RAPID SCREENING OF PARTIALLY SUBMERGED COASTAL STRUCTURE DESIGNS USING FUNWAVE

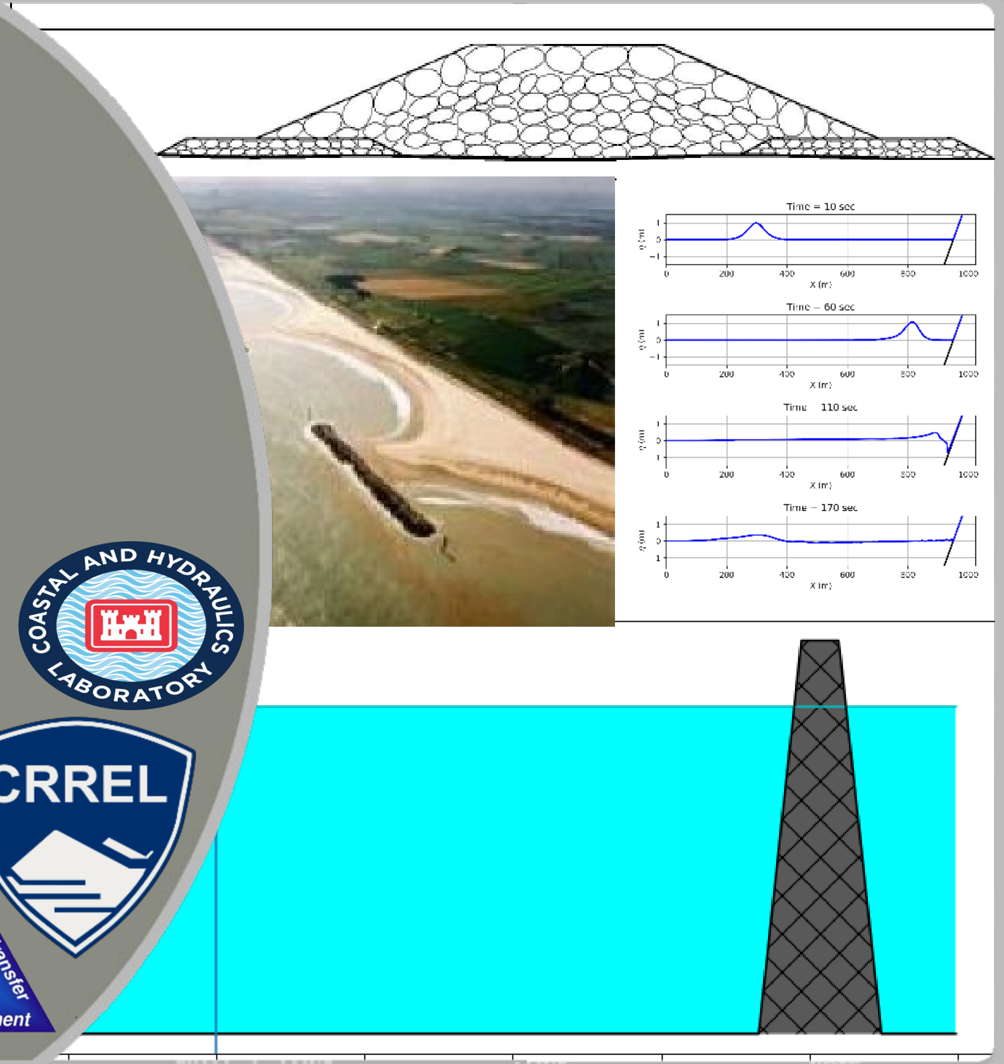
COASTAL INLETS RESEARCH PROGRAM

TECHNICAL DISCUSSION

22 JUNE 2021

Marissa J. Torres (CRREL)
Marissa.J.Torres@erdc.dren.mil

Matt Malej (CHL)
Michael-Angelo Y. Lam (CHL)



Outline

- **Problem statement**
- **Impacts & benefits**
- **Objectives, approach, & accomplishments**
  - **Scope**
  - **Simulation matrix**
  - **Preliminary results**
- **Tech transfer initiative**
- **Future work**

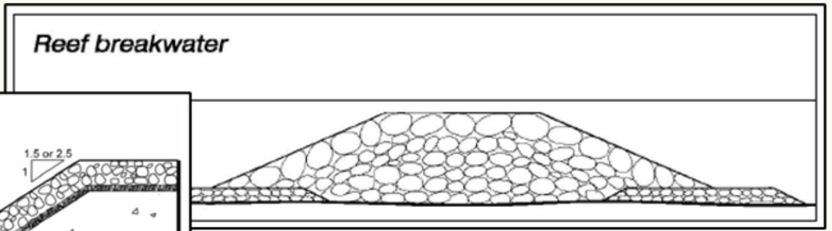
Buffalo District
Breakwater repair

Detroit District
Duluth-Superior Harbor

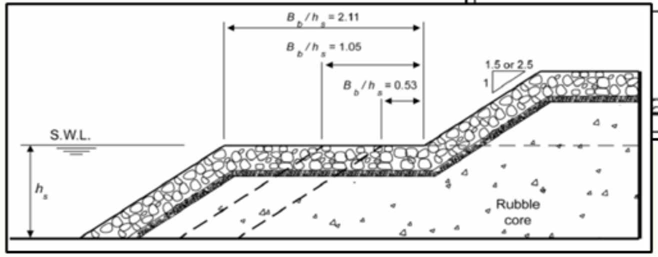
Problem Statement

- Coastal structures (e.g., breakwaters and jetties) are vital for navigation, shore protection, and beach stabilization
- There is rarely enough time, money, and resources to execute screening of structure design alternatives or robust assessment of wave-structure interactions
- Connect coastal engineering applications to the phase-resolving, nearshore numerical wave modeling environment

