Application of a Multidirectional Circular Wave Basin Using DualSPHysics

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Contents

1. Background and Objectives
2. Overviews of the FloWave
3. Application to the FloWave
4. Long/Short-Crested wave
5. Further applications
6. Conclusions
## Background

### Multi-directional wave basins

<table>
<thead>
<tr>
<th>Deep-sea basin of NMRI in Tokyo</th>
<th>The FloWave in the University of Edinburgh</th>
</tr>
</thead>
<tbody>
<tr>
<td>The AMOeba tank in Osaka Univ.</td>
<td>The Maneuvering and Seakeeping Basin (MASK) in U.S. Navy</td>
</tr>
</tbody>
</table>
Objectives

➢ To develop a numerical water tank for multi-directional wave basin, the FloWave using DualSPHysics.

Large domain
25m diameter, 2m water depth

Large deformation
Breaking wave, Spike wave, etc.

Fluid structure interactions
Ocean wave energy converter, mooring, etc.


http://www.wetfeet.eu/wetfeet-tests-in-flowave-edinburgh/
## Research Flow

- To develop a numerical water tank for multi-directional wave basin, the FloWave using DualSPHysics.

### Wave Model
- **Done**
- **Future work**
  - Comparison to unidirectional long-crested regular/irregular wave trains
  - Multidirectional short-crested wave

### Current Model
- **Comparison to flow field captured by CAT or ADV measurements.**

### Wave-Current Model
- **Combined wave and current model**

### FSI Model
- **Fluid Structures Interactions solver to compute 6DoF motion of floating body**

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*4th DualSPHysics Users Workshop in Lisbon 22nd-24th/10/2018*
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Overviews of the FloWave

- Institute for Energy Systems at The University of Edinburgh in UK since Nov. 2013
- Unique test facility: Combining multidirectional waves and tidal currents.
- Designed specifically to support marine energy deployment.
- 25m Diameter, 2m depth
- 700mm Wave height, 3s Period
- 2.0m/s Max current speed.
- 168 Hinged-flap type wave makers
- 28 Impellers with 1.7m diameter
- Upper floor: Test section
- Lower floor: Current circulation

Exhibition video: Concentric wave singularity
https://www.flowavett.co.uk/home
## Demonstration in the FloWave

<table>
<thead>
<tr>
<th>Psudo-random waves</th>
<th>Spike wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psudo-random waves using a JONSWAP spectrum</td>
<td>Concentric wave</td>
</tr>
</tbody>
</table>

- **Sea Power Platform (WES)**
- **Floating OWC spar buoy (WETFEET)**
Contents

1. Background and Objectives
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3. Application to the FloWave
4. Long/Short-Crested wave
5. Further applications
6. Conclusions
# Application to the FloWave

## Numerical Setup for FloWave

<table>
<thead>
<tr>
<th>Configuration of FloWave</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter ($D$)</td>
<td>25 m</td>
</tr>
<tr>
<td>Water depth (h)</td>
<td>2 m</td>
</tr>
</tbody>
</table>

### Wave maker (WM)

<table>
<thead>
<tr>
<th>Type</th>
<th>Hinged-flap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hinge depth ($h_0$)</td>
<td>0.32 m</td>
</tr>
<tr>
<td>Number of WM</td>
<td>168</td>
</tr>
</tbody>
</table>

- **WM42**: Wave maker
- **WM84**: Wave maker
- **WM126**: Wave maker

## Layout of wave makers

![Wave direction diagram](image)

- Wave direction: $\theta$
- Diameter ($D$)
- Wave maker (WM)
- Hinged-flap type wave makers

## Graph

- Rotation angle ($\omega$) vs. Time (s)
- Water depth ($h$)
- Hinge depth ($h_0$)

### Legend:

- WM: Wave maker
- $D$: Diameter
- $h_0$: Hinge depth
- $h$: Water depth
- $\omega$: Rotation angle
- $\theta$: Wave direction
How to Generate Waves in the FloWave

