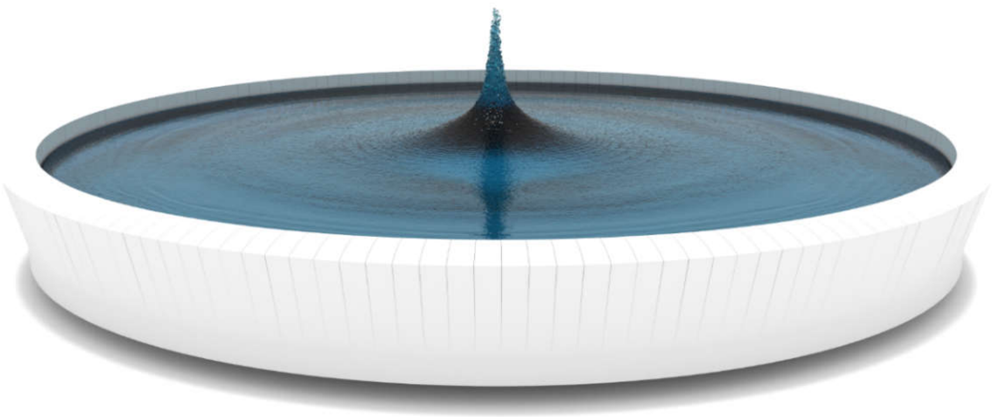
Application of a Multidirectional Circular Wave Basin Using DualSPHysics



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Background

Multi-directional wave basins

Deep-sea basin of NMRI in Tokyo

The FloWave in the University of Edinburgh

The AMOEBA tank in Osaka Univ.

The Maneuvering and Seakeeping Basin (MASK) in U.S. Navy

Objectives

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

https://www.eng.ed.ac.uk/sites/eng.ed.ac.uk/files/images/news/Flowave-aerial-view-credit-Callum-Bennetts.jpg

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

Large domain

25m diameter, 2m water depth

Large deformation

Breaking wave, Spike wave, etc.

Fluid structure interactions

Ocean wave energy converter, mooring, etc.

cpu gpu DualSPHysics

Research Flow

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

Wave Model (Done)	• Comparison to unidirectional long-crested regular/irregular wave trains • Multidirectional short-crested wave
Future work: Current Model	• Comparison to flow field captured by CAT or ADV measurements.
Future work: Wave-Current Model	• Combined wave and current model
Future work: FSI Model	• Fluid Structures Interactions solver to compute 6DoF motion of floating body

Contents

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

Psudo-random waves

D. Ingram , Proc. of Oceans, 2014

Psudo-random waves using a JONSWAP spectrum

Sea Power Platform (WES)

Spike wave

D. Ingram , Proc. of Oceans, 2014

Concentric wave

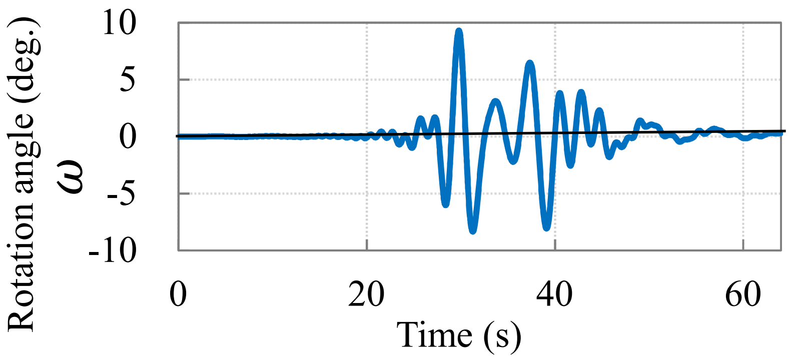
Floating OWC spar buoy (WETFEET)

Contents

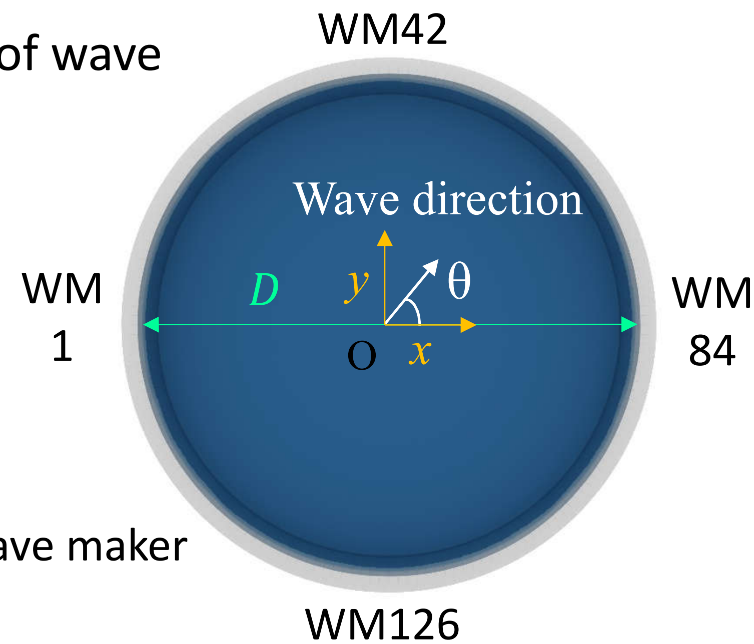
Application to the FloWave

Numerical Setup for FloWave

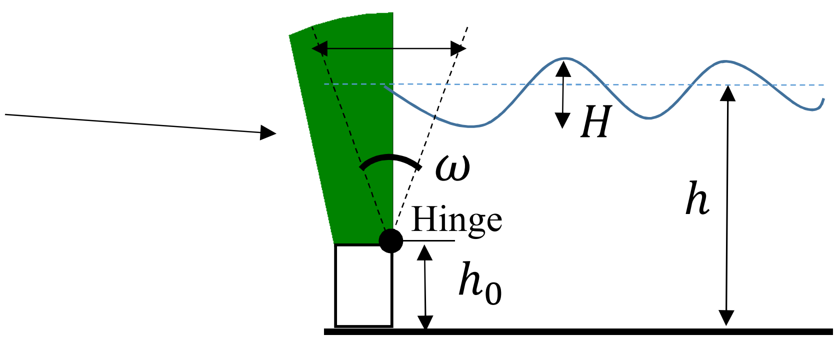
Configuration of FloWave	
Diameter (D)	25 m
Water depth (h)	2 m
Wave maker (WM)	
Type	Hinged-flap
Hinge depth (h_0)	0.32 m
Number of WM	168



