Analysis of wave transmission over submerged structures using FUNWAVE-TVD: A comparison of two methods

Coastal Inlets Research Program
Technical Discussion
12 September 2023

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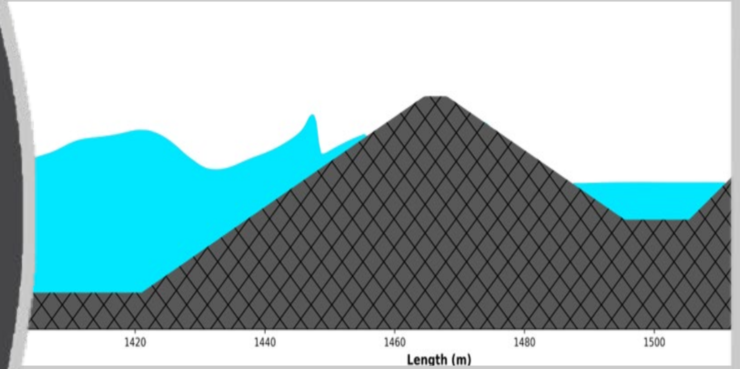

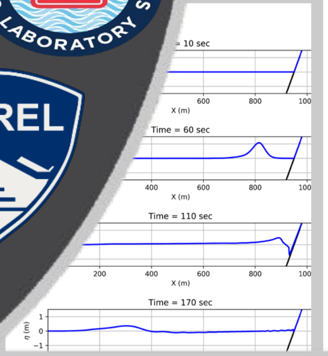

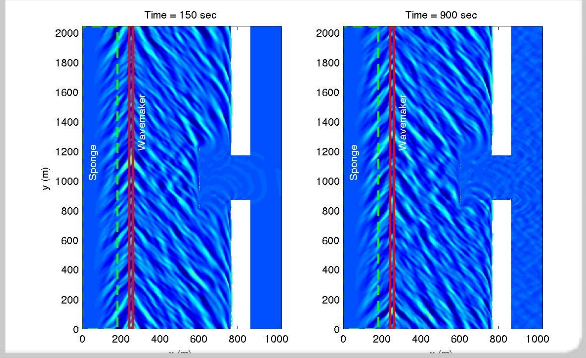

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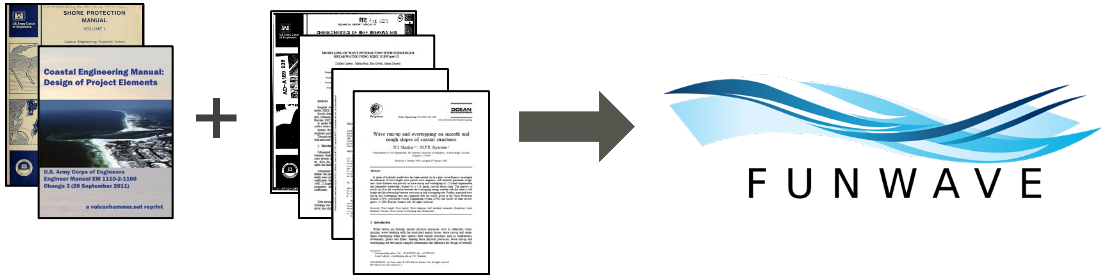
Project Overview

Project schedule by MONTH FY

YEAR 1	YEAR 2	YEAR 3
APR FY22 – FEB FY23	FEB FY23 – DEC FY24	FEB/MAR FY24 – DEC FY25
Completed	Ongoing (current)	Upcoming (Final)

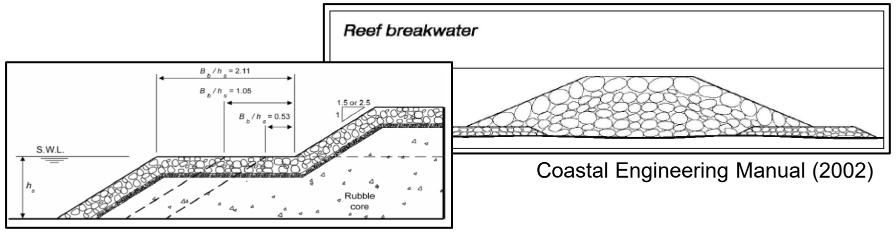
APR 22 · JUL 22 · OCT 23 · JAN 23 · APR 23 · JUL 23 · OCT 24 · JAN 24 · APR 24 · JUL 24 · OCT 25

<u>Objective</u>: To provide practical guidance for implementing impermeable coastal structures in FUNWAVE-TVD for the rapid environmental assessment of design alternatives in coastal engineering applications.



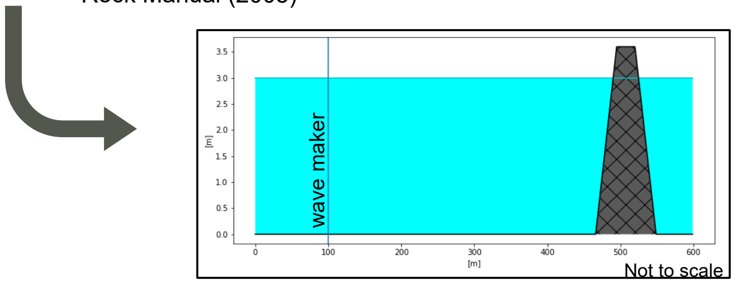
<u>Goals</u>:

- Define numerical parameter equivalents in FUNWAVE to replicate real breakwater design and its respective wave attenuation effects
- Enhance accessibility and usability of the model for users of all levels
- Help Nation stay resilient to coastal storms and floods by providing tools and resources to coastal practitioners



Coastal Engineering Manual (2002)

Rock Manual (2005)



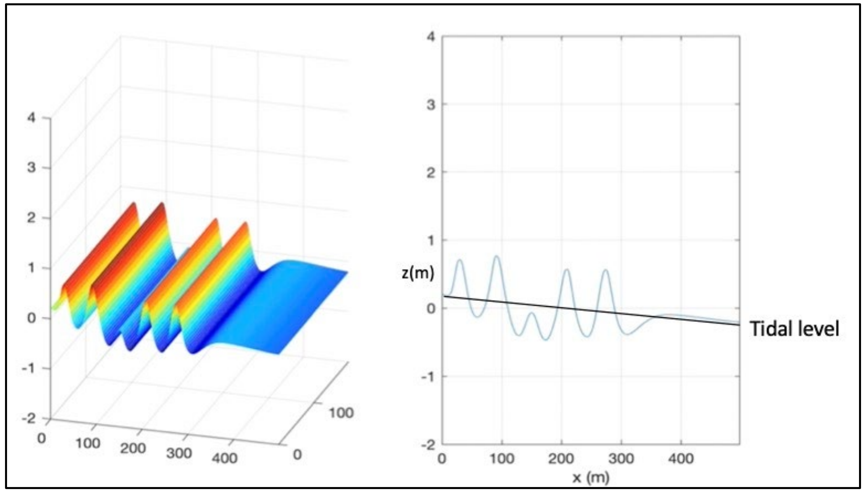
<u>PDT Members</u>:

- Hans (Rod) Moritz, NWP
- Matthew Wesley, SPL
- Rachel Malburg, LRE
- Jessica Podoski & Catie Dillon, POH
- Gabriel Todaro, SAJ
- Patrick Kerr, SWG
- Drew Condon, CHL

Ongoing Work

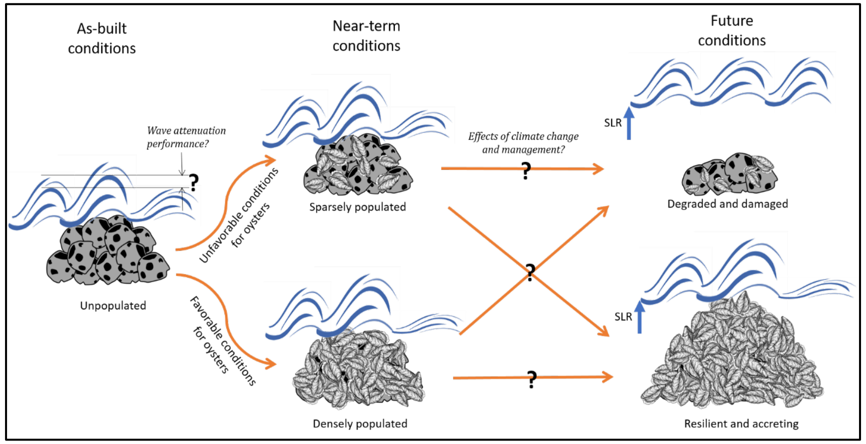
CIRP

- *FY22-25 – Practical wave response guidance over emergent and submerged coastal structures using FUNWAVE-TVD*
- FY22-25 – Extension of FUNWAVE-TVD for modeling highly-dispersive waves induced by vessels and winds in relatively deep water and variable water level (Malej, PI)



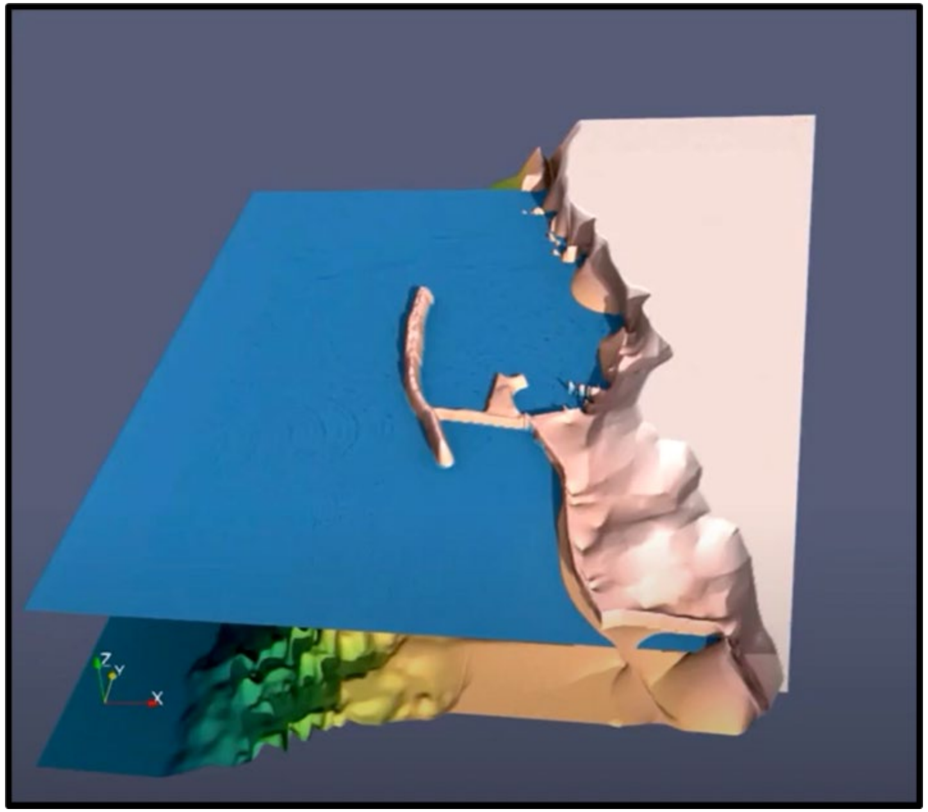
EWN

- FY22-26 – Computational modeling of manmade oyster reefs: life cycle, wave attenuation, performance and reliability (Piercy, co-PI)



FUNWAVE

- A nearshore shallow-to-intermediate water phase-resolving Boussinesq-type numerical wave model that resolves many processes
- A bridge between computationally expensive high-fidelity Navier-Stokes equation models and phase-averaged models
- Quick turn around using parallel computing on high performance computers
- Collaborative effort with University of Delaware



Comprehensive Wiki

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

OPEN SOURCE SOFTWARE

https://github.com/fengyanshi/FUNWAVE-TVD

DOD HPC DEPARTMENT OF DEFENSE HIGH PERFORMANCE COMPUTING PORTAL

https://portal.erdc.hpc.mil/erdchydro/#

Wave Response Guidance: Wave Transmission

- Investigate the performance of two structure implementation methods natively available in FUNWAVE

- Understand the limitations these methods in the context of submerged breakwaters

- Inform practical modeling guidance for environmental assessment of traditional and nature-based structure designs using FUNWAVE, including sea level rise impacts on structure wave transmission

Wave Response	Dimension	Wave Climate	Structure Properties
Overtopping	1D	Regular Irregular	Emergent Smooth / Rough Impermeable
	2D	Regular (normal, oblique) Irregular (normal, oblique)	Emergent Smooth / Rough Impermeable
Runup	1D	Regular Irregular	Emergent Smooth / Rough Impermeable
	2D	Regular (normal, oblique) Irregular (normal, oblique)	Emergent Smooth / Rough Impermeable
Transmission (over structure)	**1D**	**Regular** Irregular	**Submerged** **Smooth / Rough** **Impermeable / permeable**
	2D	Regular (normal, oblique) Irregular (normal, oblique)	Submerged Smooth / Rough Impermeable / permeable
Reflection	1D	Regular Irregular	Emergent Smooth / Rough Impermeable
	2D	Regular (normal, oblique) Irregular (normal, oblique)	Submerged Smooth / Rough Impermeable / permeable

Wave Transmission

- Wave transmission relates the proportion of the incident wave transmitting past the structure

- For a rubble mound structure:
    - Overtopping transmission
        - Energy as a function of wave height propagating on the leeside of the structure (not an overtopping rate or volume)
    - Transmission through the structure
    - Diffraction around the structure

