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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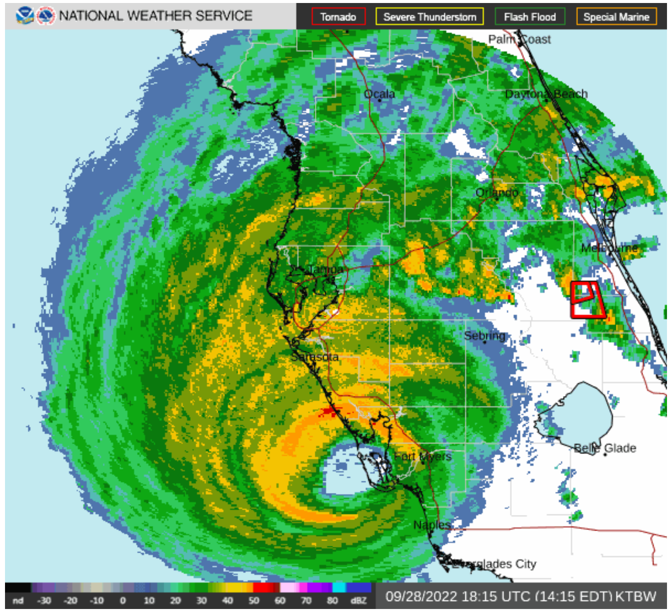
GRIP Meeting

August 13th, 2026

# 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.






# 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

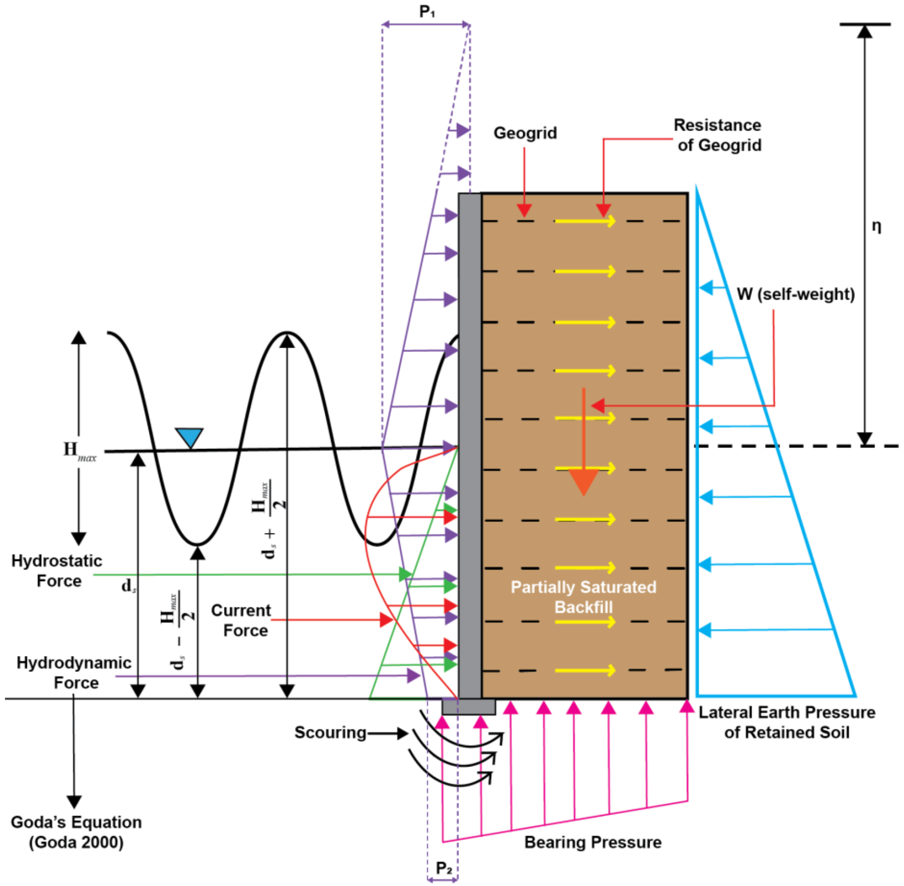
# Task 1: Review of Prototype MSE Wall Design, Hydrodynamic Data, and Literature

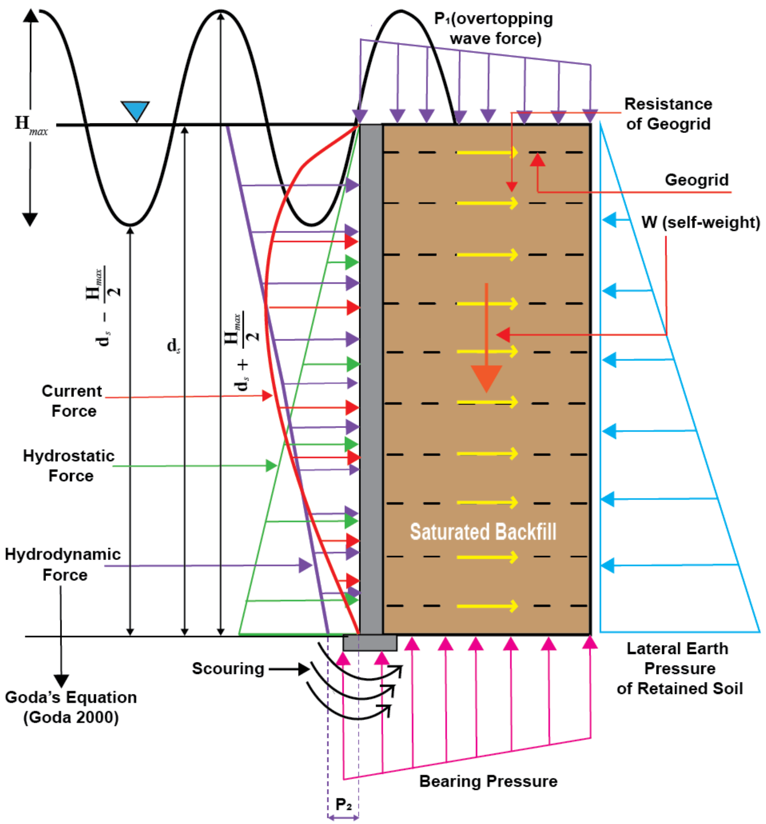
- Collect design and forensic data on coastal MSE wall failures from tropical storms
  - Elevations, wall dimensions, reinforcement and connection type, panel dimensions, backfill properties, roadway structural layer info, bearing soil properties, revetment dimensions
- Collect bathymetry for the Gulf 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)*

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

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

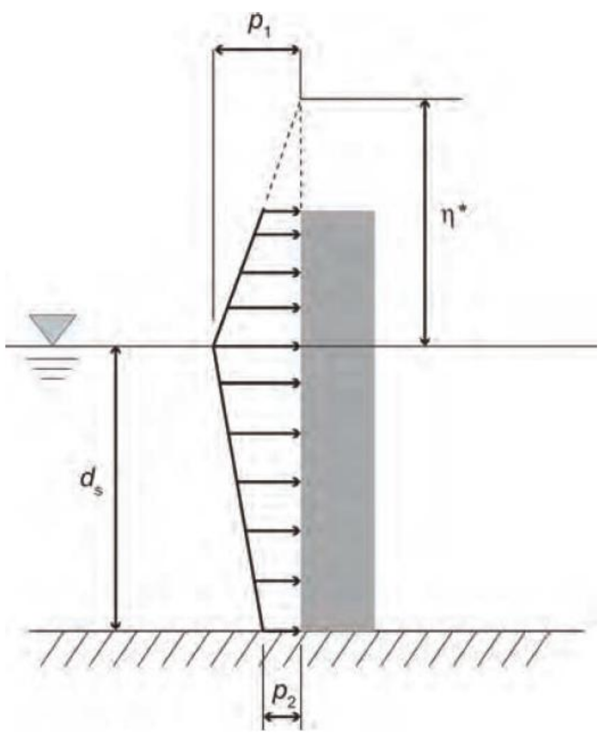
in which:

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

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

where:

- $p_1$ = pressure at storm water level (kip/ft$^2$)
- $p_2$ = pressure at mudline (kip/ft$^2$)
- $\alpha_1$ = coefficient
- $\theta$ = 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)
- $\lambda$ = wave length (ft)
- $\gamma_w$ = unit weight of water taken as 0.064 kip/ft$^3$
- $\eta^*$ = 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:

- $\rho_w$ = 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)***

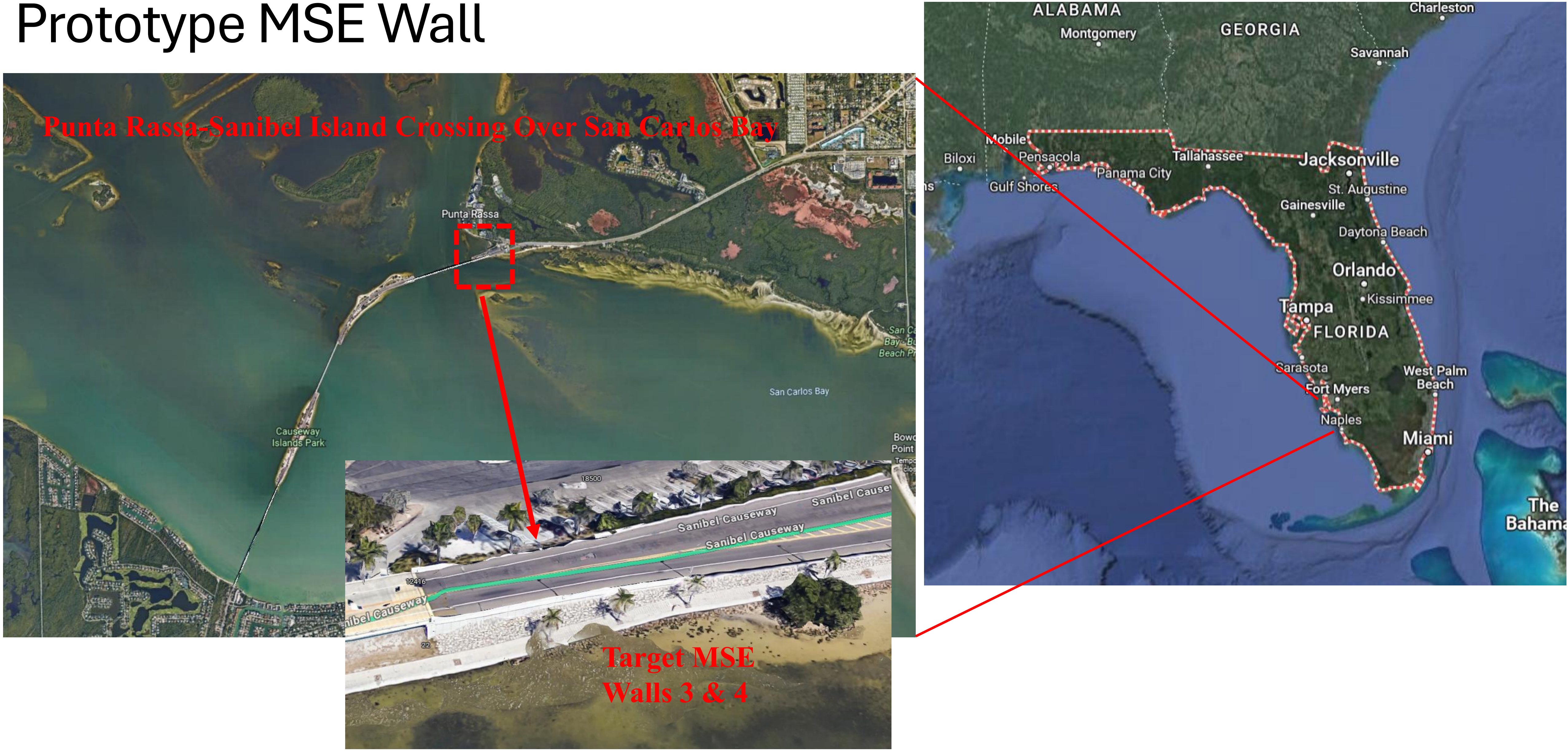
shallow water corrections (constant depth, d):

