FAMU-FSU College of Engineering

DEPARTMENT OF
CIVIL & ENVIRONMENTAL
ENGINEERING

Resiliency of MSE Wall to Surge and Wave Loading (BED30 977-15)

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GRIP Meeting
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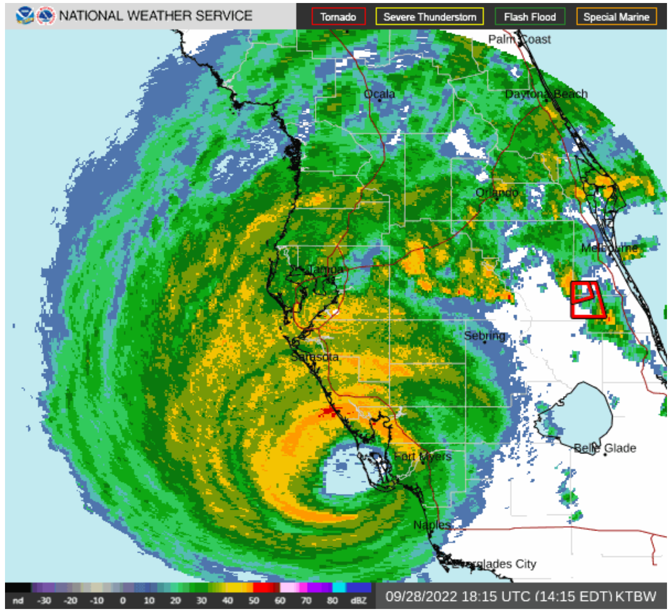
Introduction and Motivation

- Many barrier island communities are served by bridges.
- In most places, the causeway bridges are the only emergency access (evacuation and post event aid).
- In Florida, many of these bridges have MSE wall approaches and abutments.
- Coastal MSE walls are much more likely to experience the storm tide associated with extreme tropical hydrodynamics.
- Storm tide is the storm surge + short waves + tide.
- The west coast and panhandle of Florida is prone to large surge (shallow offshore slope).
- MSE wall stability is susceptible to hydrodynamic forcing.

Introduction and Motivation

Hurricane Ian Impact on Florida (2022)



•**Wind Speed**: 150 mph sustained winds.
•**Storm Surge**: 12 – 18 ft near the coast, 8 ft recorded in downtown Fort Myers (NOAA).
•**Wave Heights**: 6 – 13 ft (USGS).
•**Timing**: Struck shortly after high tide (+2.5 ft).
•**Rainfall**: 15 inches of rain.

Background

- **AASHTO Guide Specifications for Bridges Vulnerable to Coastal Storms** – design methods for wave loading and surge that results in both horizontal and vertical loading.
- The hydrodynamic loading is based on 100-year storm event (1/100 likelihood of occurrence in any given year) - may not capture the current observed frequencies of extreme hydrodynamic events.
- Predictions of the loading based on geomorphological factors, and atmospheric conditions, the forecasted loading should be modeled, in particular, for the abutments and MSE walls as well.
- Previous MSE Wall Stability Modeling (BDK75 977-22).
  - Centrifuge tests able to model MSE wall stability at 1/40th scale
  - Internal miniature sensors for total stress demonstrated
- Wave loading on bed has been demonstrated in centrifuge tests at similar scales.
- Backfill and bearing bed stresses and high resolution strains can be measured in centrifuge models with miniature pore pressure sensors and fiber optic.

Project Objectives

- Review of literature, reports, AASHTO and USACE design guidelines.
- Collect hydrodynamic data and shoreline bathymetry.
- Collect MSE wall information for those that failed during Hurricane Ian.
- Identify mode(s) of failure with numerical and centrifuge model experiments of representative MSE wall cases subjected to storm wave and surge loading.
- In centrifuge experiments, measure: hydrodynamics (wave heights and currents), hydrodynamic loading on the model MSE walls, wall displacements and pore pressure in soil.
- Test remediation measures that include larger mean particle size of the backfill and test external porous protection elements.
- Based on experimental findings make recommendations for design revisions and remediation measures of existing MSE walls.

Project Tasks

- Task 1: Review of Prototype MSE Wall Design, Hydrodynamic Data, and Literature
- Task 2: Experimental Design and Numerical Model Predictions
- Task 3: Centrifuge Tests of Model MSE Walls Exposed to Hydrodynamics
- Task 4: Comparison Analysis Between Experiments and Predictions with Recommendations for Mitigation and Design
- Task 5: Draft Final Report and Closeout Teleconference
- Task 6: Final Report

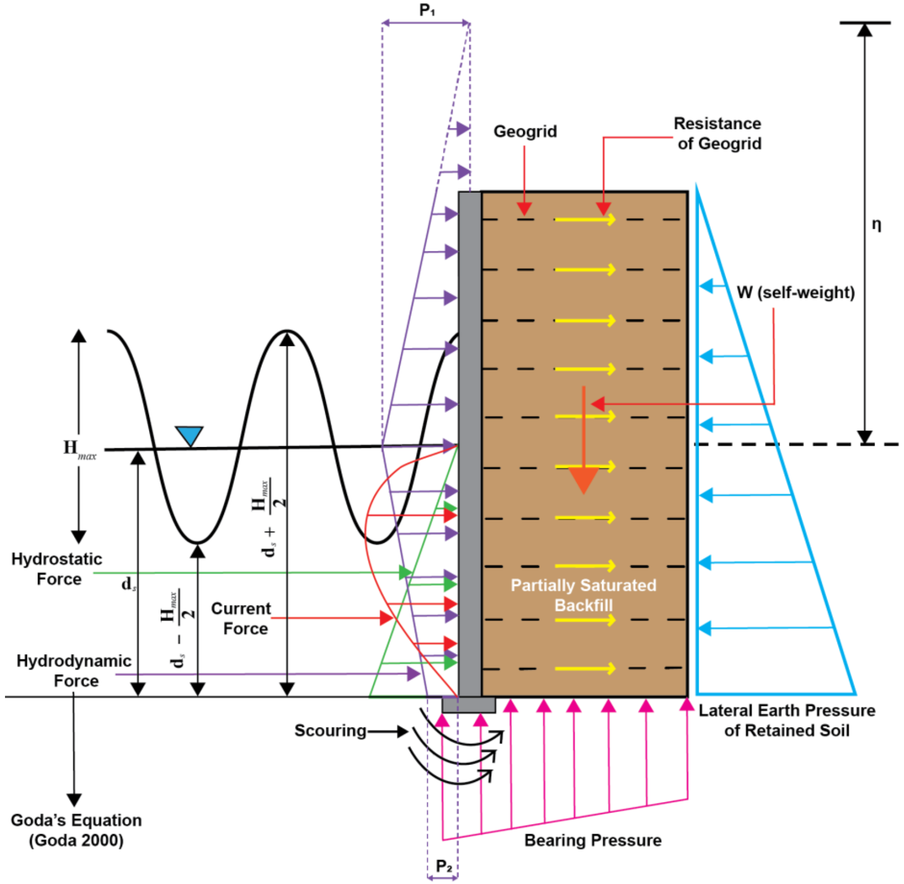
Task 1: Review of Prototype MSE Wall Design, Hydrodynamic Data, and Literature

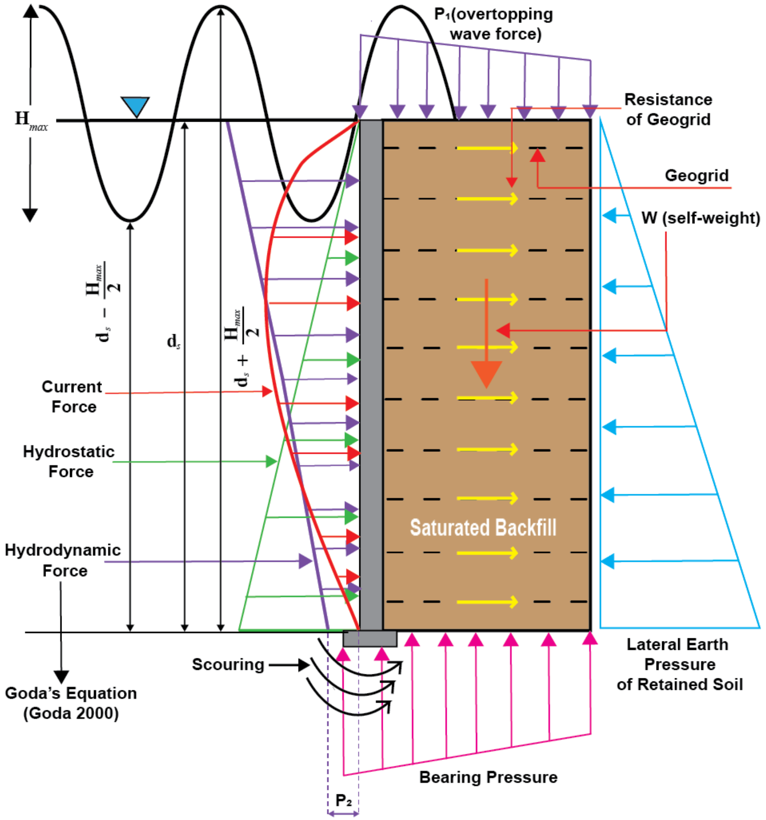
- Collect design and forensic data on coastal MSE wall failures from tropical storms
  - Elevations, wall dimensions, reinforcement and connection type, panel dimensions, backfill properties, roadway structural layer info, bearing soil properties, revetment dimensions
- Collect bathymetry for the Gulf of Mexico and San Carlos Bay
- Collect available pre, during, and post storm hydrodynamic data
  - Data for storms other than Ian also
  - NOAA-NDBC and IOOS HF Radar wave data
  - FL agencies and universities

Task 1: Review of Prototype MSE Wall Design, Hydrodynamic Data, and Literature

- Review AASHTO and USACE design guidelines
  - AASHTO specifications for bridges vulnerable to coastal storms includes recommendations for estimating horizontal and vertical wave forces associated with intact and breaking waves and direct currents
  - USACE Coastal Structures manual includes methods and approaches for estimating non-linear hydrodynamics and scour
- Prototype MSE wall and hydrodynamic parameters will be identified based on the review findings and in consultation with FDOT engineers

