Numerical simulation of an array of Floating Point Absorber Wave Energy Converters using OpenFOAM

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OpenFOAM user meeting @ HPC-UGent
13\textsuperscript{th} September 2017, Ghent, Belgium
Overview of the presentation

• **Introduction**
  - Problem statement
  - Main goal

• **Models**
  - Experimental (wave basin)
  - Numerical (CFD simulations)

• **Numerical results**
  - 2WEC-array
  - 5WEC-array
  - Outlook: 9WEC-array

• **OpenFOAM modelling at AWW**
  - Vincent GRUWEZ
  - Ine VANDEBEEK
  - Carlos ARBOLEDA CHAVEZ

• **Conclusions (part I)**

• **Conclusions (part II)**
Introduction

• Problem statement
  ▶ Wave Energy Converters (WECs) are arranged in arrays → array effects
  ▶ OpenFOAM: solve the 3D viscous flow field and the response of a WEC array in an incident wave field using IHFOAM
  ▶ Why CFD? → viscous forces, turbulent and nonlinear effects

• Main goal
  ▶ Validation of the numerical model by using experimental data
  ▶ Different tests and array configurations
Experimental modelling: WECwakes project

Project coordinated by Ghent University (Dept. of Civil Engineering)

DHI shallow water wave basin (Denmark)
Numerical modelling: Numerical Wave Flume / Numerical Wave Tank

- = box filled with water (red) and air (blue)

- p and U: Navier-Stokes equations
- volume fraction: Volume of Fluid (VoF) method
- interFoam / interDyMFoam solver (OpenFOAM-2.2.2 and OpenFOAM-3.0.1)

- Boundary conditions are needed to generate and absorb the waves
Numerical modelling: floating WECs

- Fluid solver
  - Navier-Stokes equations (only laminar solutions)
  - Turbulence? Article Coastal Eng.: Application of a buoyancy-modified k-ω SST turbulence model to simulate wave run-up around a monopile subjected to regular waves using OpenFOAM® (doi.org/10.1016/j.coastaleng.2017.04.004)

- Motion solver
  - force → position

- Multiple WECs in an array configuration
  - Arbitrary Mesh Interfaces (AMIs)

- Mesh motion
  - only heave motion
Numerical modelling: friction forces

Vertical supporting axis

$$F_{LD} = -cv(t)$$

PTO system

$$F_{PTO} = -\mu F_{spring} \text{sign}(v(t))$$

$$= -\mu 4dxk_{spring} \text{sign}(v(t))$$
REGULAR WAVES
2WEC-ARRAY

H = 0.074 m
T = 1.26 s
d = 0.70 m

out of the water

PTO activated

WEC 1
WEC 2
WEC 3
WEC 4
WEC 5
Results: regular wave test 2WEC-array

Surge force due to wave action $\rightarrow$ 2\textsuperscript{nd} Coulomb damper $\rightarrow$ difference in heave amplitudes: 60 % $\rightarrow$ 20 %
Results: regular wave test 2WEC-array

WEC4: $F_s$

WEC5: $F_s$
REGULAR WAVES
5WEC-ARRAY

H = 0.074 m
T = 1.26 s
d = 0.70 m

PTO activated
Results: regular wave test 5WEC-array

$Z_{WEC}$

![Experimental vs CFD comparison graphs]

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Results: regular wave test 5WEC-array

![Wave height comparison](image)

- Experimental
- CFD

![Wave concentration](image)

- η

eta

Time: 50.00

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OUTLOOK:
REGULAR WAVES
9WEC-ARRAY
Outlook: regular wave test 9WEC-array
Conclusions (part I)

- CFD modelling of WEC-arrays in a numerical wave tank (OpenFOAM)
- Numerical model is validated with experimental data (WECwakes)
  - 2WEC-array
  - 5WEC-array

- Further research
  - Validation of a larger number of WECs and different array configurations
  - Importance of viscous forces and non-linear effects
  - Including turbulent effects using our buoyancy-modified turbulence model
THERE IS MORE THAN WAVE ENERGY…
Wave run-up around a monopile

Wave breaking: turbulence modelling

…AND IT’S NOT ONLY ME…
Modelling of wave overtopping for a climate resilient coastal defence system with a very shallow foreshore

• Goal
  ‣ A prediction methodology for wave overtopping, wave impact forces on sea defences, and risk of casualties in buildings

• Methods
  ‣ Numerical modelling (OpenFOAM, SWASH, + coupling)
  ‣ Validation by using experimental data and field measurements

• Status
  ‣ Validation for regular wave transformation and wave forces
  ‣ Next step: coupling SWASH–OpenFOAM
Numerical modelling of beach profile dynamics for very shallow foreshores

• Goal:
  ‣ The influence of sediment transport and dynamic beach profiles on wave loading forces and overtopping volumes

• Methods:
  ‣ CFD modelling with OpenFOAM using the VoF method and a sediment transport module with dynamic beach profiles
  ‣ Validation by using experimental data

• Status:
  ‣ Sediment transport and morphology module included in foam-extend

source: ASBPA and U.S. Army Corps of Engineers
Scour protection around wind turbine monopile foundations in a combined wave and current condition

• Goal:
  ‣ CFD modelling of combined waves and current
  ‣ CFD modelling of the flow field inside porous media

• Methods
  ‣ CFD modelling with OpenFOAM using the VoF method
  ‣ Validation by using experimental data

• Status
  ‣ Wave propagation towards the monopile

source: Sumer & Fredsøe (2011)
PhD Carlos ARBOLEDA CHAVEZ (Ghent University, Department of Civil Engineering)
Conclusions (part II)

• CFD simulations in a numerical wave tank using OpenFOAM

• Offshore and coastal engineering processes:
  ‣ Wave energy converters (arrays)
  ‣ Wave propagation and wave run-up around a monopile
  ‣ Turbulence modelling for wave breaking over a sloped beach profile
  ‣ Wave overtopping at and impact forces on coastal structures
  ‣ Sediment transport in the nearshore zone
  ‣ Porous flow inside the scour protection around a monopile foundation
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