



U.S. ARMY

RAPID SCREENING OF PARTIALLY SUBMERGED COASTAL STRUCTURE DESIGNS USING BOUSSINESQ NUMERICAL WAVE MODELING INLET ENGINEERING TOOLS

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COASTAL INLETS RESEARCH PROGRAM

FY21 IN PROGRESS REVIEW

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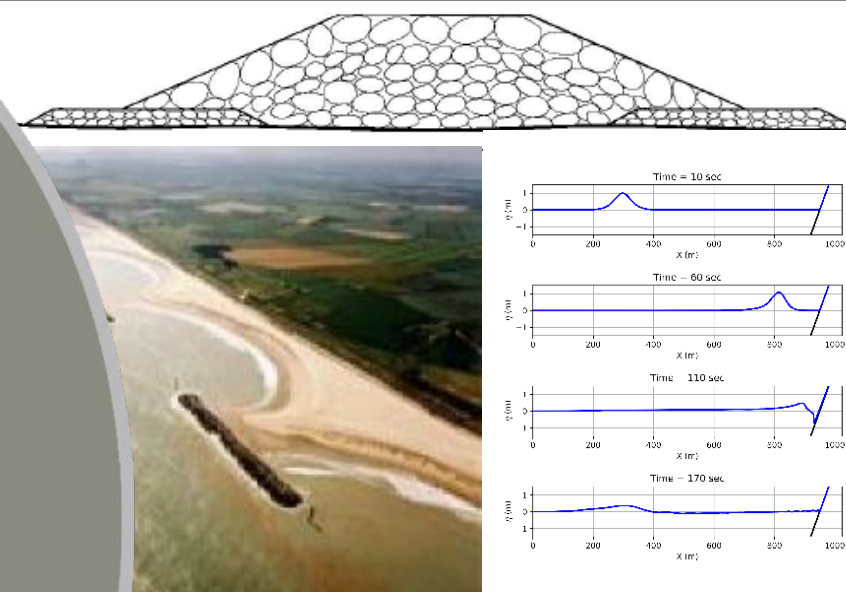
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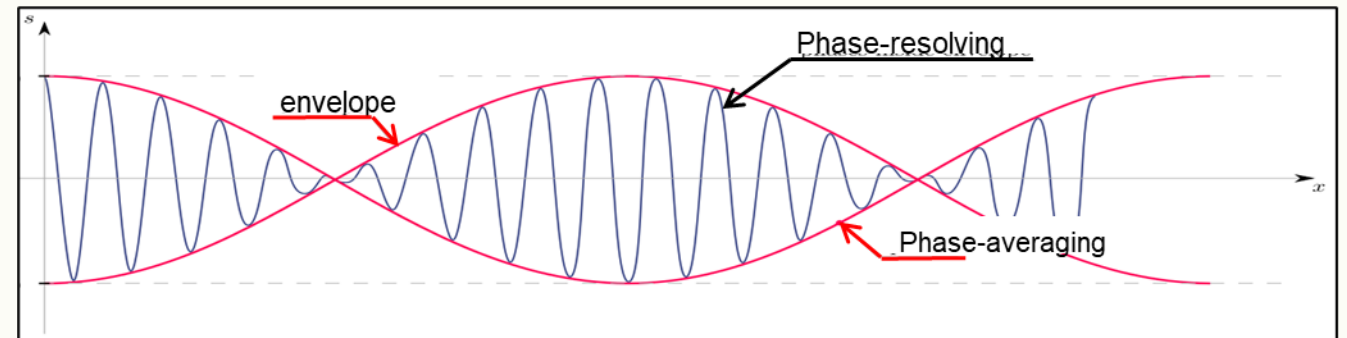
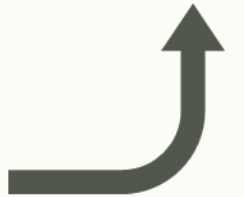
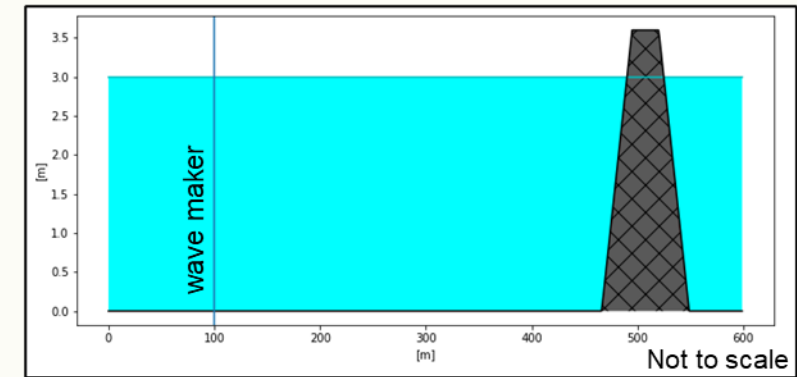
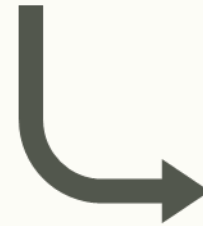
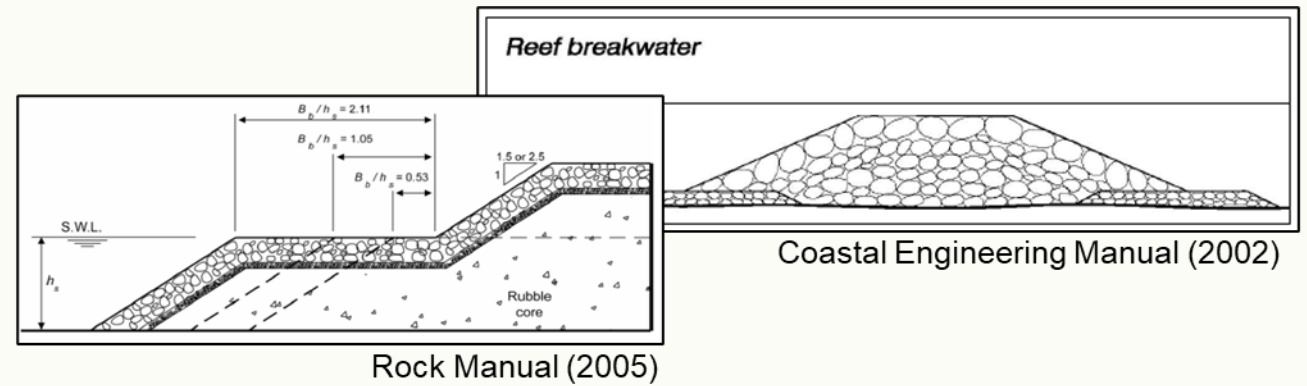
US Army Corps of Engineers



