U.S.ARMY

PRACTICAL GUIDANCE FOR NUMERICAL MODELING OF COASTAL STRUCTURES IN FUNWAVE-TVD

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COASTAL INLETS RESEARCH PROGRAM

FY22 IN PROGRESS REVIEW

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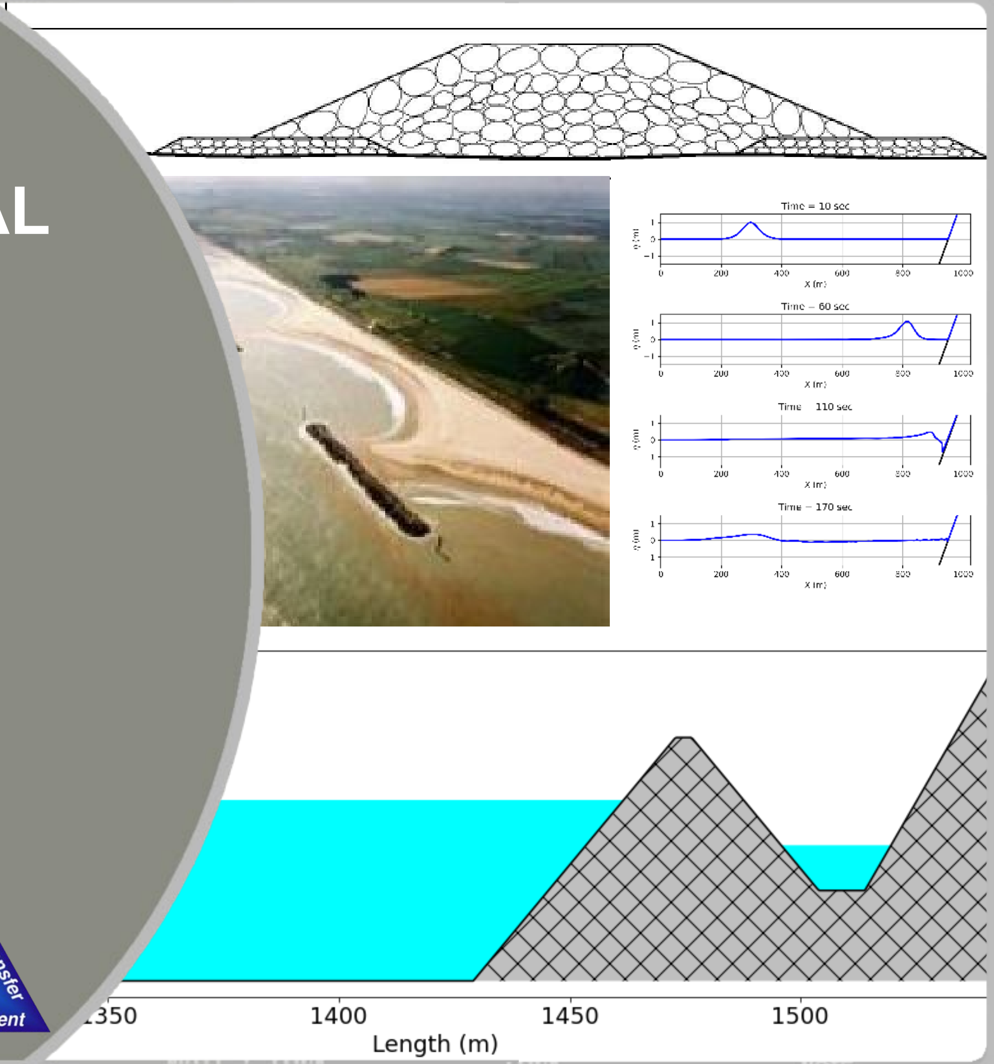
Mission Support
Technology Transfer
CIRP
Research & Development



