Towards the Experimentally Based Design of an Effective and Eco-friendly Modular Shoreline Protection System for High Energy Tidal Flow

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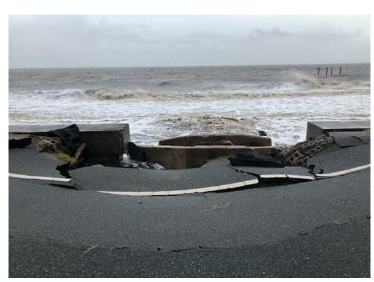
Context

MOTIVATION

The recent impacts of hurricanes Harvey, Irma, Maria and more recently Michael have highlighted there is a great need to explore novel **effective and eco-friendly methods for shore protection**.



Credit: Charles Ferrell

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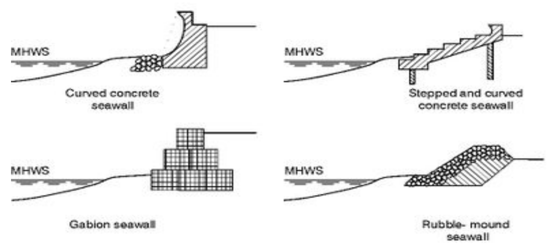
MOTIVATION

Seawalls are often considered as the **most applicable and reliable solution** for shore protection.

There are different seawall types: vertical walls, curved walls, riprap embankments, and submerged artificial reefs.



Source: Mangor (2007)

MOTIVATION

Existing seawall designs (bulkheads, revetments, living shorelines) do not provide the **desired levels of protection and biocompatibility**.

Common issues reported:
- Prone to collapse (seawalls)
- Not effective for high tidal flow (living shorelines)
- Expensive with often high environmental impact

⚠ Raising or replacing a 100-foot seawall can range from $10,000 to $125,000

MOTIVATION

Shoreline hardening reduces habitat value with revetments (seawalls) typically supporting 23% lower biodiversity and 45% fewer organisms than riprap and natural shorelines.

Gittman et al. 2016

Type	Material Cost/LF	Installed Cost/LF	Projected Lifespan	Repair Cost/LF	Replace Cost/LF	External Functions	External Cost/Benefit
Concrete Bulkhead	$476	$1,022	30+	$100-500	%120	-Pollution control -Storm abatement	Loss
Granite Revetment Type 1	$164	$469	20+	$100-200	%120	-Carbon Sink -Nutrient Fix -Sediment Retention	Loss
Living Shoreline	$120	$361	Indefinite	N/A	N/A	-Wild life	Gain

Source: Governor's South Atlantic Alliance

DESIGN PROBLEM STATEMENT AND SOLUTION

An efficient and cost-effective shoreline protection system for areas with high energy tidal flow with adaptive features for various applications and topography that creates an ecofriendly environment for marine life

⇨ **SEAHIVE**: a series of perforated concrete tube elements that allow wave-energy to dissipate within the structure

Goal and objectives

DESIGN PROBLEM STATEMENT AND SOLUTION

An **efficient** and cost-effective shoreline protection system for areas with high energy tidal flow with adaptive features for various applications and topography that creates an ecofriendly environment for marine life

⇨ **SEAHIVE**: shape adapted for stability as well as to increase wave-energy dissipation and structural complexity

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Goal and objectives

DESIGN PROBLEM STATEMENT AND SOLUTION

An efficient and **cost-effective** shoreline protection system for areas with high energy tidal flow with adaptive features for various applications and topography that creates an ecofriendly environment for marine life

⇨ **SEAHIVE**: concrete elements produced with traditional pipe making equipment

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DESIGN PROBLEM STATEMENT AND SOLUTION

An efficient and cost-effective shoreline protection system for areas with **high energy tidal flow** with adaptive features for various applications and topography that creates an ecofriendly environment for marine life

⇨ **SEAHIVE**: system designed based on physical testing under hurricane conditions at the SUrge STructure Atmosphere Interaction (SUSTAIN) Facility