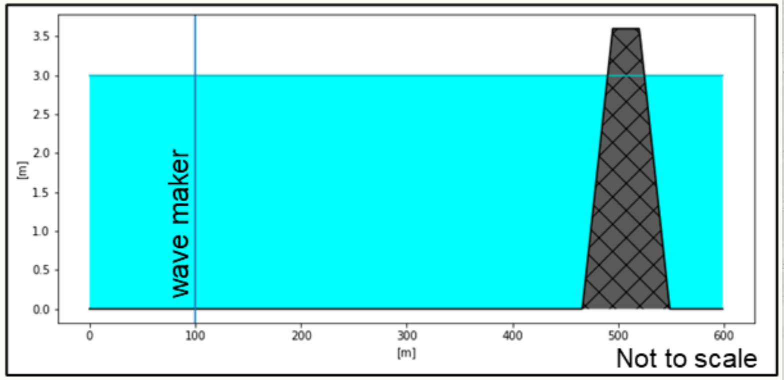
FUNWAVE

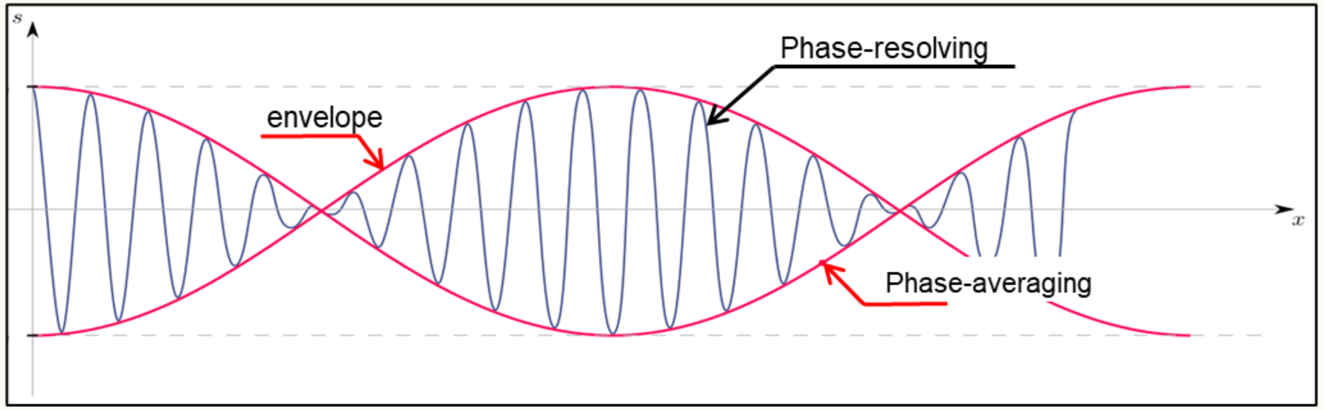


Coastal Engineering Manual (2002)



Rock Manual (2005)



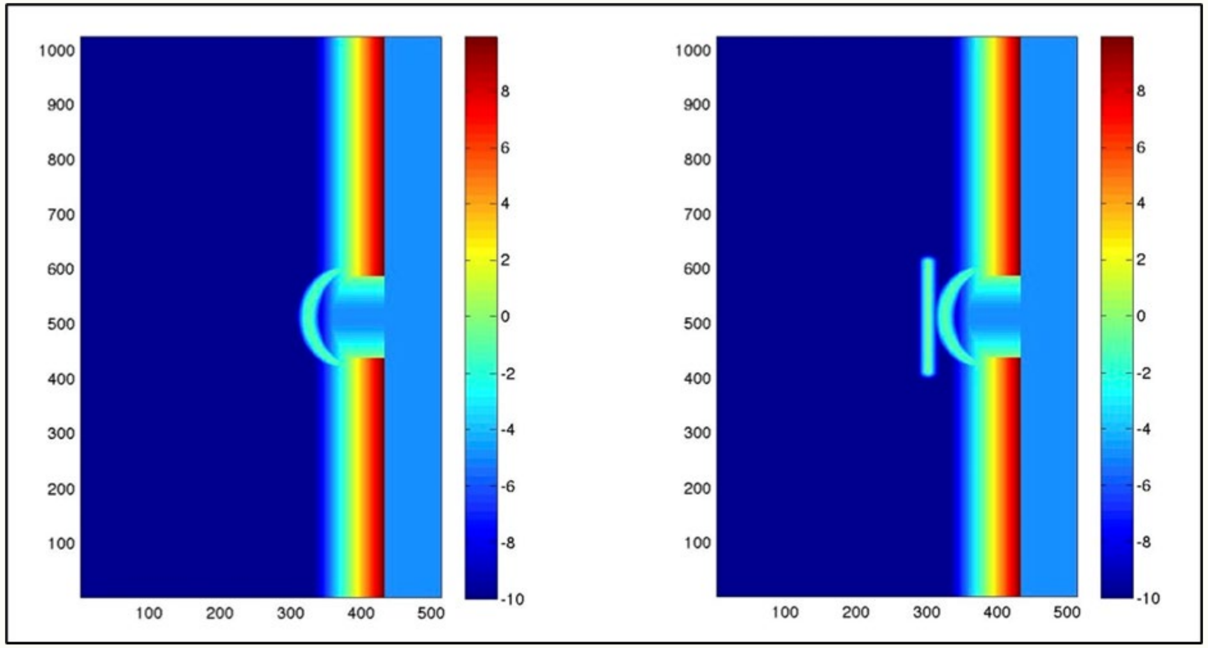


Impact & Benefit

- Empowering, educating, and enhancing the skillsets of novice and intermediate users to implement complex, nonlinear numerical wave models

- Facilitate rapid screening of design alternatives for efficient and effective decision-making under environmental uncertainty

- Save time, money, and resources on SMART planning initiatives



Sample FUNWAVE bathymetry without (left) and with (right) breakwater

- PDT Members:
  - Hans (Rod) Moritz, NWP
  - Matthew Wesley, SPL
  - Rachel Malburg, LRE
  - Jessica Podoski, POH
  - Andrew (Drew) Condon, SAJ
  - Patrick Kerr, SWG

Objective & Approach

Phase 1 – FY21
Phase 2 – FY22+

- Objective: To enhance the transition of structure design materials and their respective porosity (transmission), reflection, and absorption properties directly and seamlessly into a phase-resolving nearshore wave modelling framework.