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

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

for sloped bottom → use "equivalent water depth"

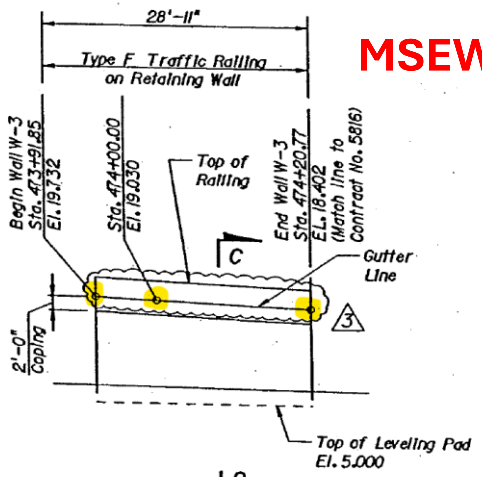
# Prototype MSE Wall



# Prototype MSE Wall

## Dimensions of MSEWs

MSEW-3




MSEW-4

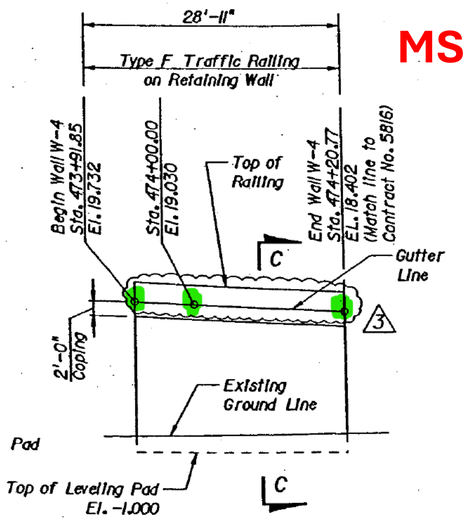



**Table 2. Elevations and Heights of Wall W-4 at Key Points for MSEW-3**

| 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 |

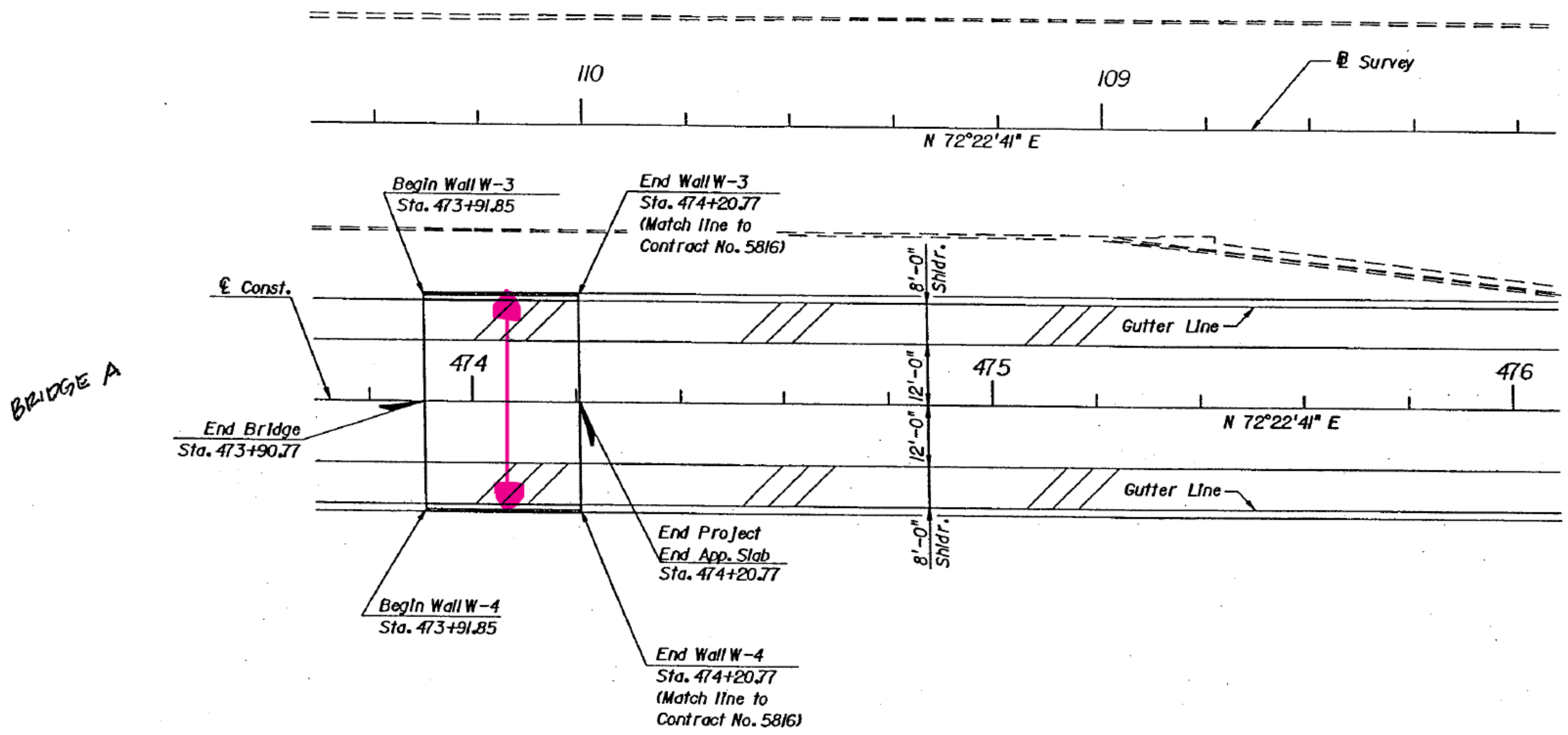
**Table 3. Elevations and Heights of Wall W-4 at Key Points for MSEW-4**

| 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

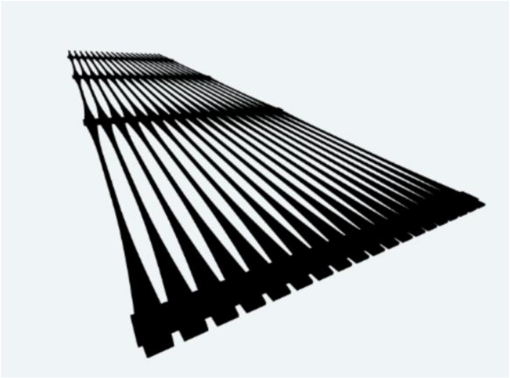
# Prototype MSE Wall

## 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 |

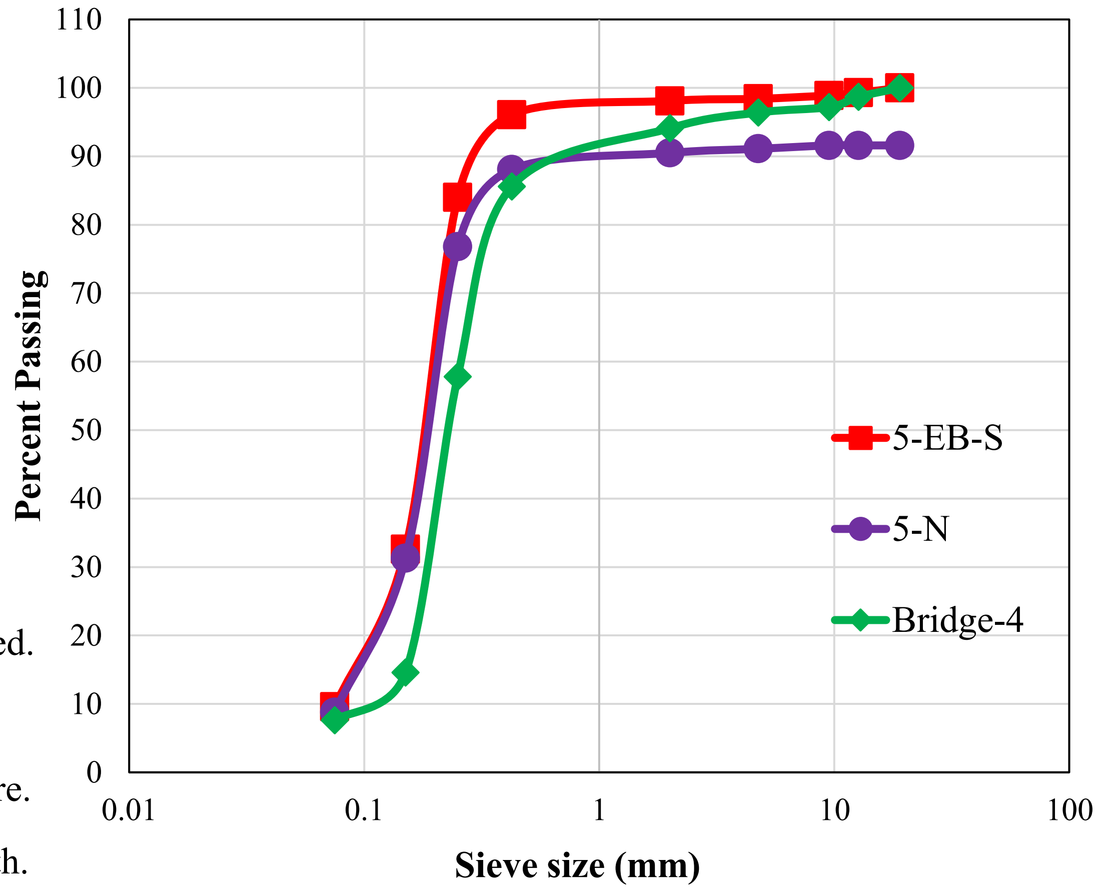
**Table 7. Direct Shear and Permeability Tests (Lab tests of Soil from Failed MSE Wall)**

| Sample ID | $\gamma_{max}$ (pcf) | OMC (%) | $\phi_{max}$ | $\phi'_r$ | k (cm/sec) | k (ft/day) |
|---|---|---|---|---|---|---|
| Bridge-4 | 110.2 | 11.2 | 32.5 | 30.2 | $9.96 \times 10^{-4}$ | 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.

