FACULTY OF ENGINEERING AND ARCHITECTURE

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

Brecht DEVOLDER[1,2], Pieter RAUWOENS[2], Peter TROCH[1]

[1]Ghent University, Department of Civil Engineering, Belgium

[2]KU Leuven, Department of Civil Engineering, Technology Cluster Construction, Belgium

OpenFOAM user meeting @ HPC-UGent

13th 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
- **Conclusions (part I)**

← Wave Energy Converter = WEC

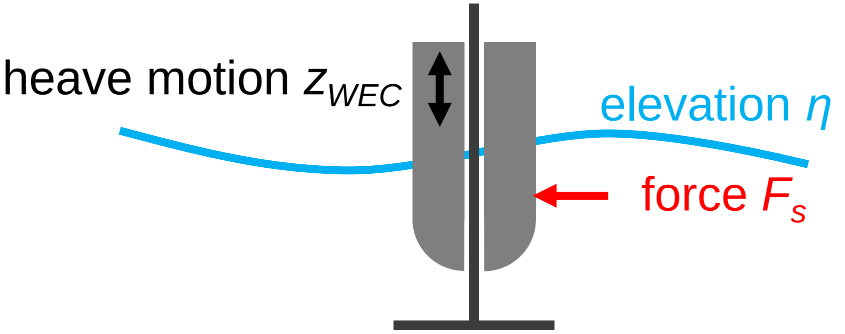
- **OpenFOAM modelling at AWW**
  - Vincent GRUWEZ
  - Ine VANDEBEEK
  - Carlos ARBOLEDA CHAVEZ
- **Conclusions (part II)**

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

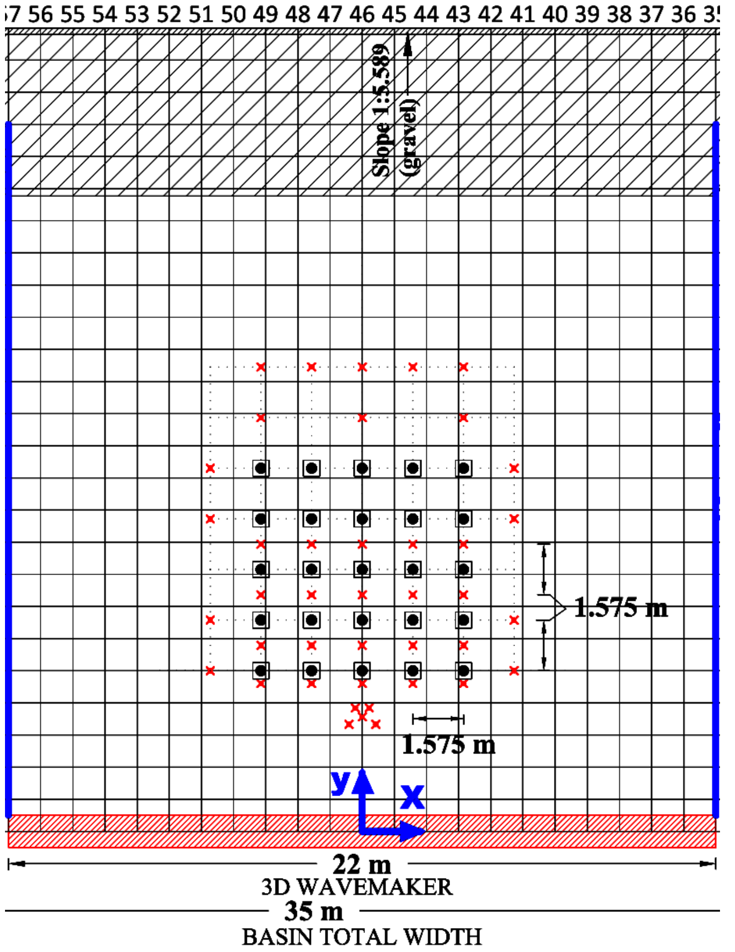
- **Main goal**
  - Validation of the numerical model by using experimental data
  - Different tests and array configurations

Experimental modelling: WECwakes project



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

DHI shallow water wave basin (Denmark)