+

FUNWAVE

- Technical approach:
  - Outline numerical & physical considerations
  - Wave responses:
    - Wave reflection and absorption
    - Wave run-up
    - Wave overtopping and transmission
  - Overall guidance – Value Added:
    - Amount of wave energy dissipation provided by the structure
    - Wave run-up exceedance probability
    - Wave overtopping rate in extreme scenarios

Structure Design Properties

Height (freeboard)	Surface	Porosity
Emergent	Smooth	Impermeable
Submerged	Rough	Permeable

Wave Climate Properties

Wave Type	Dimension
Regular (Monochromatic)	1D 2D normal 2D oblique
Irregular (TMA)	1D 2D normal 2D oblique

Accomplishments & Results

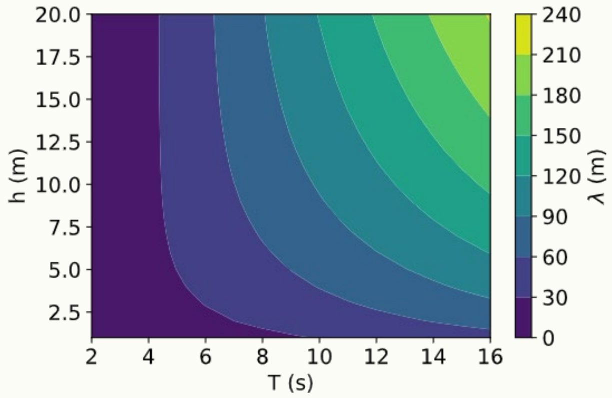
- Accomplishments:
  - Development of simulation test bed
  - Connection to the practitioner
  - Visibility in the 2021 RARG

Accomplishments & Results

Regular wave conditions (monochromatic)

- Accomplishments:
  - Development of simulation test bed
    - Meets numerical and physical limitations for modeling in FUNWAVE
    - Presented best practices guidance to PDT
    - Discussion of nonlinear effects on wave energy transformation in FUNWAVE
  - Connection to the practitioner
  - Visibility in the 2021 RARG

Wavelength λ



- Simulation matrix:
  - Range of wave periods – T = 2 - 16 s
  - Range of water depths – h = 1 - 20 m
  - Range of wave heights – H = 0.2 - (H/h < 0.8) m

257 sims

24,129 sims

  - Internal wavemaker located @ 400 m
  - Flat bottom bathymetry
  - CFL = 0.5

- Numerical considerations:
  - Range of validity
    - Finite depth: $\lambda > 2h$ or $kh < \pi$
  - Spatial resolution: points per wavelength
    - $DX < \lambda / 60$
  - Spatial resolution: numerical stability
    - $DX / h > 1 / 15$

Accomplishments & Results

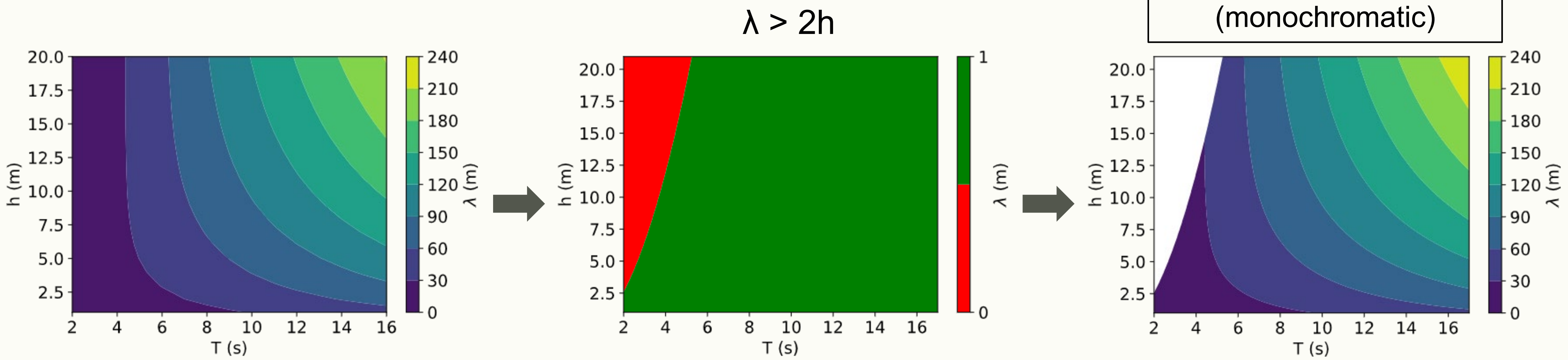
$$\omega = \sqrt{gk * \tanh(kh)}$$
$$\omega = \frac{2\pi}{T}, \qquad k = \frac{2\pi}{\lambda}$$
$$g = 9.81\ \mathrm{m/s^2}$$

- Accomplishments:
  - Development of simulation test bed
    - Meets numerical and physical limitations for modeling in FUNWAVE
    - Presented best practices guidance to PDT
    - Discussion of nonlinear effects on wave energy transformation in FUNWAVE
  - Connection to the practitioner
  - Visibility in the 2021 RARG

- Numerical considerations:
  - Range of validity
    - Finite depth: $\lambda > 2h$ or $kh < \pi$
  - Spatial resolution: points per wavelength
    - $DX < \lambda / 60$
  - Spatial resolution: numerical stability
    - $DX / h > 1 / 15$

Regular wave conditions (monochromatic)