Layout of wave makers



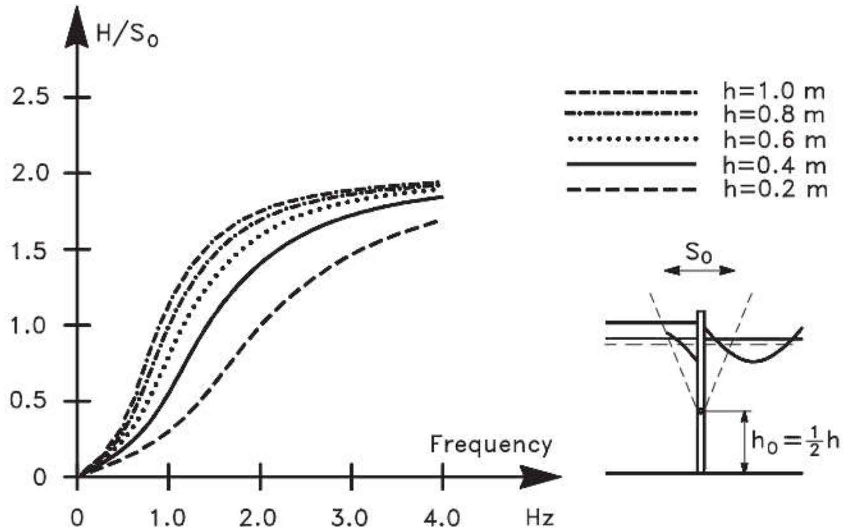
Hinged-flap type wave makers

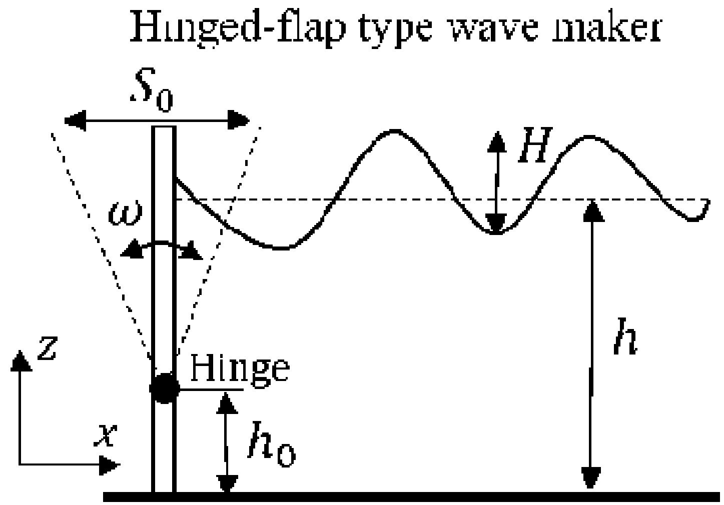


How to Generate Waves in the FloWave

Biesel transfer functions (Biesel and Suquet 1951)

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





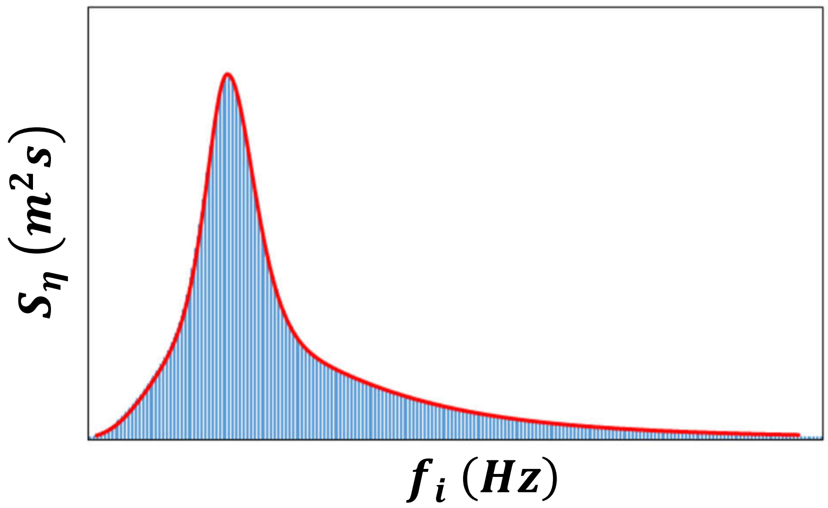
$$S(z) = S_0 \cdot \frac{h + z - h_0}{h - h_0} \quad \text{at } (z+h) > h_0 \qquad S(z) = 0 \quad \text{at } (z+h) < h_0$$

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

How to Generate Waves in the FloWave

To generate irregular wave trains

Example of wave spectra



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:

$$\frac{H_i}{S_{0,i}} = \frac{2}{k(h-h_0)} \left[\frac{\sinh(kh)\{(h-h_0)k\sinh(kh)-\cosh(kh)+\cosh(kh_0)\}}{\sinh(kh)\cosh(kh)+kh}\right] \qquad a_i = \sqrt{2S_\eta(f_i)\Delta f} = H_i/2$$

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

$$S(z) = \sum_{i=1}^{N} S_{0,i} \cdot \frac{h+z-h_0}{h-h_0}$$

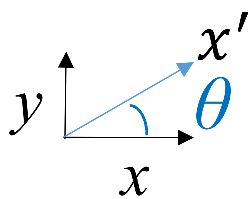
How to Generate Waves in the FloWave

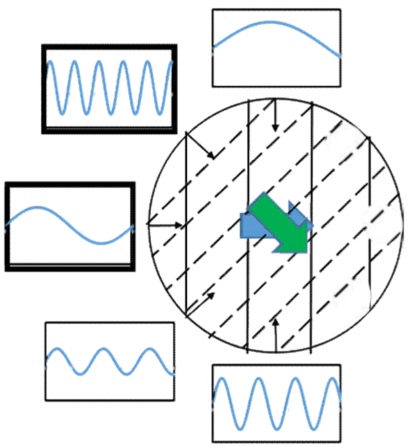
Single summation method

(Miles and Funke, 1989)

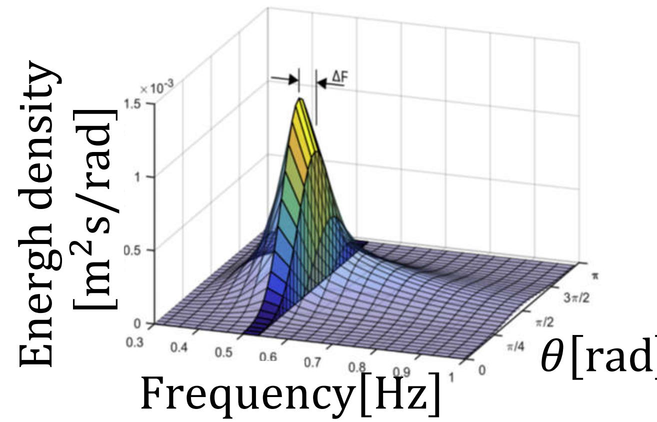
$$\eta_i = \sum_{i=1}^{M} A_i \cos[\omega_i t + k_i(x\cos\theta_i + y\sin\theta_i) + \epsilon_i]$$

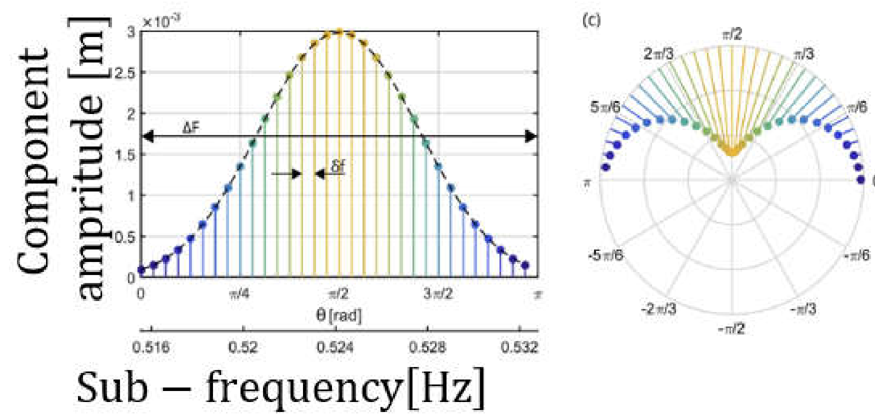
$$= \sum_{i=1}^{M} A_i \cos[\omega_i t + k_i x' + \epsilon_i]$$





Directional spectrum





S. Draycott, Ocean Engineering, 2018

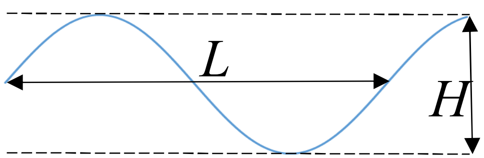
Contents

Regular Wave

0.4Hz_2% (frequency_steepness)