- Difficult to separate transmission via overtopping and transmission through the structure in physical modeling studies

$$\boxed{K_t = {}^{E_t}/_{E_i}}$$

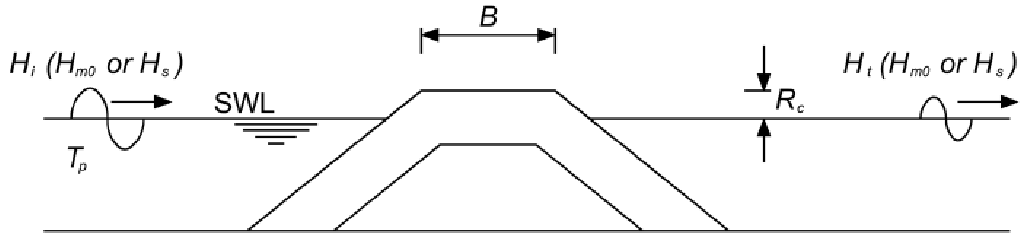
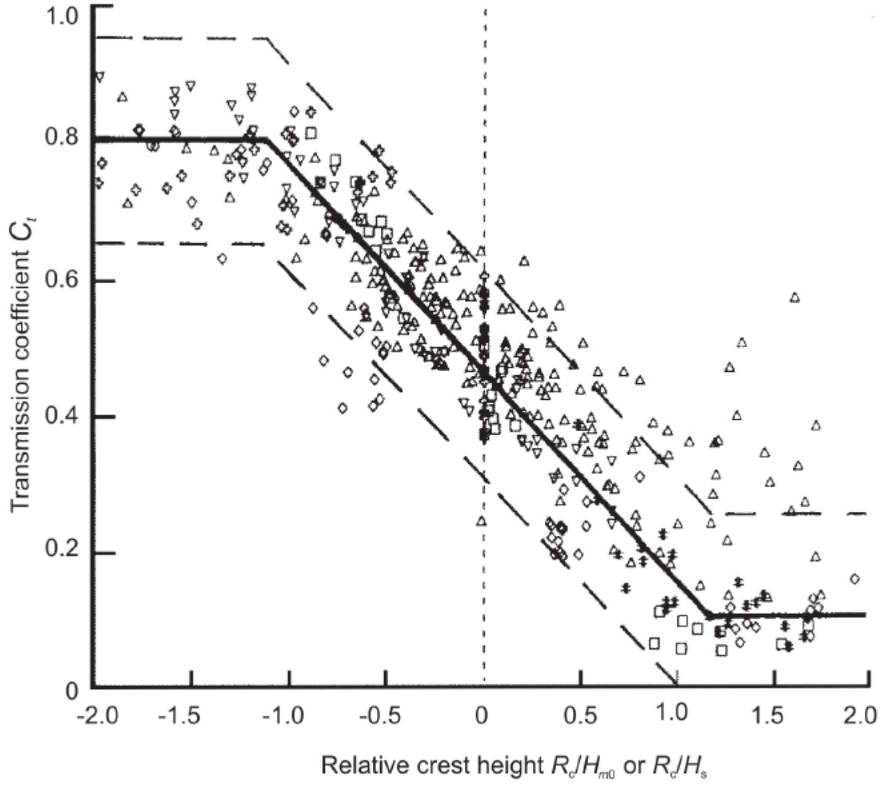


Figure 5.16 *Cross-section illustrating parameters influencing wave transmission*

Rock Manual (2005)



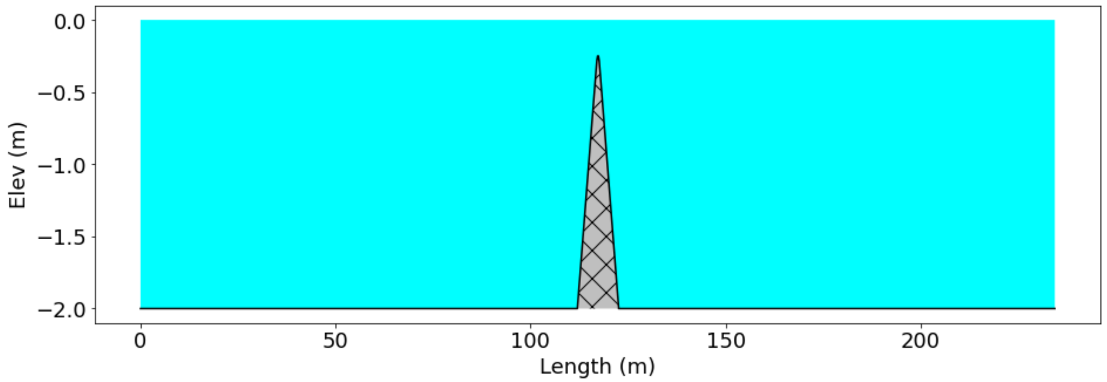
Rock Manual (2005)
CIRIA/CUR (1991)

Incorporating Structures in FUNWAVE

Two primary methods for incorporating coastal structures in domain natively:

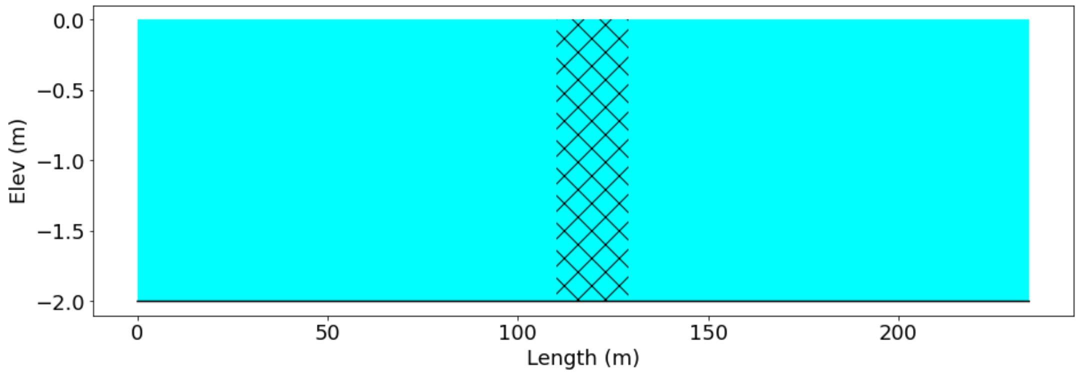
Bathymetry Modification (impermeable)

- Direct modification of bathymetry data (*depth.txt*)
- Maintain shape and size characteristics of structure explicitly
- Incorporate bottom friction layer over structure



Breakwater File (permeable)

- Define location and width of internal dissipative sponge layer “through the water column” (*breakwater.txt*)
- Cannot maintain shape and size characteristics of structure explicitly
- Width and strength of sponge require more trial and error – need guidance to relate to physical conditions



Study Design

Recreate conditions within a protected water body (monochromatic):