Kinematics of MSE Wall Under Loading





Pressure and Force Equations

Wave: Goda's equation (AASHTO 2008; Goda 2000)

$$p_1 = \frac{1}{2}(1+\cos\theta)(\alpha_1)\gamma_w H_{max} \qquad (6.1.3.3\text{-}1)$$

$$p_2 = \frac{p_1}{\cos h(2\pi d_s/\lambda)} \qquad (6.1.3.3\text{-}2)$$

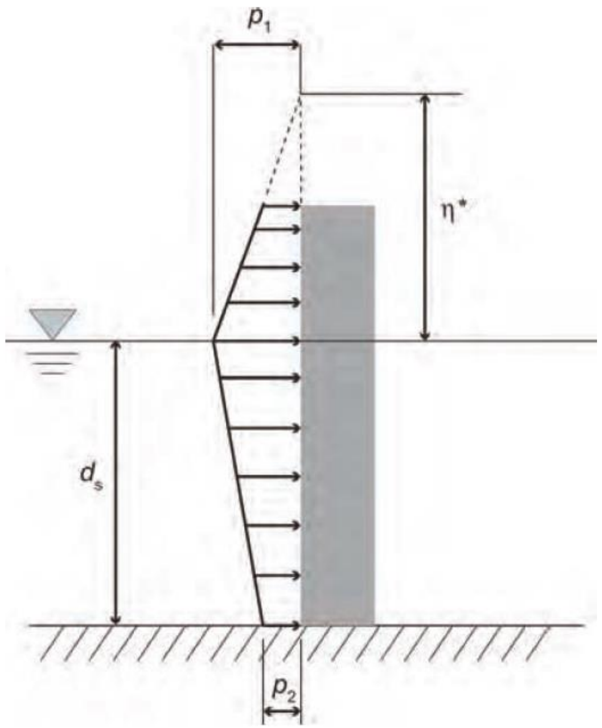
in which:

$$\alpha_1 = 0.6 + \frac{1}{2}\left[\frac{4\pi d_s/\lambda}{\sin h(4\pi d_s/\lambda)}\right]^2 \qquad (6.1.3.3\text{-}3)$$

$$\eta^* = 0.75(1+\cos\theta)H_{max} \qquad (6.1.3.3\text{-}4)$$

where:

p_1	=	pressure at storm water level (kip/ft^2)
p_2	=	pressure at mudline (kip/ft^2)
α_1	=	coefficient
θ	=	angle between direction of wave approach and a line normal to the structure (deg)
H_{max}	=	maximum probable wave height (ft), which may be determined as specified in Article 6.2.2.4 for a Level I analysis, and by storm modeling for Levels II and III
d_s	=	water depth at or near the bridge including surge, astronomical tide, and local wind set-up (ft)
λ	=	wave length (ft)
γ_w	=	unit weight of water taken as 0.064 kip/ft^3
η^*	=	potential height above the storm water level to which wave pressure could be exerted (ft)



Wave Force on Large Element

Current: Force equation (AASHTO 2008)

$$F_{HC} = C_d A\left(\frac{\rho_w}{2}\right)\frac{U_c^{\,2}}{1000} \qquad (6.1.2.4\text{-}1)$$

where:

ρ_w	=	mass density of water taken as 2.0 slugs/ft^3
U_c	=	current velocity (ft/sec) taken as specified in Article 6.2.2.6
A	=	projected area per unit length of superstructure subjected to current at the storm water level (ft^2/ft)
C_d	=	drag coefficient taken as 2.5

Estimate Wave Height and Period

Empirical equations (USACE Coastal Engineering Manual)

shallow water corrections (constant depth, d):

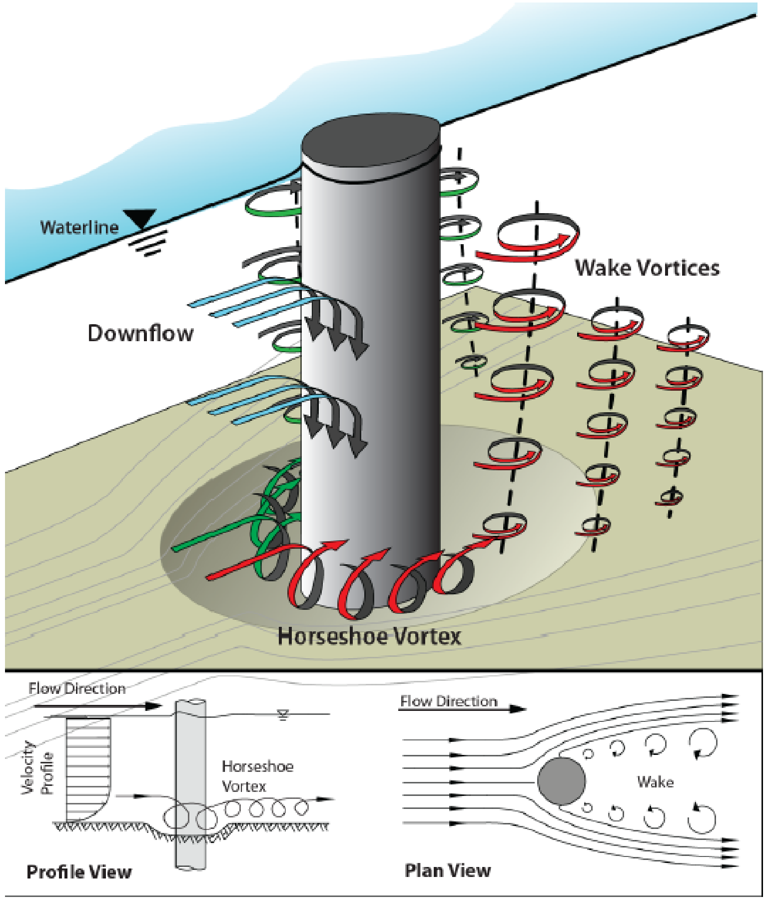
$$\frac{gH}{U_A^2} = 0.283 \tanh\left[0.530\left(\frac{gd}{U_A^2}\right)^{3/4}\right] \tanh\left\{\frac{0.00565\left(\frac{gF}{U_A^2}\right)^{1/2}}{0.530\left(\frac{gd}{U_A^2}\right)^{3/4}}\right\}$$

$$\frac{gT}{U_A} = 7.54 \tanh\left[0.833\left(\frac{gd}{U_A^2}\right)^{3/8}\right] \tanh\left\{\frac{0.0379\left(\frac{gf}{U_A^2}\right)^{1/3}}{0.833\left(\frac{gd}{U_A^2}\right)^{3/8}}\right\}$$

for sloped bottom → use "equivalent water depth"

Estimate Local Scour

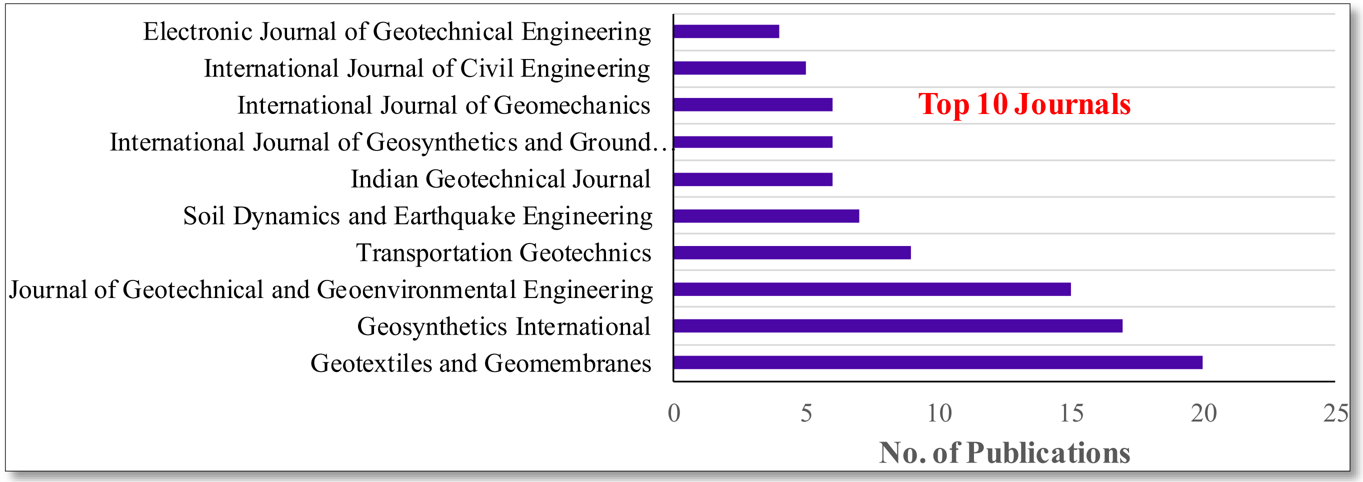
Schematic drawing of local scour processes at a cylindrical pier. (FDOT 2024)



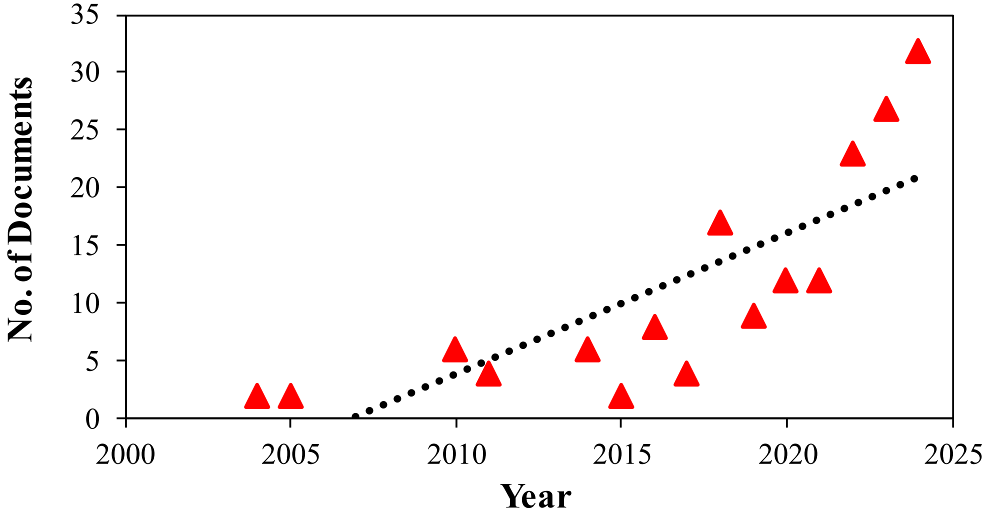
$$y_s = f(\rho, \mu, \ , g, D_{50}, \sigma, \rho_S, y_0, V, \ D^* \ \theta)$$

- y_s is the equilibrium scour depth
- ρ and ρ_s are the densities of water and sediment, respectively
- μ is the dynamic viscosity of water, temperature dependent
- g is the acceleration due to gravity
- D_{50} is the median diameter of the sediment
- σ is the gradation of sediment
- y_0 is the depth of flow upstream of the structure
- V is the depth-average velocity upstream of the structure
- D* is the effective diameter of the structure, which is the diameter of a circular pile that would experience the same scour depth as the structure under the same sediment and flow conditions
- Θ is a parameter that quantifies the concentration of fine sediments in suspension.

Scientometric Analysis



Number of publications according to the top 10 journals.



Number of annual publications per year targeting MSE.

•Research on MSE walls and GRS (geosynthetic reinforced soil) walls has increased steadily from 2004 to 2024.

•This rise reflects advancements in geotechnical engineering and growing interest in soil reinforcement techniques.

Observation

- **Scientometric analysis shows growing interest in MSE wall research, especially in improving their strength and performance.**
- **Since MSE walls are a type of retaining wall often used near the coast, it's important to understand how they behave under hydrodynamic forces like waves and currents.**
- **Some research has been done on coastal retaining wall failures under wave and surge forces, but MSE walls in coastal areas are not yet well studied.**
- **The growing number of publications on MSE walls, centrifuge testing, and numerical modeling demonstrates the increasing demand for improved design and resilience strategies.**

Literature Review

Table 1. Summary of key aspects of retaining wall behavior under hydrodynamic forces.