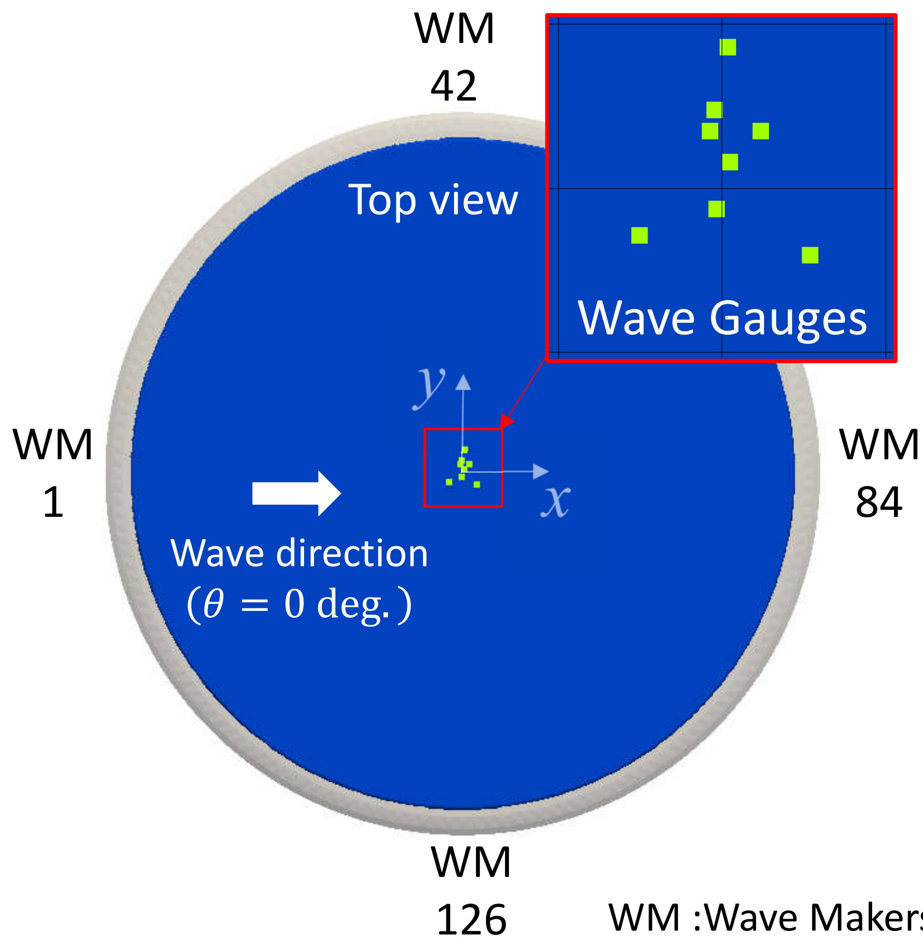
Regular wave conditions

Test case	Frequency (Hz)	Steepness (%)
Case 1	0.3	2
Case 2	0.4	1
Case 3	0.4	2
Case 4	0.4	4
Case 5	0.5	2
Case 6	0.6	2



$$\textbf{Steepness} = \frac{wave\ height\ (H)}{wave\ lengh\ (L)}$$

Positions of wave gauges and coordinate system in the FloWave



Irregular Wave

Pierson Moskowitz 0.075m_3s (H_{m0}_T_p)

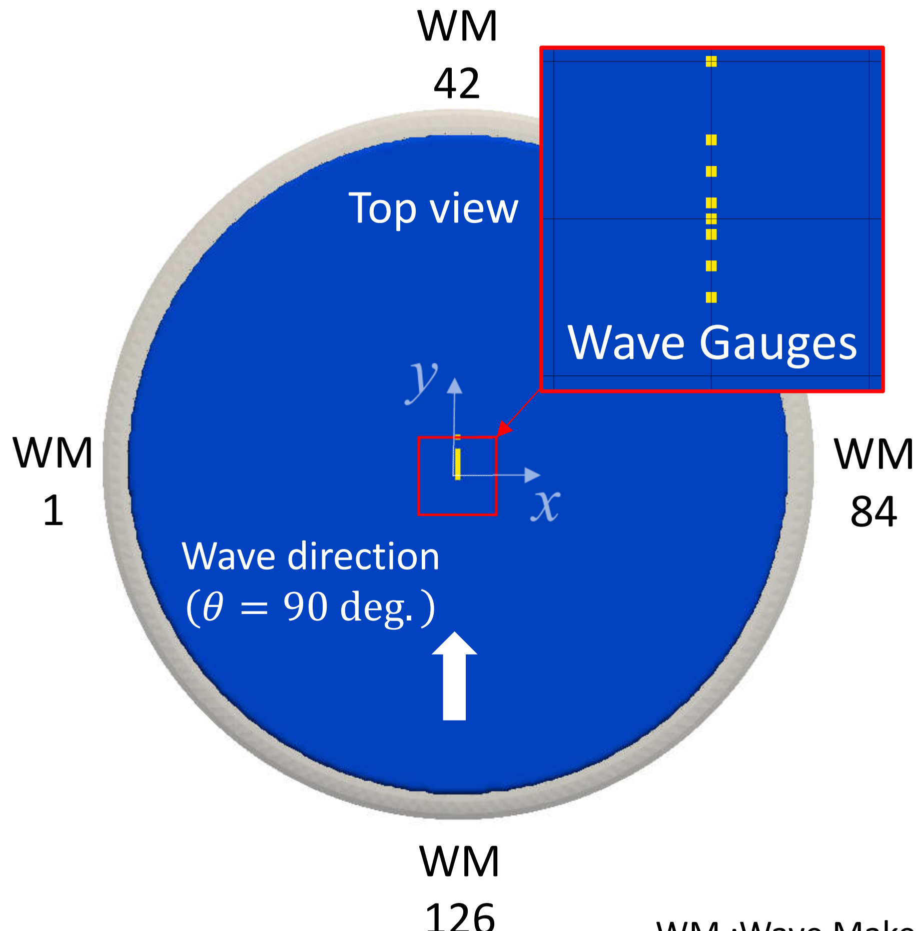
Irregular wave conditions

Test case	H_{m0}(m)	T_p(s)
Case 7	0.15	1.5
Case 8	0.15	2.0
Case 9	0.075	1.5
Case 10	0.075	2.0
Case 11	0.075	2.5
Case 12	0.075	3.0

The PM spectra defined by the significant wave height (H_{mo}) and the peak wave period (T_P)

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

Positions of wave gauges and coordinate system in the FloWave



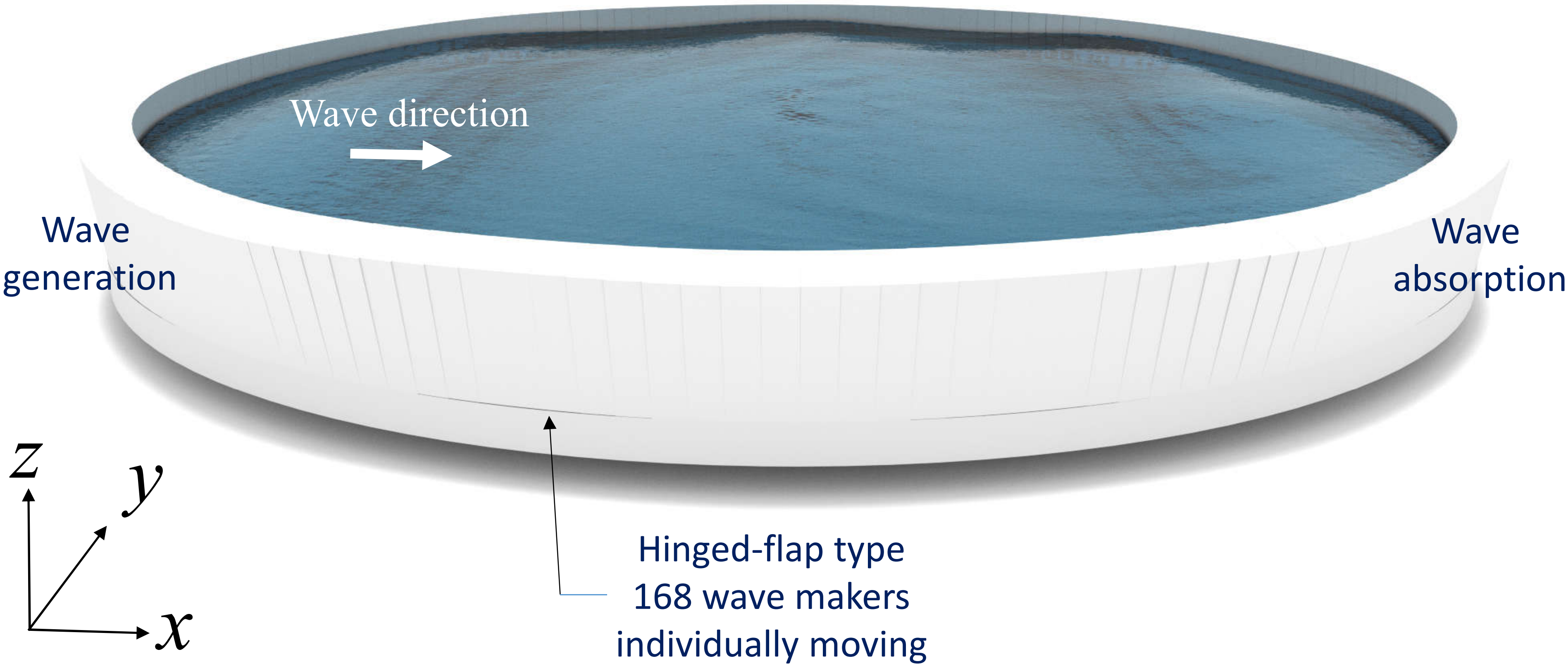
WM :Wave Makers

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.