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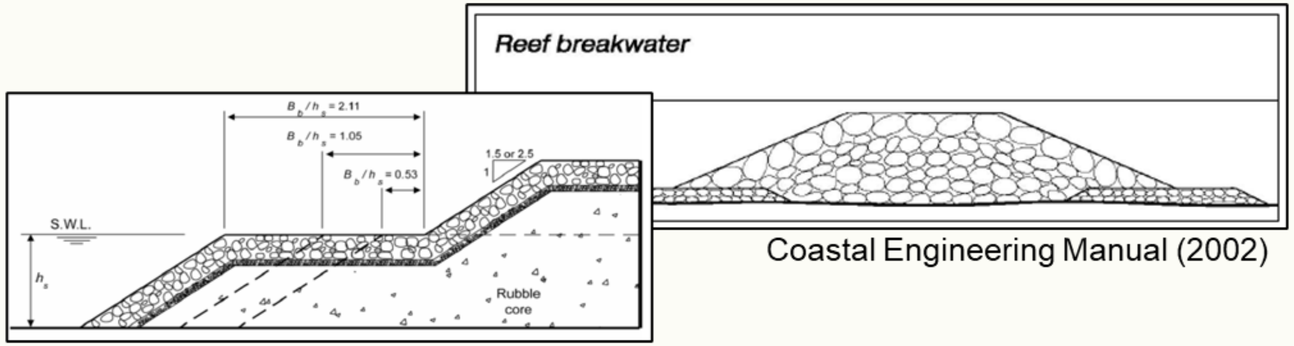
CHL COASTAL & HYDRAULICS LABORATORY

ERDC ENGINEER RESEARCH & DEVELOPMENT CENTER

DISCOVER | DEVELOP | DELIVER

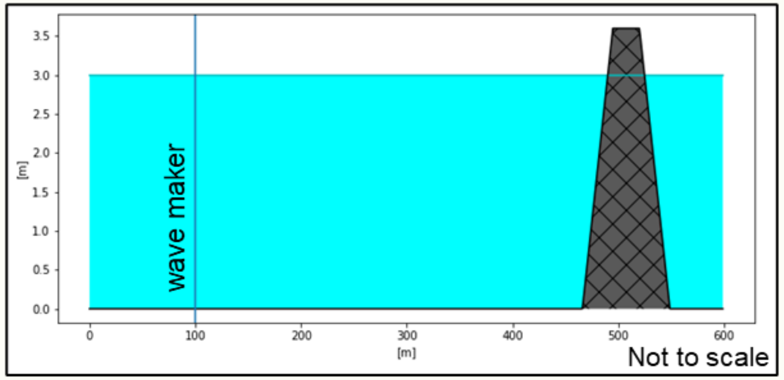
Problem Statement

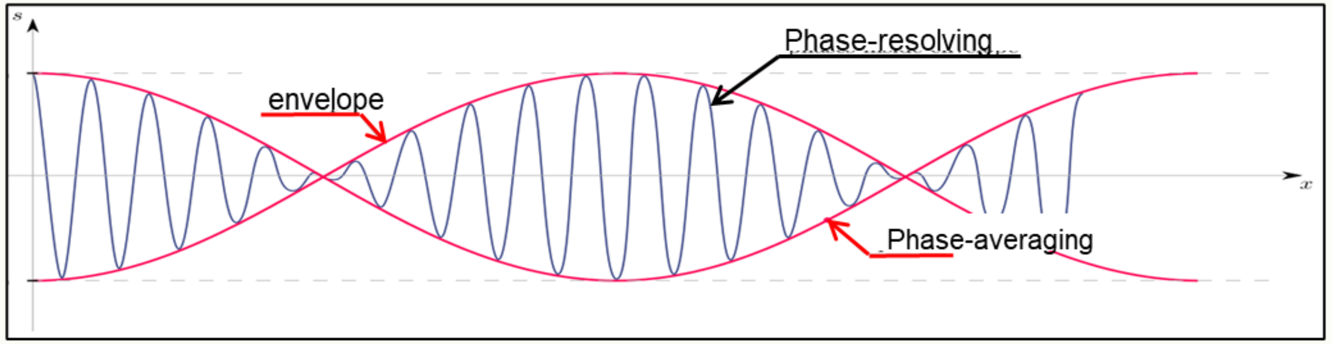
- Coastal structures (e.g., breakwaters and jetties) are vital for navigation, shore protection, and beach stabilization
- There is rarely enough time, money, and resources to execute screening of structure design alternatives or robust assessment of wave-structure interactions
- Connect coastal engineering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



Coastal Engineering Manual (2002)