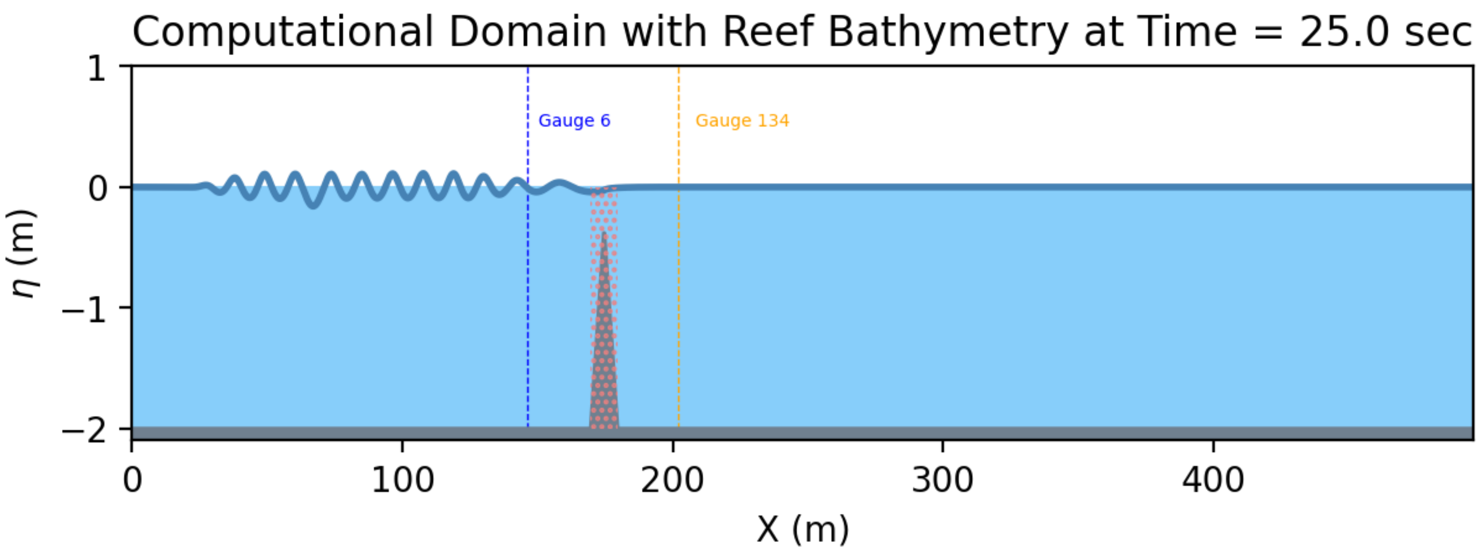
- Typical – T = 3s, H = 0.2m (h = 2m)
- Windy – T = 4s, H = 0.5m (h = 5m)
- Stormy – T = 6s, H = 1.0m (h = 10m)

Constants:

- Relative wave height – H/h = 0.1
- Relative crest width – B/L = 0.03

Variables:

- Relative freeboard – F/H = -1.9 to -0.2
- Coefficient of friction – Cd = 0.0 to 0.05
- Sponge width – breakwater.txt = 0.1*L to 1.5*L
- Sponge strength – BreakwaterAbsorptionCoefficient = 0.01, 0.10, 1.0, 5.0, 10.0



Two sets of simulations:

- Bathymetry modification
- Dissipative sponge layer

Wave transmission:

- Two gauges 4*L before and after reef-like feature

$$\hat{f}(k) = \int_{-\infty}^{\infty} f(x) e^{-2\pi i k x}\, dx$$ Fourier Transform

$$E = \int_{-\infty}^{\infty} |X(f)^2|\, df$$ Total energy of Power Spectral Density

$$K_t = {}^{E_t}/_{E_i}$$

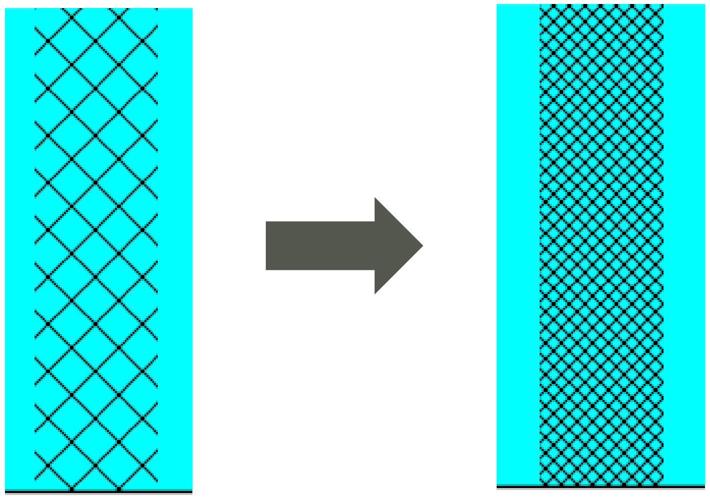
T – period (s)
H – wave height (m)
h – water depth (m)
B – crest width (m)
F – freeboard (m)
Cd – coefficient of friction
L – wavelength (m)

Hypotheses

1. **Breakwater absorption coefficient** is analogous with relative freeboard and sponge width is analogous with crest width

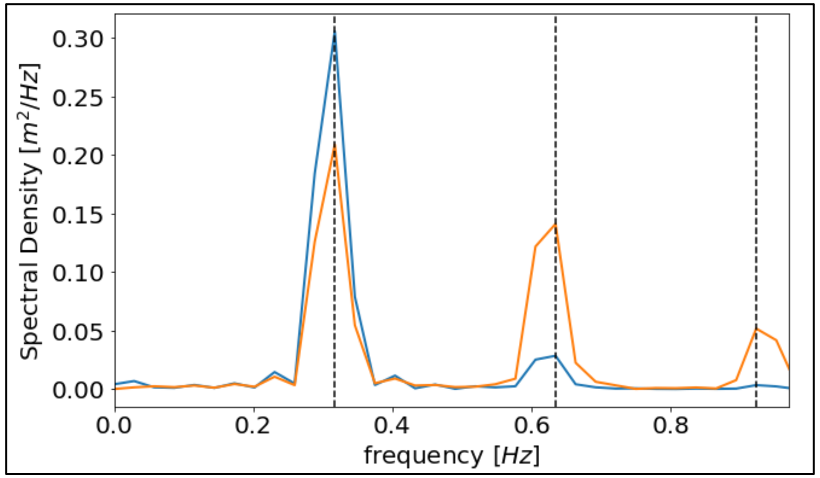
2. Bottom friction would have more of an effect on the energy transmission at shallower freeboards