ERDC
ENGINEER RESEARCH & DEVELOPMENT CENTER

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 & make numerical wave modeling more accessible to practitioners**



Capability and Strategic Impact Statement

- **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**

FUNWAVE-TVD

What is FUNWAVE-TVD?

FUNWAVE-TVD is the Total Variation Diminishing (TVD) version of the fully nonlinear Boussinesq wave model (FUNWAVE) developed by Shi et al. (2012). The FUNWAVE model was initially developed by Kirby et al. (1998) based on Wei et al. (1995). The development of the present version was motivated by recent needs for modeling of surf-zone-scale optical properties in a Boussinesq model framework, and modeling of Tsunami waves in both a global/coastal scale for prediction of coastal inundation and a basin scale for wave propagation.

This version features several theoretical and numerical improvements, including:

1. A more complete set of fully nonlinear Boussinesq equations;
2. Monotonic Upwind Scheme for Conservation Laws (MUSCL)-TVD solver with adaptive Runge-Kutta time stepping;
3. Shock-capturing wave breaking scheme;
4. Wetting-drying moving boundary condition with incorporation of Harten-Lax-van Leer (HLL) construction method into the scheme;
5. Lagrangian tracking;
6. Option for parallel computation.

The most recent developments include ship-wake generation (Chi et al., 2018), meteo-tsunami generation (Tehrani et al., 2016, Malek et al., 2018), and sediment transport and morphological changes (Tehrani et al., 2016, Malek et al., 2018).

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 `inout.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 c_b 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.

of the breakwater or coastal feature relative to the total water depth is variable, and overall wave responses will differ greatly for a fully submerged breakwater to an emergent breakwater.

to breakwaters. Other structures of interest may include, but are not limited to, jetties, piers, and groins. These structure types and their configurations may be added to the numerical model as described above. For more information on wave-structure interactions, visit [http://www.funwave.org](#).

ERDC HYDRO MODEL TOOL KIT

The ERDC Hydro Model Kit is a collection of hydrodynamic and hydraulic models used throughout the U.S. Army Engineer Research and Development Center (ERDC) and available to the public. The kit includes the following models:

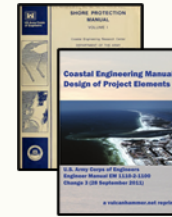
FUNWAVE	CFDROM Framework Coupler	ARI (Adaptive Hydraulic)	STWAVE
Prisms (Computational Physics Tools)	CRS (CRS)	CRS FLOW	ADRC (Adaptive Modeling)
WSP (WSP)	HydroWeb 2.0	HydroWeb 2.0 (Surface Water Model) (SWM)	

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The screenshot shows the FUNWAVE web interface. At the top, there is a search bar and a 'New Project' button. Below that, the 'Your Private Workspace' section is visible, featuring a 'Beach 2D' model with a description: 'Monochromatic waves with 32 incidence'. There is also a 'Video Tutorials' section with a '[3 members]' indicator and an 'Add Simulation' button.

Approach

Phase 1 – FY21
Phase 2 – FY22+



+



■ 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

■ Single impermeable trapezoidal breakwater

- Slope – $m = 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8$
- Crest width – $B = 3, 5, 10$ m
- Crest height – $h_s = (1.1, 1.2, 1.3, 1.4, 1.5) \cdot h$

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

Ensemble Variables

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*

Summary

FY21 Major Advances in Capability

- Fundamental knowledge transfer of physical and numerical considerations when using FUNWAVE
- Development of simulation test bed and structure design ensemble
- Aggregation of tools and resources in open-source forum – comprehensive Wiki

FY21 Major Products & Collaborations

- 1 ERDC TN & 1 ERDC TR
- 1 CIRP TD
- 1 CWG Presentation (date: TBD)
- 10 video tutorials on FUNWAVE HPC Portal
- 6 SoNs related to FUNWAVE in the Super RARG
- Connection to the practitioner

Planned Outyear Products/Advances

- Evaluation of wave-structure response in 1D & 2D applications
- Additional project and/or application specific video tutorials
- Contributions to the functionality of the FUNWAVE HPC Portal App