**Particle Size distribution**

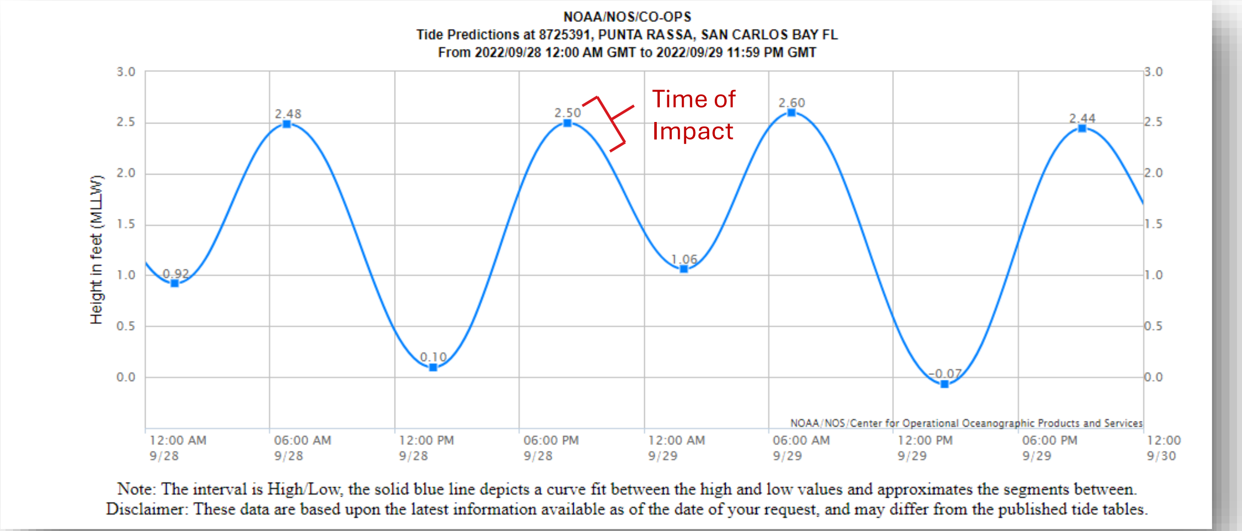



**GSD for backfill soil**

# Prototype MSE Wall

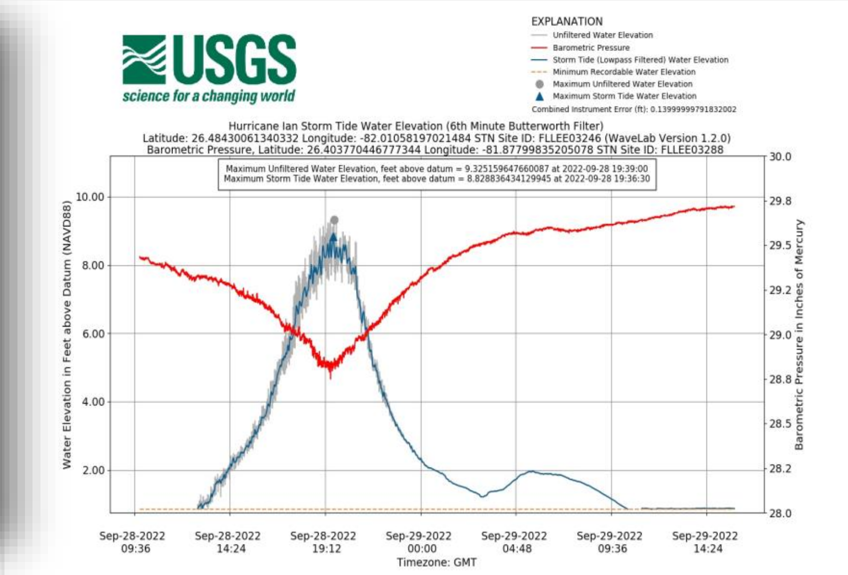
## *Hydrodynamic Data*

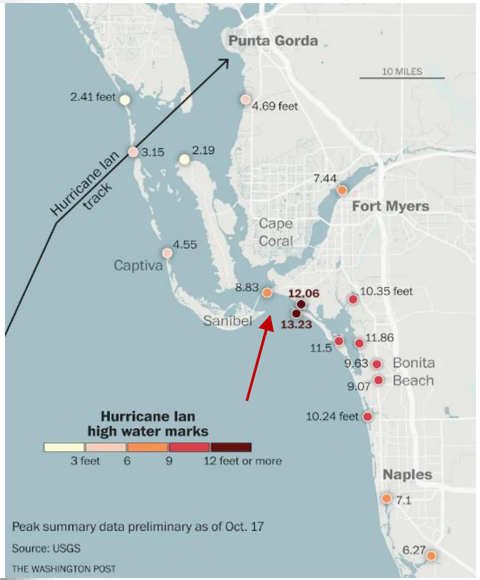
### Hurricane Ian – Predicted Tide




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

### Hurricane Ian – Measured Storm Surge

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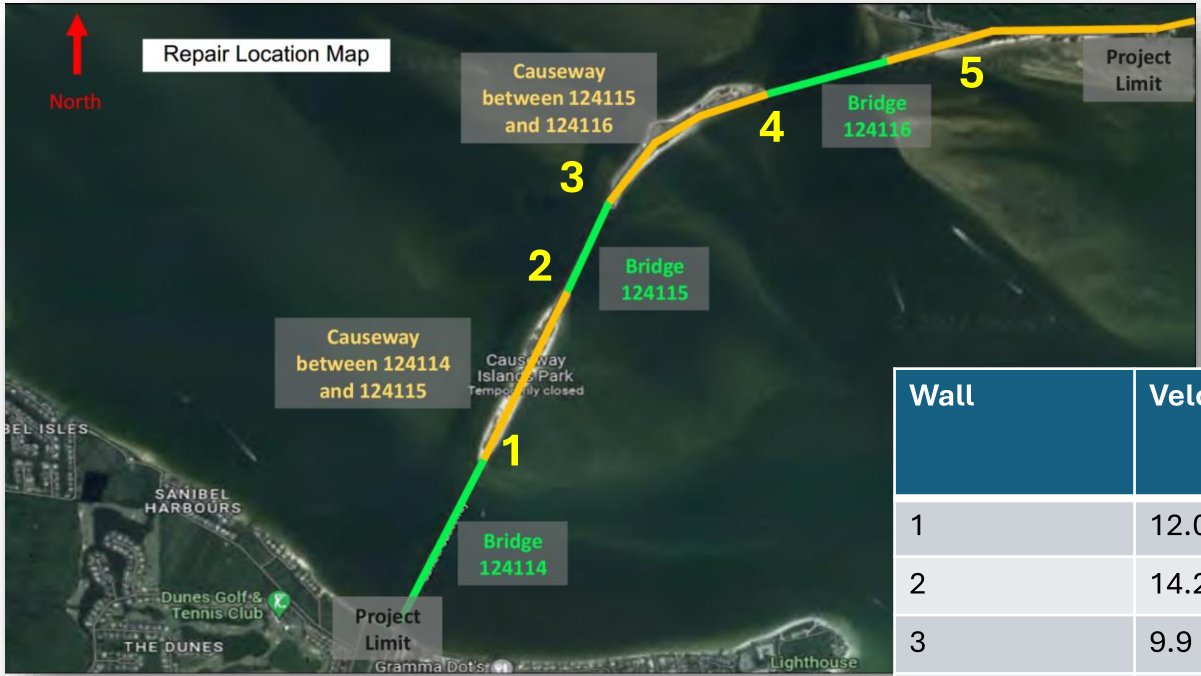
# Prototype MSE Wall

## *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**

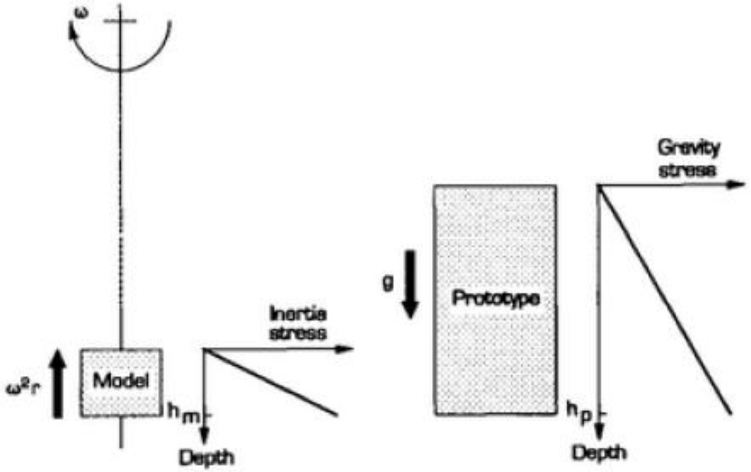
**Centrifuge Specifications**:

- **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

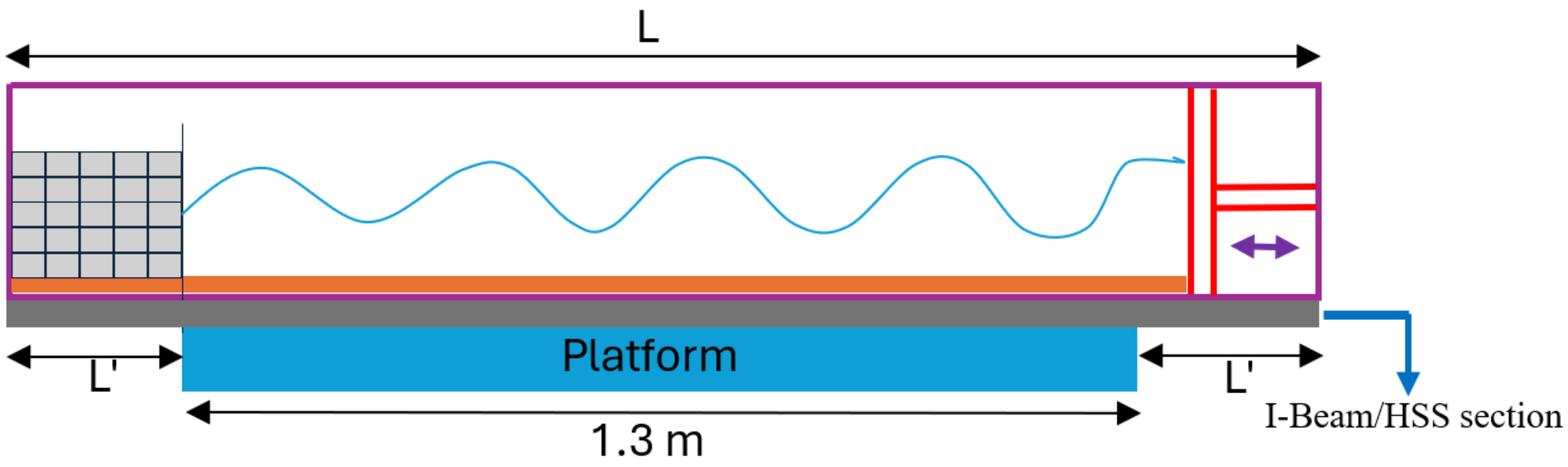
Centrifuge at the US ERDC



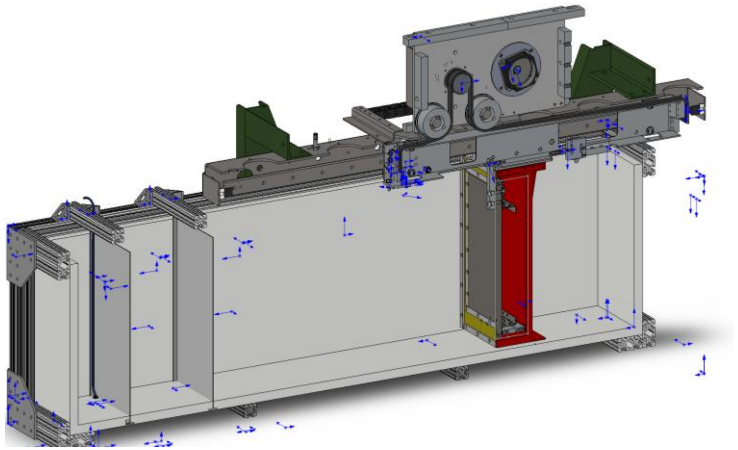

## Why Centrifuge, not Wave Flume?

- ✓ **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

# Centrifuge Testing

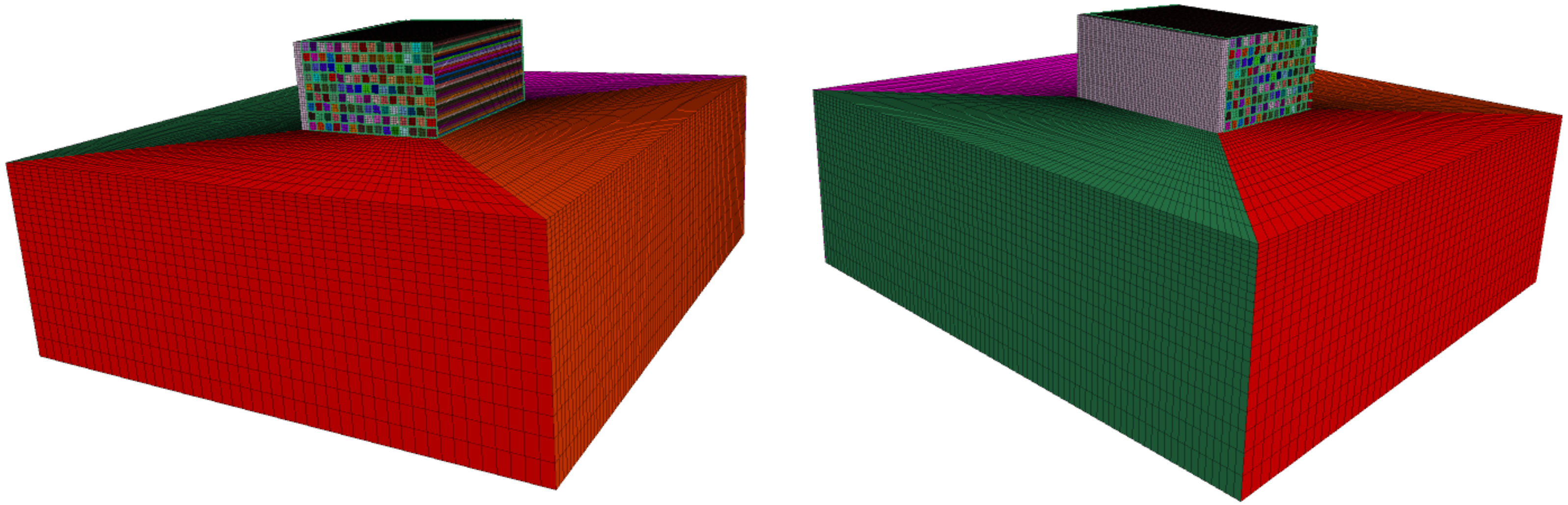
## *Model MSE Wall for 35g Centrifuge Test*

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

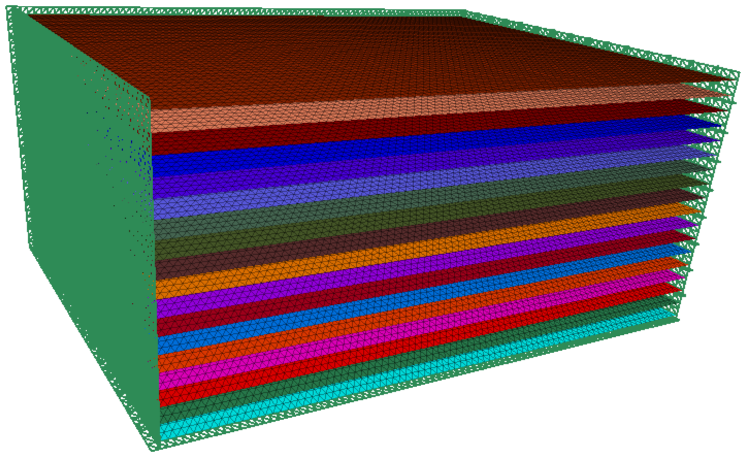
| Location | Prototype MSE Wall | | Model MSE Wall | | Prototype MSE Wall | | Model MSE Wall | | Prototype MSE Wall | | Model MSE Wall | | Prototype MSE Wall | | Model MSE Wall | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Height (ft) | | Height (ft) | | Length (ft) | | Length (ft) | | Width (ft) | | Width (ft) | | Reinforcement Length (ft) | | 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 | 14.73 | 20.73 | 0.49 | 0.69 | | | | | | | | | | | | |
| Midpoint | 14.03 | 20.03 | 0.46 | 0.66 | 28.92 | 28.92 | 0.96 | 0.96 | 40 | 40 | 1 | 1 | 26 | 26 | 0.4 | 0.4 |
| End Wall | 13.40 | 19.40 | 0.44 | 0.64 | | | | | | | | | | | | |

- **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.**

# 3-D Numerical Model



Full 3D model with foundation soil, cheek wall and MSE wall



Interfaces and geogrids

# Properties of Model

Table 1. Material models and properties used in the numerical analysis

| Component | Constitutive Model | Density ($kg/m^3$) | Strength Parameters | Elastic Properties (Pa) | Additional Parameters |
|---|---|---|---|---|---|
| **Foundation Soil** | Mohr–Coulomb | 1762 | $\phi = 30°$, $c = 0$, tension = 0 | $K = 4.1667 \times 10^7$ $G = 1.9231 \times 10^7$ | — |
| **MSE Backfill Soil** | Mohr–Coulomb | 1683 | $\phi = 30°$, $c = 0$, dilation = 1° | $K = 2.5 \times 10^8$ $G = 1.15 \times 10^8$ | — |
| **Concrete Panel** | Linear Elastic | 2400 | — | $E = E = 2.5 \times 10^{10}$ $\nu = 0.15$ | — |
| **Cheek Wall** | Linear Elastic | 2800 | — | $E = 4.5 \times 10^{10}$ $\nu = 0.25$ | Fully restrained boundary condition |
| **Geogrid (Reinforcement)** | Linear Elastic Membrane | — | — | $E = 5.39 \times 10^8$ $\nu = 0.33$ | Thickness = 0.005 m Coupling stiffness = $1.0 \times 10^6$ $N/m^3$ Coupling cohesion = 0 Coupling friction = 30° |

Table 2. Interface properties used in the model

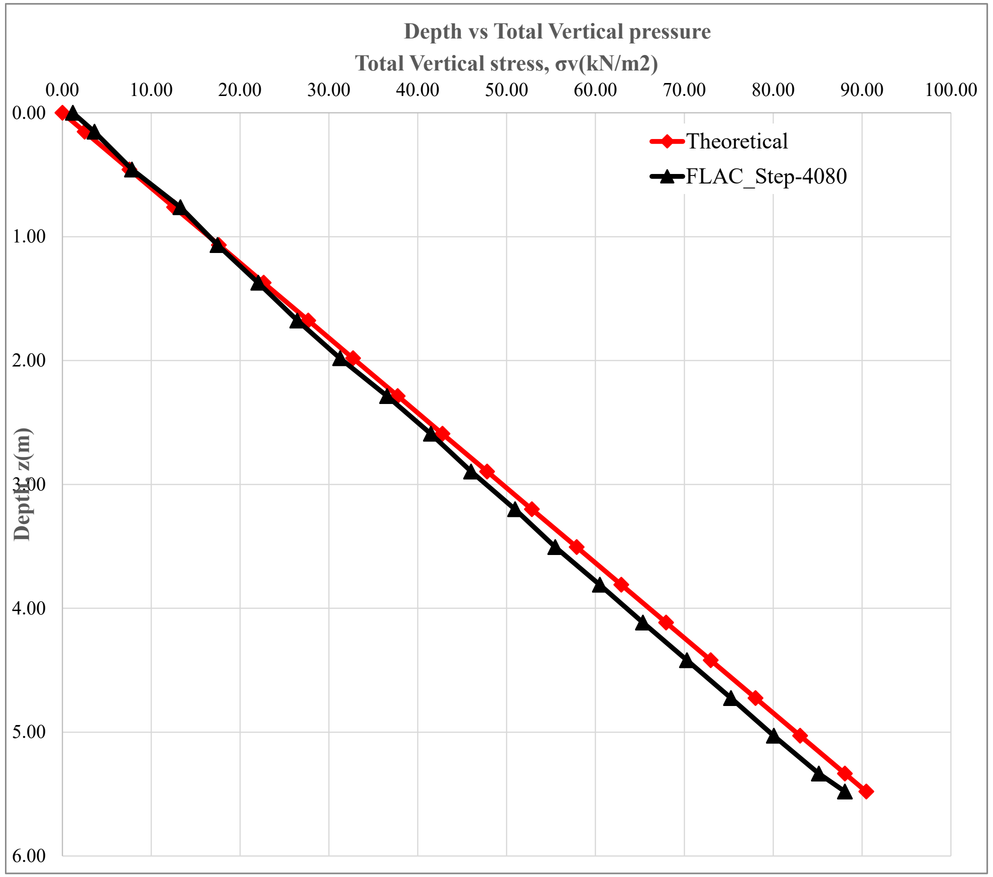
| Interface Type | $k_n$ (Pa/m) | $k_s$ (Pa/m) | Friction (°) | Cohesion (Pa) |
|---|---|---|---|---|
| **Panel – Foundation** | $5.0 \times 10^7$ | $5.0 \times 10^7$ | 20 | $6.6 \times 10^4$ |
| **Panel – Backfill** | $5.0 \times 10^7$ | $5.0 \times 10^7$ | 20 | $6.6 \times 10^4$ |
| **Panel – Panel** | $1.0 \times 10^9$ | $5.0 \times 10^7$ | 57 | $4.6 \times 10^4$ |
| **Cheek Wall – Backfill** | $5.0 \times 10^7$ | $5.0 \times 10^7$ | 20 | $6.6 \times 10^4$ |