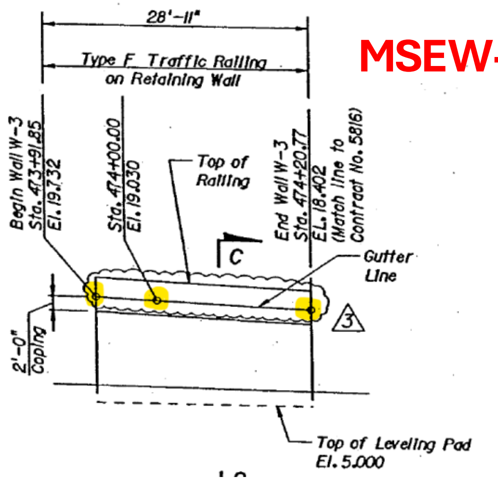
Reference	Types of retaining wall	Methodology	Hydrodynamic forces	Calculation methods/formulas
Feygin (2012)	Flexible seawalls, a modified version of: • Sheet pile bulkheads • Diaphragm walls • **Vertical retaining walls** supported by tiebacks	**Analytical** and conceptual design approach, supported by case studies and theoretical modeling.	• **Breaking wave** pressures (impulsive and pulsating) • Uplift and suction forces due to overtopping and backflow • **Overtopping discharge** effects • Impact loads from debris or elevated water levels during extreme weather events	• **Goda's Modified Formula** (for wave pressures on vertical walls) • Used Eurotop (2007) criteria to classify wave impulsiveness based on: - Surf similarity index
Dang et al. (2021)	• **Vertical Wall (VW)** • Trapezoidal Wall (TW) • Stepped-face Wall (SW) • Galveston-type Curved Seawall (GSW) • Curved Parabolic-Stepped Wall (CPS)	**Numerical modeling** using the **Smoothed Particle Hydrodynamics (SPH)** method via **DualSPHysics code**. The numerical results were validated against well-established **analytical formulas** (**Goda**, Tanimoto & Kimura, and Takahashi)..	• Horizontal wave-induced forces (from non-breaking and breaking waves) • **Wave overtopping volume** over seawall crests	• Hydrodynamic forces were calculated using the **SPH method** in **DualSPHysics** Validated against: • **Goda's formula** (vertical wall) • Tanimoto and Kimura (trapezoidal wall) • Takahashi's modification for breaking wave-induced impulsive pressures
Reddy & Neelamani (2005)	**Vertical seawall** (impervious wall or caisson) subjected to wave forces; studied in conjunction with a fronting low-crested rubble mound breakwater.	- **Physical modeling** conducted in a 30 m long, 2 m wide, 1.7 m deep **wave flume** at IIT Madras. - Parameters varied: • **Breakwater height-to-water depth ratio** (h/d) • Distance between **breakwater and seawall** - **Wave height**, wave period, and wave steepness	• Shoreward (positive) forces • Seaward (negative) forces • Qualitative discussion of wave overtopping and run-up behavior	• Measured experimentally using force balance sensors • Compared against Goda's analytical formula for pulsating wave forces • Proposed a modification factor (S_n) to estimate reduced force.
Chen et al. (2014)	Two vertical seawalls: • NTOU seawall • PTT seawall Both located in Keelung, Taiwan, and were damaged by Typhoon Sinlaku (2002).	**Numerical modeling** using the **Smoothed Particle Hydrodynamics (SPH)** method.	• **Wave overtopping** and impact forces on seawalls. • Resulting vertical jet velocities, horizontal throw speeds, and downward impact from falling water. • No direct pressure force calculations; focus was on velocity fields and overtopping discharges that damaged the seawalls.	**Hydrodynamic behavior** was computed using the SPH governing equations for continuity and momentum.
Ravindar et al. (2022)	Vertical seawall (plain) - Retrofitted with three types of recurve parapets: • Small Recurve (SR) • Medium Recurve (MR) • Large Recurve (LR)	**Numerical modeling** using OpenFOAM with the waves2Foam library.	• **Breaking wave** impact pressures • **Wave run-up and overtopping behavior** • Pressure impulse (area under pressure-time curve) • Jet-induced forces and air entrapment-induced pressure spikes	• Solved **Navier-Stokes equations** using OpenFOAM + VOF technique. • Wave breaking and impact modeled using **high-resolution transient simulations**. • Pressure sensors placed at various locations on the parapets to extract time histories.

Prototype MSE Wall

Prototype MSE Wall

Dimensions of MSEWs

MSEW-3



MSEW-4

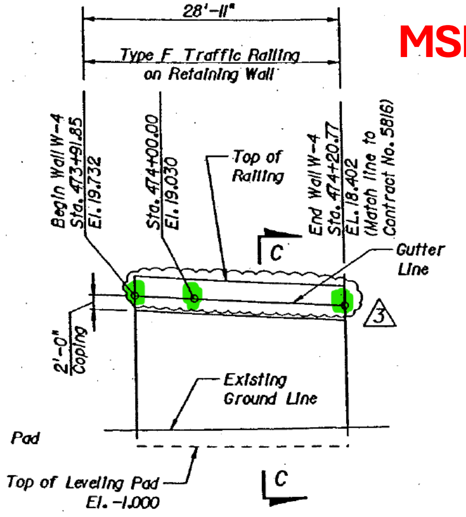


Table 2. Elevations and Heights of Wall W-4 at Key Points for MSEW-3

Location	Station Point	Top of Retaining Wall Elevation (ft)	Leveling Pad Elevation (ft)	Height (ft)
Begin Wall W-3	Sta. 473+91.85	19.732	5	14.732
Midpoint	Sta. 474+00.00	19.03	5	14.03
End Wall W-3	Sta. 474+20.77	18.402	5	13.402

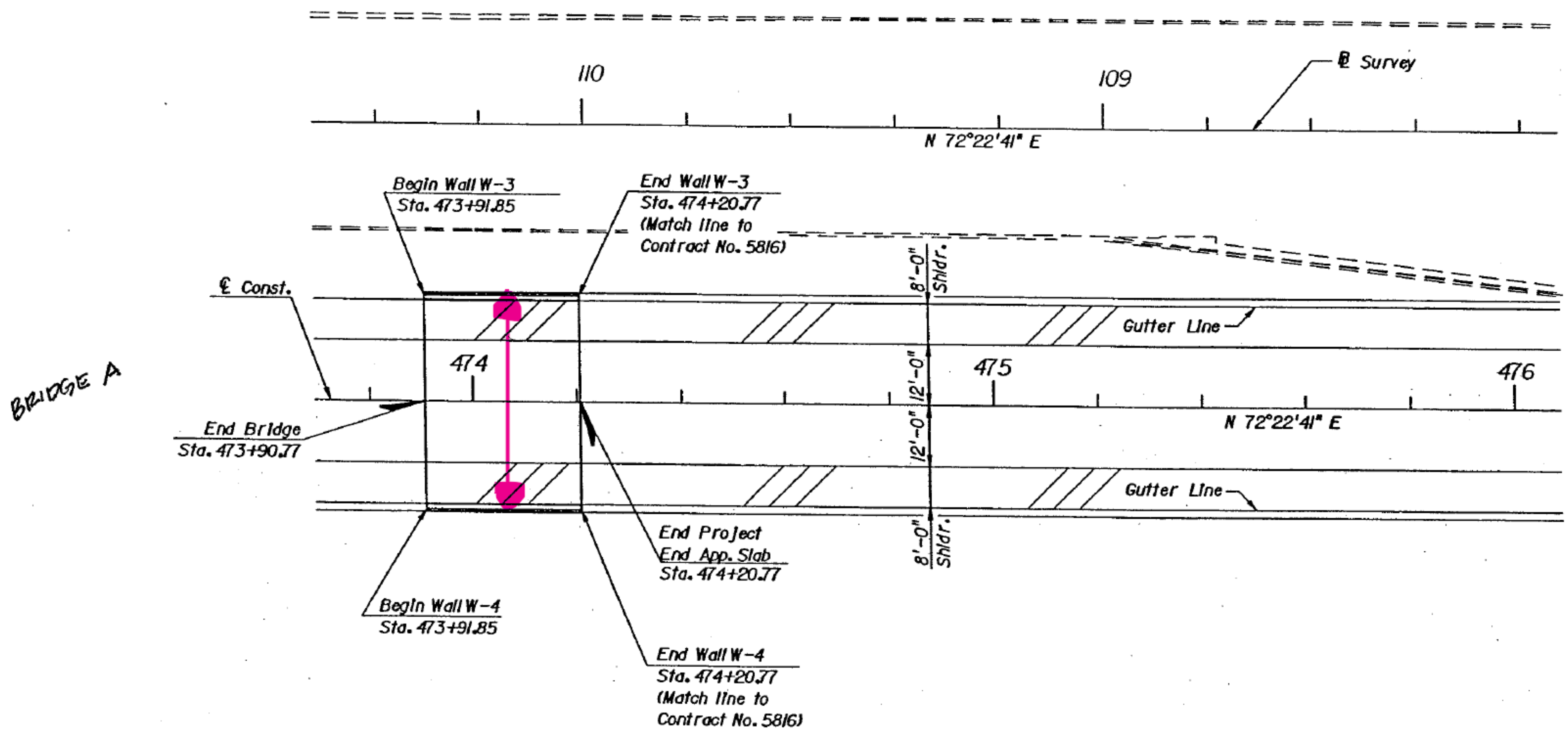
Table 3. Elevations and Heights of Wall W-4 at Key Points for MSEW-4

Location	Station Point	Top of Retaining Wall Elevation (ft)	Leveling Pad Elevation (ft)	Height (ft)
Begin Wall W-4	Sta. 473+91.85	19.732	-1	20.732
Middle Point	Sta. 474+00.00	19.03	-1	20.03
End Wall W-4	Sta. 474+20.77	18.402	-1	19.402

The length of the MSE wall is 28'-11" (28.92 feet).

Prototype MSE Wall

Dimensions of MSEWs



The width of the MSE wall both for 3 and 4 is = (12+12+8+8) ft = 40 ft

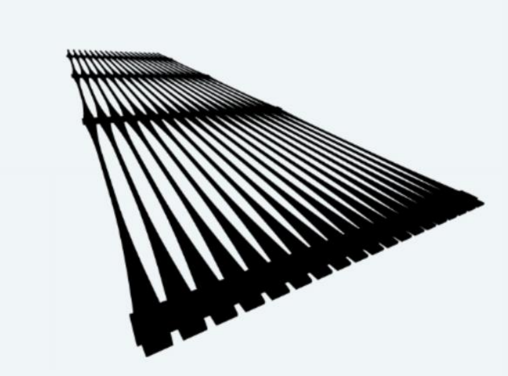
Prototype MSE Wall

Geogrid properties of Target MSEWs

Table 4. Tensar UX1600 Manufacturer's Technical Datasheet

Property	Value
Material Type	Extruded High-Density Polyethylene (HDPE)
Applications	MSE walls, Panel walls
Tensile Strength (5% Strain)	58 kN/m (3,980 lbs/ft)
Ultimate Tensile Strength	144 kN/m (9,870 lbs/ft)
Junction Strength	135 kN/m (9,250 lbs/ft)
Flexural Stiffness	6,000,000 mg-cm
UV Degradation Resistance	95%
Durability	100% resistance to long-term degradation
Max Design Life Strength	52.7 kN/m (3,620 lbs/ft) over 120 years
Roll Dimensions	Width: 4.36 ft, Length: 61 ft
Roll Weight	~216 lbs

Tensar UX1600 Geogrid



Prototype MSE Wall

Properties for Soil for MSEW

Table 5. Properties of soil for MSE wall.

