RAPID SCREENING OF PARTIALLY SUBMERGED COASTAL STRUCTURE DESIGNS USING FUNWAVE

COASTAL INLETS RESEARCH PROGRAM
TECHNICAL DISCUSSION
22 JUNE 2021

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Outline

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

PDT Members:

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

**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.

**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

<table>
<thead>
<tr>
<th>Structure Design Properties</th>
<th>Wave Climate Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Height (freeboard)</strong></td>
<td>Wave Type</td>
</tr>
<tr>
<td>Emergent</td>
<td>Regular (Monochromatic)</td>
</tr>
<tr>
<td>Submerged</td>
<td>Irregular (TMA)</td>
</tr>
<tr>
<td><strong>Surface</strong></td>
<td>Dimension</td>
</tr>
<tr>
<td>Emergent</td>
<td>1D</td>
</tr>
<tr>
<td>Submerged</td>
<td>2D normal</td>
</tr>
<tr>
<td><strong>Porosity</strong></td>
<td>2D oblique</td>
</tr>
<tr>
<td>Emergent</td>
<td>Smooth</td>
</tr>
<tr>
<td>Submerged</td>
<td>Rough</td>
</tr>
<tr>
<td>Emergent</td>
<td>Impermeable</td>
</tr>
<tr>
<td>Submerged</td>
<td>Permeable</td>
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</tbody>
</table>

Phase 1 – FY21
Phase 2 – FY22+
Accomplishments & Results

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

- **Accomplishments:**
  - Development of simulation test bed
    - Meets numerical and physical limitations for modeling in FUNWAVE
    - Presented best practices guidance to PDT
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- **Simulation matrix:**
  - Range of wave periods – $T = 2 - 16 \text{ s}$
  - Range of water depths – $h = 1 - 20 \text{ m}$
  - Range of wave heights – $H = 0.2 - (H/h < 0.8) \text{ m}$
  - Internal wavemaker located at 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
    - $DX / h > 1 / 15$
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Wavelength $\lambda$

Regular wave conditions (monochromatic)

$$\omega = \sqrt{gk \cdot \tan h(\frac{kh}{2\pi})}$$

$$\omega = \frac{2\pi}{T}, \quad k = \frac{2\pi}{\lambda}$$

$g = 9.81 \text{ m/s}^2$
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Spatial resolution $DX$

<table>
<thead>
<tr>
<th>DX = $\lambda / 70$</th>
<th>DX / h &gt; $1 / 15$</th>
<th>Regular wave conditions (monochromatic)</th>
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- 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
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Spatial resolution effects on wave energy
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Spatial resolution effects on wave energy

\[ T = 11 \text{ s} \]
\[ h = 6 \text{ m} \]
\[ H = 0.4 \text{ m} \]
\[ DX = \lambda / 70 \]

Regular wave conditions (monochromatic)

- \[ T = 11 \text{ s} \]
- \[ h = 6 \text{ m} \]
- \[ H = 0.4 \text{ m} \]
- \[ DX = \lambda / 70 \]
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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

Irregular wave conditions (TMA)
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    - 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
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Visibility in the 2021 RARG

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

- “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
Tech Transfer Initiative

- 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

Phase 1 – FY21
Phase 2 – FY22+

Tech Transfer Initiative

- **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

Phase 1 – FY21
Phase 2 – FY22+
FY21 Outlook & Beyond

- Wave responses with impermeable trapezoidal breakwater structure

<table>
<thead>
<tr>
<th>Structure variables</th>
<th>Wave variables</th>
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<tbody>
<tr>
<td>Crest height</td>
<td>Wave period</td>
</tr>
<tr>
<td>Crest width</td>
<td>Wave height</td>
</tr>
<tr>
<td>Slope</td>
<td>Wave direction</td>
</tr>
<tr>
<td>Roughness</td>
<td>Peak frequency</td>
</tr>
<tr>
<td>“Sponge” layer width</td>
<td>First moment wave height</td>
</tr>
<tr>
<td>“Sponge” layer strength</td>
<td>Water depth*</td>
</tr>
</tbody>
</table>

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

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

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

Phase 1 – FY21  
Phase 2 – FY22+

- 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)
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

Source: Briggs (2013)
Thank you!

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