# Vertical Stress

**Vertical Stress:** $\sigma_v(z) = \gamma\, z$

**At-Rest Earth Pressure Coefficient:** $K_o = (1 - \sin\phi) OCR^{\sin\phi}$

**Horizontal Stress:** $P(z) = K_o\, \sigma_V(z)$



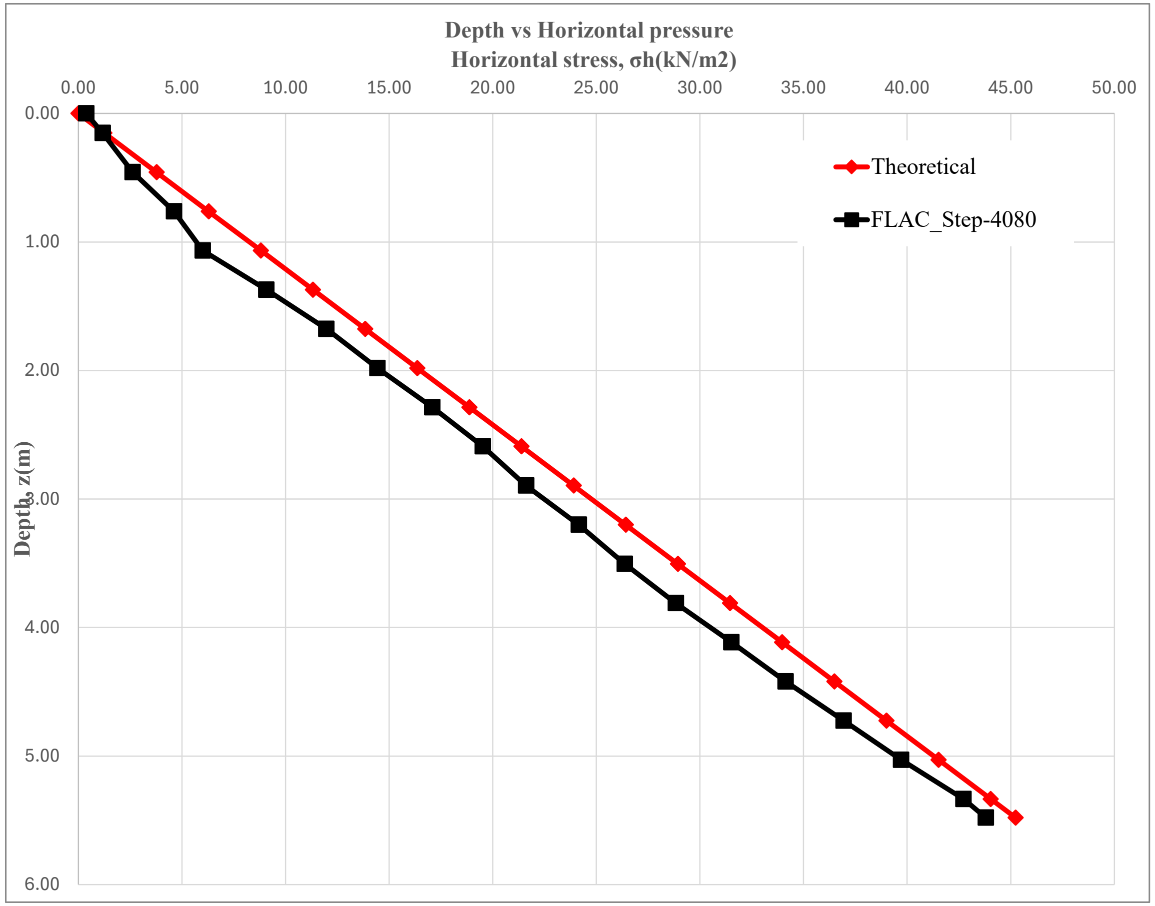

| Calculated | | |
|---|---|---|
| Depth z (m) | Vertical Stress, $\sigma_v$ (kN/m$^2$) | % Diff |
| 0 | 16.51 × 0.00 = 0.00 | |
| 0.15 | 16.51 × 0.15 = 2.52 | -35.8 |
| 0.46 | 16.51 × 0.46 = 7.55 | -3.7 |
| 0.76 | 16.51 × 0.76 = 12.58 | -5.5 |
| 1.07 | 16.51 × 1.07 = 17.61 | 0.8 |
| 1.37 | 16.51 × 1.37 = 22.65 | 2.7 |
| 1.68 | 16.51 × 1.68 = 27.68 | 4.6 |
| 1.98 | 16.51 × 1.98 = 32.71 | 4.6 |
| 2.29 | 16.51 × 2.29 = 37.74 | 3.2 |
| 2.59 | 16.51 × 2.59 = 42.77 | 3.1 |
| 2.9 | 16.51 × 2.90 = 47.81 | 3.9 |
| 3.2 | 16.51 × 3.20 = 52.84 | 3.7 |
| 3.51 | 16.51 × 3.51 = 57.87 | 4.2 |
| 3.81 | 16.51 × 3.81 = 62.90 | 3.9 |
| 4.11 | 16.51 × 4.11 = 67.94 | 3.9 |
| 4.42 | 16.51 × 4.42 = 72.97 | 3.7 |
| 4.72 | 16.51 × 4.72 = 78.00 | 3.6 |
| 5.03 | 16.51 × 5.03 = 83.03 | 3.6 |
| 5.33 | 16.51 × 5.33 = 88.06 | 3.4 |
| 5.48 | 16.51 × 5.48 = 90.47 | 2.7 |

# Horizontal Stress

**Vertical Stress:** $\sigma_v(z) = \gamma z$

**At-Rest Earth Pressure Coefficient:** $K_o = 1 - \sin\phi$

**Horizontal Stress:** $P(z) = K_o\, \sigma_V(z)$




| Calculated | | |
|---|---|---|
| Depth z (m) | Horizontal Stress, $\sigma_h$ (kN/m$^2$) | % Diff |
| 0 | 0.00 × 0.333 = 0.00 | |
| 0.15 | 2.52 × 0.333 = 1.26 | 6.7 |
| 0.46 | 7.55 × 0.333 = 3.77 | 35.9 |
| 0.76 | 12.58 × 0.333 = 6.29 | 30.6 |
| 1.07 | 17.61 × 0.333 = 8.81 | 37.8 |
| 1.37 | 22.65 × 0.333 = 11.32 | 22.0 |
| 1.68 | 27.68 × 0.333 = 13.84 | 14.5 |
| 1.98 | 32.71 × 0.333 = 16.35 | 12.5 |
| 2.29 | 37.74 × 0.333 = 18.87 | 9.9 |
| 2.59 | 42.77 × 0.333 = 21.39 | 9.1 |
| 2.9 | 47.81 × 0.333 = 23.90 | 10.1 |
| 3.2 | 52.84 × 0.333 = 26.42 | 9.0 |
| 3.51 | 57.87 × 0.333 = 28.94 | 9.3 |
| 3.81 | 62.90 × 0.333 = 31.45 | 8.7 |
| 4.11 | 67.94 × 0.333 = 33.97 | 7.5 |
| 4.42 | 72.97 × 0.333 = 36.48 | 6.7 |
| 4.72 | 78.00 × 0.333 = 39.00 | 5.4 |
| 5.03 | 83.03 × 0.333 = 41.52 | 4.4 |
| 5.33 | 88.06 × 0.333 = 44.03 | 3.0 |
| 5.48 | 90.47 × 0.333 = 45.24 | 3.2 |

# Hydrodynamic Model Process

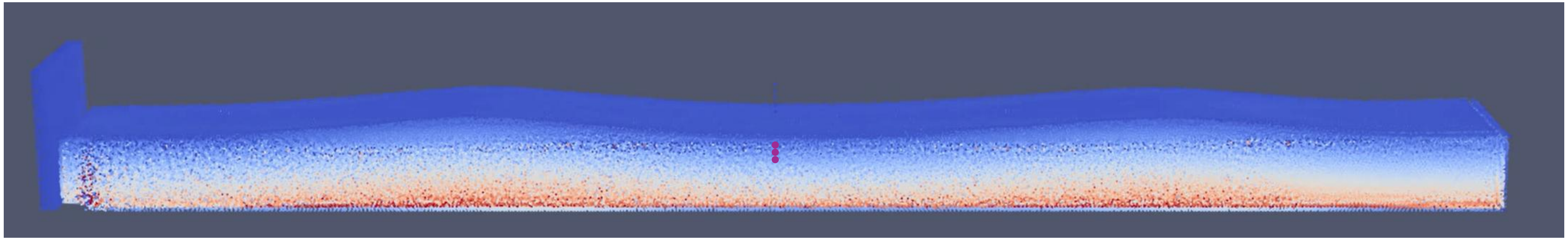
**Level 1: Global WW3 Model**
At the outermost scale, a global WAVEWATCH III (WW3) model provides large-scale wave conditions during Hurricane Ian. The wind forcing comes from the ERA5 reanalysis and the bathymetry comes from the IFREMER Integrated Ocean Waves for Geophysical and other Applications (IOWAGA) global WW3 dataset. This level covers from July to September 2022 and supplies spectral wave boundary information to the nested regional model.

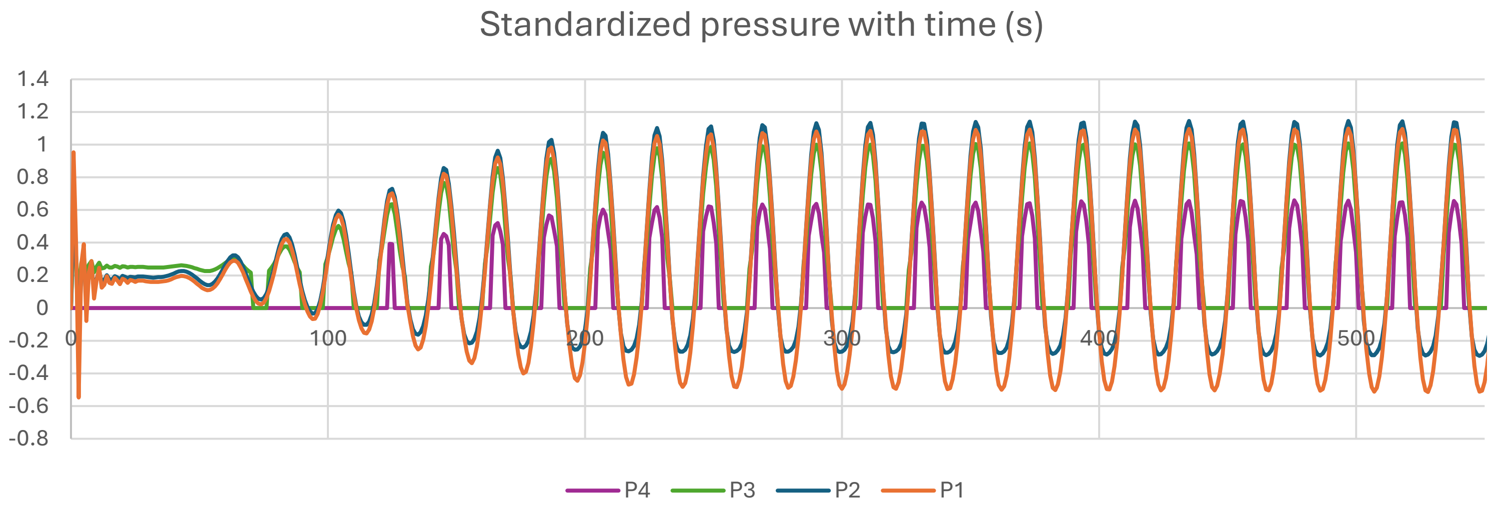
**Level 2: Northwest Atlantic WW3 Model**
A Northwest Atlantic WW3 model is nested within the global system to refine storm-wave propagation across the western North Atlantic covering also from July to September 2022. The bathymetry comes from the IFREMER IOWAGA northwest Atlantic WW3 dataset. Boundary forcing for this level is provided by Level 1 (global WW3) and uses the same wind forcing, and Level 2 outputs are used to force the local coastal model.

**Level 3: Coupled ROMS-WW3 Model**
This level of the model consists of a coupled Regional Ocean Modeling System (ROMS) and WAVEWATCH III (WW3) framework covering from September 26$^{th}$ to 30$^{th}$ of 2022. This model is 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 the level 2 WW3 model. This level provides the essential hydrodynamic and wave climate context over a broad coastal domain.