DESIGN PROBLEM STATEMENT AND SOLUTION

An efficient and cost-effective shoreline protection system for areas with high energy tidal flow with **adaptive features for various applications and topography** that creates an ecofriendly environment for marine life

⇨ **SEAHIVE**: modular system with elements being installed horizontally or vertically, stacked in a tight configuration or with an offset

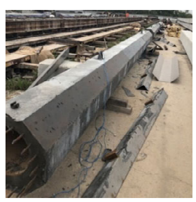
DESIGN PROBLEM STATEMENT AND SOLUTION

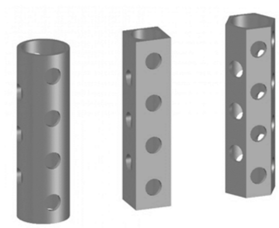
An efficient and cost-effective shoreline protection system for areas with high energy tidal flow with adaptive features for various applications and topography that creates an **ecofriendly environment for marine life**

⇨ **SEAHIVE**: made with low alkalinity cement, seawater concrete and non-corrosive reinforcement, and an increased structural complexity

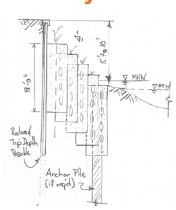
DESIGN PROBLEM STATEMENT AND SOLUTION

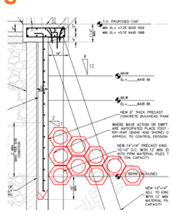
Concrete pipe and **SEAHIVE elements**

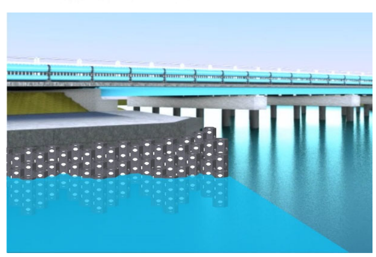




SEAHIVE system configurations

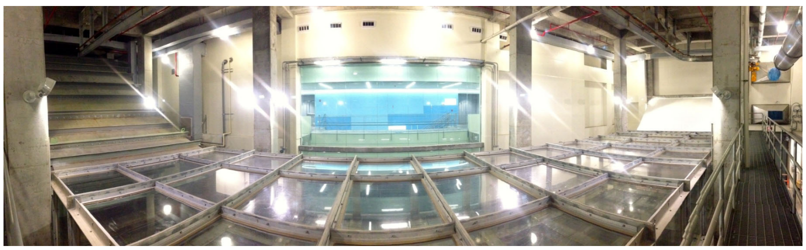






EXPERIMENTALLY BASED DESIGN

In the absence of design guidelines for green/gray infrastructure, SEAHIVE is studied through **physical testing under extreme conditions** at the SUrge STructure Atmosphere Interaction (SUSTAIN) Facility



NIST National Institute of Standards and Technology U.S. Department of Commerce

University of Miami Rosenstiel School of Marine & Atmospheric Science

University of Miami College of Engineering

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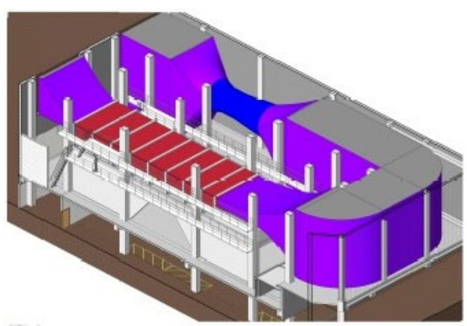
Surge Structure Atmosphere Interaction (SUSTAIN) Facility

- Dimensions 23 x 6 x 2 m, max. water depth 1 m
- Wind speeds up to 62 m/s in tank (scaled > 100 m/s U10)
- Fully controllable 12-element directional wave generation
- Louvered inlet with vortex generators