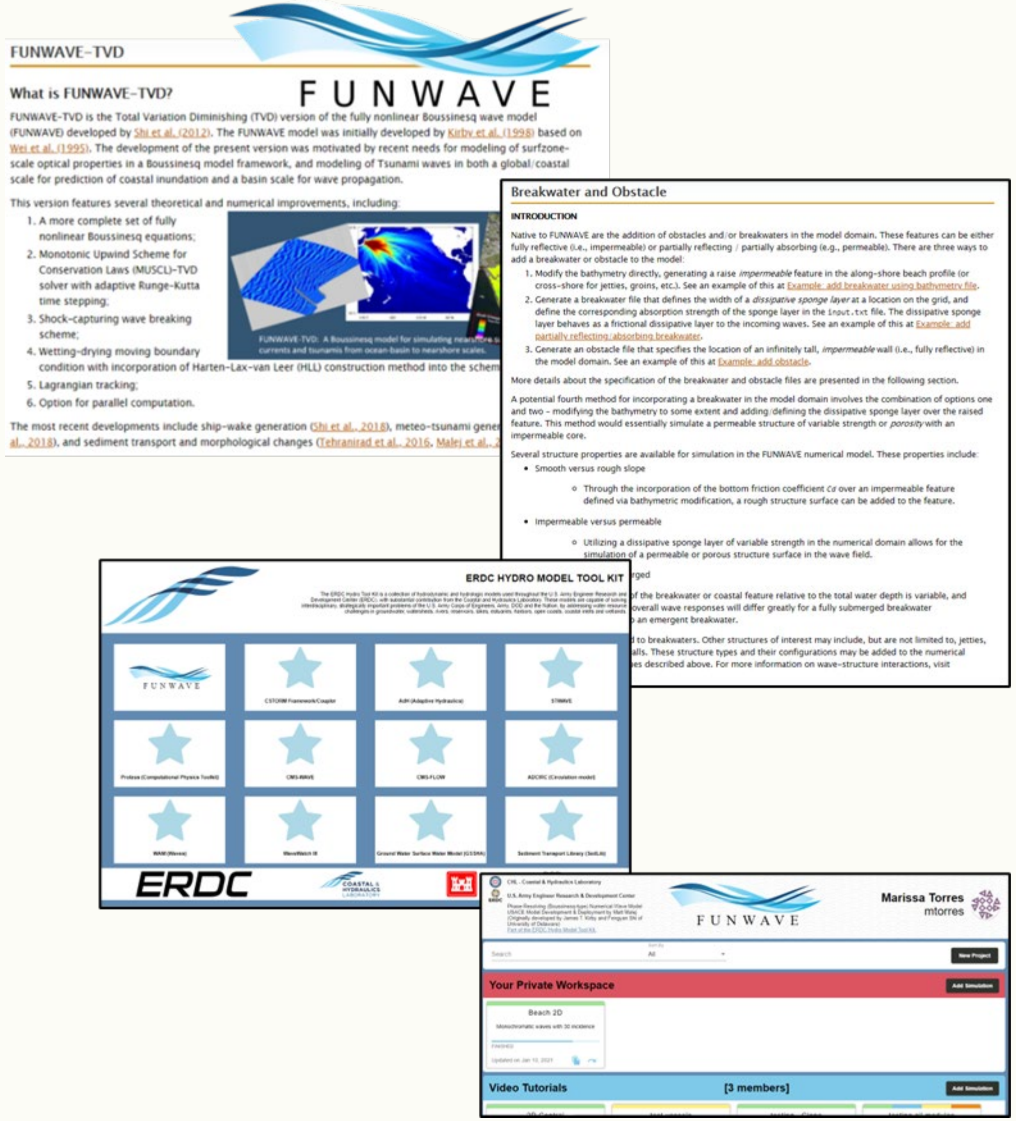
Rock Manual (2005)





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 surfzone-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 schem
5. Lagrangian tracking;
6. Option for parallel computation.

FUNWAVE-TVD: A Boussinesq model for simulating nearshore s currents and tsunamis from ocean-basin to nearshore scales.

The most recent developments include ship-wake generation (Shi et al., 2018), meteo-tsunami gener al., 2018), and sediment transport and morphological changes (Tehranirad et al., 2016, Malej et al., 2

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.

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f 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 an emergent breakwater.

d to breakwaters. Other structures of interest may include, but are not limited to, jetties, alls. These structure types and their configurations may be added to the numerical es described above. For more information on wave-structure interactions, visit

ERDC HYDRO MODEL TOOL KIT

CHL - Coastal & Hydraulics Laboratory
U.S. Army Engineer Research & Development Center
Phase Resolving (Boussinesq-type) Numerical Wave Model
USACE Model Development & Deployment by Matt Malej
(Originally developed by James T. Kirby and Fengyan Shi of University of Delaware)
Part of the ERDC Hydro Model Tool Kit.