Breakwater absorption coefficient
controls strength of sponge layer



Wave Transmission over Impermeable Structure

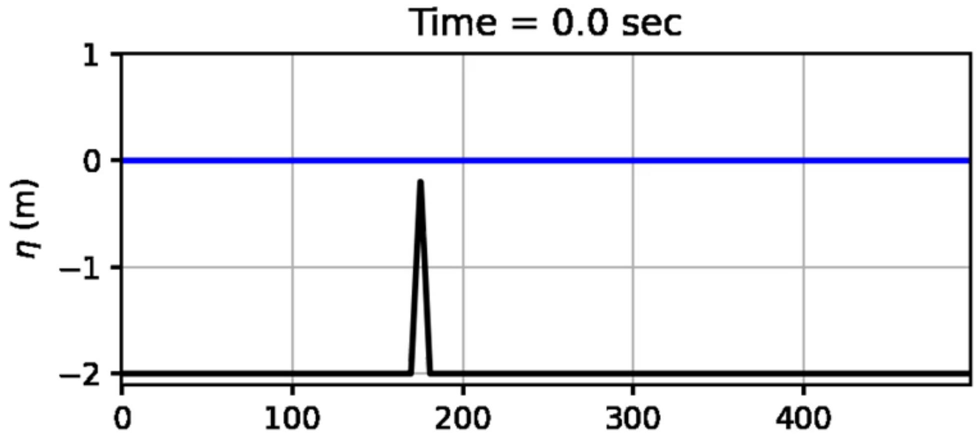
- Nonlinear effects of shoaling and breaking → Dispersion
- Spectral analysis shows minor transfer of energy from peak frequency to higher harmonics
  - Agrees with Ahrens (1987) and van der Meer (2004)
- Physics is more representative of field conditions

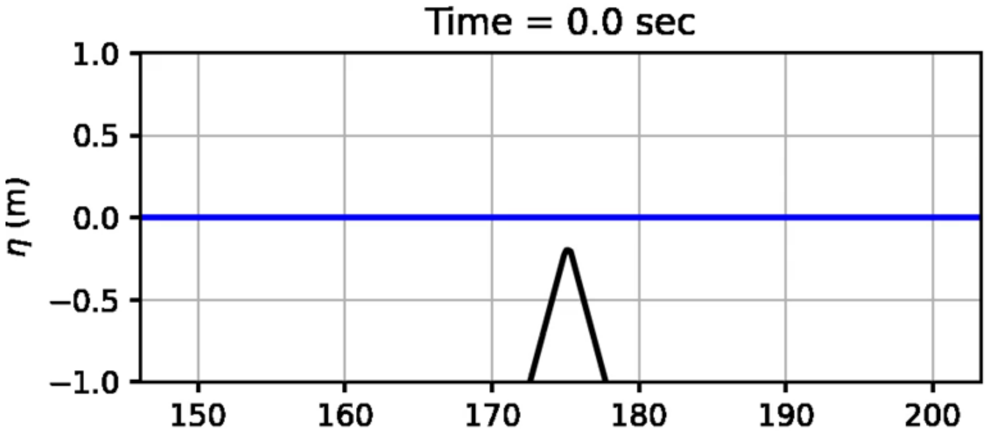


Peak Frequencies:
0.3172 Hz,
0.6344 Hz,
0.9228 Hz

Gauge 6 @ 67.7m with H_{sig}=0.2502 m

Gauge 134 @ 125.0m with H_{sig}=0.2180 m

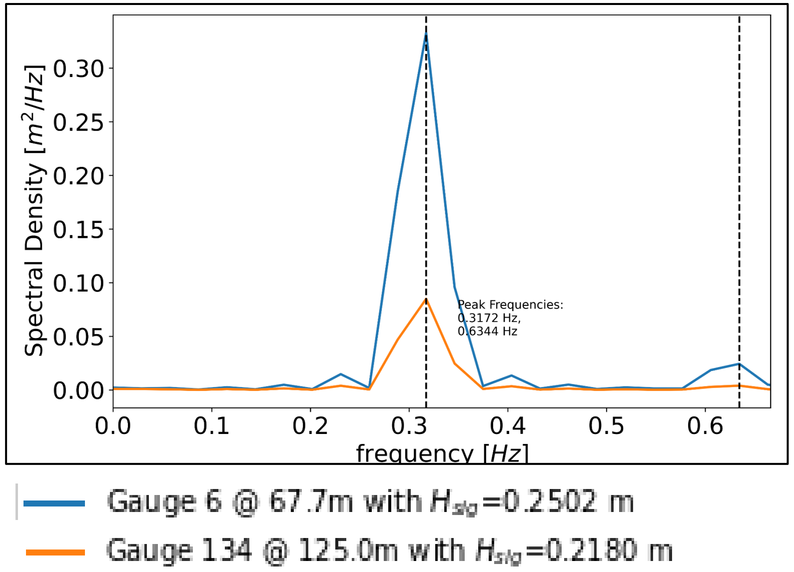




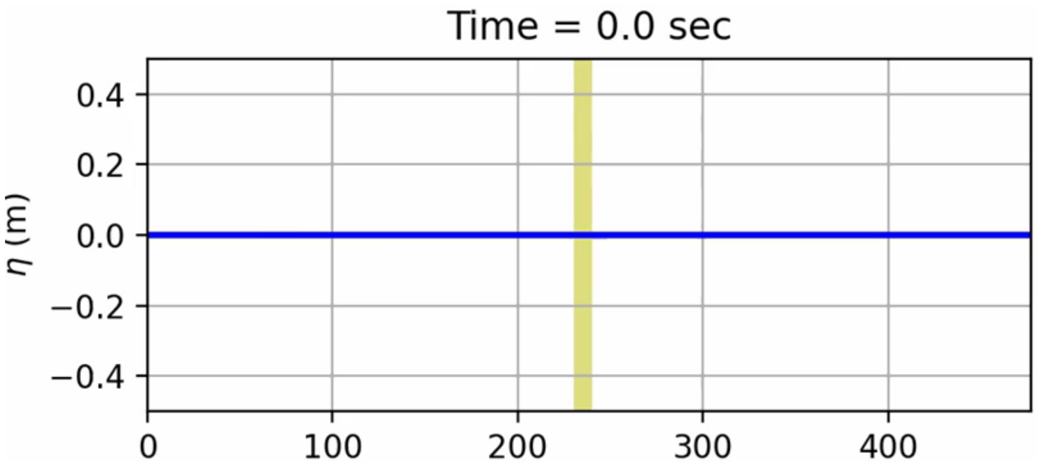
T = 3 s	F = 0.2 m
h = 2 m	B = 0.42
H = 0.2 m	Cd = 0.0

Wave Transmission through Permeable Layer

- Reduction of amplitude → Dissipation only
- Spectral analysis shows significant reduction in energy from peak frequency
- Could be representative of porous structure if used simultaneously with impermeable feature to incorporate dispersive effects



Peak Frequencies:
0.3172 Hz,
0.6344 Hz.