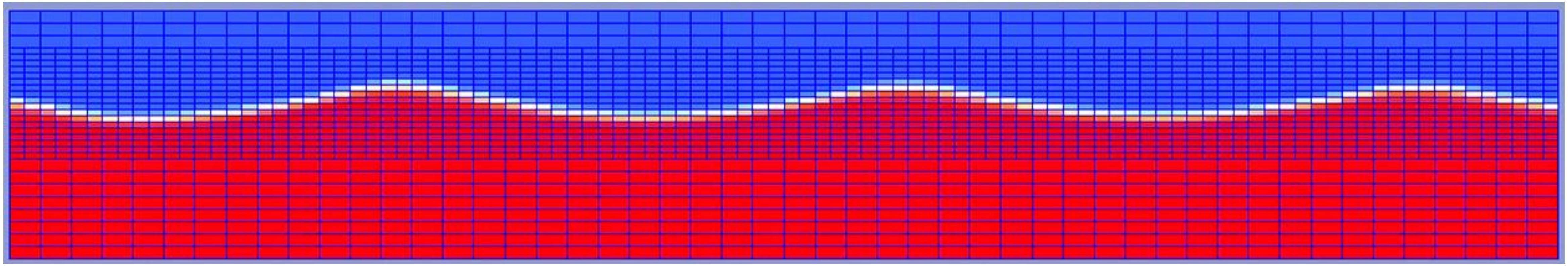


Numerical modelling: Numerical Wave Flume / Numerical Wave Tank

- = 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

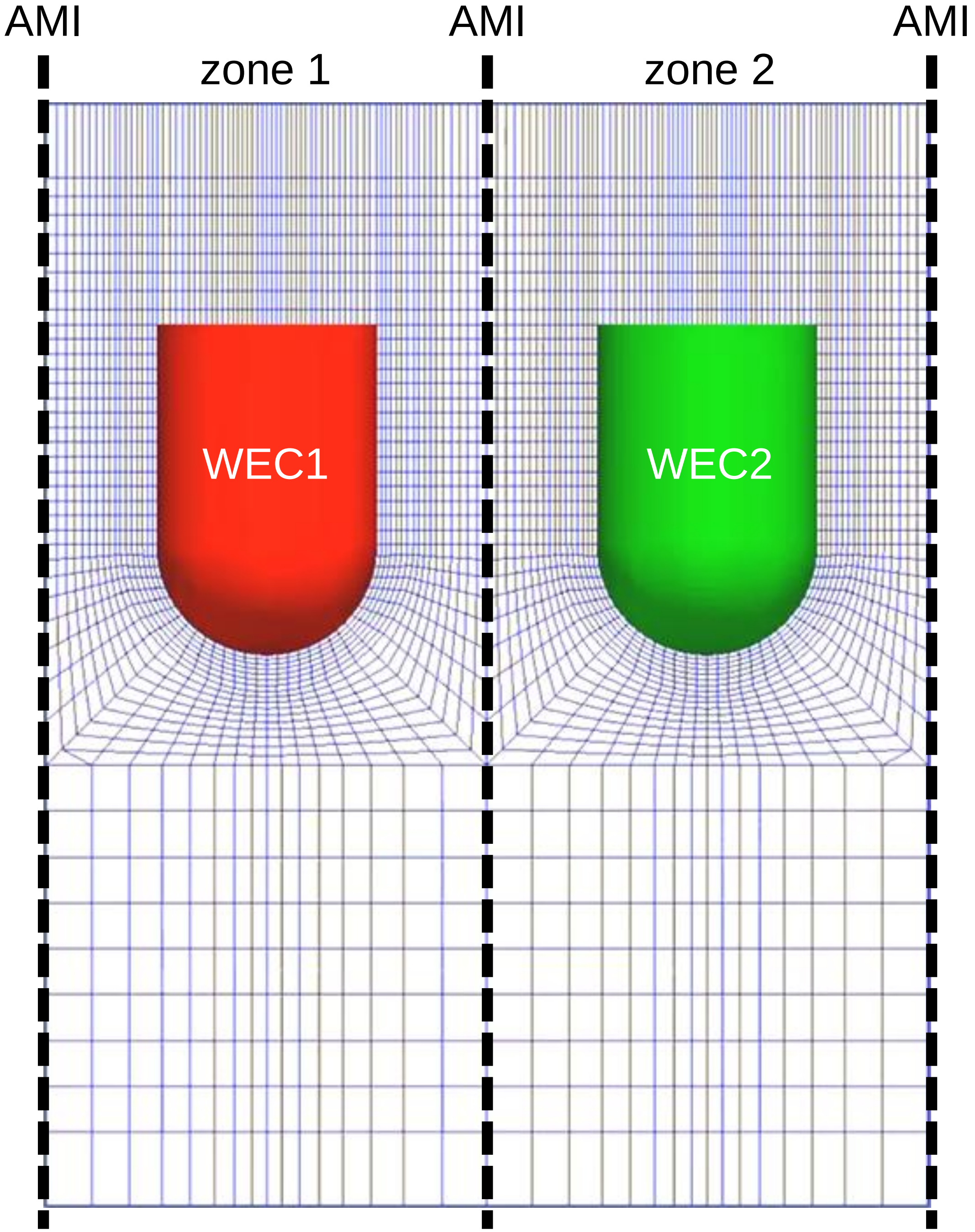


Numerical modelling: floating WECs

sub-iterations

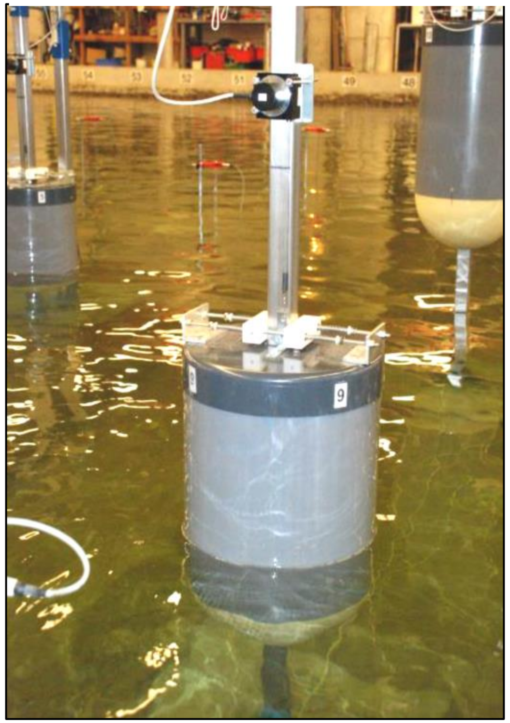
- Fluid solver
  - Navier-Stokes equations (only laminar solutions)
  - Turbulence? Article Coastal Eng.: ***Application of a buoyancy-modified k-ω SST turbulence model to simulate wave run-up around a monopile subjected to regular waves using OpenFOAM®*** (doi.org/10.1016/j.coastaleng.2017.04.004)
-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