Marissa Torres
mtorres

Your Private Workspace

Beach 2D
Monochromatic waves with 30 incidence
FINISHED
Updated on Jan 10, 2021

Video Tutorials [3 members]

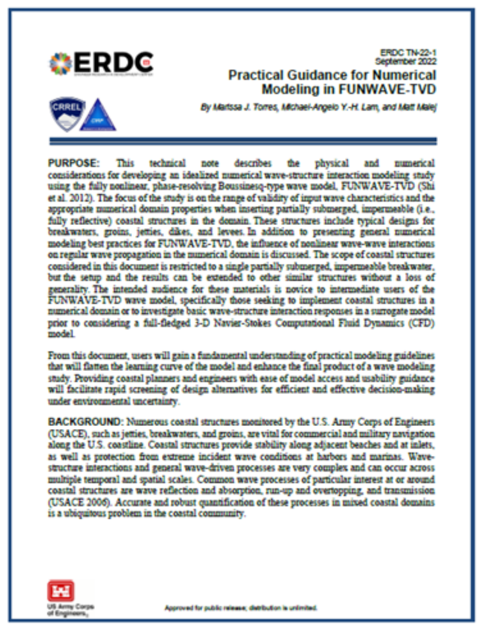
District PDT Members

Mr. Gabe Todaro, SAJ	Ms. Jessica Podoski, POH
Dr. Patrick Kerr, SWG	Ms. Catie Dillon, POH
Ms. Rachel Malburg, LRE	Mr. Matthew Wesley, SPL
Mr. Hans Moritz, NWP	(Dr. Andrew Condon, CHL)

Technical Advancements

- Script development:
  - Coastal Engineering toolbox (Python)
  - Pre-processing:
    - Validity check ($\lambda > 2h$)[1]
    - Stability check (${}^{dx}/_{h} > {}^{1}/_{15}$)[1]
    - Bathy, Eta, Friction file generator (1D)
  - Post-processing:
    - Eta movie generator (Shi, ORISE)
    - Wave reflection in 1D (Shi, ORISE)
    - Integrated wave runup & overtopping in 1D/2D – FUNWAVE outputs and EurOtop (2018) equations

- HPC Portal updates:
  - Error handling & bug fixes
  - Improved flow/aesthetic of input fields
  - Added links to corresponding YouTube tutorials



ERDC TN-22-1
September 2022

Practical Guidance for Numerical Modeling in FUNWAVE-TVD

By Marissa J. Torres, Michael-Angelo Y.-H. Lam, and Matt Malej

PURPOSE: This technical note describes the physical and numerical considerations for developing an idealized numerical wave-structure interaction modeling study using the fully nonlinear, phase-resolving Boussinesq-type wave model, FUNWAVE-TVD (Shi et al. 2012). The focus of the study is on the range of validity of input wave characteristics and the appropriate numerical domain properties when inserting partially submerged, impermeable (i.e., fully reflective) coastal structures in the domain. These structures include typical designs for breakwaters, groins, jetties, dikes, and levees. In addition to presenting general numerical modeling best practices for FUNWAVE-TVD, the influence of nonlinear wave-wave interactions on regular wave propagation in the numerical domain is discussed. The scope of coastal structures considered in this document is restricted to a single partially submerged, impermeable breakwater, but the setup and the results can be extended to other similar structures without a loss of generality. The intended audience for these materials is novice to intermediate users of the FUNWAVE-TVD wave model, specifically those seeking to implement coastal structures in a numerical domain or to investigate basic wave-structure interaction responses in a surrogate model prior to considering a full-fledged 3-D Navier-Stokes Computational Fluid Dynamics (CFD) model.

From this document, users will gain a fundamental understanding of practical modeling guidelines that will flatten the learning curve of the model and enhance the final product of a wave modeling study. Providing coastal planners and engineers with ease of model access and usability guidance will facilitate rapid screening of design alternatives for efficient and effective decision-making under environmental uncertainty.

BACKGROUND: Numerous coastal structures monitored by the U.S. Army Corps of Engineers (USACE), such as jetties, breakwaters, and groins, are vital for commercial and military navigation along the U.S. coastline. Coastal structures provide stability along adjacent beaches and at inlets, as well as protection from extreme incident wave conditions at harbors and marinas. Wave-structure interactions and general wave-driven processes are very complex and can occur across multiple temporal and spatial scales. Common wave processes of particular interest at or around coastal structures are wave reflection and absorption, run-up and overtopping, and transmission (USACE 2006). Accurate and robust quantification of these processes in mixed coastal domains is a ubiquitous problem in the coastal community.