Wavelength λ



Accomplishments & Results

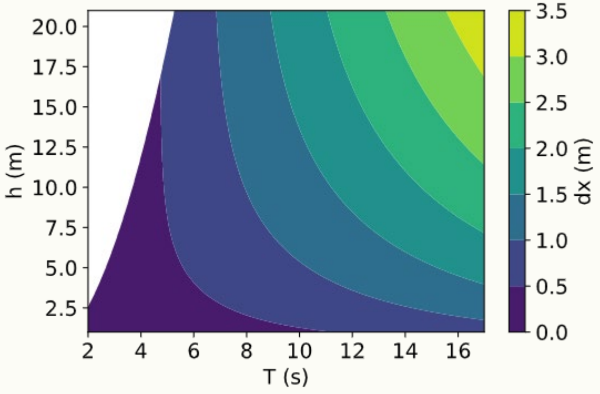
- Accomplishments:
  - Development of simulation test bed
    - Meets numerical and physical limitations for modeling in FUNWAVE
    - Presented best practices guidance to PDT
    - Discussion of nonlinear effects on wave energy transformation in FUNWAVE
  - Connection to the practitioner
  - Visibility in the 2021 RARG

- Numerical considerations:
  - Range of validity
    - Finite depth: λ > 2h or kh < π
  - Spatial resolution: points per wavelength
    - DX < λ / 60
  - Spatial resolution: numerical stability
    - DX / h > 1 / 15

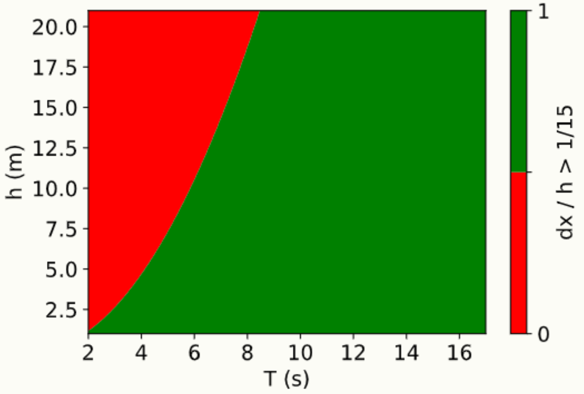
Regular wave conditions (monochromatic)

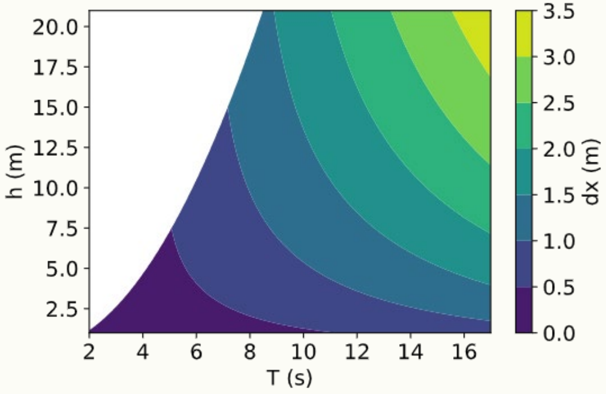
Spatial resolution DX

DX = λ / 70



DX / h > 1 / 15



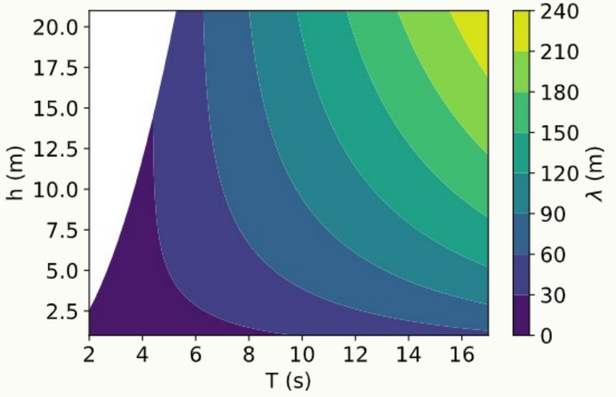


Accomplishments & Results

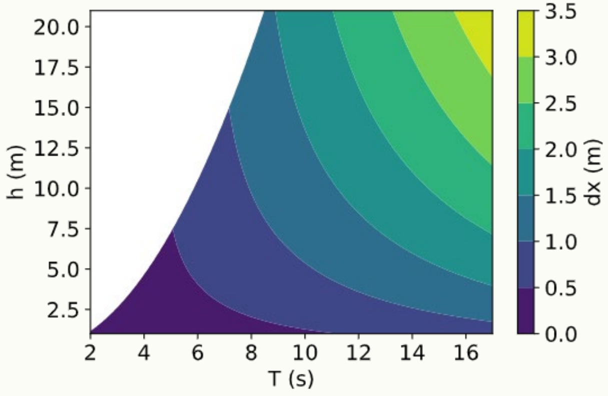
Regular wave conditions (monochromatic)

- Accomplishments:
  - Development of simulation test bed
    - Meets numerical and physical limitations for modeling in FUNWAVE
    - Presented best practices guidance to PDT
    - Discussion of nonlinear effects on wave energy transformation in FUNWAVE
  - Connection to the practitioner
  - Visibility in the 2021 RARG

Wavelength λ



Spatial resolution DX



Determine valid wave period and water depth pair (T, h) ➡ Select appropriate DX based on (T, h)

- Nonlinear effects on wave propagation:
  - Where in the domain should I place the wavemaker relative to the coastal structure?
  - How do nonlinearities transform or affect the waves as they propagate in the domain?
  - How much relative energy remains in the peak period?
- Spatial resolution effects on wave energy