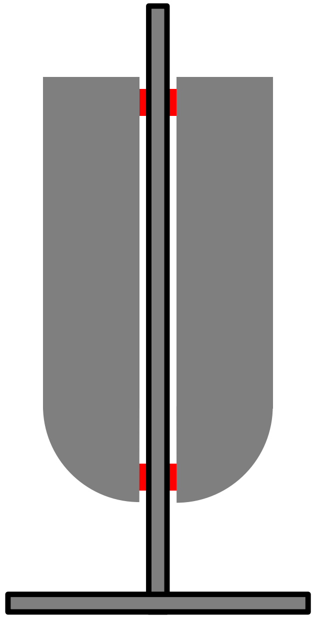
- Multiple WECs in an array configuration
  - Arbitrary Mesh Interfaces (AMIs)
- Mesh motion
  - only heave motion

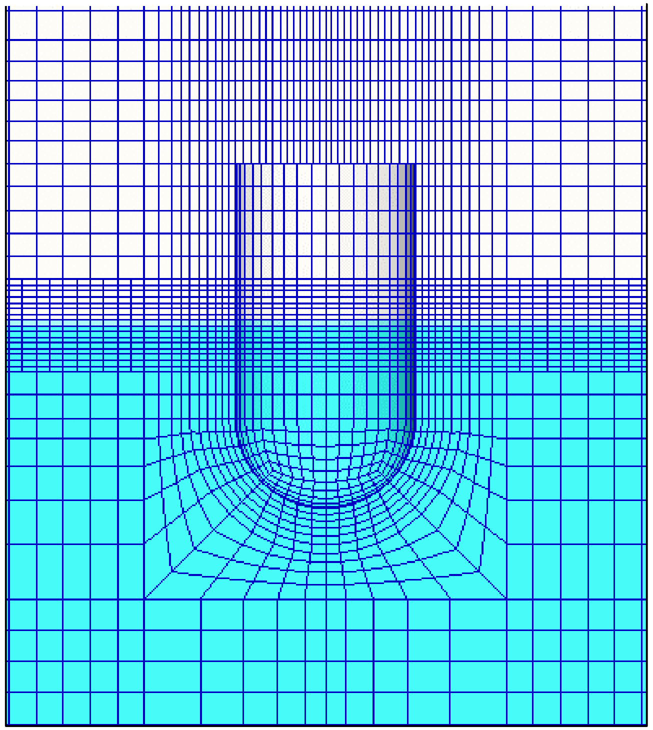


Numerical modelling: friction forces

Vertical supporting axis

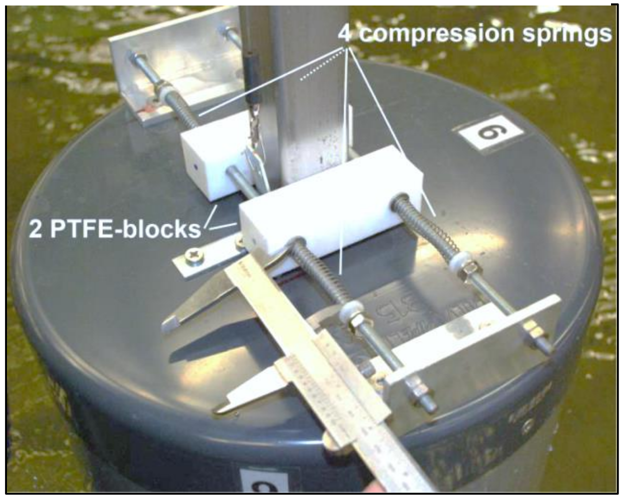




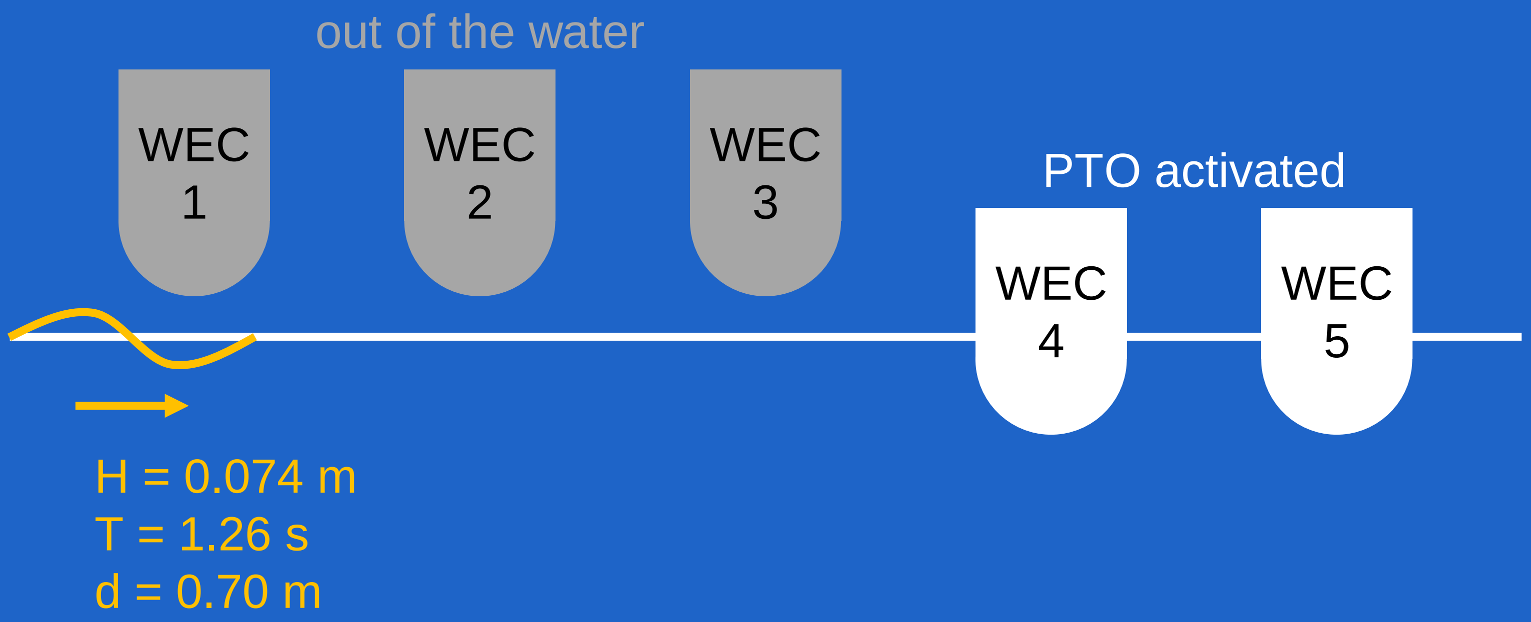


$$F_{LD} = -cv(t)$$

PTO system

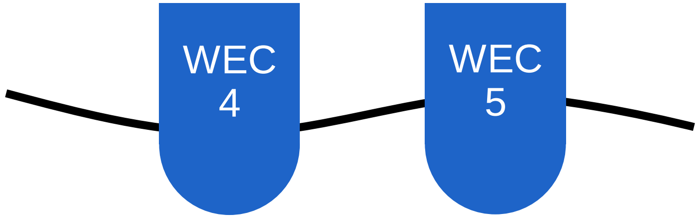