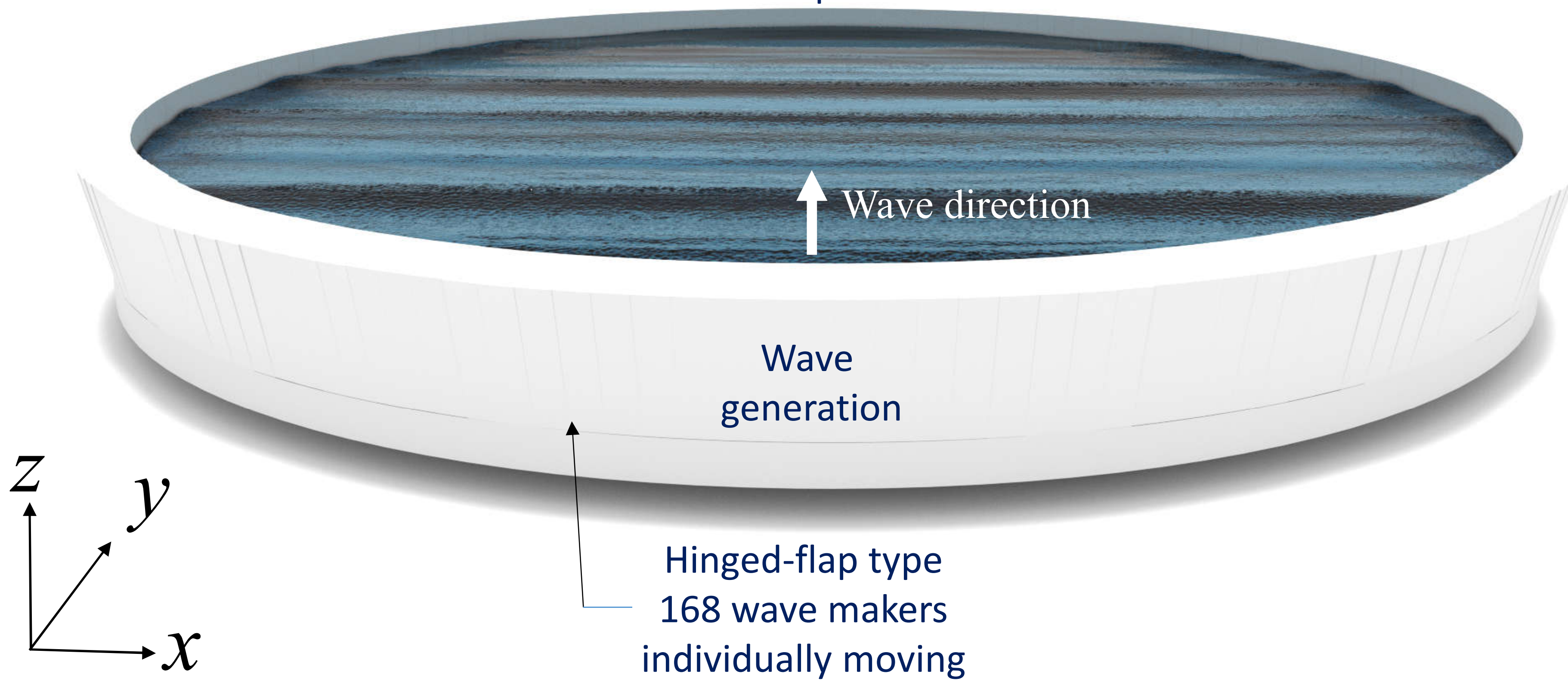


Long-Crested Wave

Pierson Moskowitz 0.075m_3s (H_{m0}_T_p)

Irregular Wave

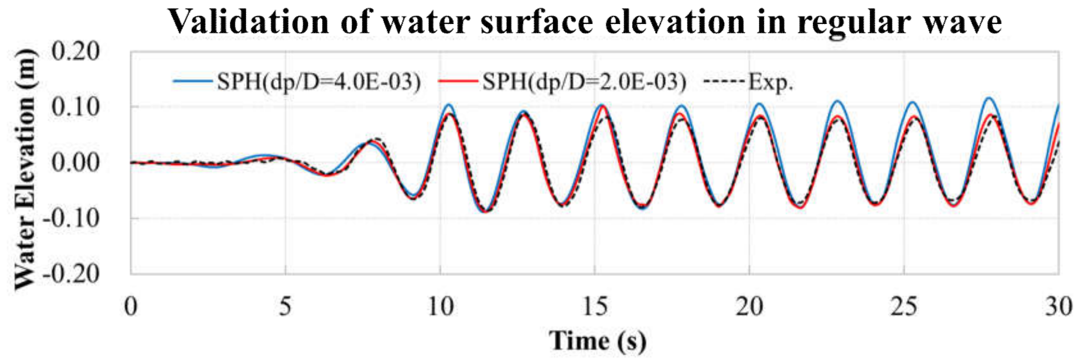
GPU: Quadro M4000
Particles: 8.6 Millions
Steps: : 157,690
Computational time: 60s
Run time: 58.9hrs.



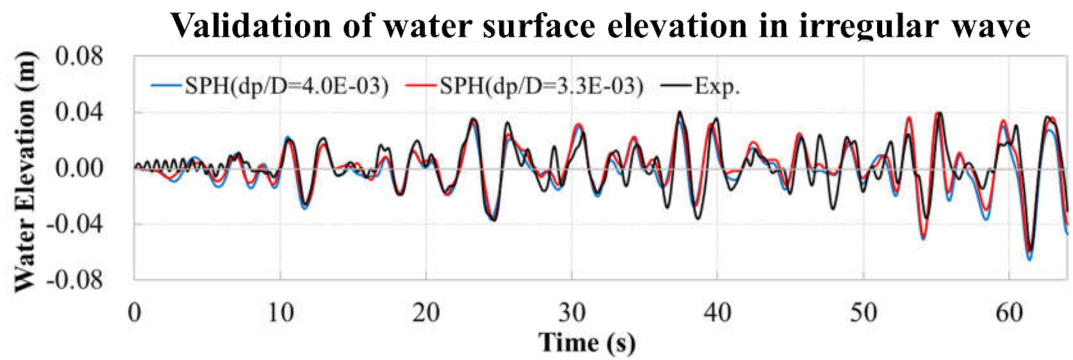
Long-Crested Wave

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

Regular



Irregular



The numerical result in the wave amplitude and the phase (especially in the fine particle case $\left(d_p/D = 2.0 \times 10^{-3}\right)$ shows pretty good agreement with the experimental one in regular/irregular wave conditions.