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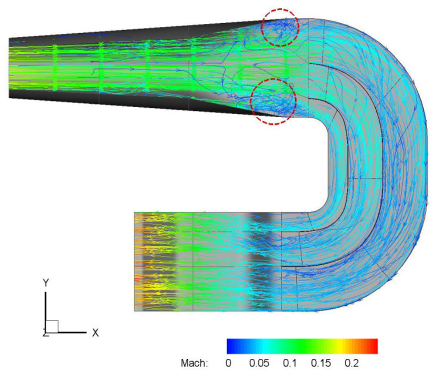
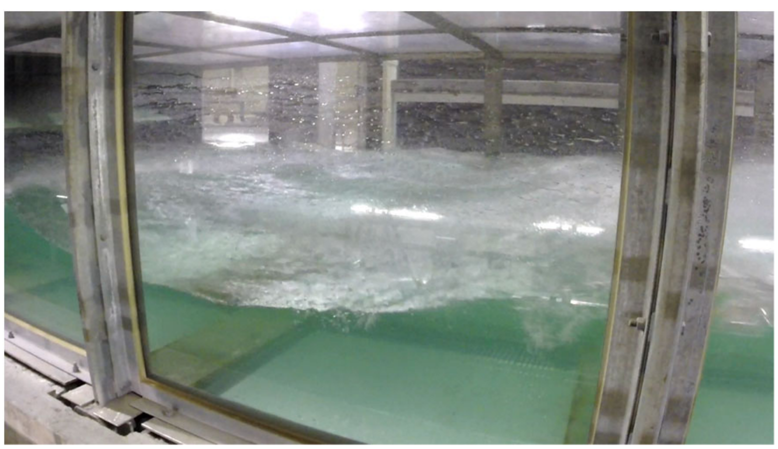
Surge Structure Atmosphere Interaction (SUSTAIN) Facility

- Parabolic beach for sensor mounting, wave dissipation
- Acrylic construction, high overhead bay and elevated base for optical, remote sensing studies
- Operational with natural seawater or freshwater
- Temperature control on water from 10-40 C



CFD of inlet duct air flow (top view)

Surge Structure Atmosphere Interaction (SUSTAIN) Facility



Winds (50 m/s) and mechanical waves (1 Hz)

Research methodology

Surge Structure Atmosphere Interaction (SUSTAIN) Facility

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Research methodology

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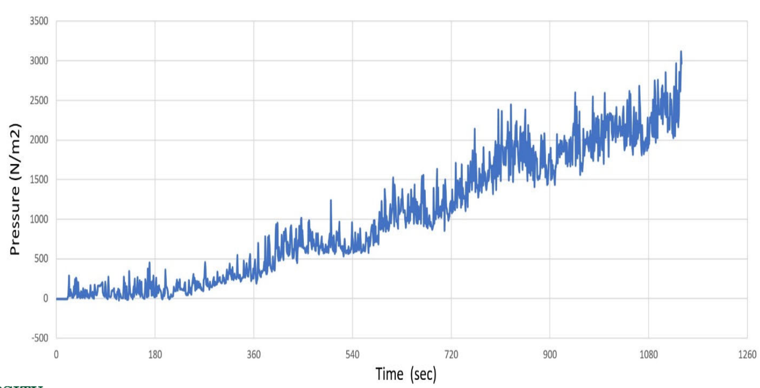
Pressure measurements from physical testing



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Research methodology

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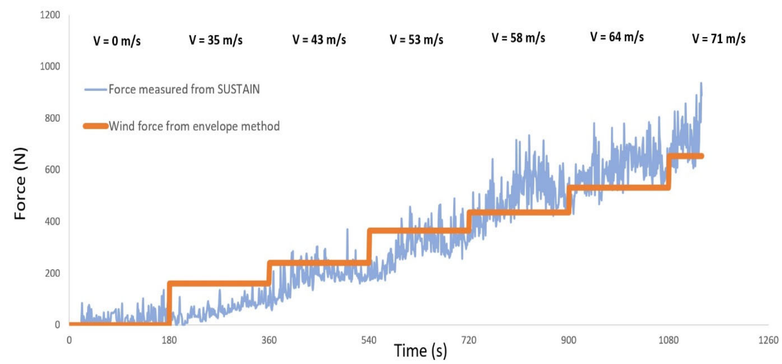
Measured force vs estimated force (wind)