**Level 4: DualSPHysics Model for Wave-Structure Interaction**
The fourth level employs the DualSPHysics smoothed particle hydrodynamics (SPH) model to simulate wave-structure interactions. It takes wave and water level input from the Level 3 ROMS-WW3 model, simulating the irregular wave propagation for 400 seconds with the highest wave during the hurricane 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





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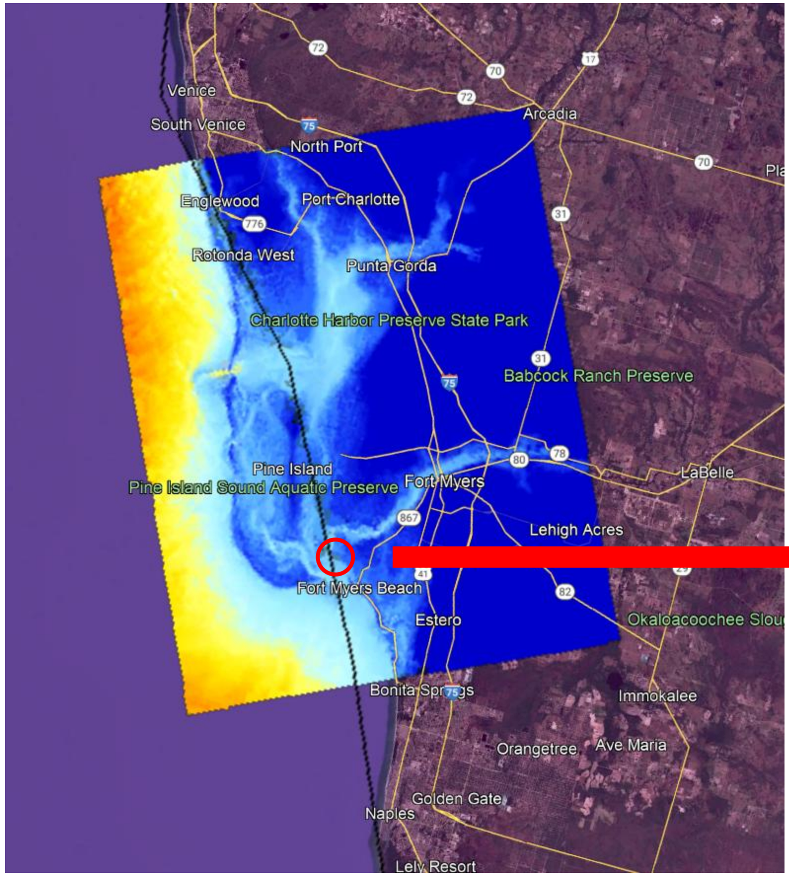
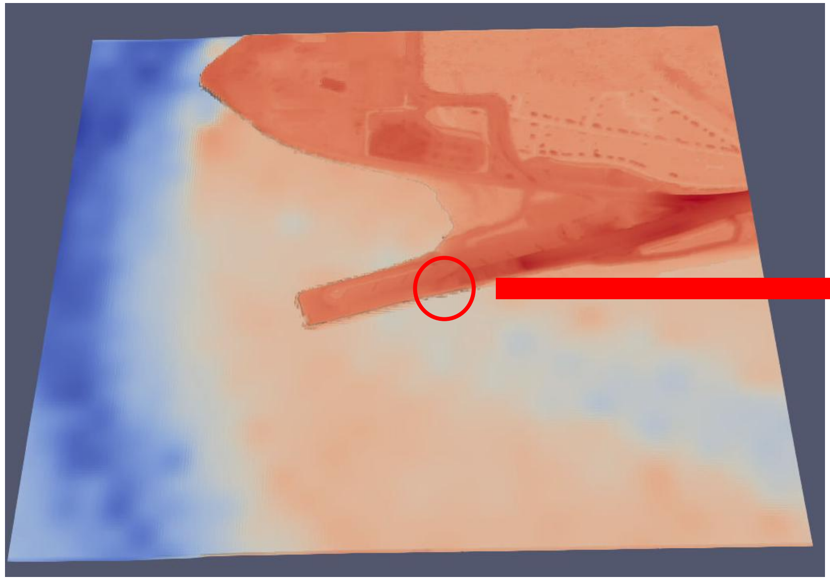
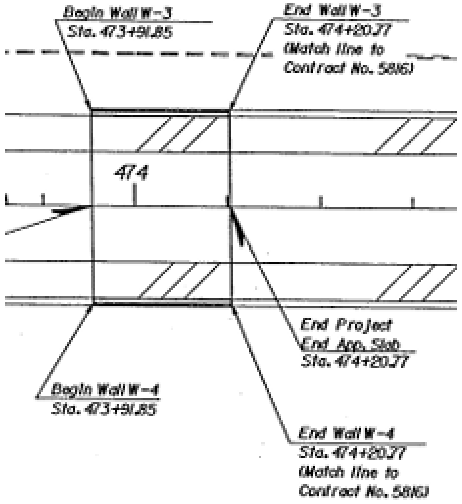
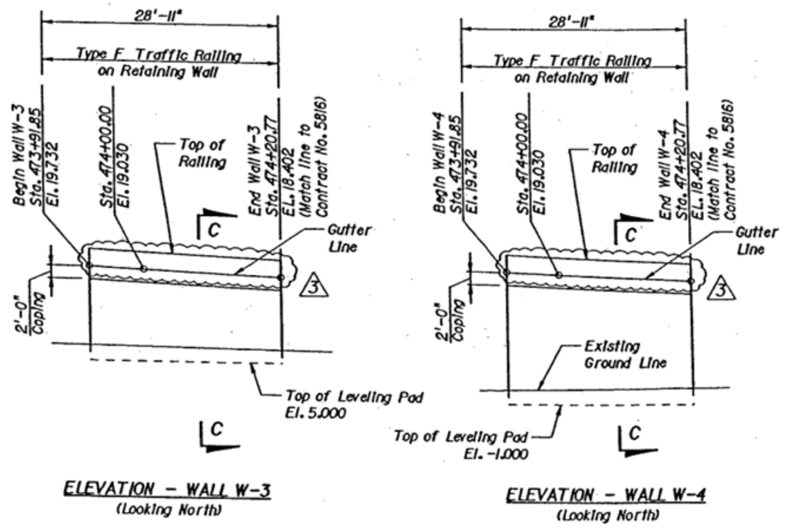
# Smoothed Particle Hydrodynamic Model Bathymetry