**Biesel transfer functions**  
(Biesel and Suquet 1951)

Far field Biesel transfer function for elevated hinged-type wave-maker

\[
\frac{H}{S_0} = S_0 \cdot \frac{h + z - h_0}{h - h_0} \quad \text{at } (z + h) > h_0 \quad S(z) = 0 \quad \text{at } (z + h) < h_0
\]

\[
\frac{H}{S_0} = \frac{2}{k(h - h_0)} \left[ \sinh(kh)(h - h_0)k\sinh(kh) - \cosh(kh) + \cosh(kh_0) \right] \sinh(kh) \cosh(kh) + kh
\]

**Hinged-flap type wave maker**
How to Generate Waves in the FloWave

To generate irregular wave trains

1. Define the wave spectrum through its characteristic parameters (peak frequency, spectrum shape, etc.).

2. Divide the spectrum in $N$ parts ($N>50$) the irregular wave is so decomposed into $N$ regular waves.

3. Convert the time series of water elevation into the time series of wave-maker movement with the help of Biesel transfer function:

$$\frac{H_i}{S_{0,i}} = \frac{2}{k(h - h_0)} \quad a_i = \sqrt{2S_\eta(f_i)\Delta f} = H_i/2$$

$$\left[ \frac{\sinh(kh)((h-h_0)k\sinh(kh)-\cosh(kh)+\cosh(kh_0))}{\sinh(kh) \cosh(kh)+kh} \right]$$

4. Compose all the components derived from the previous equation into the time series of the piston displacement as:

$$S(z) = \sum_{i=1}^{N} S_{0,i} \cdot \frac{h + z - h_0}{h - h_0}$$
How to Generate Waves in the FloWave

Single summation method
(Miles and Funke, 1989)

\[ \eta_i = \sum_{i=1}^{M} A_i \cos[\omega t + k_i (x \cos \theta_i + y \sin \theta_i) + \epsilon_i] \]

\[ = \sum_{i=1}^{M} A_i \cos[\omega t + k_i x' + \epsilon_i] \]

Directional spectrum

Energh density
\[ m^2/s/\text{rad} \]

Frequency
\[ \text{Hz} \]

\[ \theta \text{[rad]} \]

Component amplitude [m]

Sub – frequency
\[ \text{Hz} \]

S. Draycott, Ocean Engineering, 2018
Contents

1. Background and Objectives
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4. Long/Short-Crested wave
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6. Conclusions
# Regular Wave

### Regular wave conditions

<table>
<thead>
<tr>
<th>Test case</th>
<th>Frequency (Hz)</th>
<th>Steepness (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>0.3</td>
<td>2</td>
</tr>
<tr>
<td>Case 2</td>
<td>0.4</td>
<td>1</td>
</tr>
<tr>
<td>Case 3</td>
<td>0.4</td>
<td>2</td>
</tr>
<tr>
<td>Case 4</td>
<td>0.4</td>
<td>4</td>
</tr>
<tr>
<td>Case 5</td>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td>Case 6</td>
<td>0.6</td>
<td>2</td>
</tr>
</tbody>
</table>

**Steepness**

\[
\text{Steepness} = \frac{\text{wave height (H)}}{\text{wave length (L)}}
\]

---

### Positions of wave gauges and coordinate system in the FloWave

- Wave Gauges
- Wave direction \((\theta = 0 \text{ deg.})\)
- Top view

Wave Makers (WM):
- WM 42
- WM 1
- WM 84
- WM 126

**Wave Makers (WM):**

0.4Hz_2% (frequency_steepness)
Irregular Wave

Irregular wave conditions

<table>
<thead>
<tr>
<th>Test case</th>
<th>$H_{m0}$ (m)</th>
<th>$T_p$ (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 7</td>
<td>0.15</td>
<td>1.5</td>
</tr>
<tr>
<td>Case 8</td>
<td>0.15</td>
<td>2.0</td>
</tr>
<tr>
<td>Case 9</td>
<td>0.075</td>
<td>1.5</td>
</tr>
<tr>
<td>Case 10</td>
<td>0.075</td>
<td>2.0</td>
</tr>
<tr>
<td>Case 11</td>
<td>0.075</td>
<td>2.5</td>
</tr>
<tr>
<td>Case 12</td>
<td>0.075</td>
<td>3.0</td>
</tr>
</tbody>
</table>