Soil Type	Depth Below Existing Ground Line (ft)	Unit Weight (pcf)	Cohesion (psf)	Internal Friction Angle (°)
Reinforced Soil and Random Backfill		105	0	30°
Medium Dense to Loose Fine Sand with Shell	0 - 5 ft and 10 - 20 ft	110	0	30°
Loose to Very Loose Silty and Clayey Fine Sand with Shell	9 - 24 ft	105	0	24°
Medium Dense to Dense Cemented Sand	Not specified	110	0	34°

Prototype MSE Wall

Laboratory Testing of Soil from Failed MSE Wall at Sanibel Island Bridge

Table 6. Soil gradation and classification

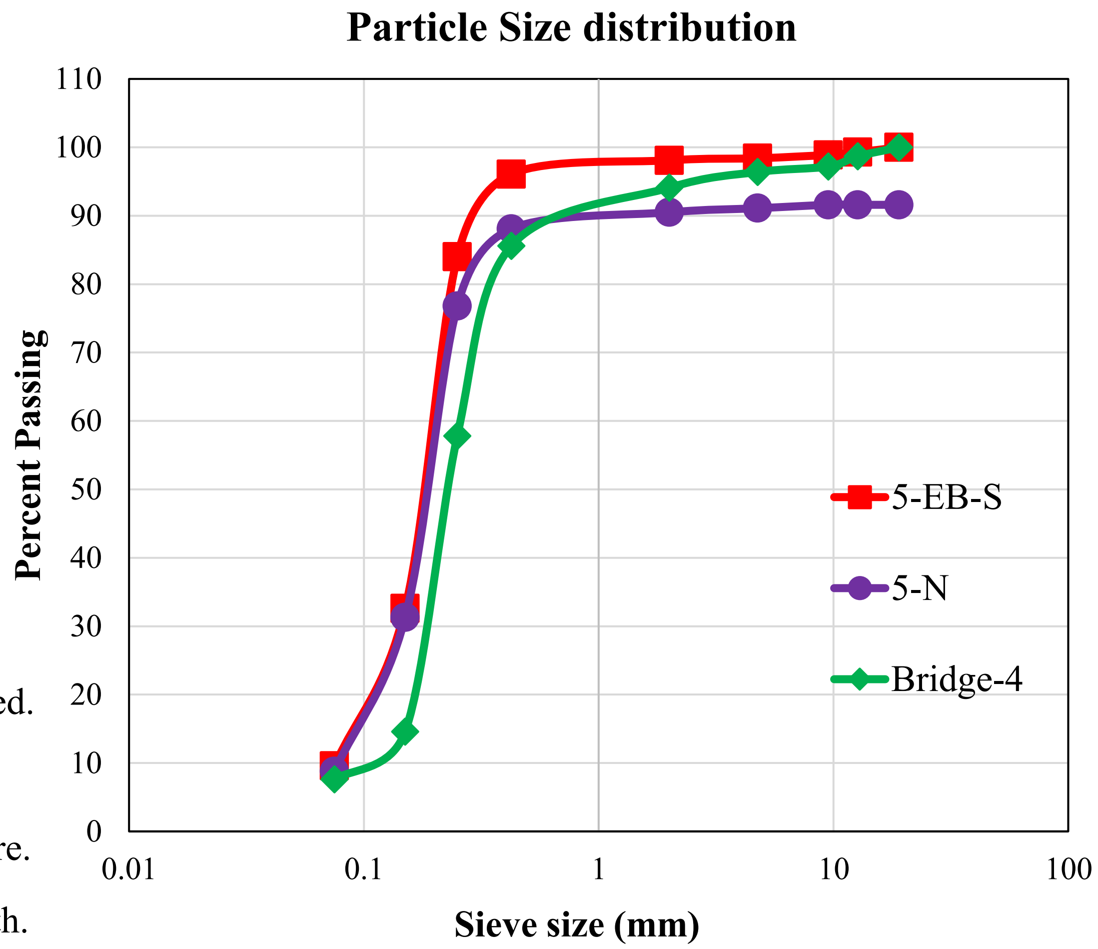
Sample	Sand (%)	Silt (%)	Clay (%)	C_u	C_c	pH	USCS	AASHTO	% Passing #200 Sieve
5-EB-S	90.4	3	6.6	1.625	1.3846	8.11	SP-SM	A-3	9.6
5-N	91.2	3.6	5.2	1.625	1.3846	8.02	SP-SM	A-3	8.8
Bridge-4	98.6	-	-	1.1667	1.006	-	SP	A-3	7.6

Table 7. Direct Shear and Permeability Tests (Lab tests of Soil from Failed MSE Wall)

Sample ID	γ_{max} (pcf)	OMC (%)	ϕ_{max}	ϕ'_r	k (cm/sec)	k (ft/day)
Bridge-4	110.2	11.2	32.5	30.2	9.96×10^{-4}	2.82

Observations

- The soils are predominantly sand (classified as A-3 under AASHTO) and poorly graded.
- The pH levels are slightly alkaline, supporting stability.
- The permeability of Sample Bridge-4 is relatively high, consistent with its sandy nature.
- The friction angles are typical for sandy soils, ensuring moderate to high shear strength.

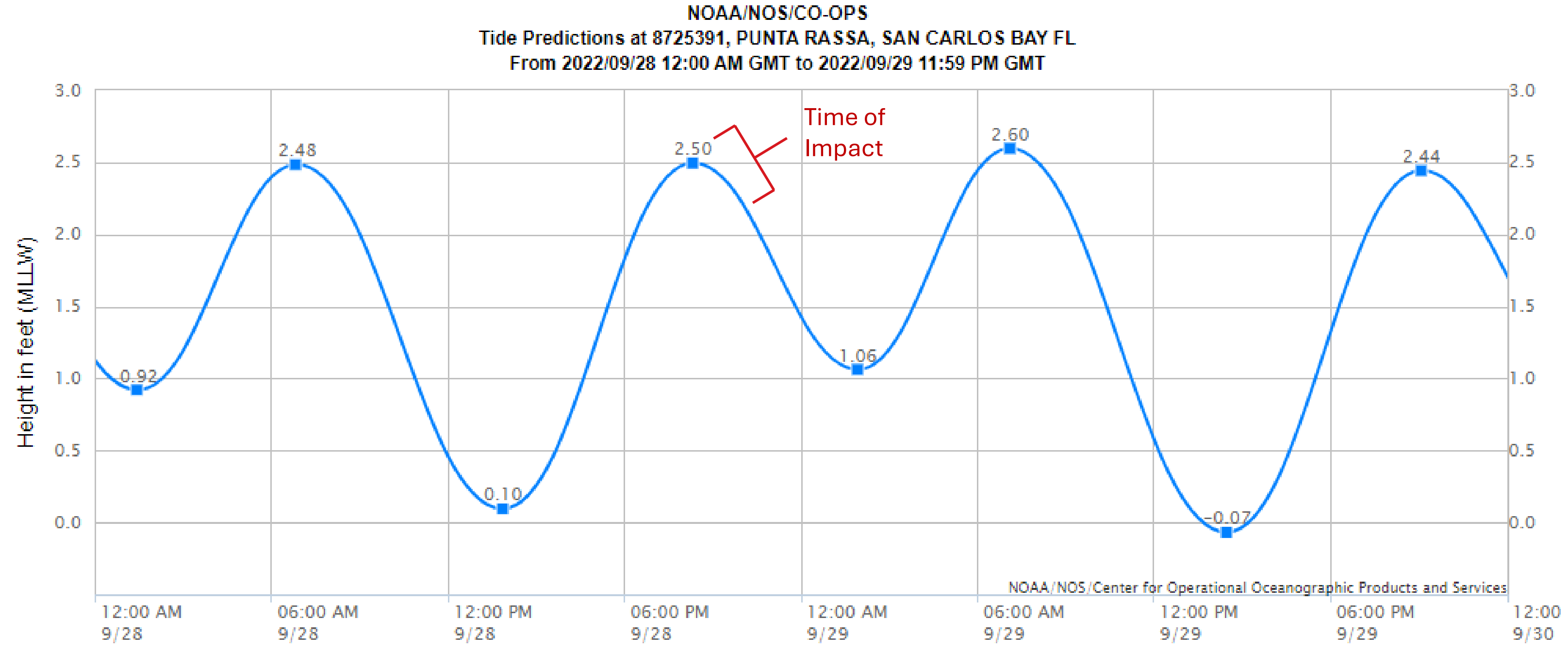


GSD for backfill soil

Prototype MSE Wall

Hydrodynamic Data

Hurricane Ian – Predicted Tide



Note: The interval is High/Low, the solid blue line depicts a curve fit between the high and low values and approximates the segments between.
Disclaimer: These data are based upon the latest information available as of the date of your request, and may differ from the published tide tables.

By: Kisan Patel, P.E. and Andrew Newman, P.E.
FDOT Districts 1 and 7 Materials Office

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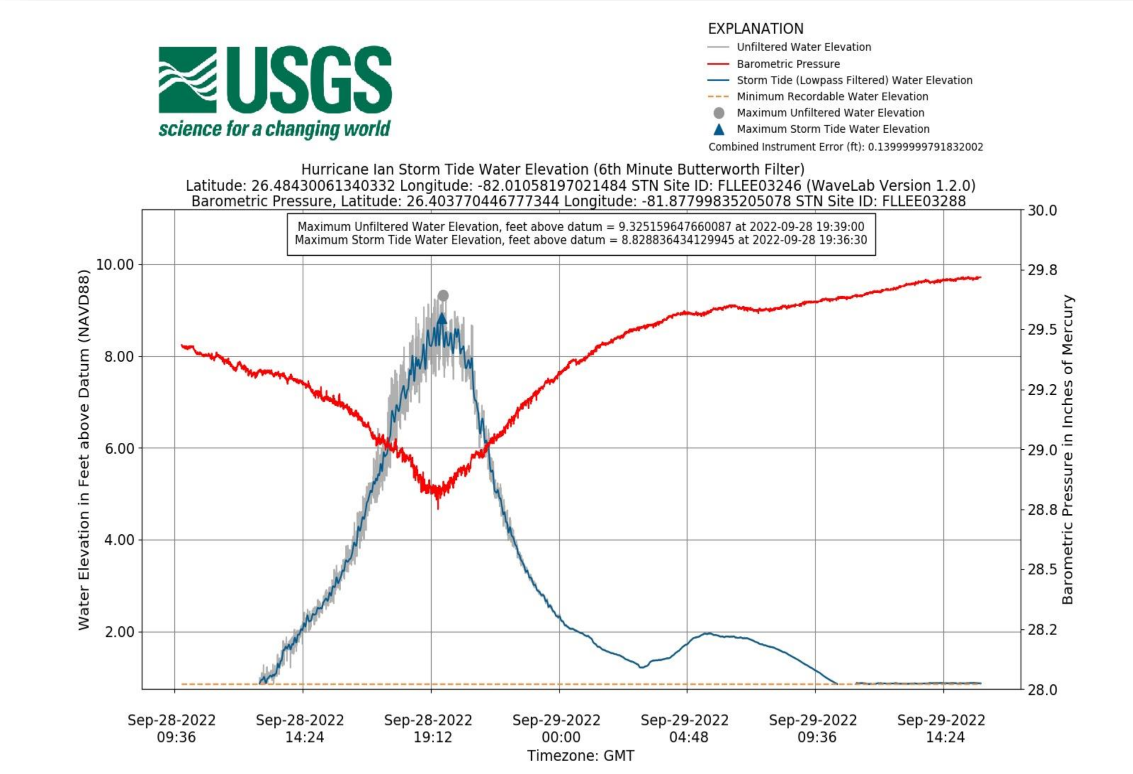
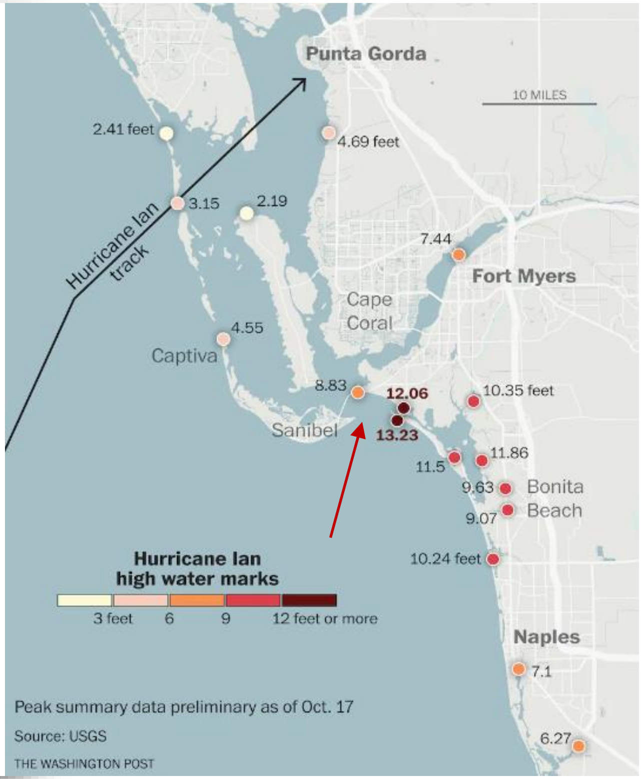
Prototype MSE Wall