$$F_{PTO} = -\mu F_{spring}\, sign(v(t))$$
$$= -\mu 4dxk_{spring}\, sign(v(t))$$

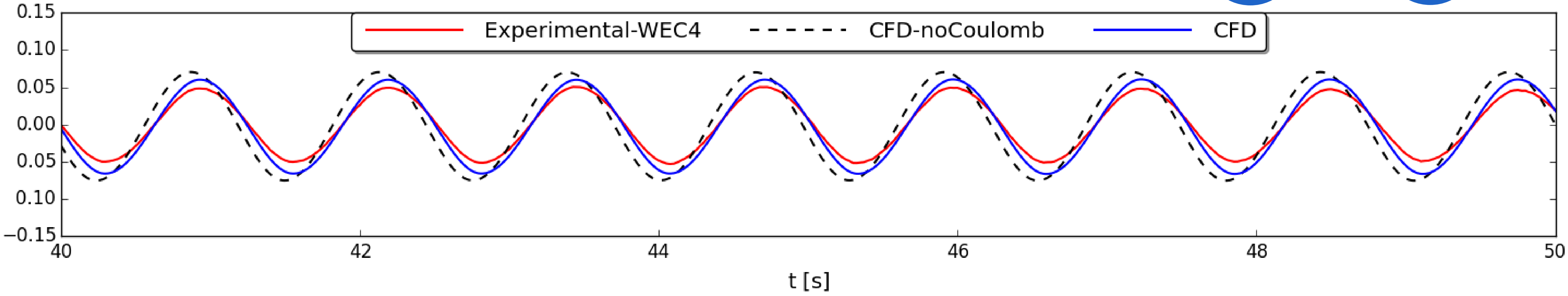


REGULAR WAVES 2WEC-ARRAY

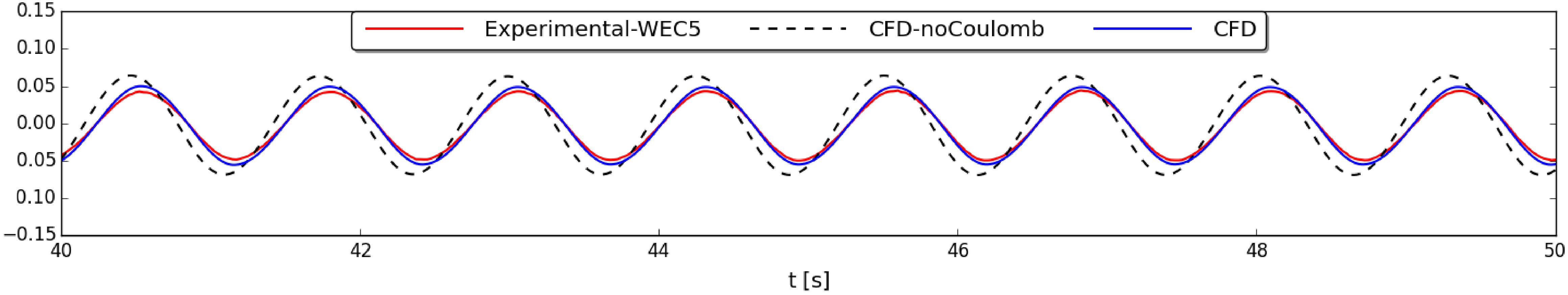
Results: regular wave test 2WEC-array



WEC4
z_{WEC}

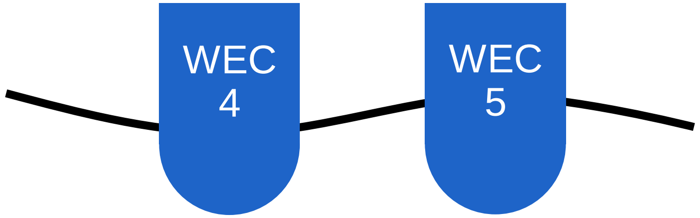


WEC5
z_{WEC}

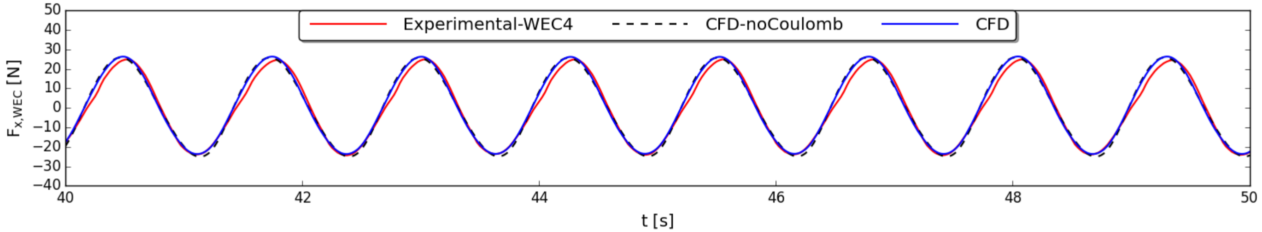


Surge force due to wave action → 2nd Coulomb damper → difference in heave amplitudes: 60 % → 20 %