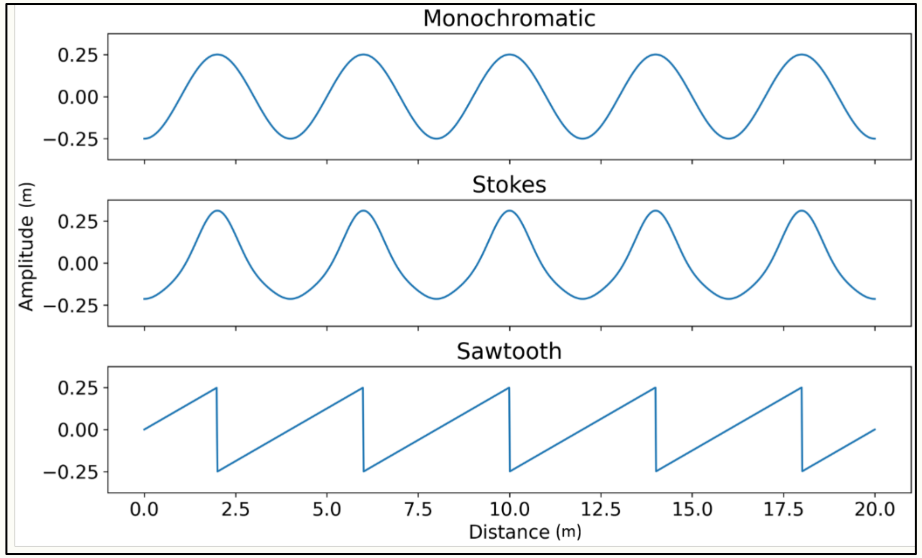
Accomplishments & Results

Regular wave conditions (monochromatic)

- Accomplishments:
  - Development of simulation test bed
    - Meets numerical and physical limitations for modeling in FUNWAVE
    - Presented best practices guidance to PDT
    - Discussion of nonlinear effects on wave energy transformation in FUNWAVE
  - Connection to the practitioner
  - Visibility in the 2021 RARG

- Nonlinear effects on wave propagation:
  - Where in the domain should I place the wavemaker relative to the coastal structure?
  - How do nonlinearities transform or affect the waves as they propagate in the domain?
  - How much relative energy remains in the peak period?

- Spatial resolution effects on wave energy



Accomplishments & Results

Regular wave conditions (monochromatic)

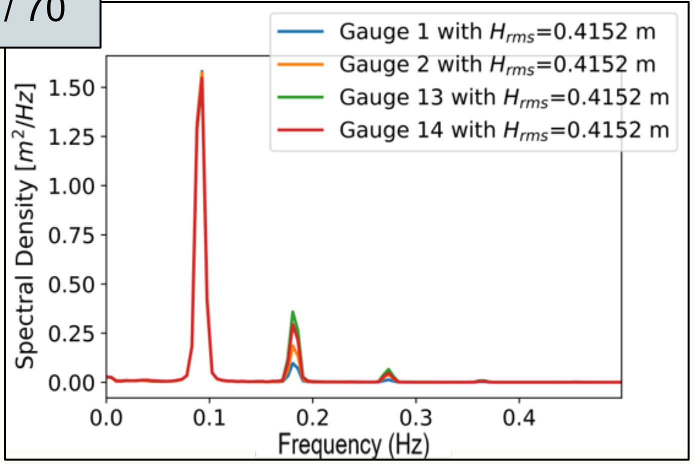
- <u>Accomplishments</u>:
  - Development of simulation test bed
    - Meets numerical and physical limitations for modeling in FUNWAVE
    - Presented best practices guidance to PDT
    - Discussion of nonlinear effects on wave energy transformation in FUNWAVE

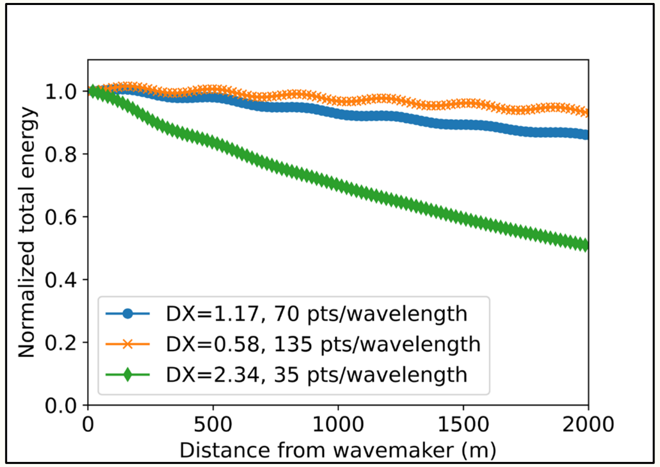
nection to the practitioner

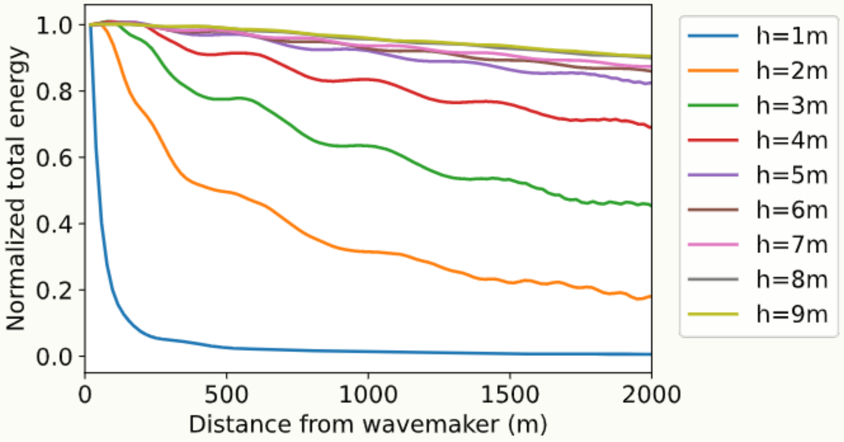
bility in the 2021 RARG

- <u>Nonlinear effects on wave propagation</u>:
  - Where in the domain should I place the wavemaker relative to the coastal structure?
  - How do nonlinearities transform or affect the waves as they propagate in the domain?
  - How much relative energy remains in the peak period?
- <u>Spatial resolution effects on wave energy</u>

T = 11 s
h = 6 m
H = 0.4 m
DX = λ / 70







Accomplishments & Results

Irregular wave conditions (TMA)