Hydrodynamic Data

Hurricane Ian – Measured Storm Surge





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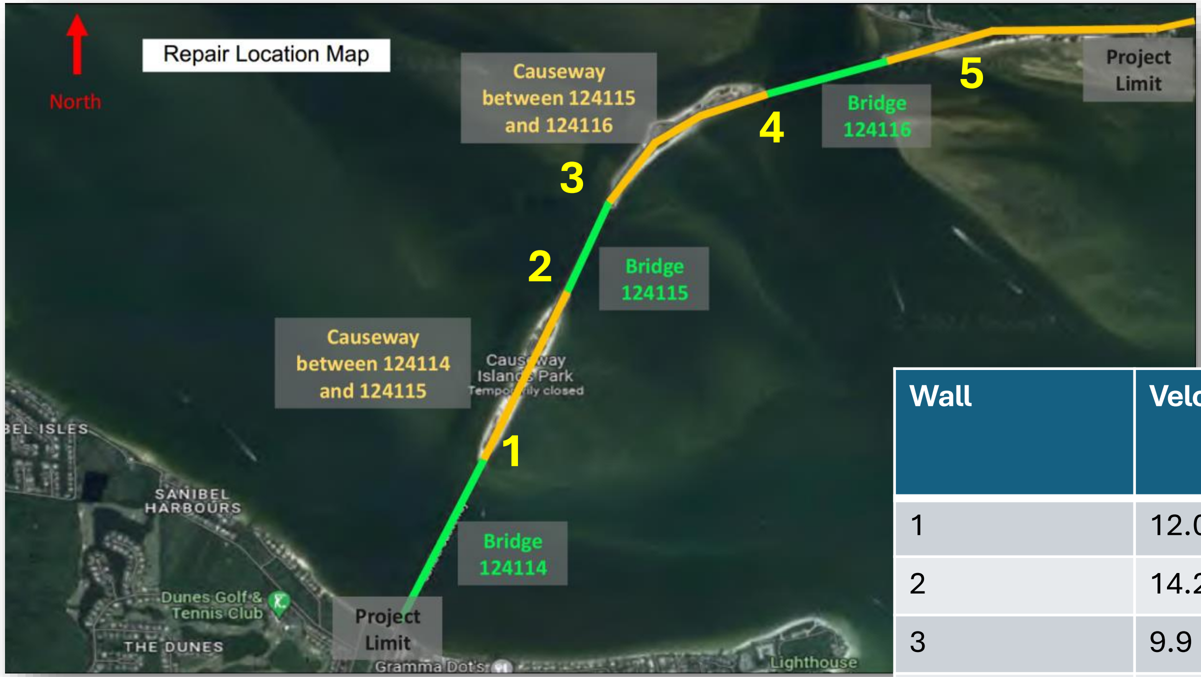
Prototype MSE Wall

Hydrodynamic Data

Impacted Area - Sanibel Causeway Bridges and Islands



Wall	Velocity (ft/s)	Significant Wave Height (ft)	Peak Period (sec)
1	12.0	6.1	4.1
2	14.2	6.5	4.8
3	9.9	7.2	4.7
4	9.6	7.9	5.1
5	14.5	6.9	5.1

Prototype MSE Wall

Hydrodynamic Data

Impacted Area - Sanibel Causeway Bridges and Islands

Task 2: Experimental Design and Numerical Model Predictions

- Numerical models will help to inform the centrifuge container and model designs
- Use models to study hydrodynamic loading (WAVEWATCH/FUNWAVE or SCHISM) and MSE wall system response (FLAC3D)
- Hydrodynamic loading per model and AASHTO guidelines (Level I and III)
- Constitutive model accounts for oscillatory and residual pore pressure effects on backfill and bearing soil contact stress
- Scaled wave and currents will be generated in a strong centrifuge container with viewing windows
- Centrifuge models will be fitted with sensing for displacements, pressures, wave heights, and water velocities

Centrifuge Testing

ERDC Centrifuge Configuration

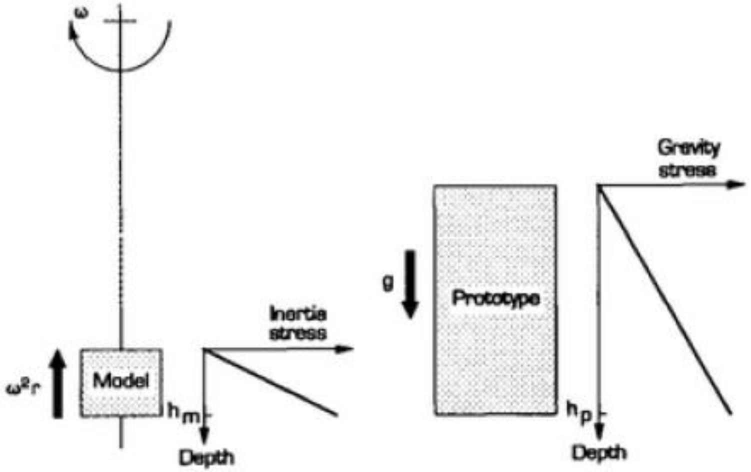
Centrifuge Specifications:

- **Capacity**: 1,200 g-ton.
- **Radius**: 6.5 meters.
- **Adjustable Counterweight**: For fine adjustments.
- **Aerodynamic Shroud**: For stability during testing.
- **Auto-Counterbalance**: To adjust for payload changes during in-flight operations.

Operational Features:

- **Payloads Capacity:** 8,000 kg.
- **Accelerations:** 10 to 350g
- **Payload Size:** 1.3 m × 1.3 m × 2 m

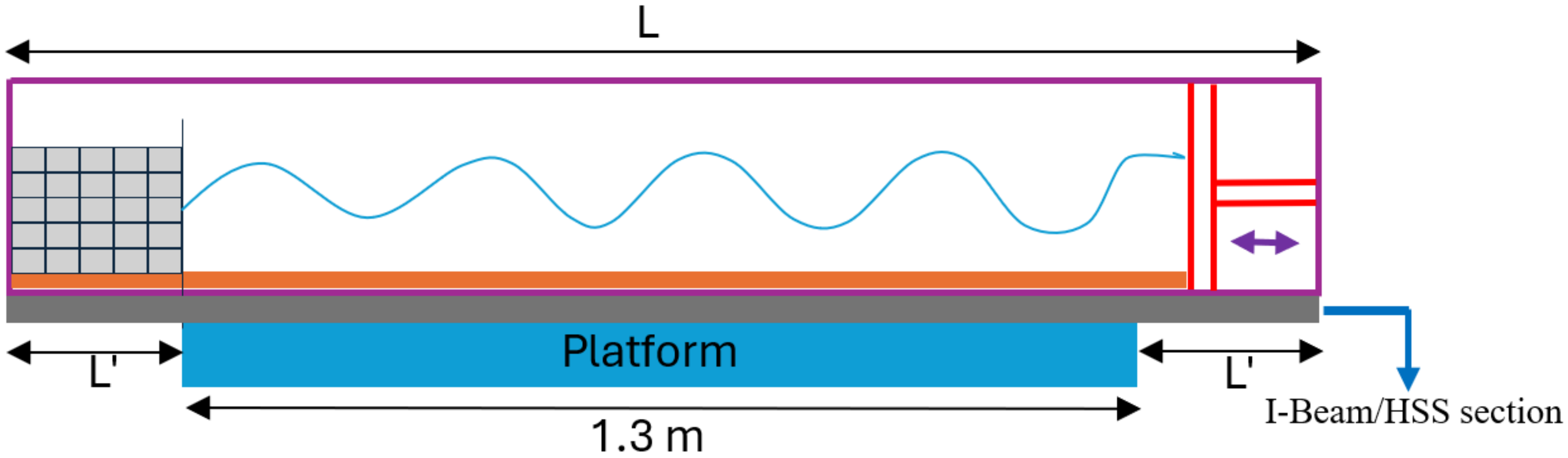
Centrifuge at the US ERDC



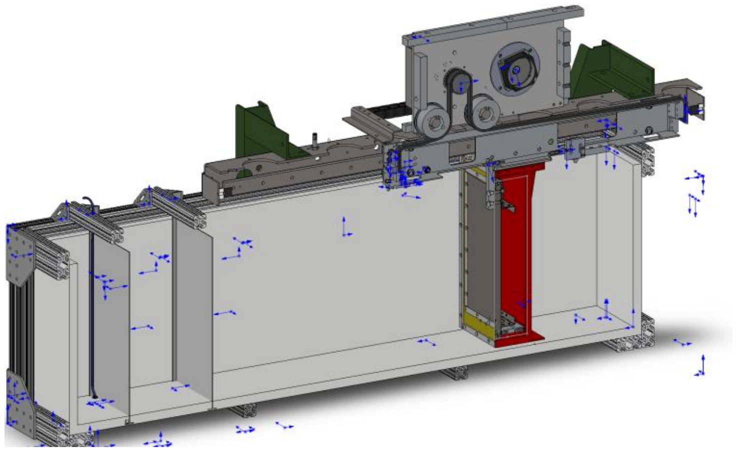
Why Centrifuge, not Wave Flume?