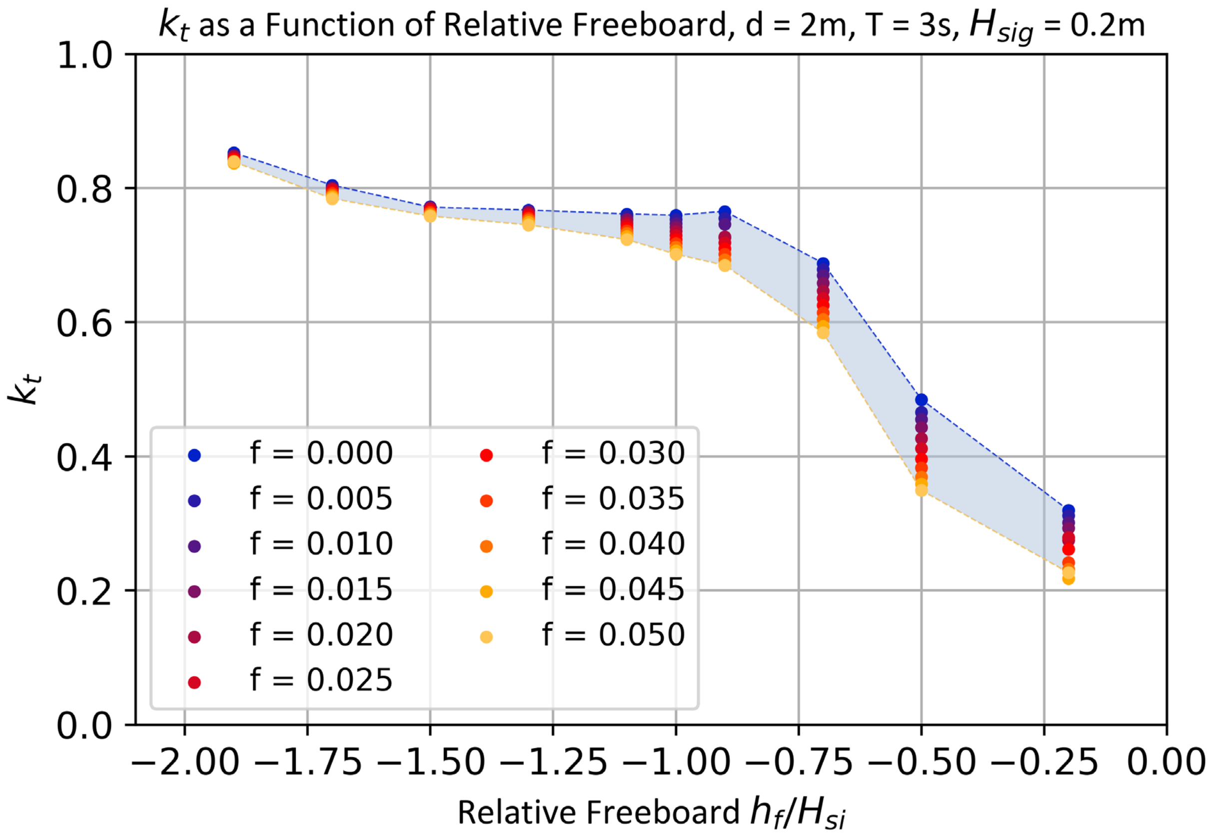


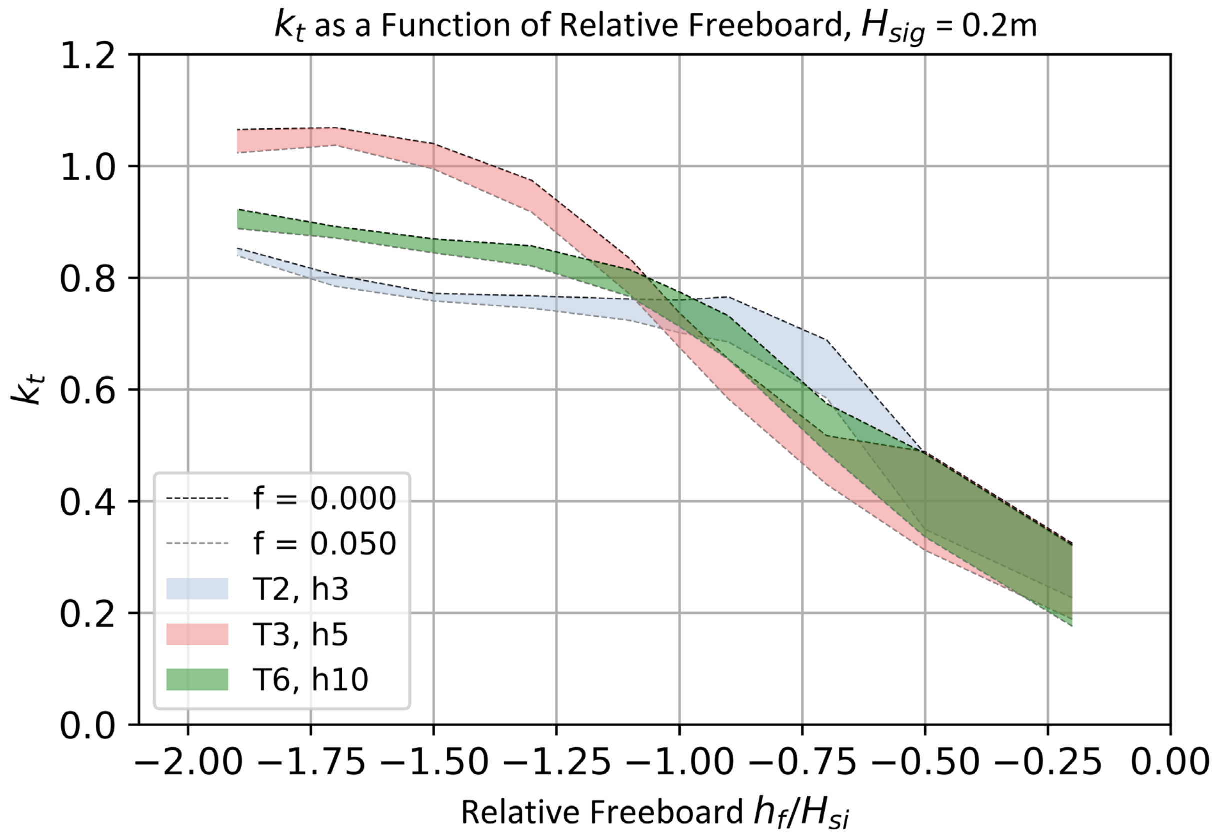
T = 3 s
h = 2 m
H = 0.2 m

Width = 0.2*L
Cdsponge = 10

Wave Transmission Coefficient, Kt

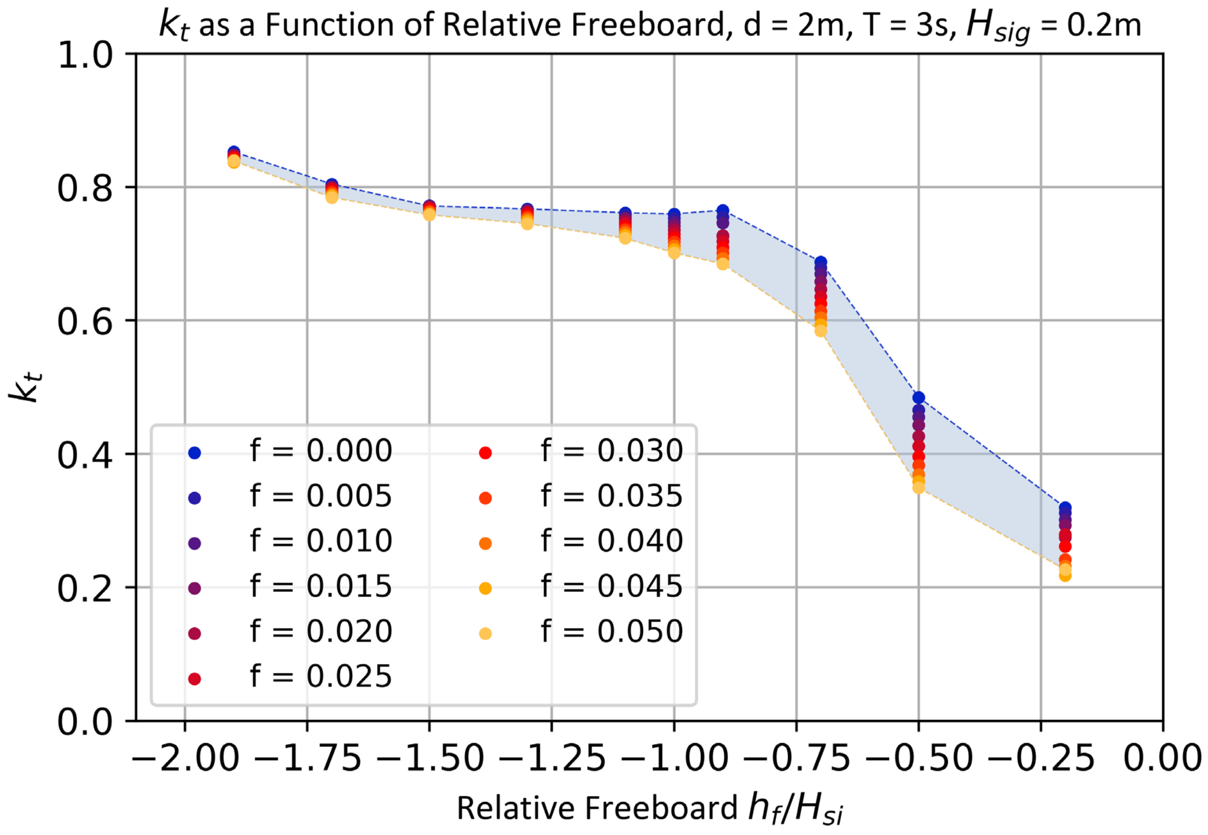