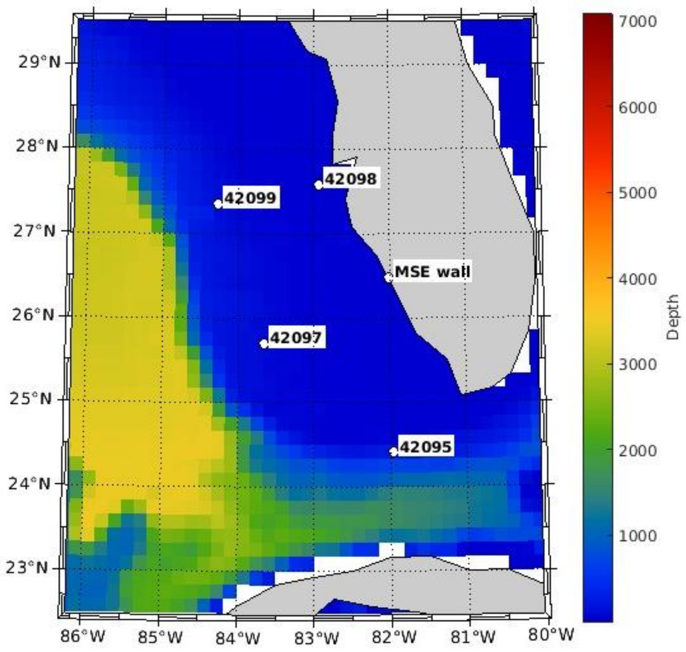


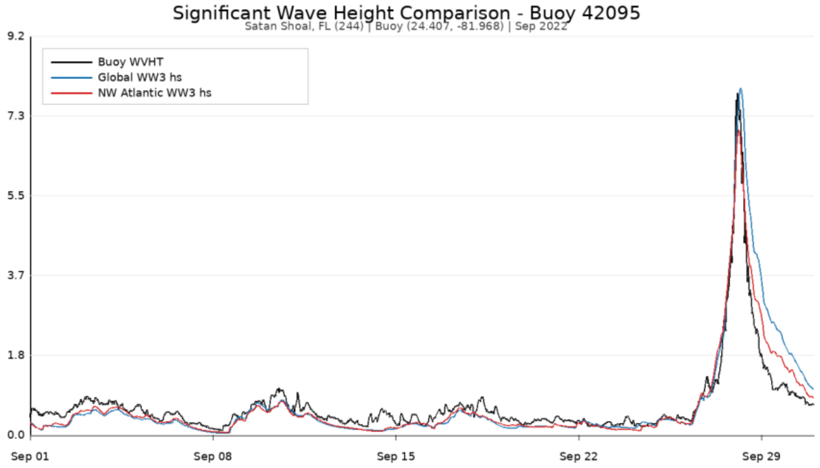


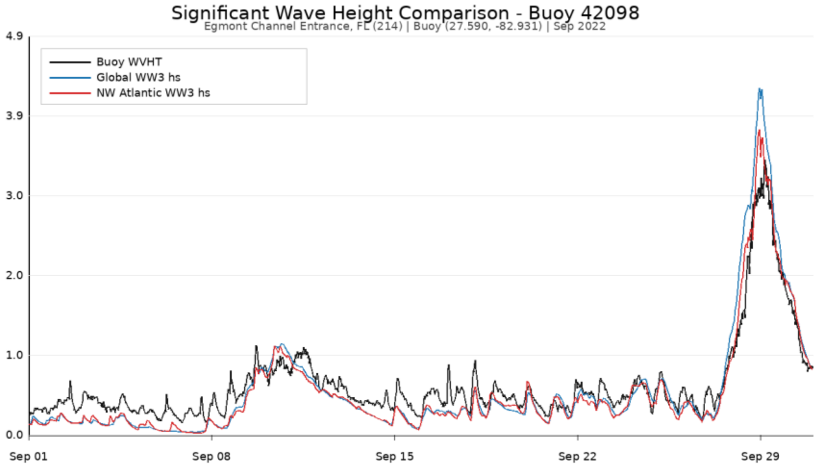



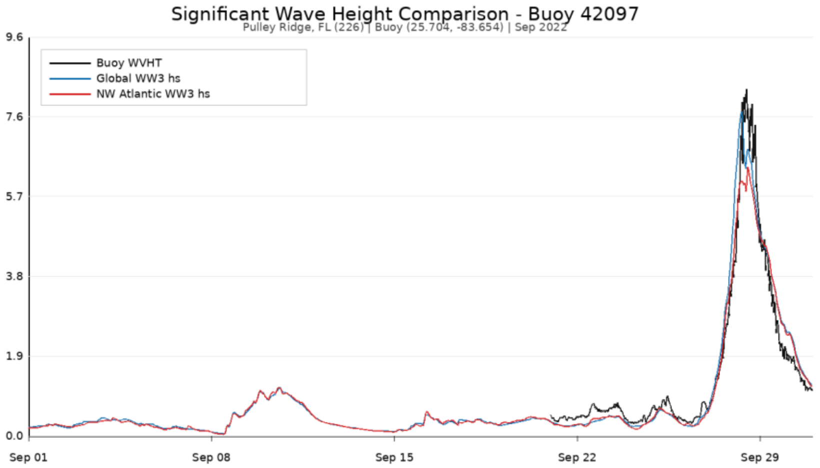
# Level 1 and Level 2 Model Results

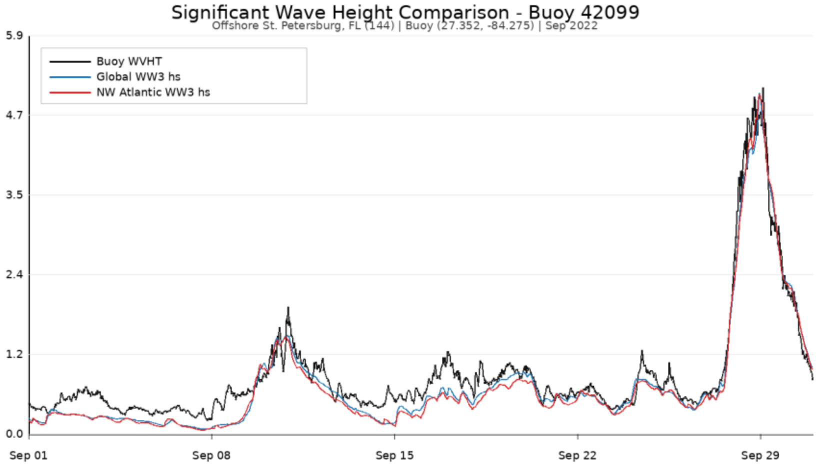



*Location of buoy stations and the MSE wall of interest*

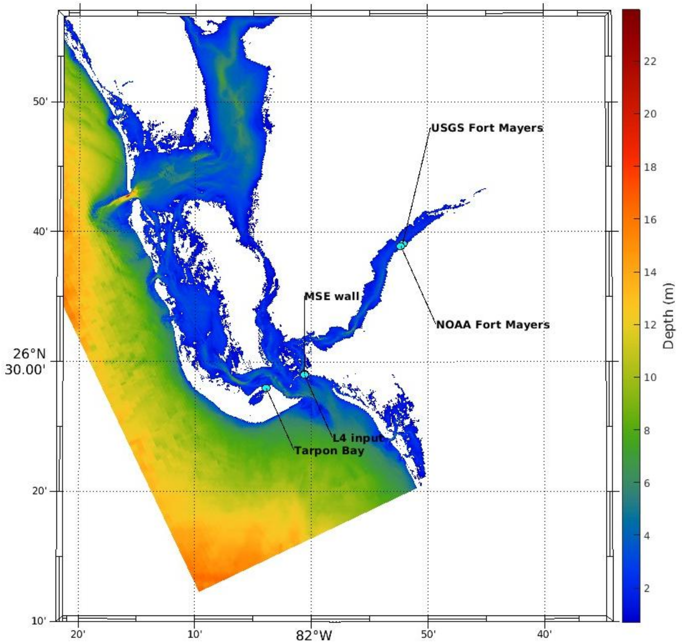


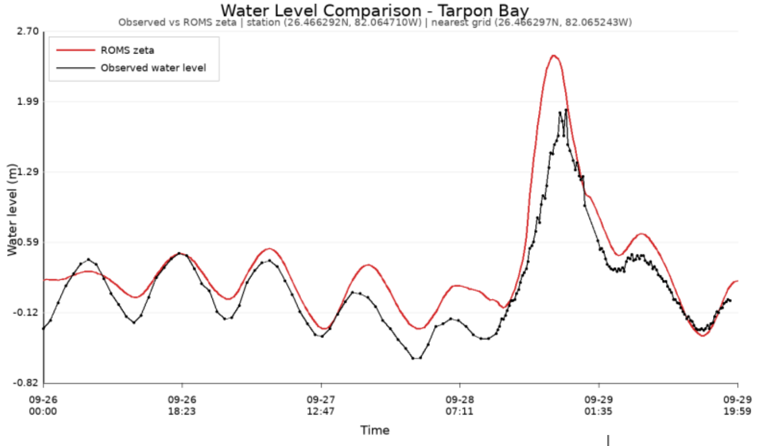



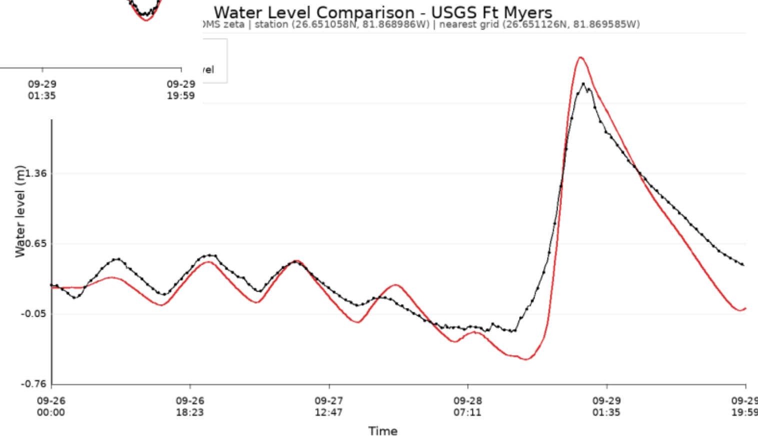



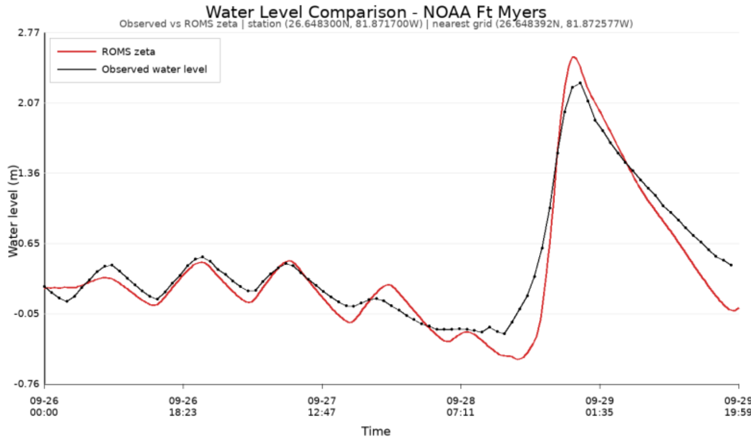
# Level 3 ROMS-WW3



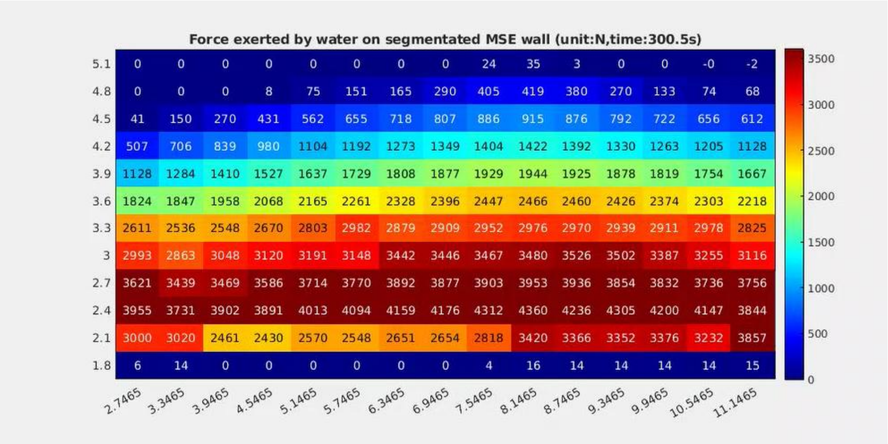

Locations of Water level stations for comparison, the MSE wall of interest, and where the water level and wave parameters were extracted for input of Level 4 model