Short Crested Wave

Definition of short crested wave

Short crested wave definition

$$E(f,\theta) = \boxed{E(f)} \cdot D(f,\theta)$$

where

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

$E(f)$ = one − directional energy spectral density function

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

f = frequency in hertz

θ = direction in radians

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

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

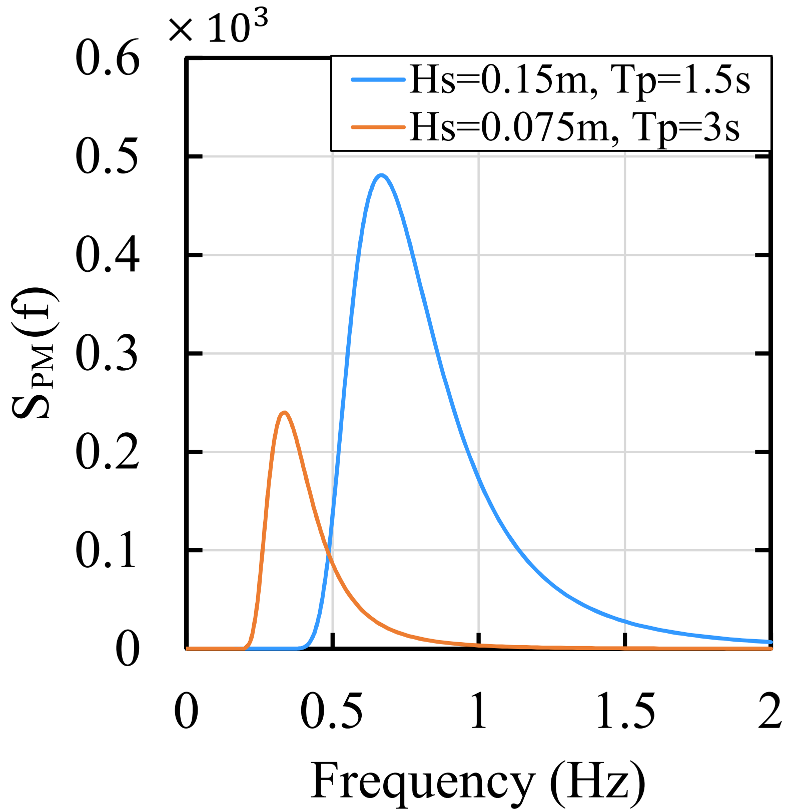


Fig. PM spectra with the significant wave height (H_S) and the peak wave period (T_P)

Short Crested Wave

Definition of short crested wave

Short crested wave definition

$$E(f,\theta) = E(f) \cdot D(f,\theta)$$

Cosine-2s directional spreading functions

Longuet-Higgins, et al. (1963).

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

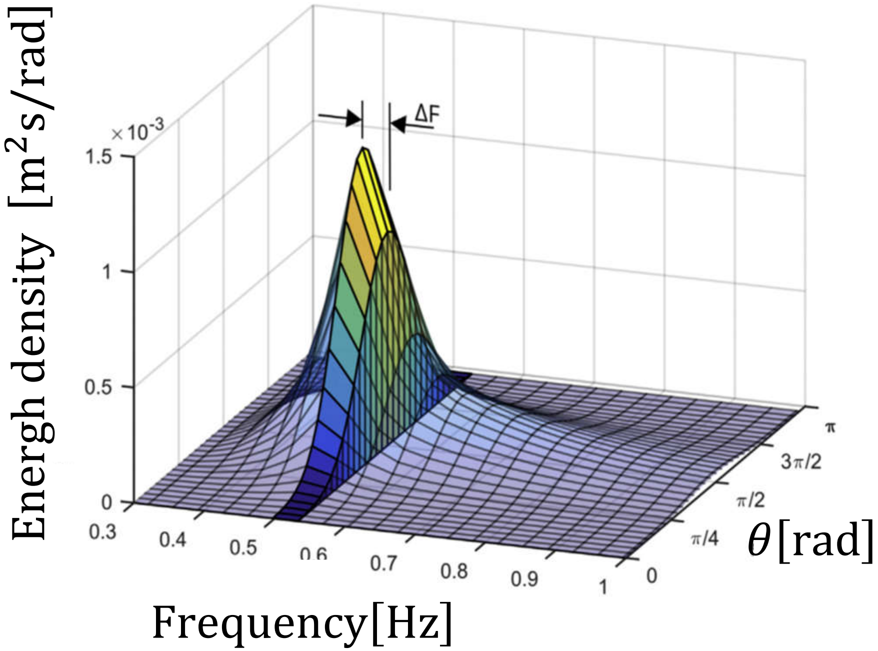
where

γ = the Gamma function

θ_0 = the mean wave direction

s = the spreading parameter which is a function of frequency and wind speed

Directional spectrum



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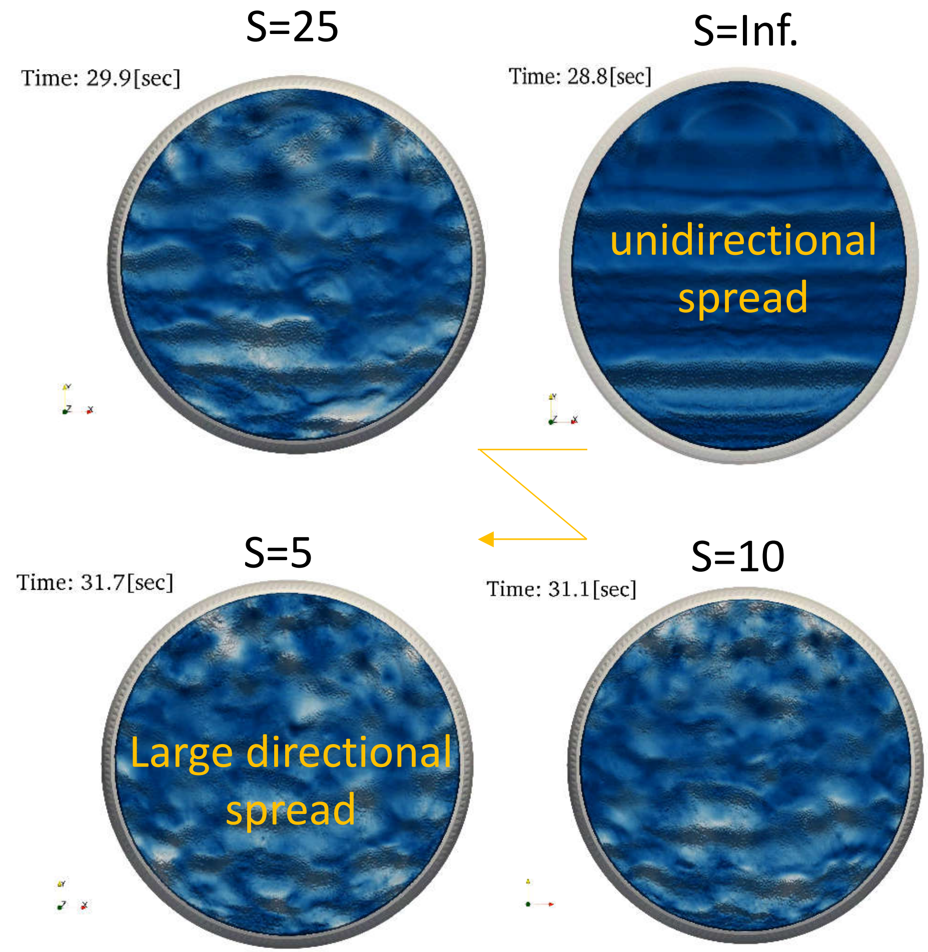
Short Crested Wave

short crested wave conditions

Short crested wave conditions

Test case	H_{m0}(m)	T_p(s)	s
Case 1	0.15	1.5	5
Case 2	0.15	1.5	10
Case 3	0.15	1.5	25
Case 4	0.15	1.5	Inf
Case 5	0.075	3.0	5
Case 6	0.075	3.0	10
Case 7	0.075	3.0	25
Case 8	0.075	3.0	Inf

where
s=Inf denotes no spreading i.e. unidirectional, and s=5 is the largest directional spread.