The PM spectra defined by the significant wave height ($H_{m0}$) and the peak wave period ($T_p$)

$$S_{PM}(\omega) = 5\pi^4 \frac{H_s^2}{T_p^4} \cdot \frac{1}{\omega^5} \exp \left[ -\frac{20\pi^4}{T_p^4} \cdot \frac{1}{\omega^4} \right]$$

Pierson Moskowitz $0.075m$ _3s $(H_{m0} \cdot T_p)$

Positions of wave gauges and coordinate system in the FloWave

Wave direction ($\theta = 90$ deg.)

WM : Wave Makers
Long-Crested Wave

0.4Hz_2% (frequency_steepness)

Regular Wave

GPU: GeForce GTX 1080 Ti
Particles: 52.4 Millions
Steps: 146,989
Computational time: 30s
Run time: 69.9hrs.

Wave generation
Wave absorption

Wave direction

Hinged-flap type
168 wave makers individually moving
Long-Crested Wave

Pierson Moskowitz 0.075m_3s ($H_{m0} T_p$)

Irregular Wave

- Wave absorption
- Wave direction
- Wave generation
- Hinged-flap type
- 168 wave makers individually moving

GPU: Quadro M4000
Particles: 8.6 Millions
Steps: 157,690
Computational time: 60s
Run time: 58.9hrs.
The numerical result in the wave amplitude and the phase (especially in the fine particle case \( d_p/D = 2.0 \times 10^{-3} \)) shows pretty good agreement with the experimental one in regular/irregular wave conditions.
**Short Crested Wave**

**Definition of short crested wave**

The PM spectra defined by the significant wave height $(H_s)$ and the peak wave period $(T_p)$

$$S_{PM}(\omega) = 5\pi^4 \frac{H_s^2}{T_p^4} \cdot \frac{1}{\omega^5} \exp \left[ -\frac{20\pi^4}{T_p^4} \cdot \frac{1}{\omega^4} \right]$$

where

$E(f, \theta) = \text{directional spectral density function}$

$E(f) = \text{one - directional energy spectral density function}$

$D(f, \theta) = \text{angular spreading function}$

$f = \text{frequency in hertz}$

$\theta = \text{direction in radians}$

Fig. PM spectra with the significant wave height $(H_s)$ and the peak wave period $(T_p)$
**Short Crested Wave**

### Short crested wave definition

\[ E(f, \theta) = E(f) \cdot D(f, \theta) \]

Cosine-2s directional spreading functions

\[ D(f, \theta) = \left( \frac{2^{2s-1}}{\pi} \right) \left( \frac{\gamma^2(s+1)}{\gamma(2s+1)} \right) \cos^{2s} \frac{\theta-\theta_0}{2} \]

where

- \( \gamma \) = the Gamma function
- \( \theta_0 \) = the mean wave direction
- \( s \) = the spreading parameter which is a function of frequency and wind speed

**Directional spectrum**

S. Draycott, Ocean Engineering, 2018
## Short Crested Wave

Short crested wave conditions

<table>
<thead>
<tr>
<th>Test case</th>
<th>$H_{m0}$ (m)</th>
<th>$T_p$ (s)</th>
<th>$s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>0.15</td>
<td>1.5</td>
<td>5</td>
</tr>
<tr>
<td>Case 2</td>
<td>0.15</td>
<td>1.5</td>
<td>10</td>
</tr>
<tr>
<td>Case 3</td>
<td>0.15</td>
<td>1.5</td>
<td>25</td>
</tr>
<tr>
<td>Case 4</td>
<td>0.15</td>
<td>1.5</td>
<td>Inf</td>
</tr>
<tr>
<td>Case 5</td>
<td>0.075</td>
<td>3.0</td>
<td>5</td>
</tr>
<tr>
<td>Case 6</td>
<td>0.075</td>
<td>3.0</td>
<td>10</td>
</tr>
<tr>
<td>Case 7</td>
<td>0.075</td>
<td>3.0</td>
<td>25</td>
</tr>
<tr>
<td>Case 8</td>
<td>0.075</td>
<td>3.0</td>
<td>Inf</td>
</tr>
</tbody>
</table>

where

$s=\text{Inf}$ denotes no spreading i.e. unidirectional, and $s=5$ is the largest directional spread.