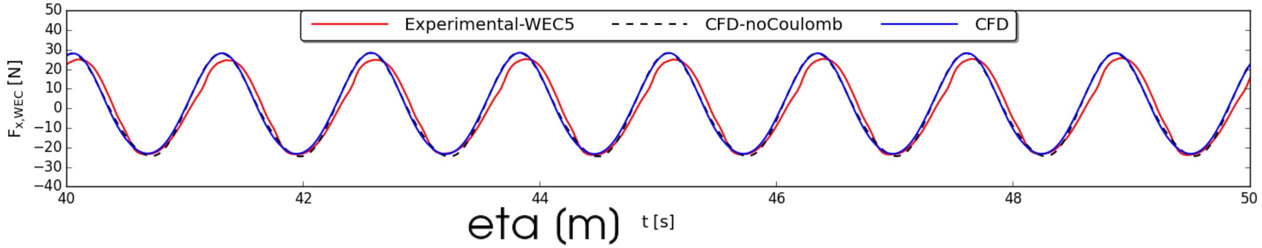
Results: regular wave test 2WEC-array



WEC4: F_s



WEC5: F_s



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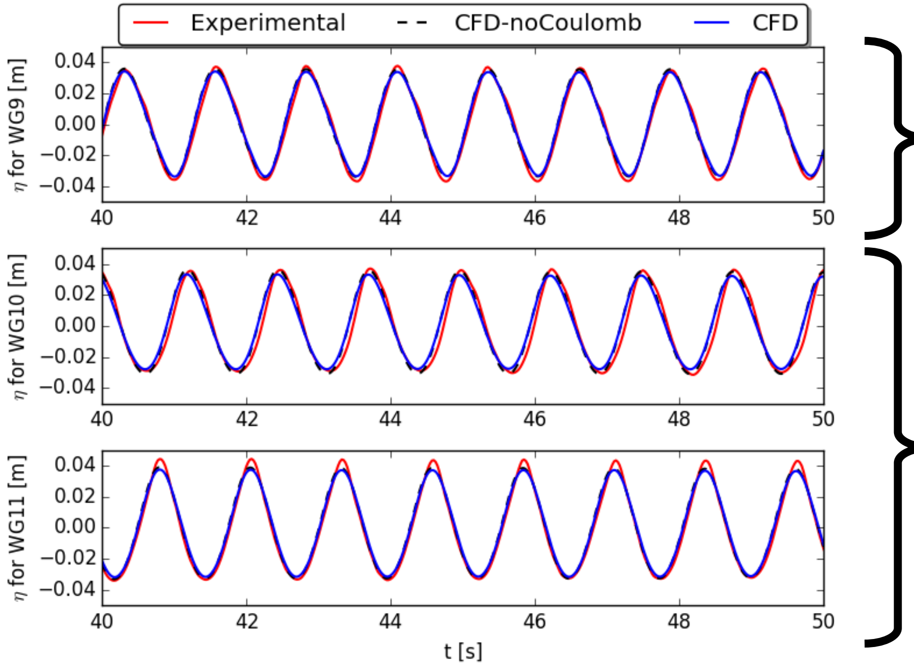
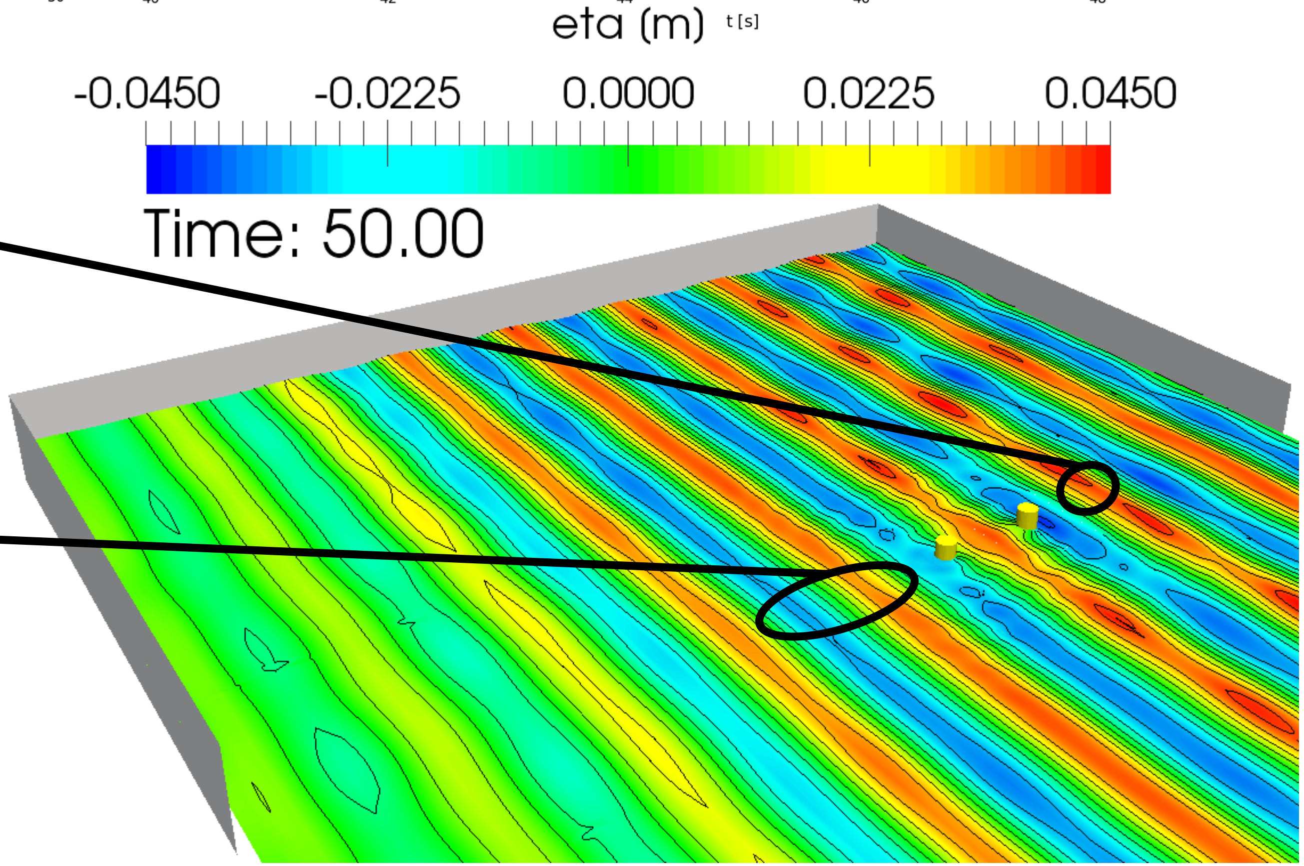
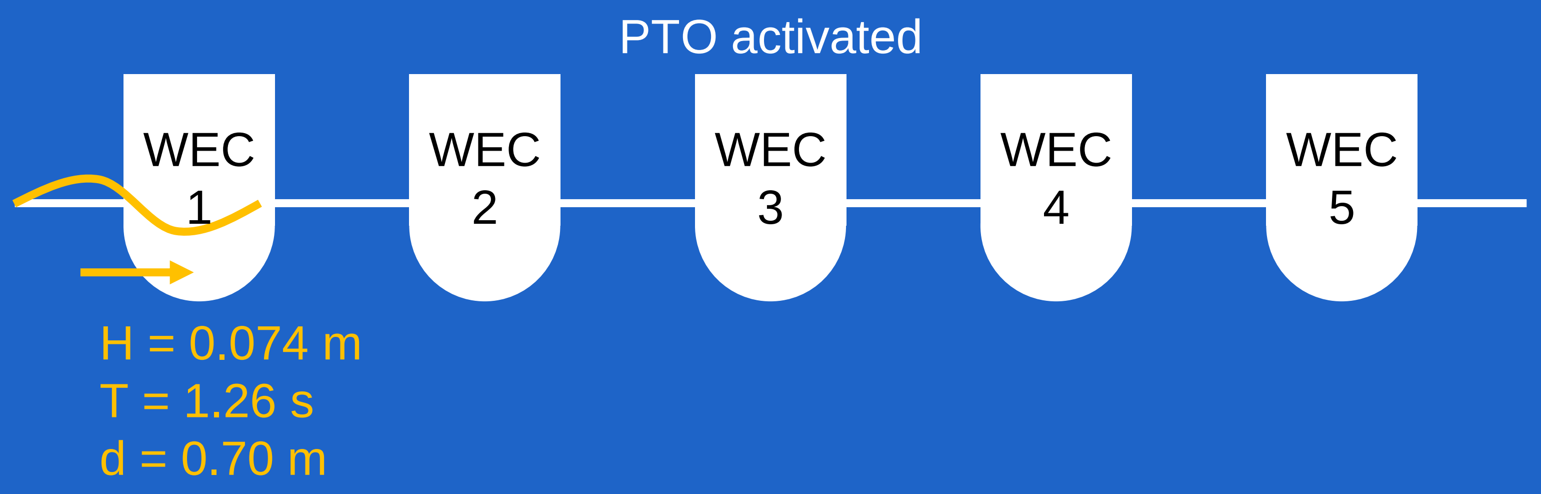