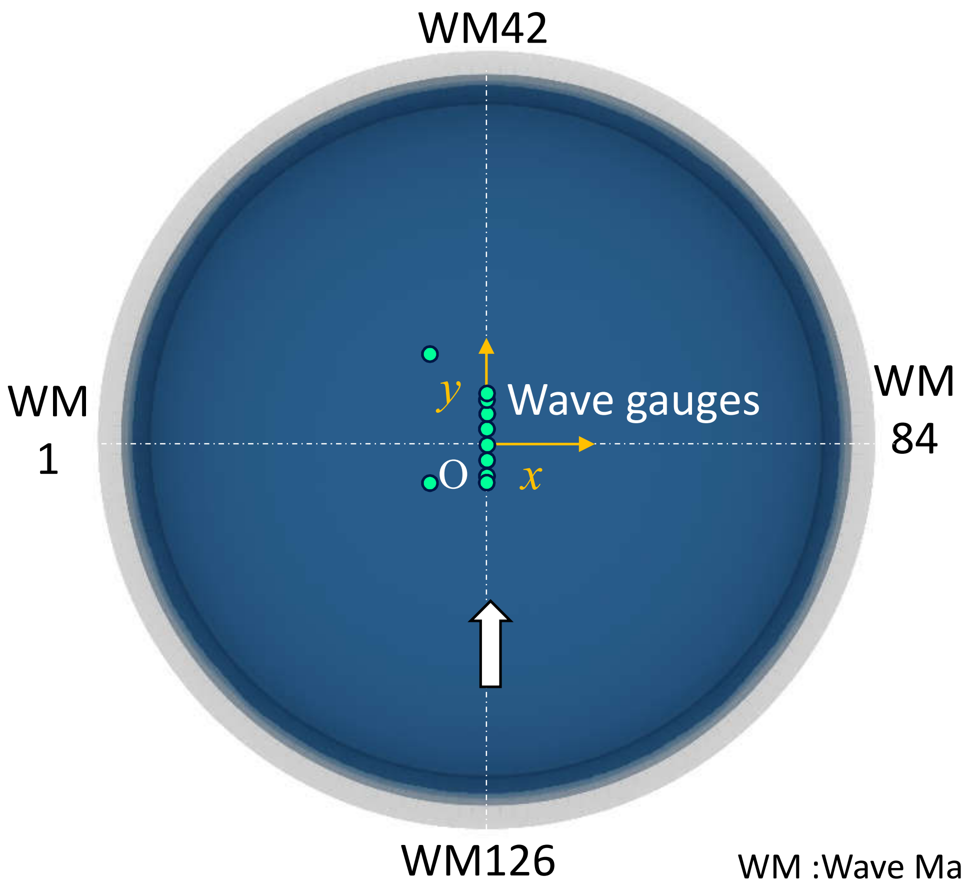


Short Crested wave

Positions of wave gauges

Gauge	x (m)	y (m)
Gauge 1	0	-0.915
Gauge 2	0	-0.81
Gauge 3	0	-0.255
Gauge 4	0	0
Gauge5	0	0.434
Gauge 6	0	0.711
Gauge 7	0	0.88
Gauge 8	0	0.93
Gauge 9	-1.32	-0.917
Gauge 10	-1.32	2.523