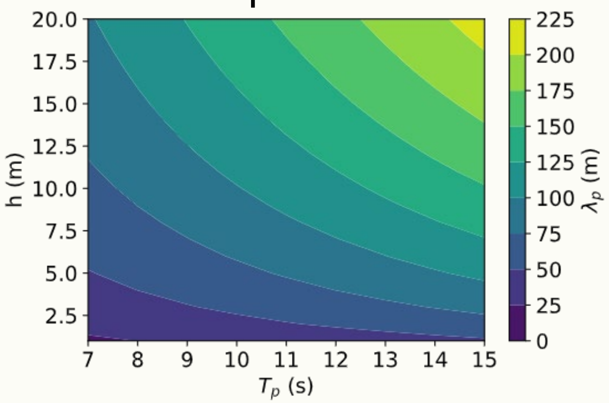
- Accomplishments:
  - Development of simulation test bed
    - Meets numerical and physical limitations for modeling in FUNWAVE
    - Presented best practices guidance to PDT
    - Discussion of nonlinear effects on wave energy transformation in FUNWAVE
  - Connection to the practitioner
  - Visibility in the 2021 RARG

- Simulation matrix:
  - Range of peak wave periods – Tp = 7 - 15 s
    - Peak frequency – fp (1/Tp) = 0.067 - 0.143 Hz
    - Minimum frequency – FreqMin = 0.3 Hz (33.3 s)
    - Maximum frequency – FreqMax = 0.03 Hz (3.3 s)
  - Range of water depths – h = 1 - 20 m
  - Range of wave heights – H = 0.2 - (H/h < 0.8) m

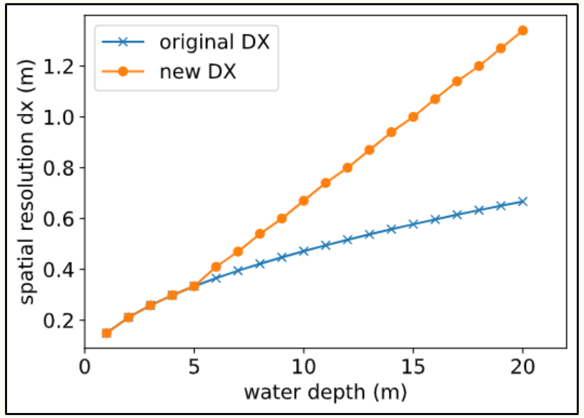
Peak wavelength λp

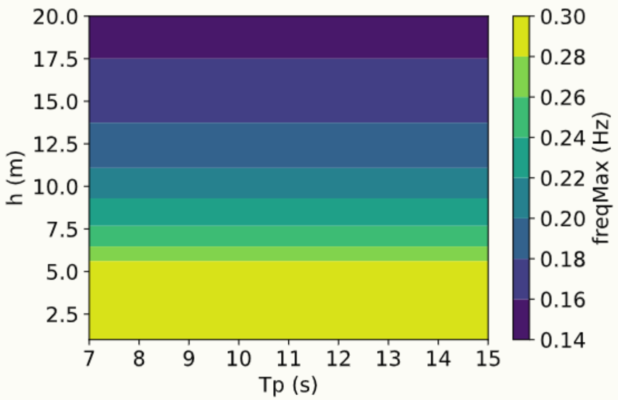
$$\lambda_p = T_p\sqrt{gh}$$

λp > 2h ✓



DX / h > 1 / 15





Accomplishments & Results

- Accomplishments:
  - Development of simulation test bed
    - Meets numerical and physical limitations for modeling in FUNWAVE
    - Presented best practices guidance to PDT
    - Discussion of nonlinear effects on wave energy transformation in FUNWAVE
  - Connection to the practitioner
    - Discussion of practical needs for operational use of FUNWAVE
    - Identify gaps in existing documentation and guidance
    - Prioritize needs for immediate capability (SoNs)
  - Visibility in the 2021 RARG

- Monthly meetings with PDT members

- Active participation and engagement

- Growing interest in utilizing FUNWAVE on current and future projects:
  - Jacksonville, FL – wind waves + ship wakes (new)
  - Los Angeles, CA – island of Saipan
  - Detroit, MI – Kenosha Dunes (new)

  - Honolulu, HI – Sunset Beach
  - Buffalo, NY – Harbors and marinas
  - Galveston, TX – ship wakes, scour/erosion

Accomplishments & Results

- Accomplishments:
  - Development of simulation test bed
    - Meets numerical and physical limitations for modeling in FUNWAVE
    - Presented best practices guidance to PDT
    - Discussion of nonlinear effects on wave energy transformation in FUNWAVE
  - Connection to the practitioner
    - Discussion of practical needs for operational use of FUNWAVE
    - Identify gaps in existing documentation and guidance
    - Prioritize needs for immediate capability (SoNs)
  - Visibility in the 2021 RARG

- "Enhanced user guidance and support tools for FUNWAVE-TVD, a Boussinesq-type numerical wave model" - Rachel Malburg
- "Extend FUNWAVE to deep water condition for expanded operational use" – Matthew Wesley
- "Mid and long-term vessel wake impacts on the ecosystem" – Patrick Kerr
- "Deep-draft vessel waves and local infrastructure flooding" – Patrick Kerr
- "Enabling Reliable Evaluation of Wave Interaction with Submerged Structures" – Rod Moritz
- "Variable water level in FUNWAVE for improved operational modeling" – Jessica Podoski

- 6 FUNWAVE SoNs in NAV mini-RARG
- Beneficial discussions in SuperRARG
- Cross-cutting objectives

Tech Transfer Initiative

Phase 1 – FY21
Phase 2 – FY22+

- Wiki updates:
  - Connecting coastal engineering applications to the numerical wave modeling environment
  - Tabulated and graphical representation:
    - Simulation test bed (regular & irregular)
    - Wave responses over *impermeable* structure
      - Reflection
      - Runup
      - Overtopping
    - Wave responses over *permeable* structure
      - Transmission
      - Absorption
      - Diffraction
  - Support functions in Python Jupyter Notebook
    - 1D applications
      - Bathymetry modifications
      - Breakwater / obstacle files
      - Friction files
    - 2D applications

https://fengyanshi.github.io/build/html/index.html

Breakwater and Obstacle

INTRODUCTION

Native to FUNWAVE are the addition of obstacles and/or breakwaters in the model domain. These features can be either fully reflective (i.e., impermeable) or partially reflecting / partially absorbing (e.g., permeable). There are three ways to add a breakwater or obstacle to the model:

1. Modify the bathymetry directly, generating a raise *impermeable* feature in the along-shore beach profile (or cross-shore for jetties, groins, etc.). See an example of this at Example: add breakwater using bathymetry file.
2. Generate a breakwater file that defines the width of a *dissipative sponge layer* at a location on the grid, and define the corresponding absorption strength of the sponge layer in the `input.txt` file. The dissipative sponge layer behaves as a frictional dissipative layer to the incoming waves. See an example of this at Example: add partially reflecting/absorbing breakwater.
3. Generate an obstacle file that specifies the location of an infinitely tall, *impermeable* wall (i.e., fully reflective) in the model domain. See an example of this at Example: add obstacle.

More details about the specification of the breakwater and obstacle files are presented in the following section.

A potential fourth method for incorporating a breakwater in the model domain involves the combination of options one and two – modifying the bathymetry to some extent and adding/defining the dissipative sponge layer over the raised feature. This method would essentially simulate a permeable structure of variable strength or *porosity* with an impermeable core.

Several structure properties are available for simulation in the FUNWAVE numerical model. These properties include:

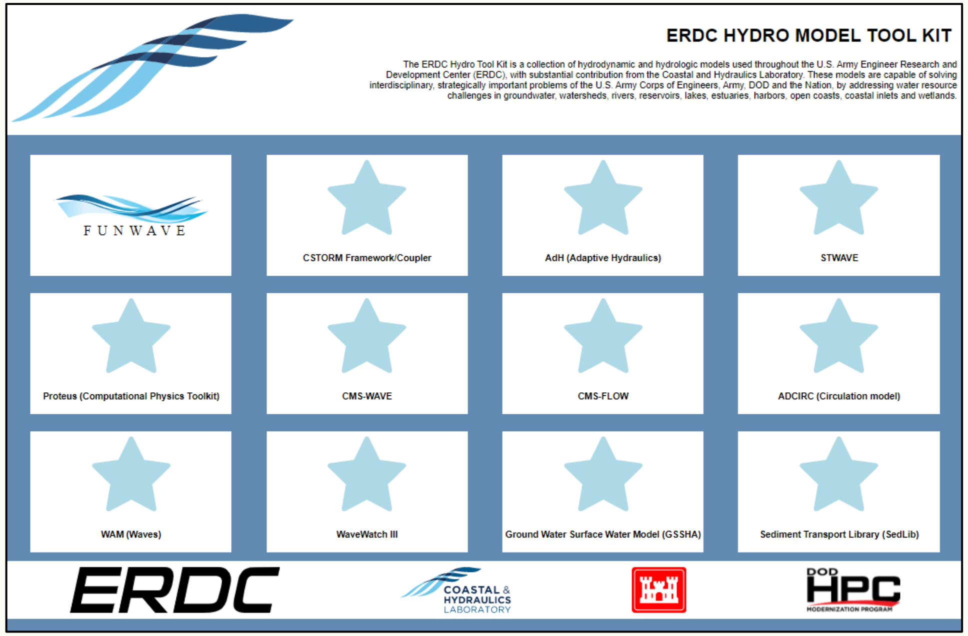
- Smooth versus rough slope
  - Through the incorporation of the bottom friction coefficient *Cd* over an impermeable feature defined via bathymetric modification, a rough structure surface can be added to the feature.
- Impermeable versus permeable
  - Utilizing a dissipative sponge layer of variable strength in the numerical domain allows for the simulation of a permeable or porous structure surface in the wave field.
- Emergent versus submerged
  - The height of the breakwater or coastal feature relative to the total water depth is variable, and as such the overall wave responses will differ greatly for a fully submerged breakwater compared to an emergent breakwater.

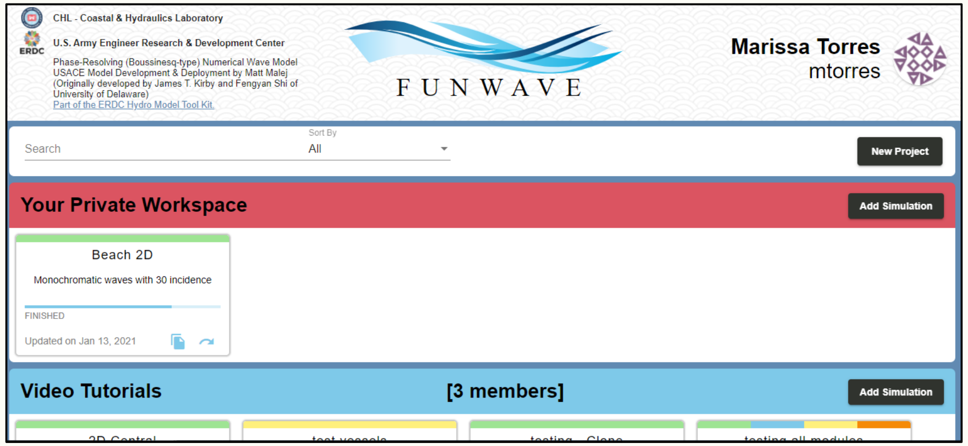
These methods are not limited to breakwaters. Other structures of interest may include, but are not limited to, jetties, groins, revetments, and sea walls. These structure types and their configurations may be added to the numerical domain using similar techniques described above. For more information on wave-structure interactions, visit literature_interactions.