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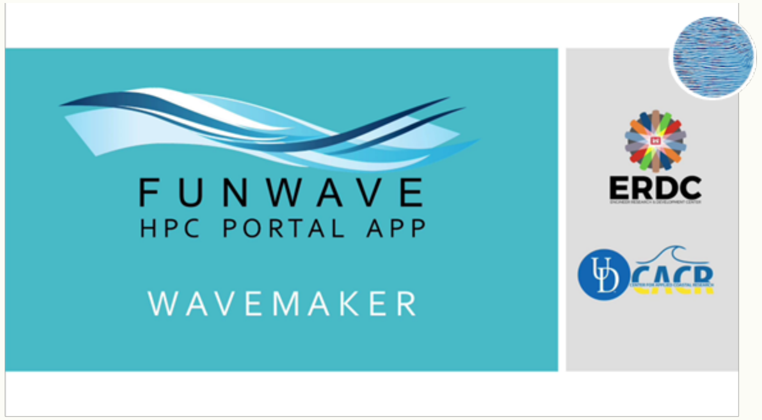

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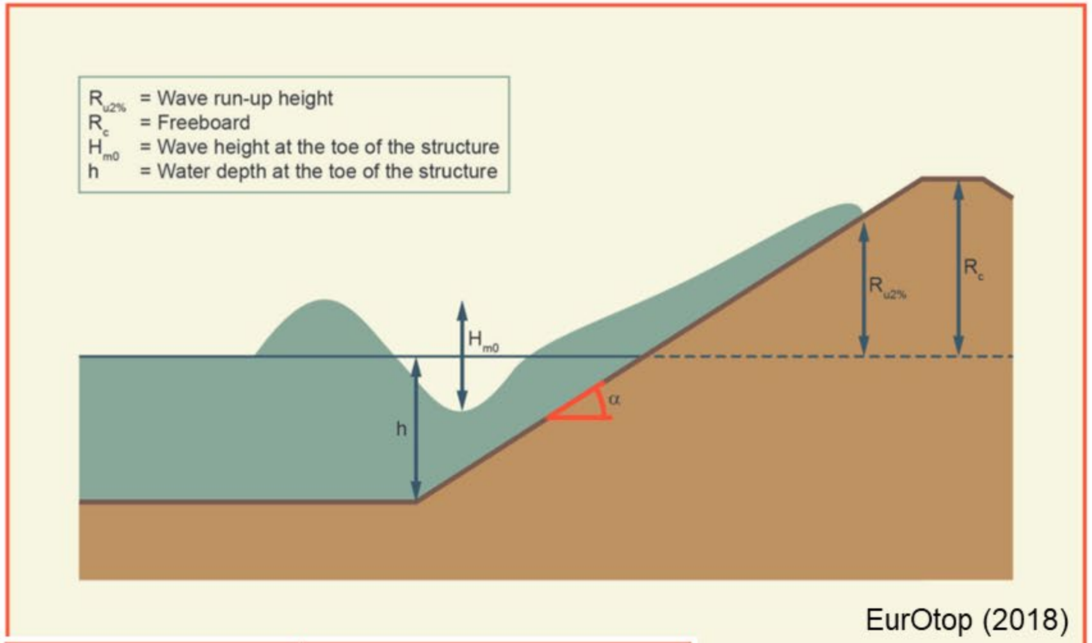
[1] Torres, M.J., M.Y. Lam, M. Malej (2022). Practical Guidance for Numerical Modeling in FUNWAVE-TVD. ERDC TN-22-1. Hanover, NH: U.S. Army Engineer Research and Development Center.