Positions of wave gauges and coordinate system of the FloWave

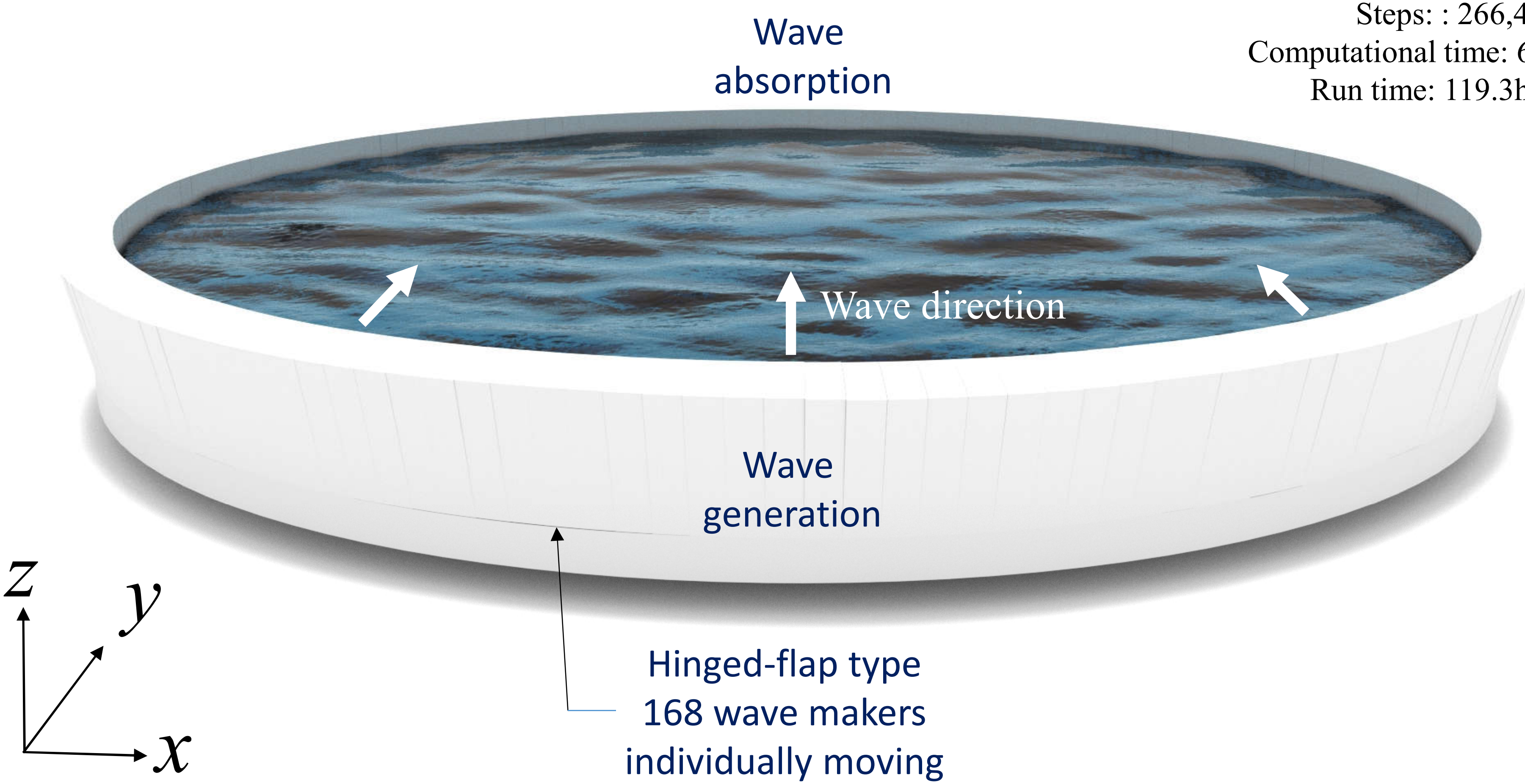


WM :Wave Makers

Short Crested Wave

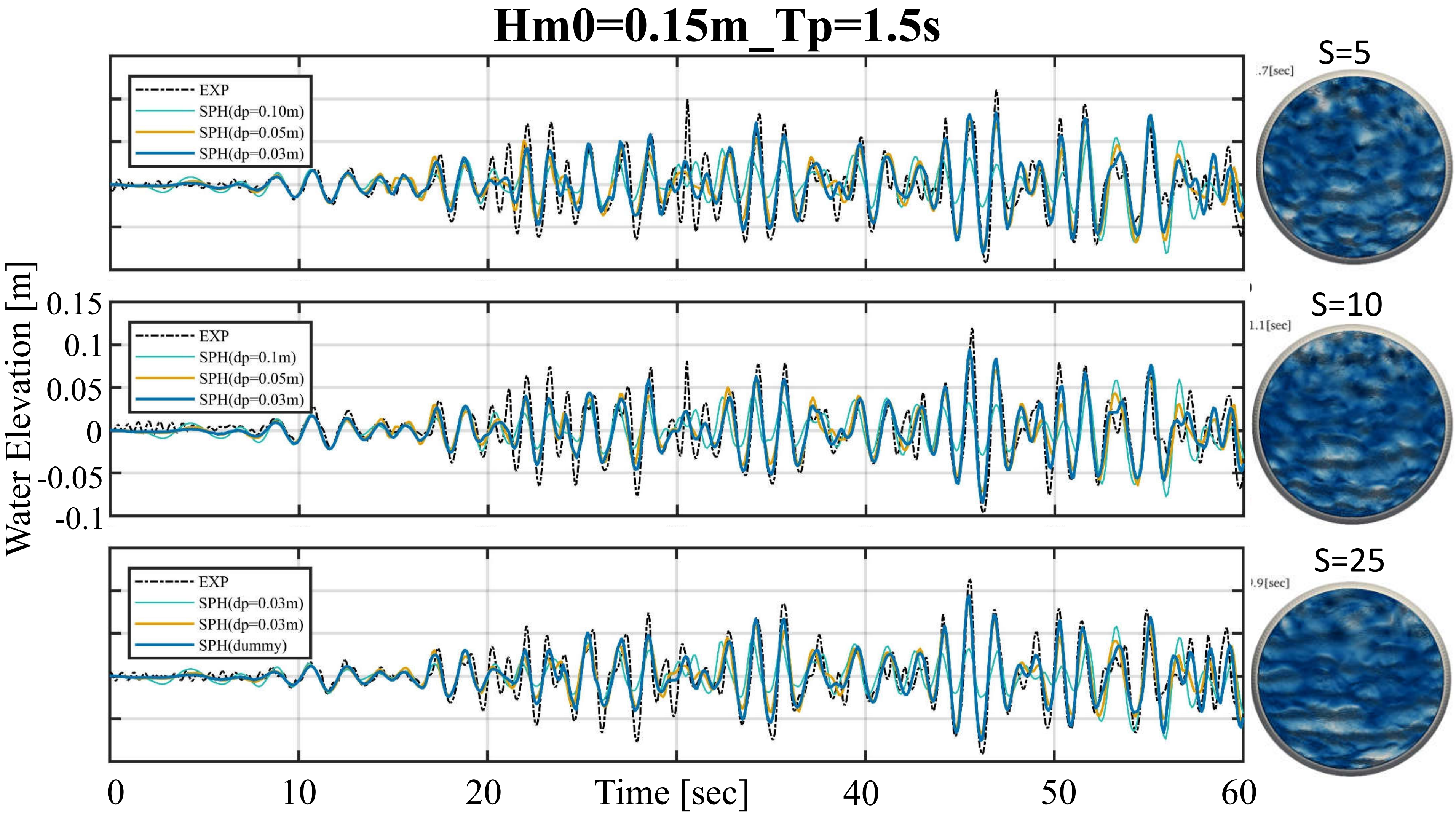
Hs=0.15m_Tp=1.5s_s=5

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



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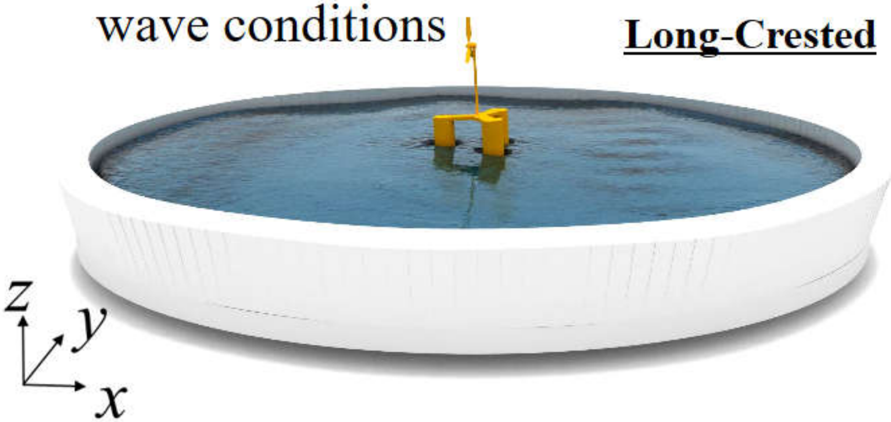
Further applications *Demonstration of fluid structure interaction*

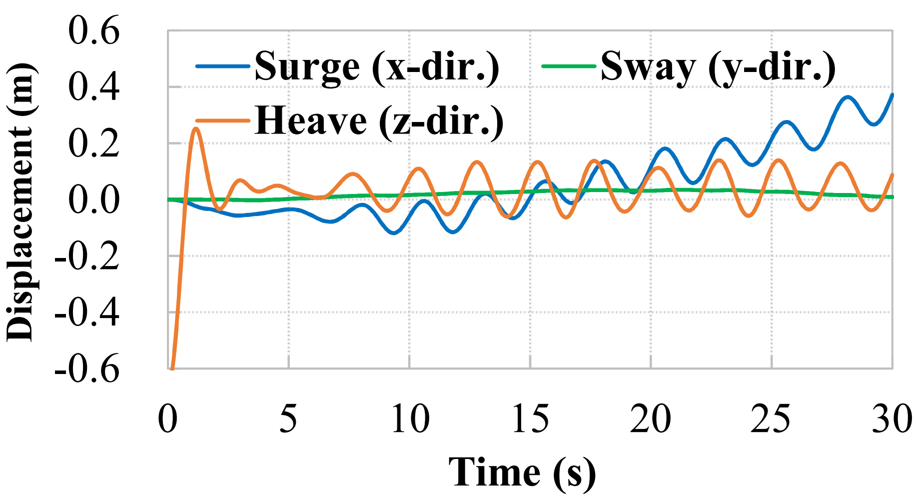
Offshore wind turbine with drift motion in long-crested regular/short crested wave conditions