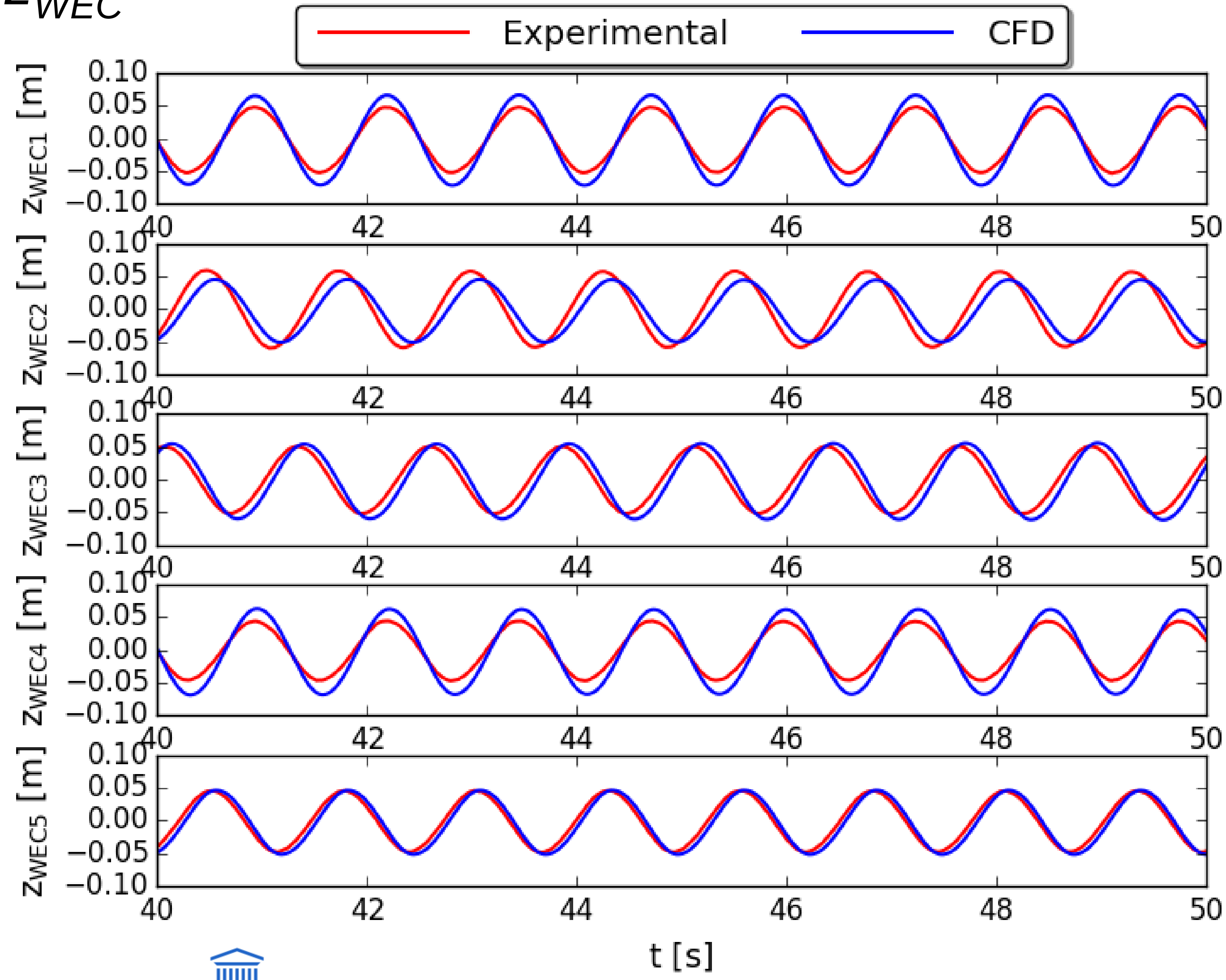


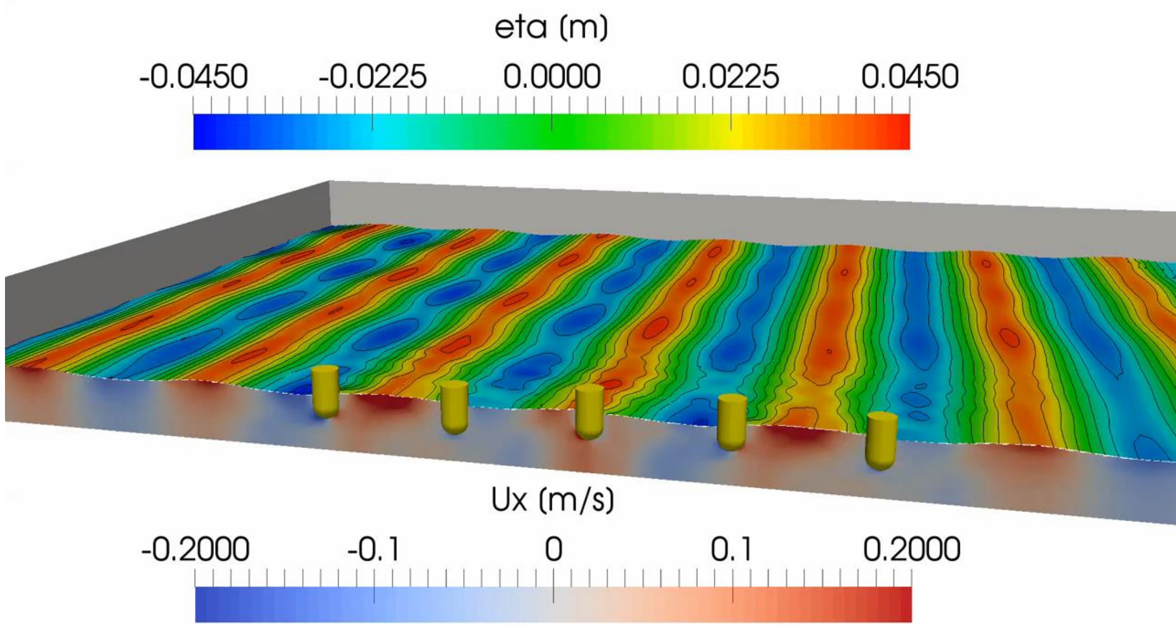