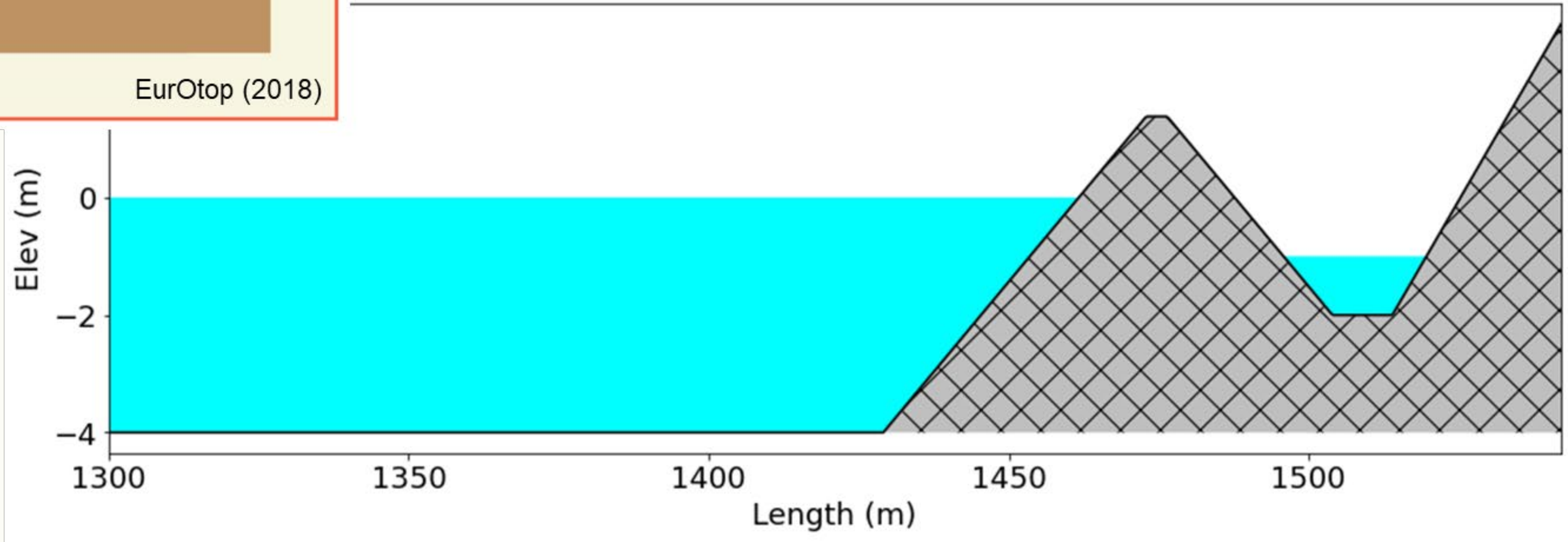
Case Studies – EurOtop #1



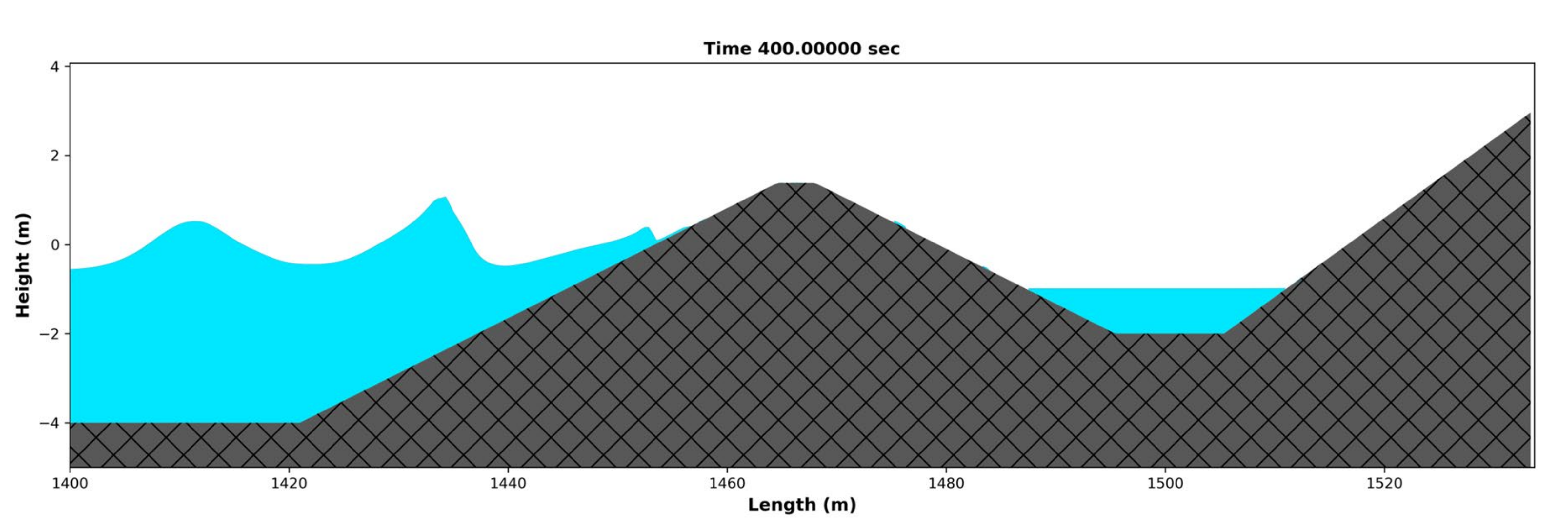
EurOtop (2018)