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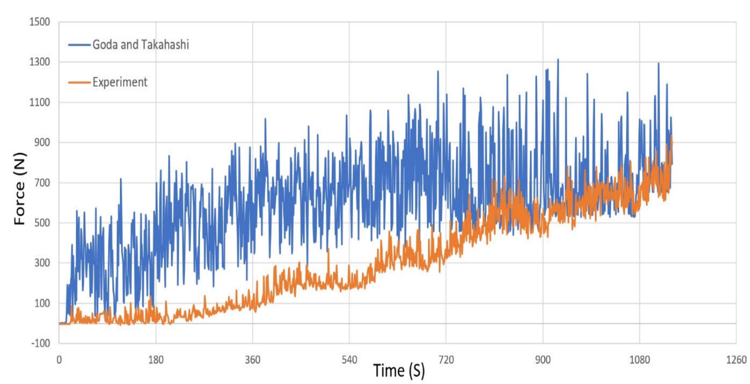
Research methodology

Surge Structure Atmosphere Interaction (SUSTAIN) Facility

Measured force vs estimated force (wind + wave)



⚠ Better understanding the wind-wave interaction

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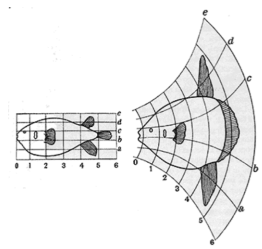
Research methodology

MORPHOLOGY AND MORPHOGENESIS

Morphology: The outward appearance (shape, structure, color, and pattern) of an organism and its components

Morphogenesis: The processes that control the organized spatial distribution of cells to form tissues, organs and overall body anatomy



D'Arcy Thompson's classic fish transformation

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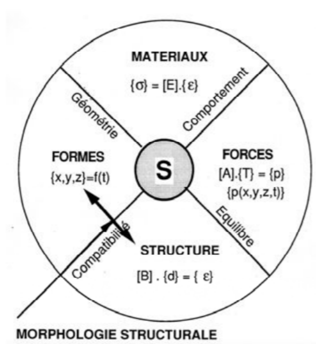
STRUCTURAL MORPHOLOGY

The study of the relation between form and structural action considering aspects, such as structural behavior, shaping structures, efficiency of structures, structural topology



Conceptual scheme by Motro (2009)

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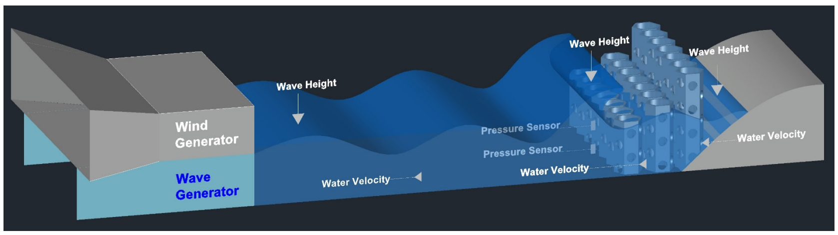
PHYSICAL MORPHOGENESIS OF SEAHIVE

SEAHIVE is tested under a range of wind-wave conditions from a tropical storm to hurricane Category 5:

- loads measured using a series of pressure sensors
- performance evaluated based on measurements of wave height and current velocity