Long-Crested

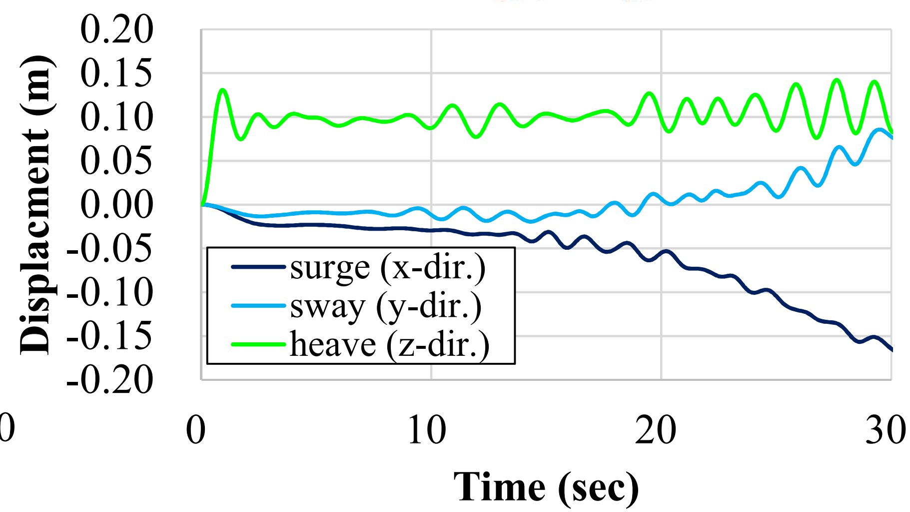


Short-Crested

Time series of surge, sway, heave motions

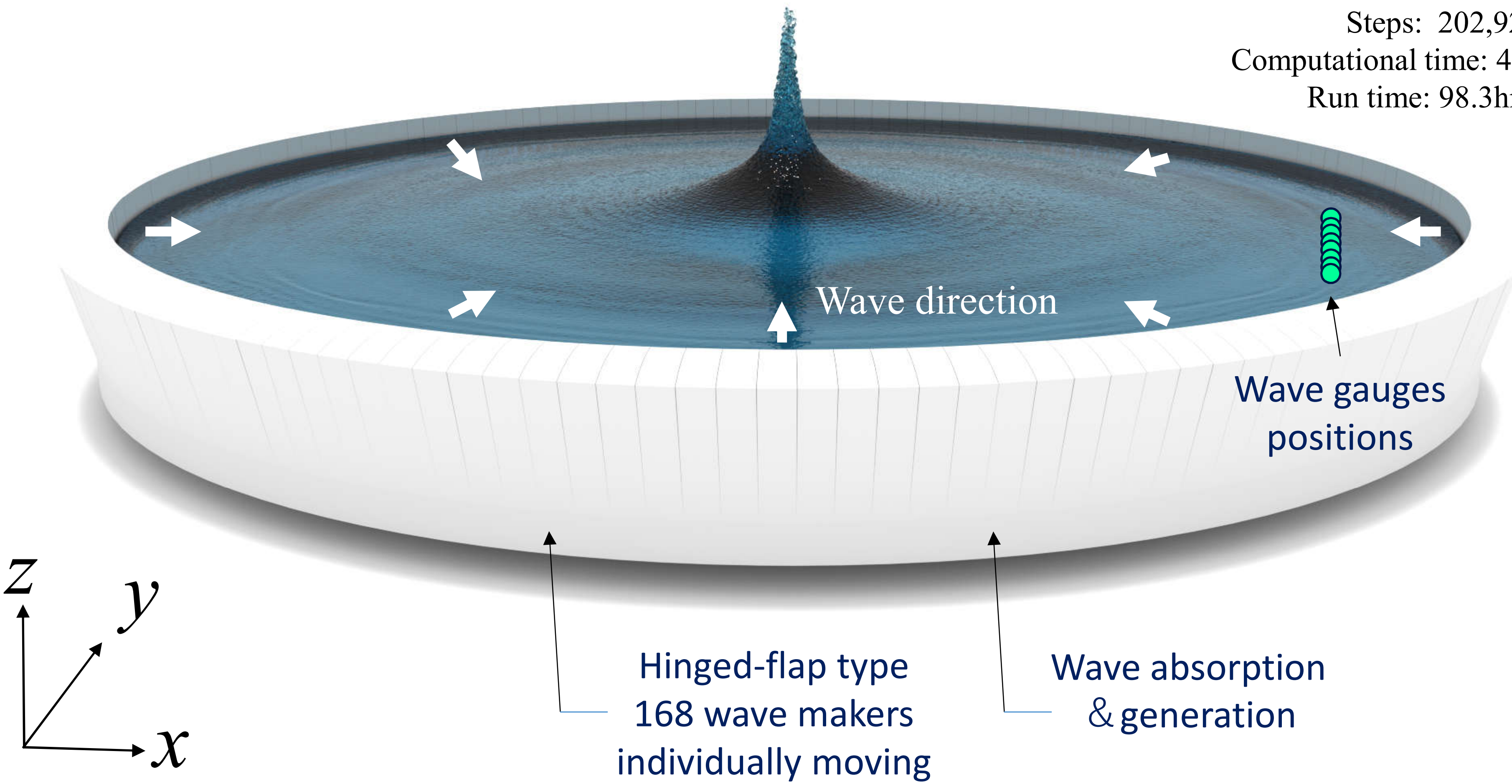


Time series of surge, sway, heave motions



Spike Wave

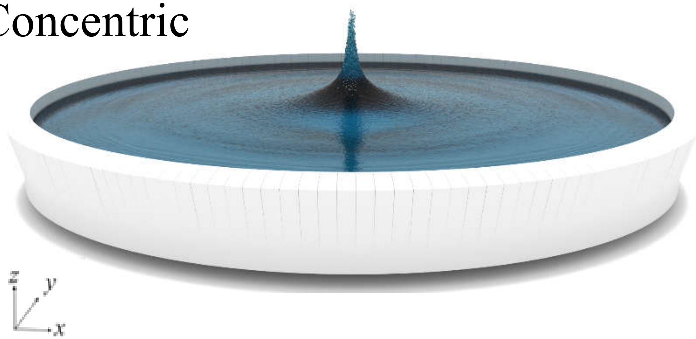
GPU: GeForce GTX 1080 Ti
Particles: 52.4 Millions
Steps: 202,928
Computational time: 40s
Run time: 98.3hrs.

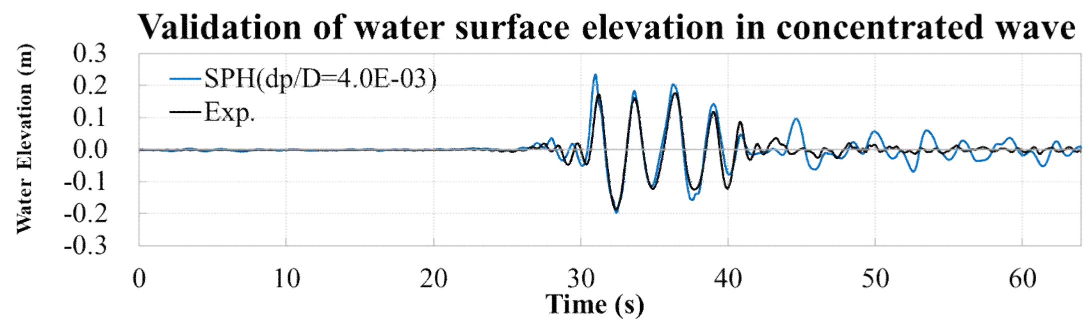


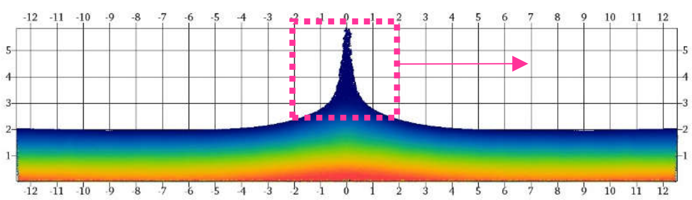
Spike Wave

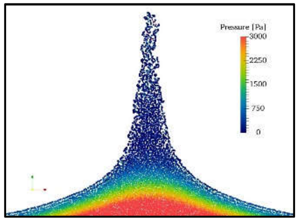
Wave propagation snapshot (right) and its validation (left)

Concentric

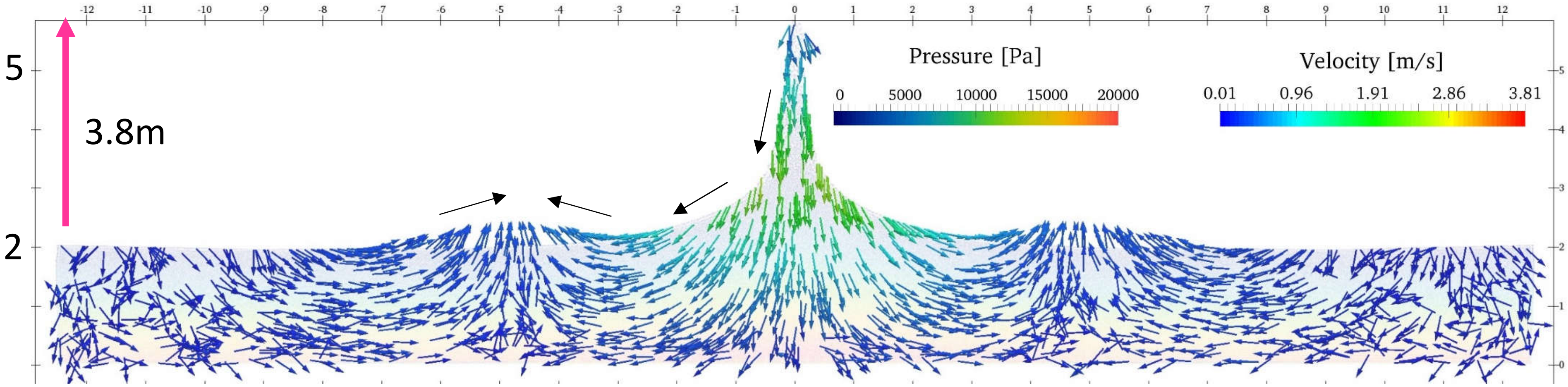








Pressure and velocity filed of spike wave, which show the rapidly down rushing column of water, shortly after impact.



Contents

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 muti-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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