Tech Transfer Initiative

Phase 1 – FY21
Phase 2 – FY22+

- Webinars & Tutorials:
  - Hold presentation / webinar for:
    - PDT District members
    - CIRP
    - CWG
  - Record a series of tutorial videos about guidance on "how-to" use the model on the HPC portal application
  - "How-to" use FUNWAVE for local applications
  - "When-to" use FUNWAVE for your project
  - Other application or project specific tutorials
- Publications:
  - ERDC/CRREL Technical Note (*in review*)
    - "Practical guidance for numerical modeling of nearshore wave-structure interactions in FUNWAVE-TVD"
  - ERDC/CRREL Technical Report (*in prep.*)
    - Comprehensive discussion of all results
    - Publish date expected in FY22





FY21 Outlook & Beyond

Phase 1 – FY21
Phase 2 – FY22+

- Wave responses with impermeable trapezoidal breakwater structure

Structure variables	Wave variables
Crest height Crest width Slope Roughness “Sponge” layer width “Sponge” layer strength	Wave period Wave height Wave direction Peak frequency First moment wave height Water depth*

  - Slope – m = 1/2 - 1/8
  - Crest width – B = 3, 5, 10 m
  - Crest height – h_s = 1.1*h - 1.5*h

  22,680 sims (regular)

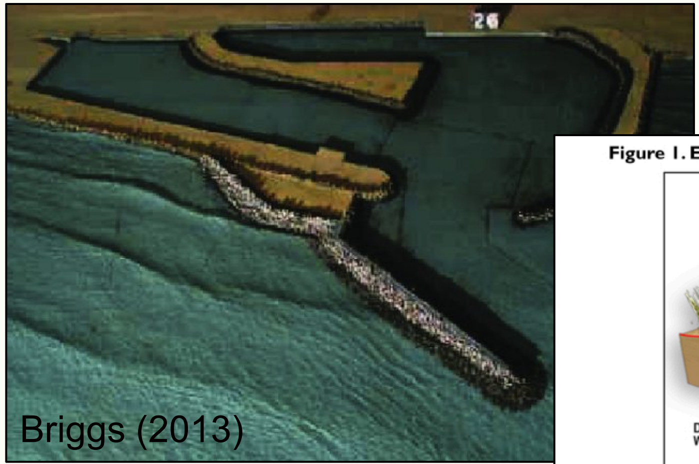
- Deliver tech transfer
  - Wiki updates
  - Video tutorials / webinars
  - Technical report

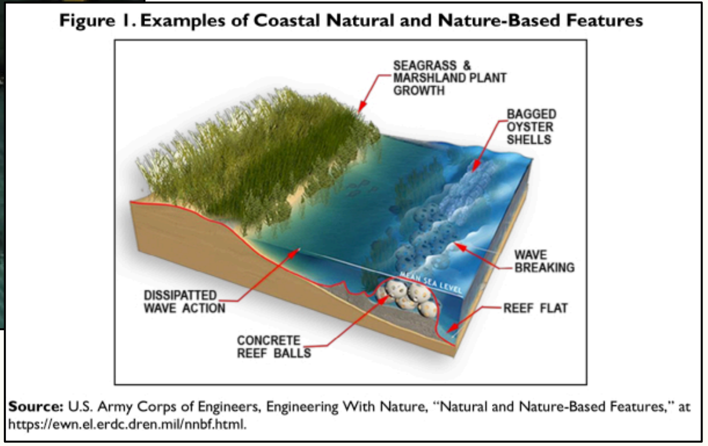
- <u>Natural next steps</u>:
  - Expansion to 2D simulations
  - Permeable submerged structures
    - Wave transmission
    - Wave absorption
    - Wave diffraction
  - Connection to EuroTop

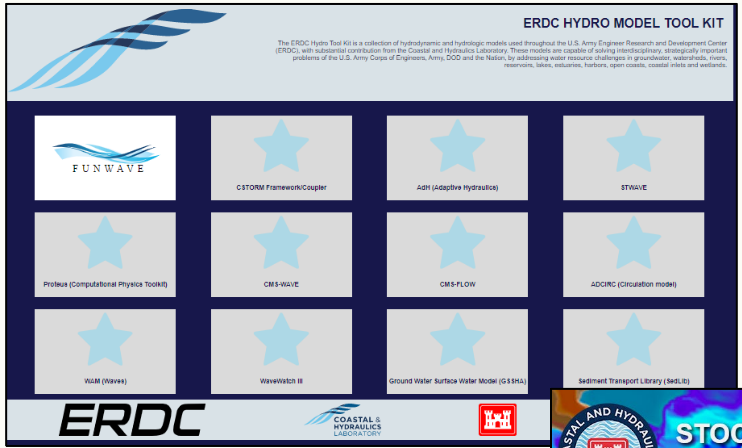
- <u>Other considerations</u>:
  - Improved HPC Portal GUI visualization and functionality, specifically for coastal structures
  - Fundamental development of model
  - Verification and validation where appropriate

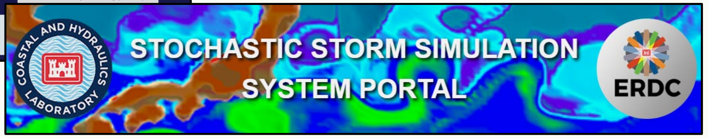
FY21 Outlook & Beyond

- Future considerations:
  - Alternate structural configurations
    - Berm, toe, step slopes
    - Multiple breakwaters in sequence
    - Expand to jetties, groins, revetments
  - Validation with physical models
    - Existing structure materials (armored rock)
    - Natural and Nature-Based materials (coral reef, oyster bed, etc.)
    - Existing or planned field experiments (Districts)
  - Expanded FUNWAVE capability
    - Sediment transport (accretion, erosion)
    - Tombolo or salient formation
    - Vessel generated waves
  - Expansion of DoD HPC Portal Application
    - Enhanced breakwater / obstacle input
    - Map-based structure placement feature
    - Visualization GUIs









Thank you!

Contact Info:

Marissa.J.Torres@erdc.dren.mil
Marissa.J.Torres2.civ@army.mil (Army Teams)

(603) 646-4283

Quonochontaug, RI