Wave and water level conditions		Return period			
		10	20	100	1000
H_{m0}	m	1.21	1.38	1.65	1.93
$T_{m-1,0}$	s	4.5	4.5	4.5	4.5
SWL	m NN	4.7	5.0	5.5	6.0
Storm duration	s	3600			

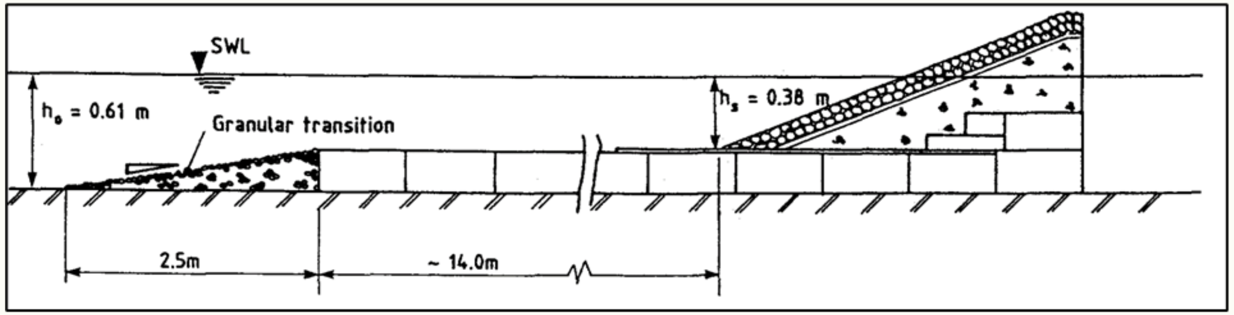
- Self-validating test case for wave overtopping
- Careful consideration required when comparing numerical results to empirical equations
- Stabilization challenges → document in ERDC Tech Note