- ✓ **Centrifuge testing replicates prototype stress conditions in model scale**, enabling realistic soil behavior under gravitational loading.
- ✗ **Wave flume tests good for hydrodynamics but cannot replicate full scale prototype stresses.**

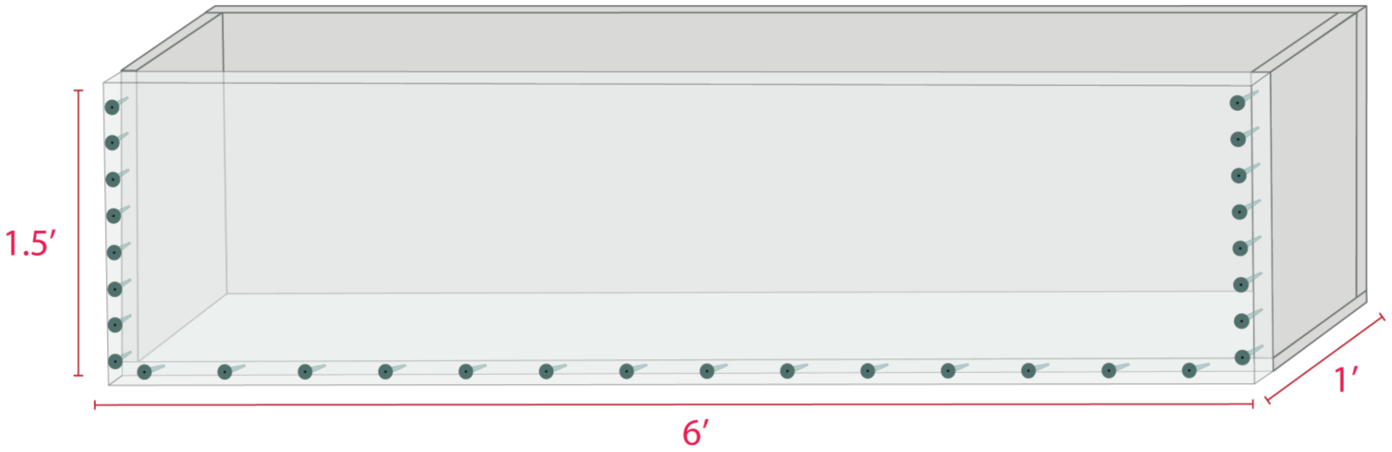
Centrifuge Testing



Schematic of centrifuge model setup with a wave tank, including platform dimensions and wave generation system.



Centrifuge flume container (6 ft (L) x 1.5 ft (W) x 1.5 ft (H)) with piston wave maker (red/gray and DC actuator) – Edinburgh Designs



Schematic of a soil container showing the bolted connections on each side wall, with dimensions

Centrifuge Testing

Prototype to Model Conversion

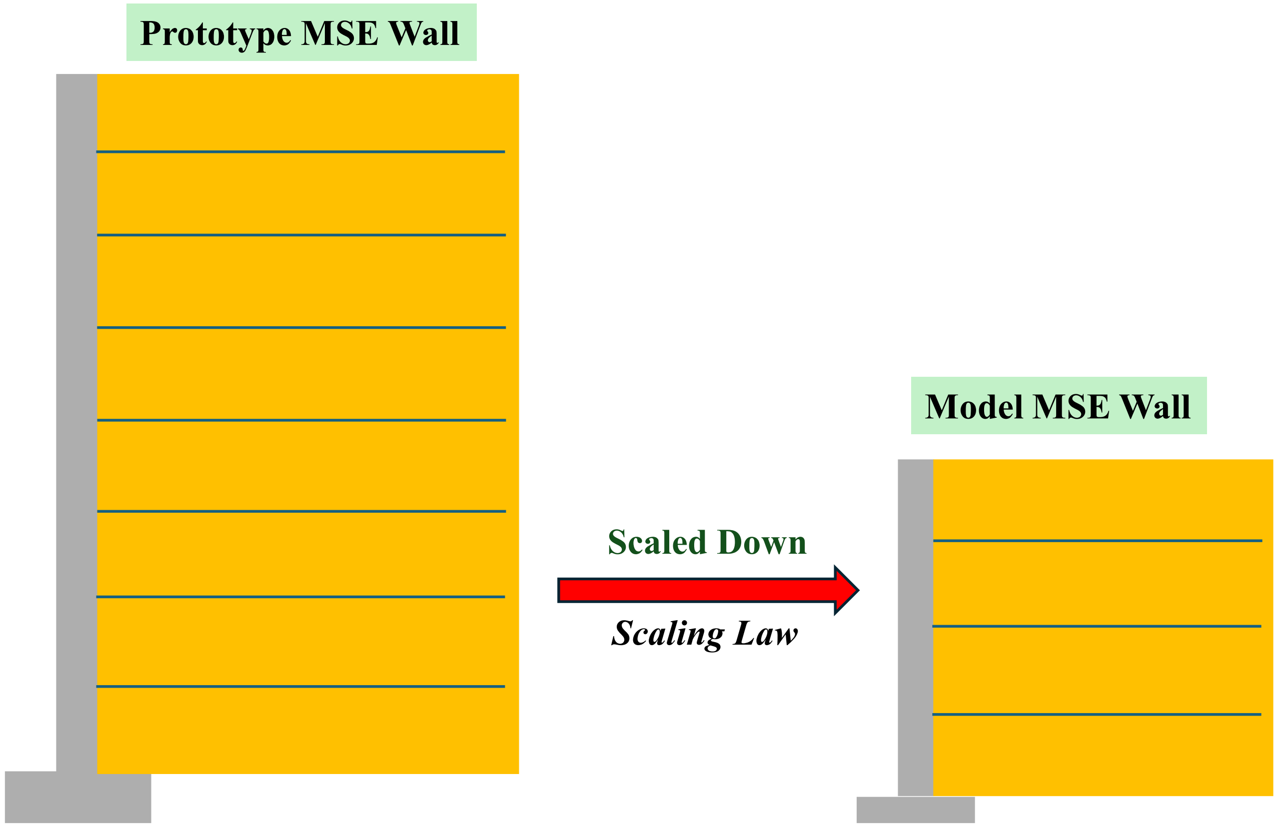


Table 6. Scaling Law

Parameter	Prototype Value	Units	Scaling Factor (Laminar)	Scaling Factor (Turbulent)	Model Value (N=10)	Units
Centrifugal Acceleration (g)	9.81	m/s^2	N	N	98.1	m/s^2
Model Length (L)	10	m	1/N	1/N	1	m
Diameter of Soil Particle (D)	0.5	mm	1/N	1/N	0.05	mm
Density (ρ)	2650	kg/m^3	1	1	2650	kg/m^3
Dynamic Viscosity (ν)	1×10^{-3}	Pa·s	1	1	1×10^{-3}	Pa·s
Water Pressure (u)	Variable	-	1	1	Variable	-
Stress (σ)	Variable	-	1	1	Variable	-
Hydraulic Gradient (i)	Variable	-	1	1	Variable	-
Displacement (d)	Variable	m	1/N	1/N	Variable	m
Strain (ε)	Variable	-	1	1	Variable	-
Mean Flow Velocity (v)	Variable	m/s	1/N	$N^{0.5}$	Variable	m/s
Time of Seepage (t)	Variable	s	$1/N^2$	$1/N^{1.5}$	Variable	s

Centrifuge Testing

Model MSE Wall for 40g Centrifuge Test

Table 8. Model MSE Wall Dimensions (Scaled by 1/N)

Location	Prototype MSE Wall Height (ft)		Model MSE Wall Height (ft)		Prototype MSE Wall Length (ft)		Model MSE Wall Length (ft)		Prototype MSE Wall Width (ft)		Model MSE Wall Width (ft)		Prototype MSE Wall Reinforcement Length (ft)		Model MSE Wall Reinforcement Length (ft)	
	W-3	W-4	W-3	W-4	W-3	W-4	W-3	W-4	W-3	W-4	W-3	W-4	W-3	W-4	W-3	W-4
Begin Wall	14.732	20.732	0.37	0.52												
Midpoint	14.03	20.03	0.35	0.50	28.92	28.92	0.723	0.723	40	40	1	1	26	26	0.65	0.65
End Wall	13.402	19.402	0.34	0.48												

- **Woven Pellon fabric will be cut into a geogrid-like pattern and used as reinforcement in the model MSE wall.**

- **The same soil material as used in the prototype MSE wall will be adopted as the backfill soil in the model. Fuglsang and Ovesen, 1988; Yamaguchi et al., 1976; Kimura et al., 1985; and Ovesen, 1985 showed that effect of grain size is negligible if model size to mean grain size is > 30.**

Centrifuge Testing

Model MSE Wall for 40g Centrifuge Test

- **A 3D-printed composite fiber panel will be used to replicate the concrete facing panel in the model.**

Table 9. Material properties of Composite fiber

Property	Onyx (Nylon + Chopped CF)
Density	1.2 g/cm³
Tensile Modulus	2.4 GPa
Tensile Strength at Yield	40 MPa
Tensile Strength at Break	37 MPa
Tensile Strain at Break	25%
Flexural Strength	71 MPa
Flexural Modulus	3.0 GPa
Heat Deflection Temp	145°C
Izod Impact (Notched)	330 J/m

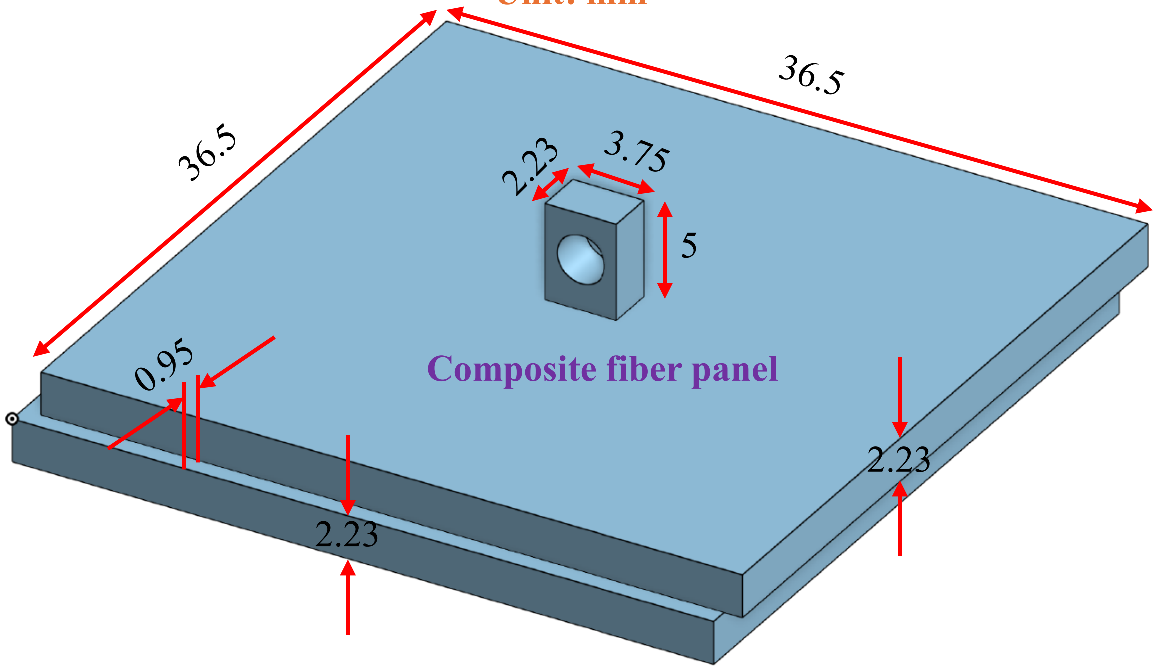
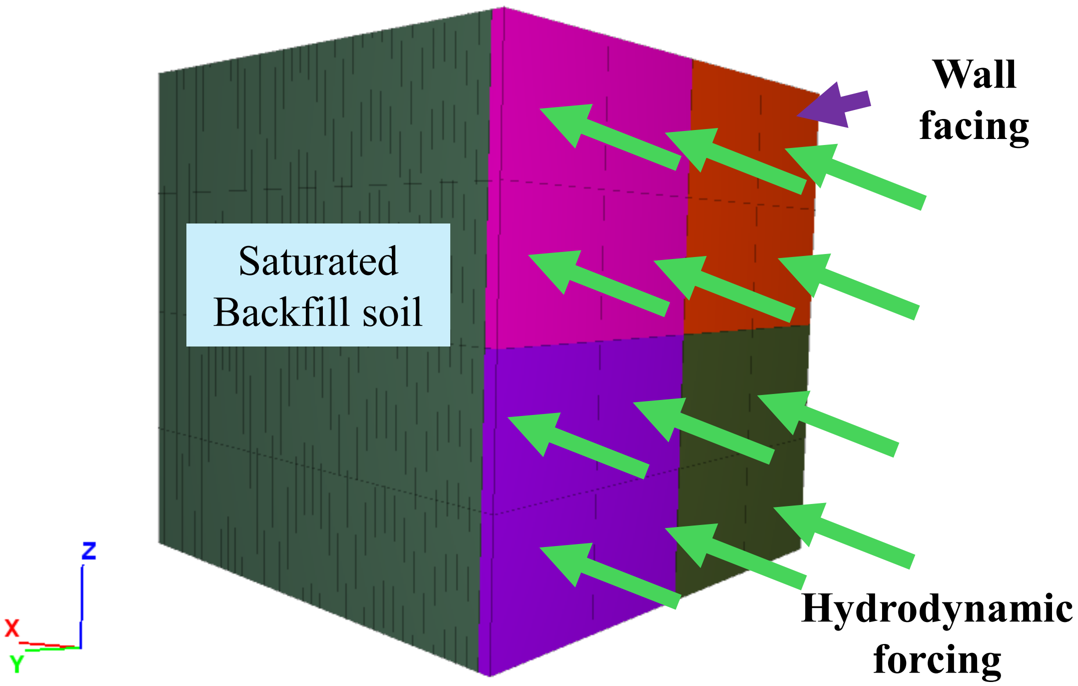


