysis and Assessment is in-progress, and the data will be shared upon completion. The re-established dune system is shown in Figure 3 above, that clearly shows relatively minimum impact to the environment and reconstruction of a Hurricane battered region in a relatively short period of time.

5. Climate Action and Quality Education

Annual mean temperatures continue to rise worldwide and are of concern with respect to Global Warming. An increase of 0.96 °C. was recorded from 2009-2018 alone. Therefore, utilizing advanced and innovative materials and selected methods, can reduce the Carbon Footprint and be sustainable.

![Figure 4: Eurostat Global and European Annual Mean Temperature (°C) Deviations from 1850-2018.](image)

![Figure 5: Florida Map, Path of Hurricane with caused Erosion and Secant-Pile Seawall Rendering.](image)

Quality Education is essential and access to equitable and quality education through all stages of life is needed. The use of new advanced materials and methods allows learning and implementation of new
technology and enables us to educate future generations. As the interest and use of FRP reinforcement for concrete structures increases, all stake holders are working on different fronts to make the technology more effective and efficient, while maintaining low cost and durability as the essential attributes. Some interesting advances from a manufacturing perspective are the use of resins other than vinyl-ester or epoxy that will allow faster production (scaling-up), the possibility of shipping bars in coils, and bending at regional fabricators (never at the site!), rather than the rebar pultrusion facility.

6. Results and Conclusions
The SR-A1A Flagler Beach, Florida, USA seawall project comprises GFRP reinforcing bars in its 1847 secant piles and continuous pile-cap. The GFRP bars are expected to significantly reduce maintenance and repair costs over the life cycle of the seawall. 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. Laboratory Testing compliance of GFRP rebars, with respect to FDOT Specifications, was demonstrated and indicated that an Average Degree of Cure of 99.3%, Average Glass Transition Temperature of 122.2 °C. (252.0 °F), Average Fiber Content (by Weight) of 84 grams, Average Short-Term Moisture Absorption of 0.16%, Average Measured Cross-Sectional Area of 525.8 mm.² (0.815 in.²), average Guaranteed Tensile Load of 46,765.4 kg. (103.1 kip), and average Tensile Modulus of Elasticity of 54,813 M Pa (7.95 Msi) was achieved. Laboratory Test Results have surpassed the minimum specified requirements with great margin.

In conclusion, seawall protection systems may not be everyone’s ideal solution for ensuring future coastal asset protection, or community mobility and continuing economic prosperity, but until societal debate on coastal defense versus retreat, or the sustainability of beach re-nourishment programs are settled, the buried GFRP Secant-Pile protection system provides one non-corrosive, effective solution, when coupled with dune restoration and re-nourishment, and can provide a relatively low-impact solution for coastal dune highway-systems.

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➢ Florida Department of Transportation [FDOT]
➢ National Science Foundation [NSF]
➢ University of Miami [UM]

8. References

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