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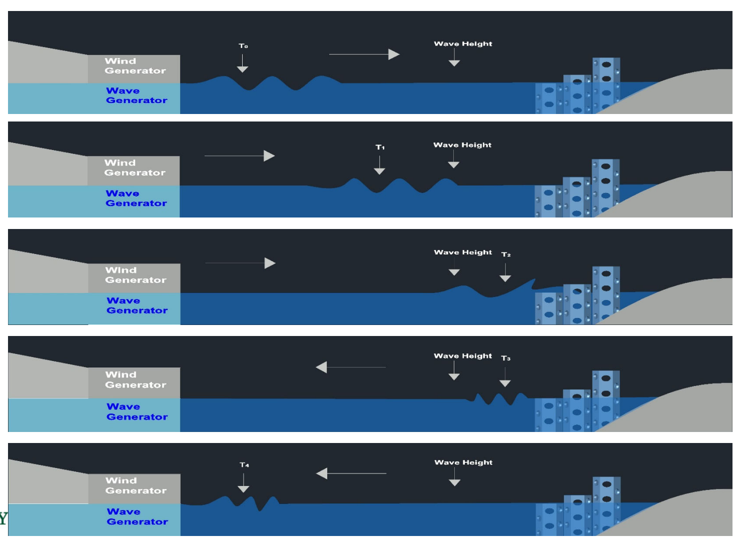
Research methodology

PHYSICAL MORPHOGENESIS OF SEAHIVE



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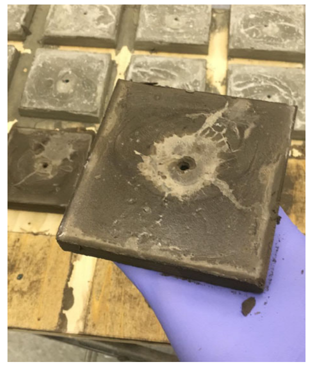
PHYSICAL MORPHOGENESIS OF SEAHIVE

Biocompatibility is evaluated through auxiliary studies on material composition and structural complexity.

Tiles fabricated using different cementitious materials are exposed to the marine environment for different time periods and evaluated based on the diversity of the microorganisms found on them.



TEST PHASES

Phase 1: Form and load definition

Experimental load definition, optimization of the outer profile and void configuration for wave energy dissipation, and element-performance characterization

Phase 2: Material, design and constructability

Deployment of sustainable sea-concrete reinforced with GFRP strands and casting using cored prefabricated formwork tested

TEST PHASES

Phase 3: System configuration

Investigation of key design parameters (e.g. orientation, distance, and offset) and system-performance characterization under extreme conditions

Important note

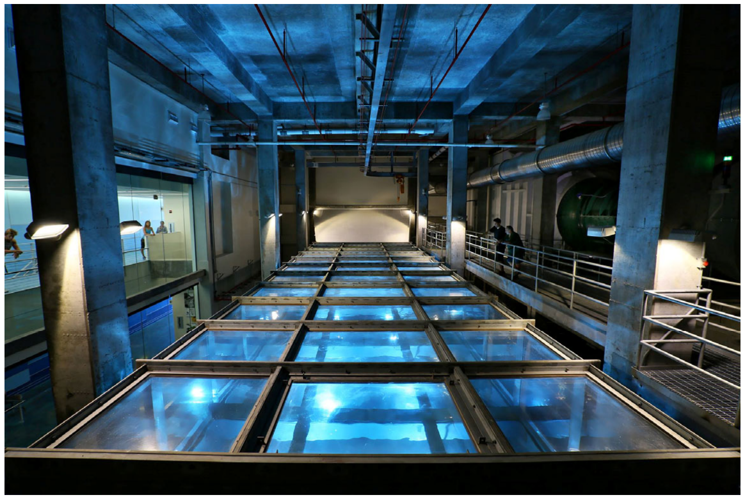
In the absence of design guidelines for biocompatibility, habitat value is ensured qualitatively by considering physical parameters (Spieler et al. 2001) and trends that have shown to increase it as well as through supplementary studies.

SUMMARY - DISCUSSION

The structural morphology of SEAHIVE, a novel efficient, eco-friendly and adaptive seawall concept, is investigated through experimental testing at the SUSTAIN tank.

The SUSTAIN tank enables the controlled testing of wind, wave and surge dissipation under extreme (winds up to Saffir-Simpson Hurricane category 5) conditions.

Experimental data from SUSTAIN is used to quantify design loads as well as to evaluate performance through criteria such as wave-energy reduction.



Website: sustain.rsmas.miami.edu

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