Table 10. Wave parameter in prototype & model

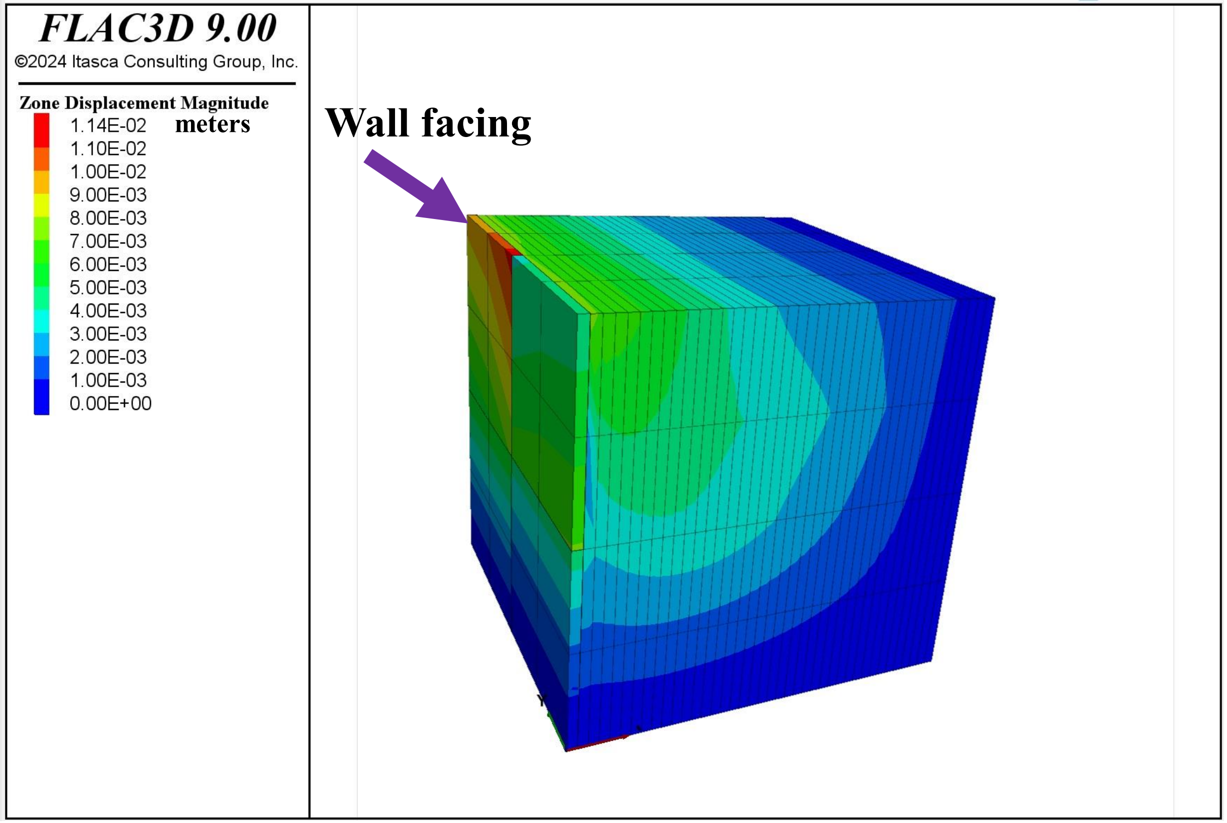
Parameter	Prototype Value	Scale Factor, N=40	Model Value
Depth of water, h (ft)*	10	1/N	0.25
Wave height, (ft)*	7	1/N	0.175
Wave Period,T (S)*	4	1/N	0.1
Frequency, f (Hz)	0.25	N	10
Wave velocity, c (ft/s)	15	1	15
Wave Length, L (ft) †	5	1/N	0.125
Angular Wave Frequency, w (rad/s)	1.570796	N	62.83184
Wave Number, k (1/ft)	1.256637		25.13274
Dimensionless Wave Number, kh	12.56637	1	
Water velocity, u (ft/s)*	15	1	15
Froude Number, Fr = $c/(gh)^{0.5}$	0.835917		0.835917
Froude Number, Fr = $c/(gL)^{0.5}$	1.182166		1.182166

Numerical Modeling using FLAC3D

- Models MSE wall behavior under hydrodynamic forces.
- Investigate backfill and pore pressures during loading.
- Calibrated to experiments for additional parametric study.



FLAC3D model of an MSE wall subjected to hydrodynamic forces on the wall facing.



Hydrodynamic Model Process

Level 1: Coupled ROMS-WW3 Model

Regional Ocean Modeling System (ROMS) and WAVEWATCH III (WW3) framework. Designed to capture large-scale oceanographic and wave conditions during Hurricane Ian. Bathymetric data is sourced from the CUDEM dataset, atmospheric forcing is provided by the Global Forecast System (GFS), ocean boundary conditions are obtained from the HYCOM model, and wave boundary conditions are derived by re-running the IFREMER Northwest Atlantic Reginal WW3 model. This level provides the essential hydrodynamic and wave climate context over a broad regional domain.

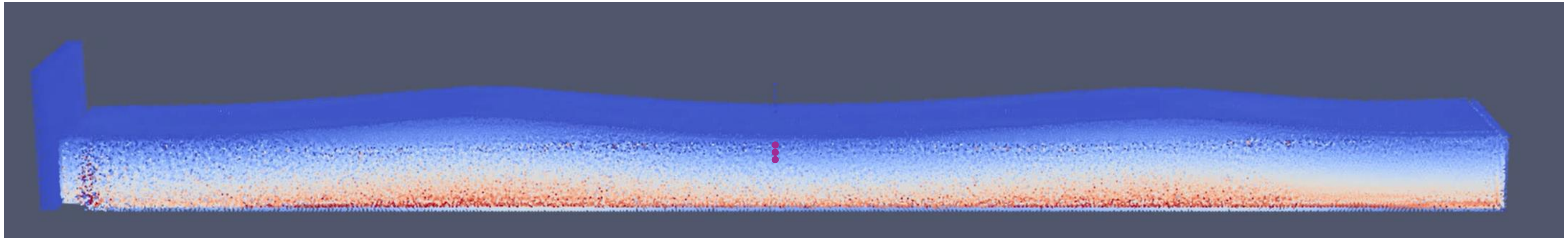
Level 2: High-Resolution WW3 Model

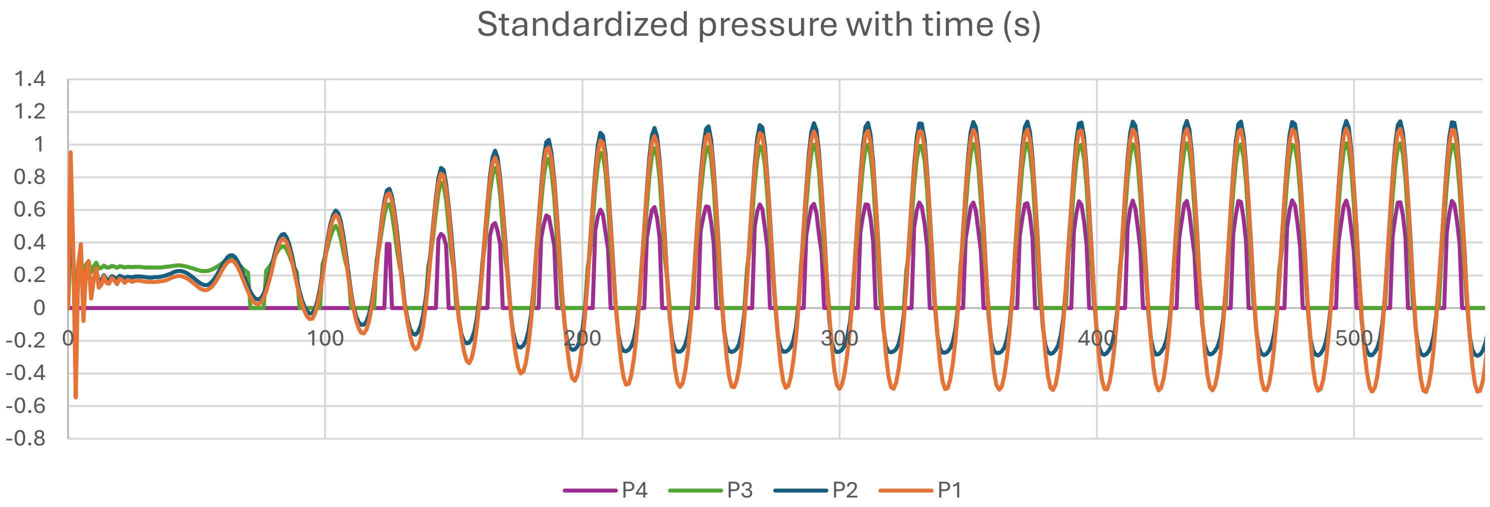
The second level downscales wave conditions using a standalone, high-resolution WW3 model. It utilizes boundary conditions and wave spectral outputs from the Level 1 model to simulate more localized and detailed wave dynamics near the MSE wall. This setup allows for refined wave transformation and interaction with the nearshore geometry and bathymetry.