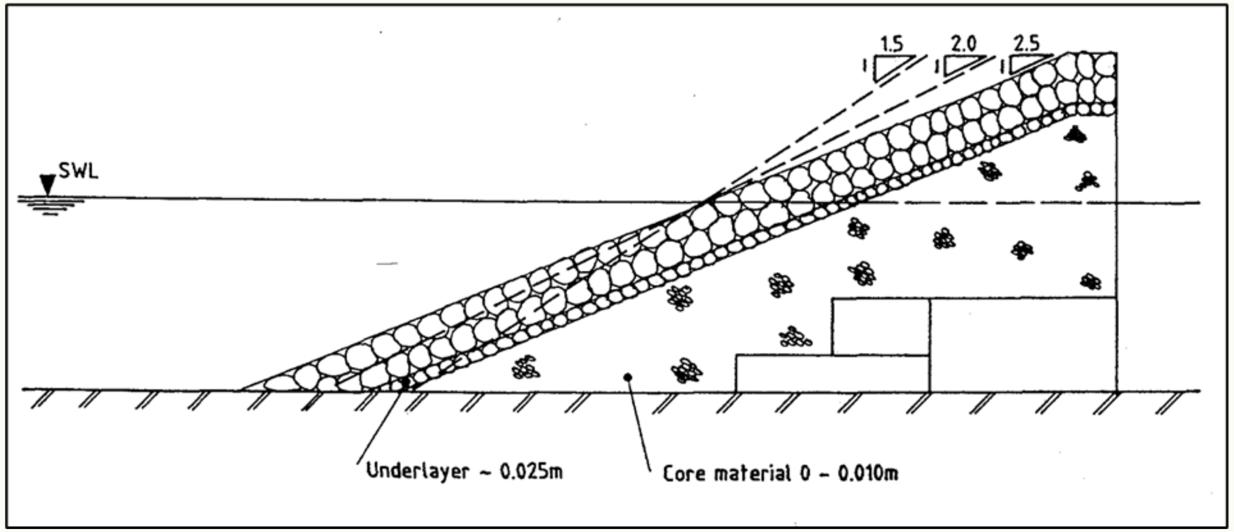


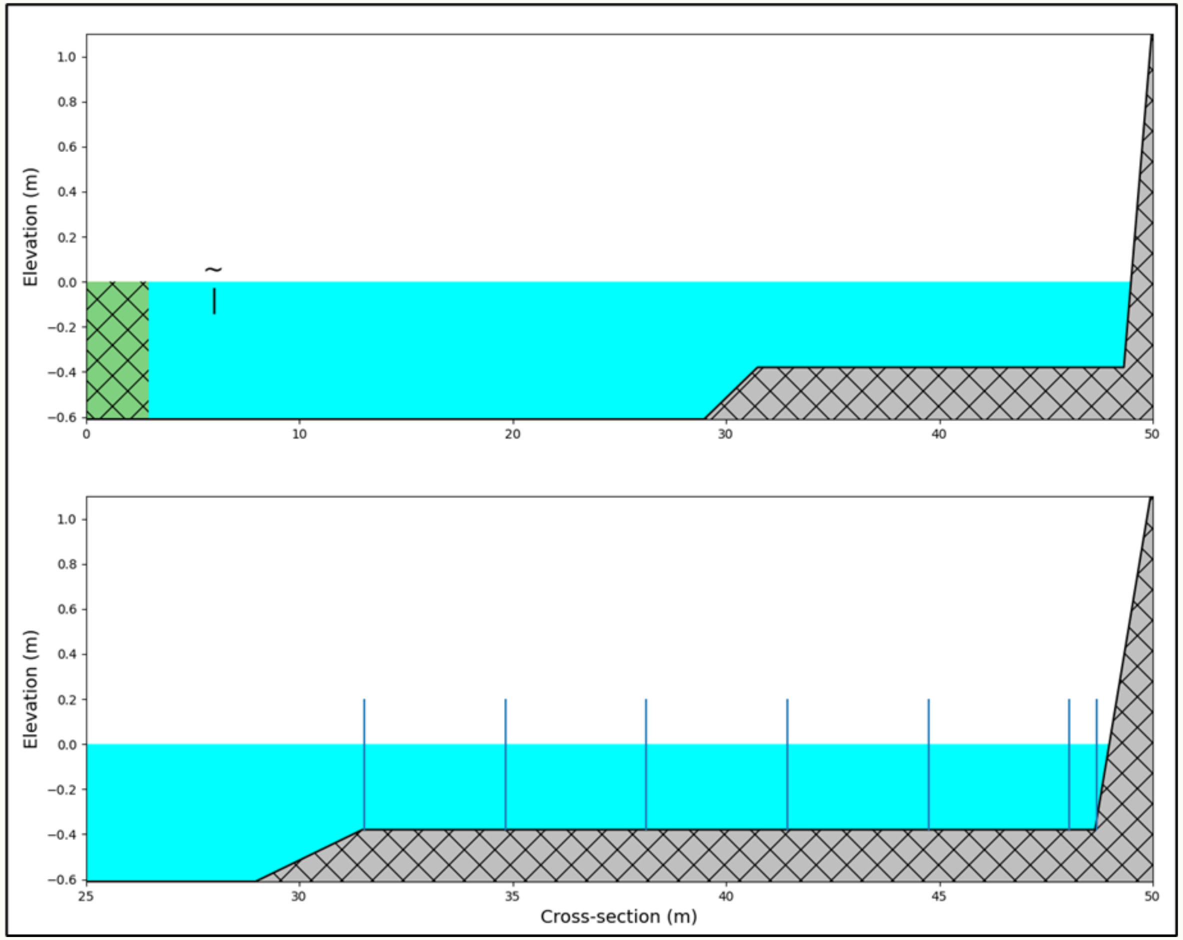
Case Studies – EurOtop #1



Case Studies – Allsop & Channell (1989)







- Goal: Test Shi (ORISE) implementation of Goda & Suzuki (1976) against wave reflection study in literature

Summary

FY22 Major Advances in Capability

- Stabilized test cases specific to coastal structures (EurOtop, Allsop & Channell)
- Pre- and post-processing script development and testing for 1D and 2D applications
- Improved HPC Portal functionality and usability

FY22 Major Products & Collaborations

- 1 ERDC TR (in review)
- 1 CIRP TD (date TBD)
- 2 Conference Presentations (RD22, ASBPA 2022)
- Quarterly Wiki Updates
- 9 video tutorials on FUNWAVE HPC Portal

Planned Outyear Products/Advances

- Evaluation & verification of wave-structure response in 1D & 2D applications with literature
  - FY23 ORISE summer students
- Describe troubleshooting recommendations
- Contributions to the functionality of the FUNWAVE HPC Portal App