Hypothesis: *Bottom friction would have more of an effect on the energy transmission at shallower freeboards*

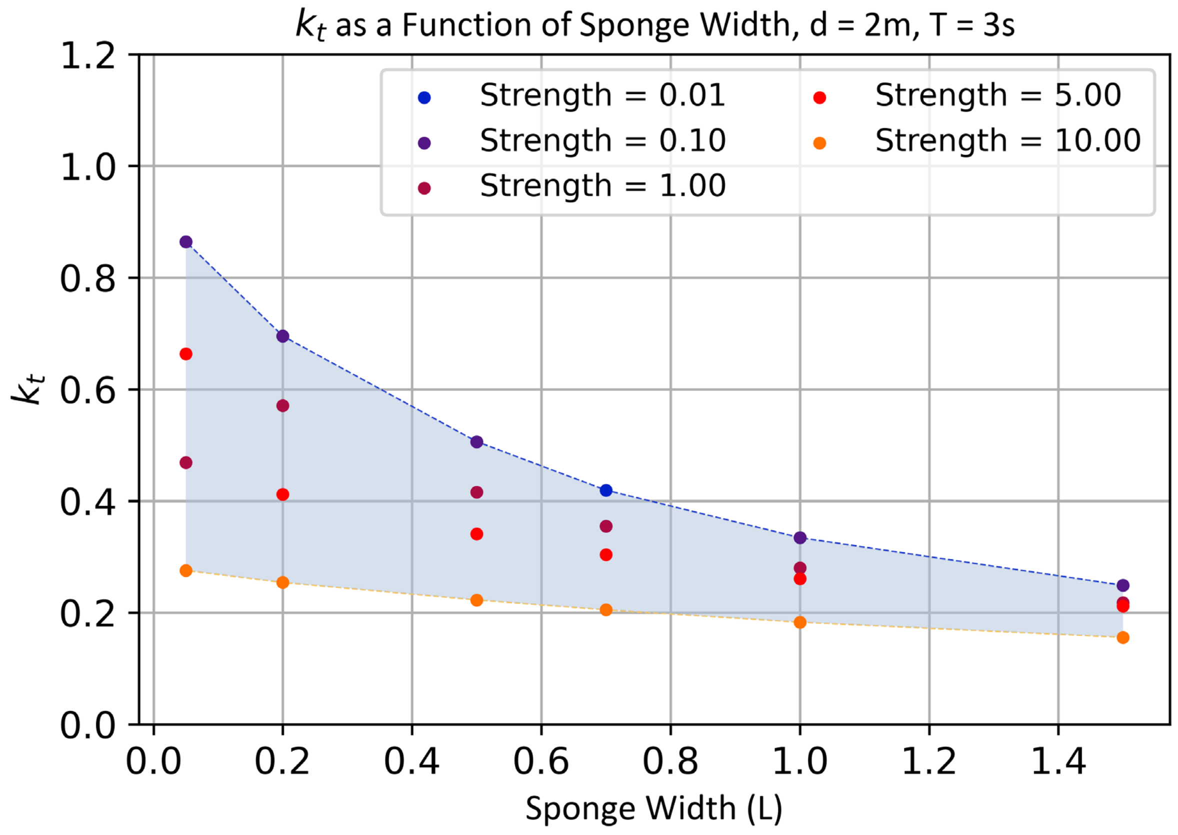




Wave Transmission Coefficient, Kt (cont.)