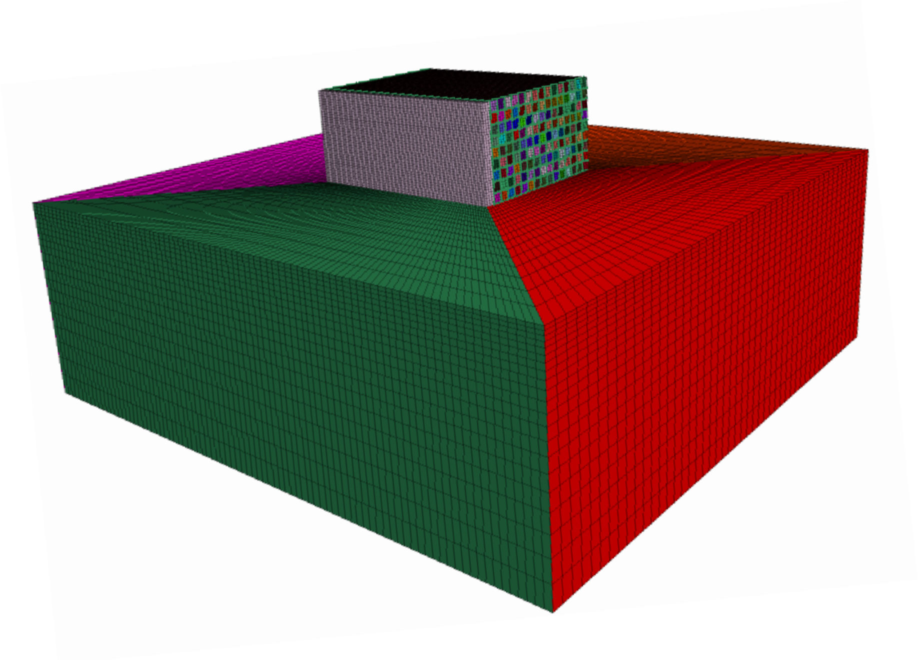


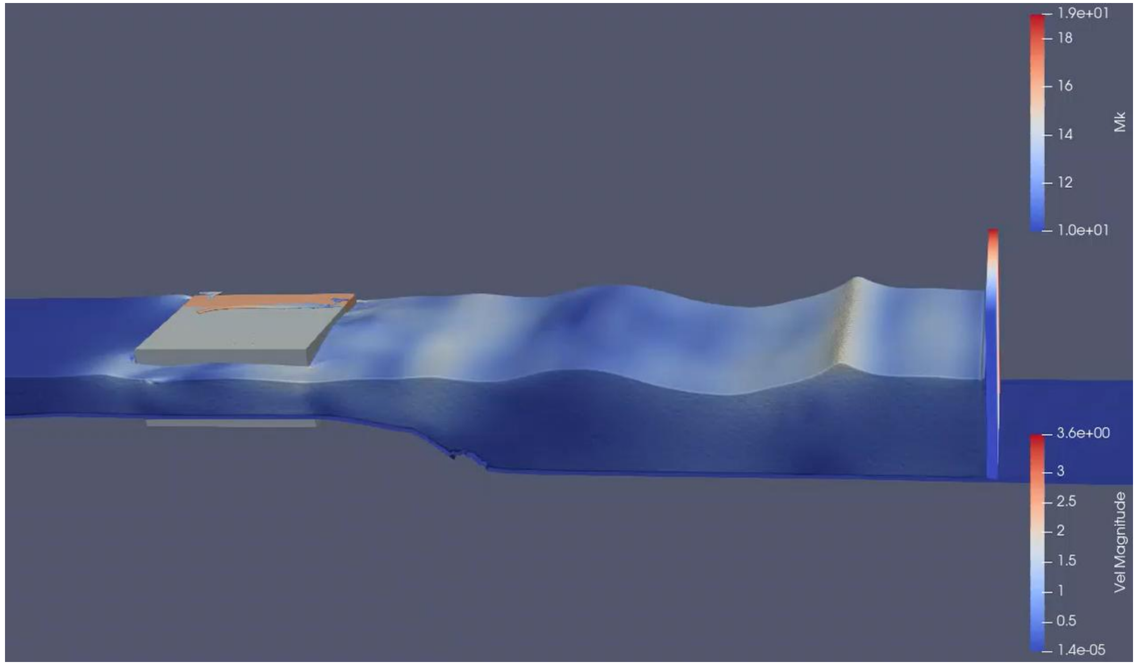



# Level 4 SPHysics: 3-D Wave on MSE Wall Model

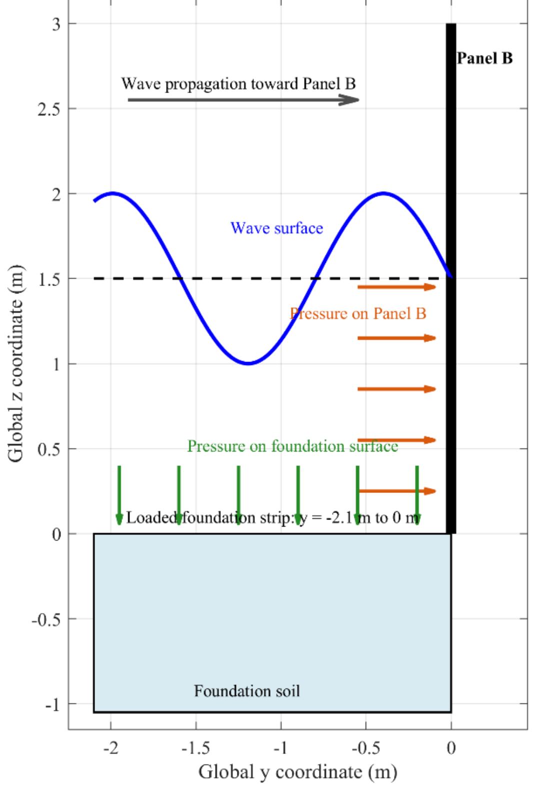


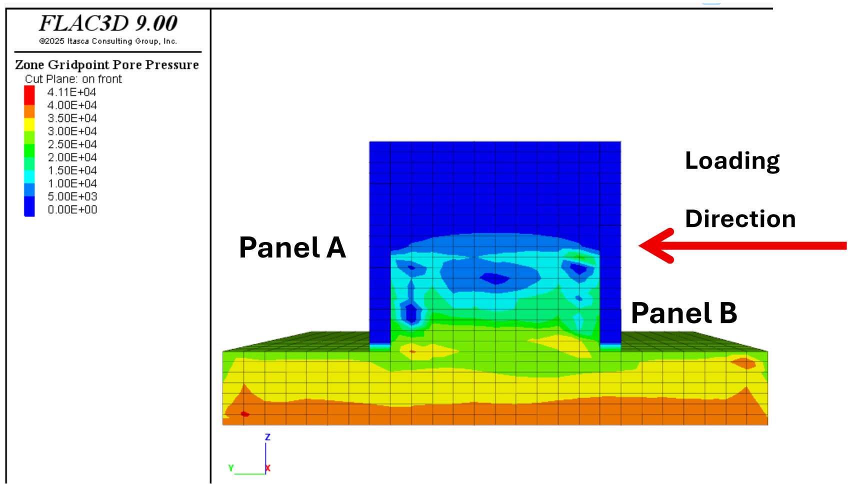



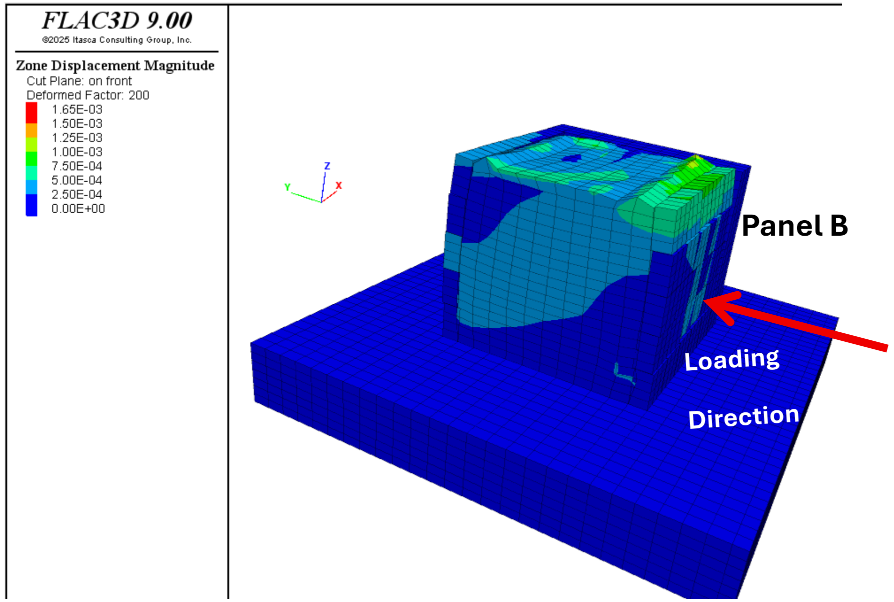


# 3-D Wave and MSE Wall Model

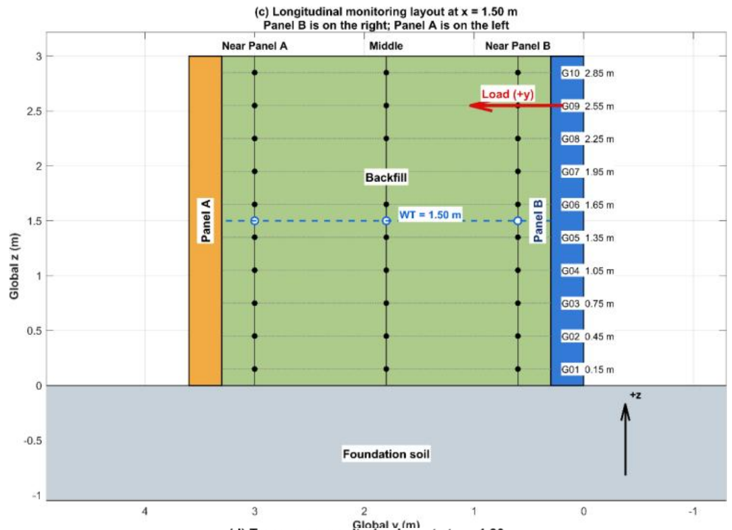
**Figure 1. Conceptual Wave Loading on Panel B and the Adjacent Foundation Surface**
**The wall and the foundation strip are loaded simultaneously using the same wave clock**

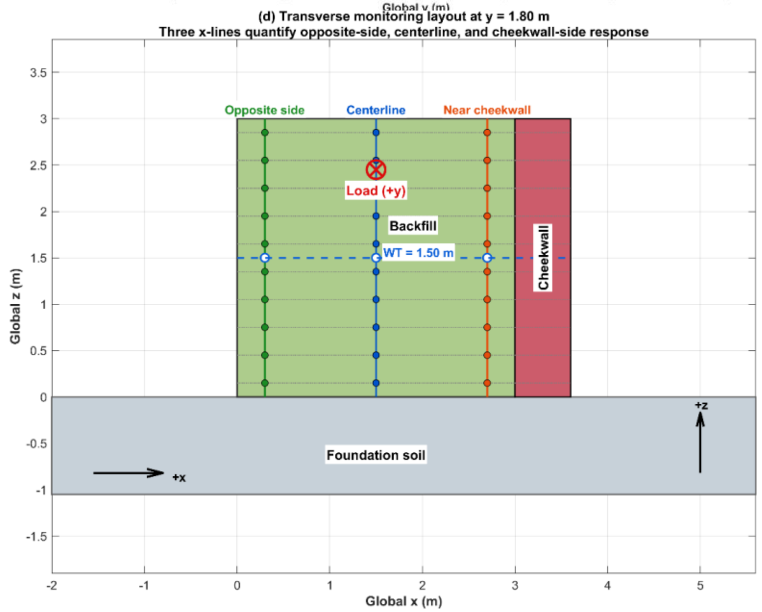


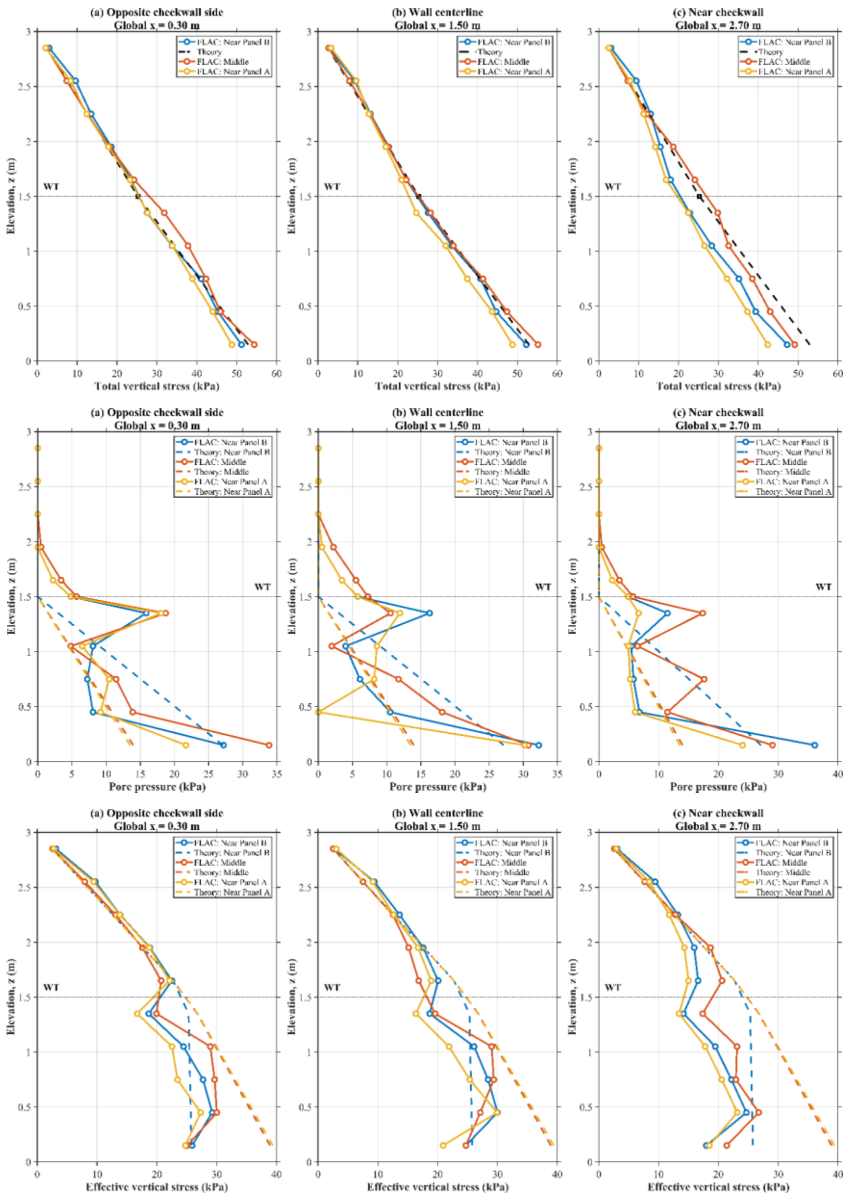



# 3-D Wave and MSE Wall Model



# Thank You