- **S=25**
  - Image: Time: 29.9[sec]
  - Image: Large directional spread

- **S=Inf.**
  - Image: Time: 28.8[sec]
  - Image: unidirectional spread

- **S=5**
  - Image: Time: 31.7[sec]

- **S=10**
  - Image: Time: 31.1[sec]
**Short Crested wave**

### Positions of wave gauges

<table>
<thead>
<tr>
<th>Gauge</th>
<th>( x ) (m)</th>
<th>( y ) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauge 1</td>
<td>0</td>
<td>-0.915</td>
</tr>
<tr>
<td>Gauge 2</td>
<td>0</td>
<td>-0.81</td>
</tr>
<tr>
<td>Gauge 3</td>
<td>0</td>
<td>-0.255</td>
</tr>
<tr>
<td>Gauge 4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gauge 5</td>
<td>0</td>
<td>0.434</td>
</tr>
<tr>
<td>Gauge 6</td>
<td>0</td>
<td>0.711</td>
</tr>
<tr>
<td>Gauge 7</td>
<td>0</td>
<td>0.88</td>
</tr>
<tr>
<td>Gauge 8</td>
<td>0</td>
<td>0.93</td>
</tr>
<tr>
<td>Gauge 9</td>
<td>-1.32</td>
<td>-0.917</td>
</tr>
<tr>
<td>Gauge 10</td>
<td>-1.32</td>
<td>2.523</td>
</tr>
</tbody>
</table>

Positions of wave gauges and coordinate system of the FloWave
Short Crested Wave

$H_s=0.15m \; T_p=1.5s \; s=5$

GPU: GeForce GTX 1080 Ti
Particles: 38.6 Millions
Steps: 266,484
Computational time: 60s
Run time: 119.3hrs.
Short Crested Wave

Validation of water surface elevation

Hm0=0.15m_Tp=1.5s

Water Elevation [m]

Time [sec]

0 10 20 30 40 50 60

S=5

S=10

S=25

Hm0=0.15m_Tp=1.5s
Contents

1. Background and Objectives
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5. Further applications
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Further applications

Demonstration of fluid structure interaction

Offshore wind turbine with drift motion in long-crested regular/short crested wave conditions

Long-Crested

Short-Crested

Time series of surge, sway, heave motions

Displacement (m)

Surge (x-dir.)

Sway (y-dir.)

Heave (z-dir.)

Displacement (m)

Surge (x-dir.)

Sway (y-dir.)

Heave (z-dir.)

Time (s)

Time (sec)
Spike Wave

GPU: GeForce GTX 1080 Ti
Particles: 52.4 Millions
Steps: 202,928
Computational time: 40s
Run time: 98.3hrs.

Hinged-flap type
168 wave makers individually moving

Wave absorption & generation

Wave gauges positions

Wave direction
Spike Wave

Wave propagation snapshot (right) and its validation (left)

Concentric

Pressure and velocity field of spike wave, which show the rapidly down rushing column of water, shortly after impact.
Contents

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4. Further applications
5. Conclusions
Conclusions

- We developed the numerical wave tank for the multidirectional wave basins, the FloWave using DualSPHysics.

- The numerical tank with the 168 hinged-flap type wave makers can reproduce not only long-crested regular/irregular wave trains but also short-crested waves with multi-spectrum.

- It can also reproduce spike wave (focused breaking wave), the maximum wave height in centre of tank is about 3.8m in fine particle case. This model can obtain a lot of information regarding wave filed such as velocity, pressure, and wave height of FloWave.
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