Hypothesis: *Breakwater absorption coefficient analogous with relative freeboard and sponge width analogous with crest width*

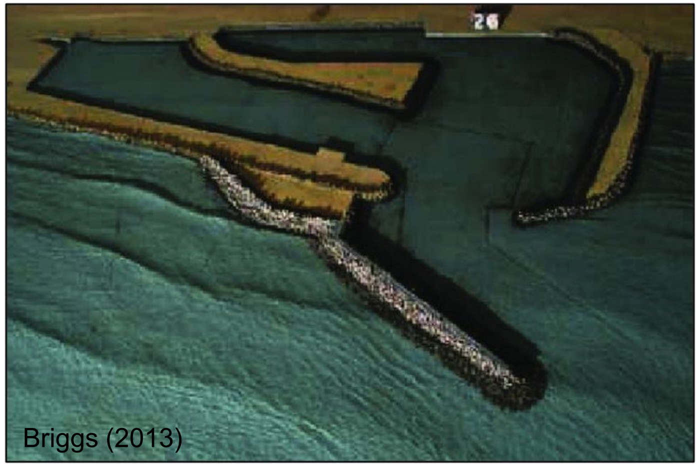




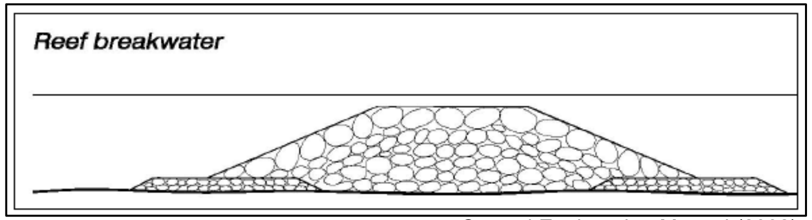
Conclusions

- Internal sponge layer is, in fact, dissipative
    - Sponge layers are not representative of the physical structure shape
    - May be able to combined with bathymetric changes to model dissipative and dispersive effects of porous structures
    - Comparison data with porous structures is needed to verify

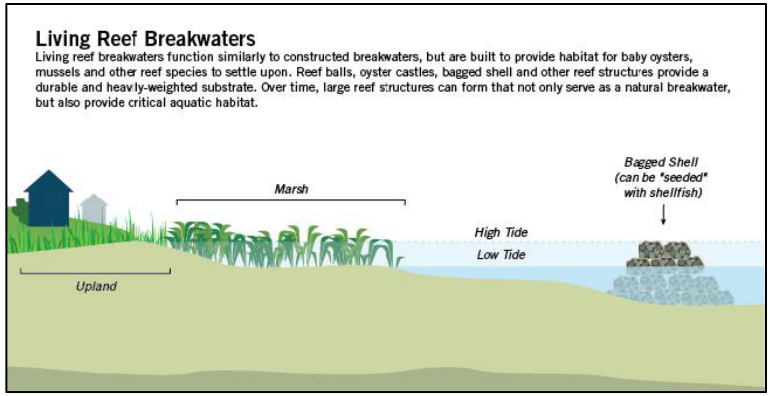
- Bathymetric methods are more dispersive
    - Physical structure shape can be replicated directly
    - Bottom friction can increase dissipative effect of structure, though less so when more submerged
    - Amplification of wave energy possible at larger freeboards (F/H < -1.25) under certain wave conditions



Briggs (2013)



Coastal Engineering Manual (2002)



Preliminary guidance

- Sponge layers are best used to simulate known wave height changes from an obstacle with no dispersive effects (maintaining incident wave spectrum).
  - If the incident wave climate and resultant wave spectrum from the obstacle are known, a sponge layer can be used to modify the wave heights in a simplified way for hindcasting and forecasting.
  - The sponge layer should be kept at a smaller width and the breakwater strength coefficient varied to create more precise transmitted wave conditions.

- Bathymetric methods are best used to understand how an impermeable structure design will impact transmitted waves in real-world applications (at this time).

Looking ahead

Next Steps (FY24)

- Combine bathymetry with sponge layer to test porous structure modeling
- Complete test suite with monochromatic and irregular waves for a wider variety of wave climates (414,720+ simulations)
- Develop guidance on how sponge layer values translate to transmitted wave conditions

Future Work (FY25+)

- Review of existing literature and laboratory data (where possible / available) for friction values, porous structures, etc.
- Consider completing physical modeling study in-house if existing datasets are insufficient
- Determine if incorporation of porous media into FUNWAVE code is better solution (e.g, CMS-Wave) (potential SoN?)

THANK YOU

Tech Transfer

- ERDC TR: FUNWAVE-TVD Testbed (*in editing, exp. Oct 2023*)
- ERDC TN: Troubleshooting guidance and recommendations when getting started with FUNWAVE-TVD (*in prep, exp. Dec 2023*)
- ERDC TR: Wave response guidance for emergent and submerged coastal structures using FUNWAVE-TVD (*in prep, exp. Dec 2024*)

- Wiki updates quarterly → new Simulation Checklist (https://fengyanshi.github.io/build/html/definition.html#simulation-checklist)
- ASBPA Presentation October 11-13

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ORISE, MAY – AUG 2023

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SSEP, JUN 2023 – MAY 2025

Table of Contents

Simulation Checklist

After the FUNWAVE-TVD model has been downloaded and compiled on either your local machine or remote computing environment (e.g., HPC or AWS Cloud), and you've familiarized yourself with the simple cases in the model repository, you're ready to begin running numerical wave simulations for your application. If you haven't yet downloaded and compiled the model, follow the instructions on the Model Download and Setup page.

Below is a simple checklist to review before hitting "go" on a simulation. This checklist was designed to reduce the probability of experiencing an error when initiating a new simulation; however, it is not comprehensive of all possible input parameters and input file conditions for all applications.

1. Input wave conditions are within the valid range of the model.
2. For stability, the ratio of DX and water depth is greater than 1/15, DX/h > 1/15.
3. The number of processors to request on the HPC or local machine matches the product of PX and PY from "input.txt". This number should be a divisor of the number of available processors or cores per compute node (e.g., if 1 node supports 44 processors, -np must be 1, 2, 4, 11, 22, or 44).
4. Cross-reference the name and path of the FUNWAVE executable file to be used for the simulation in the run command or PBS script (if submitting a job on an HPC environment).
5. Cross-reference input file names (input.txt, depth.txt, gauges.txt or stations.txt, friction.txt, etc.) across the working directory, "input.txt", and the PBS script (if submitting a job on an HPC environment).
6. Global input filetypes (e.g., depth.txt and friction.txt) are the same size as the domain (Mglob x Nglob) starting from the south-west corner. If generating files in Python, the bathy array will have Nglob rows and Mglob columns.
7. If using a depth type of FLAT or SLOPE, the DEPTH_FLAT = DEP_WK at the wavemaker. If using a depth type of DATA, ensure that the DEP_WK at XC_WK matches the depth at that location in the "bathy.txt". For stability, it is best to artificially smooth the bathymetry to a constant depth at and around the wavemaker.
8. If transferring files from a Windows to a Linux machine (in an HPC environment, for example), run `dos2unix [filename]` on input files to eliminate any possible Windows return characters (^M) at the end of a line.

FUNWAVE

CIRP Research & Development