Level 3: DualSPHysics Model for Wave-Structure Interaction

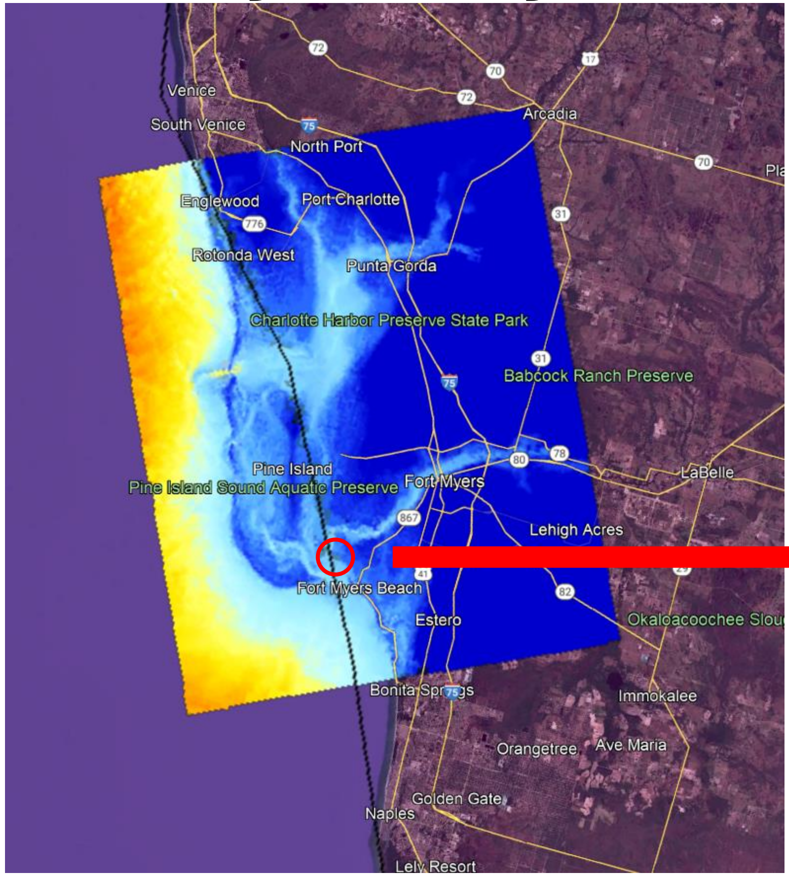
The third level employs the DualSPHysics smoothed particle hydrodynamics (SPH) model to simulate wave-structure interactions. It takes wave input conditions from the Level 2 WW3 model to analyze localized hydrodynamic loads on the MSE wall. This model resolves detailed pressure fields and free surface dynamics to accurately assess the impact forces exerted by hurricane-driven waves on coastal infrastructure.

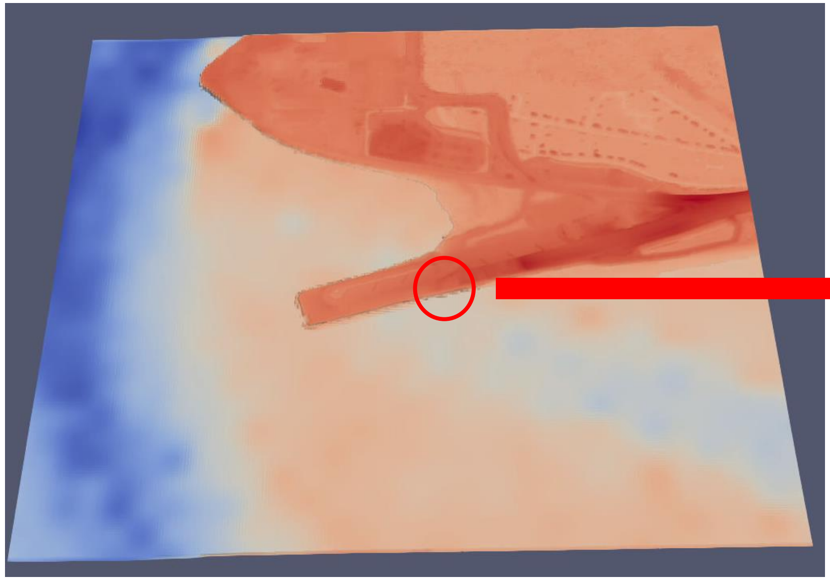
Validating Smoothed Particle Hydrodynamic model

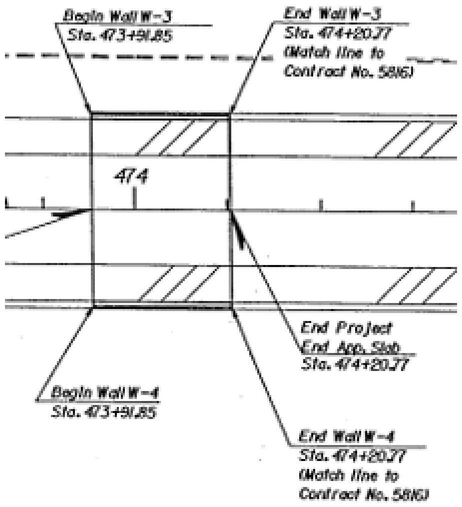


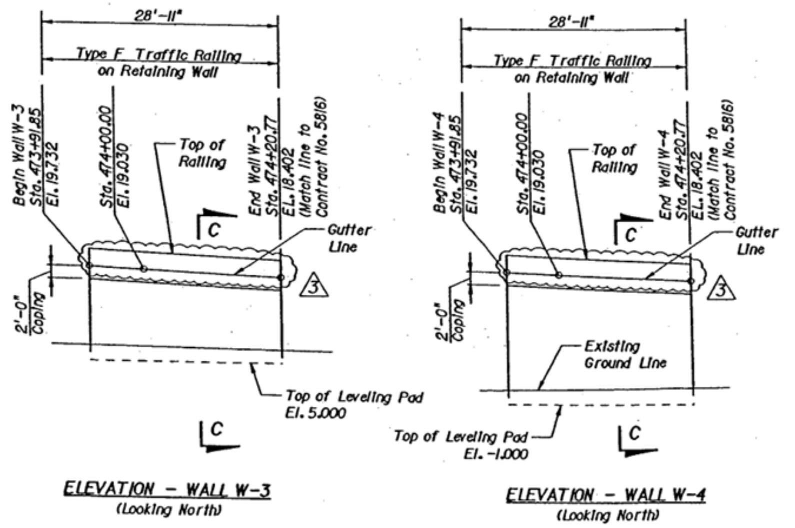


Smoothed Particle Hydrodynamic Model Bathymetry



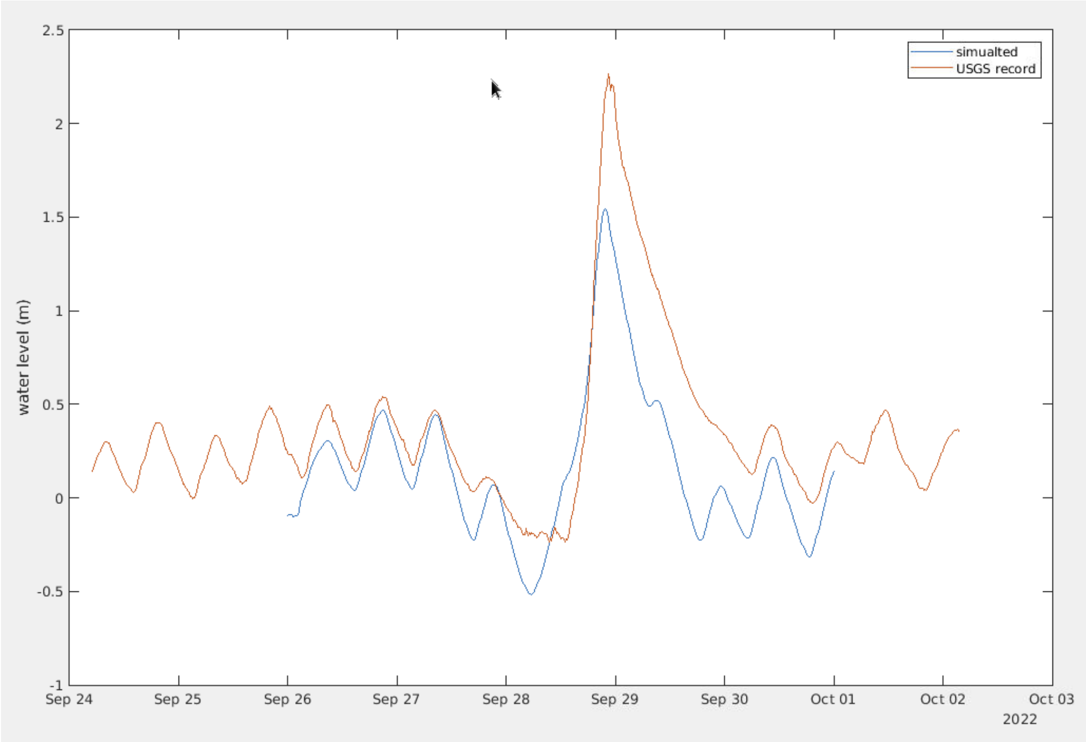




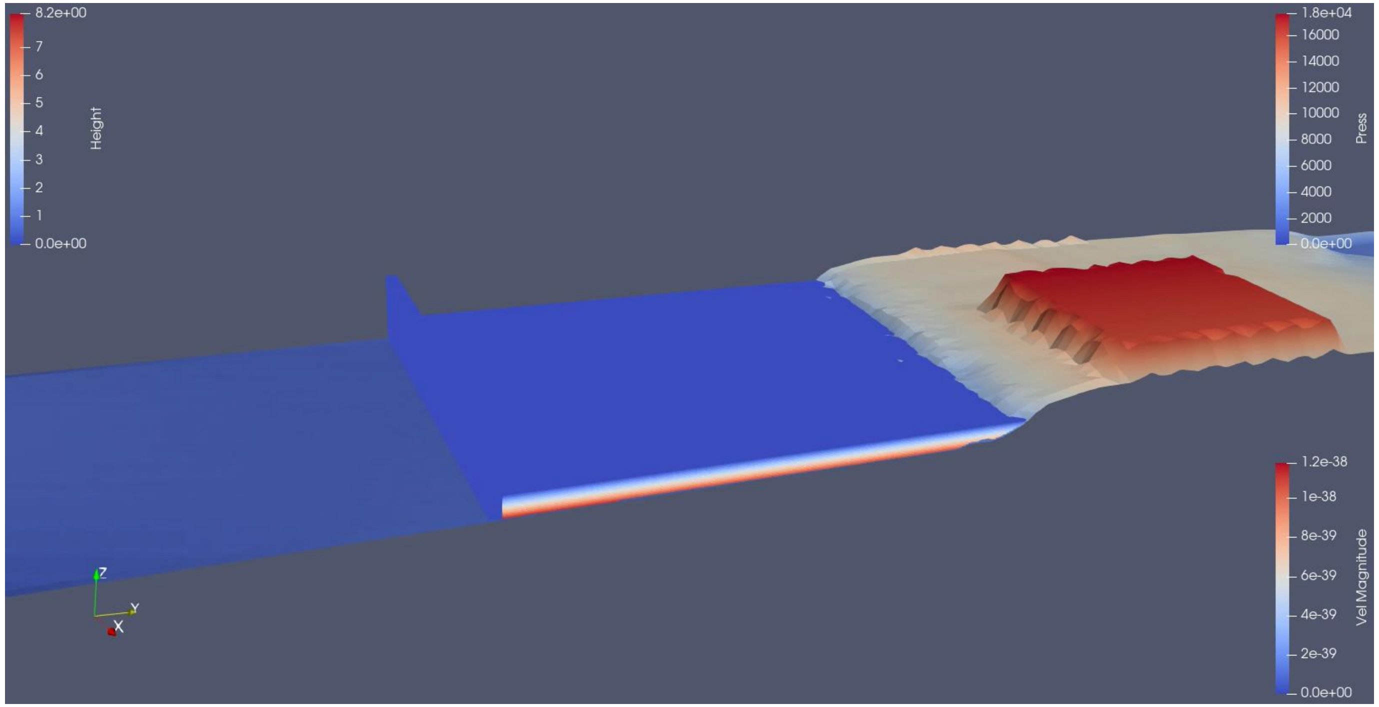


Level 1 and Level 3 Model Results

Level 1: Coupled ROMS-WW3 Model



Level 3: DualSPHysics Model for Wave-Structure Interaction



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Thank You