REGULAR WAVES 5WEC-ARRAY

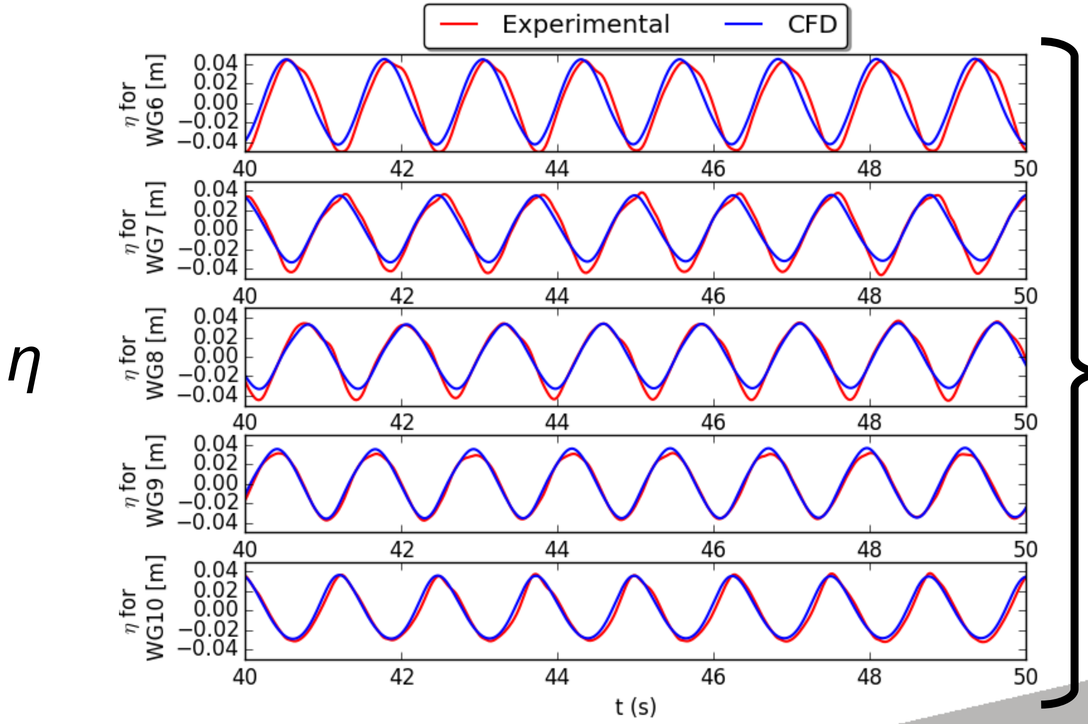
Results: regular wave test 5WEC-array

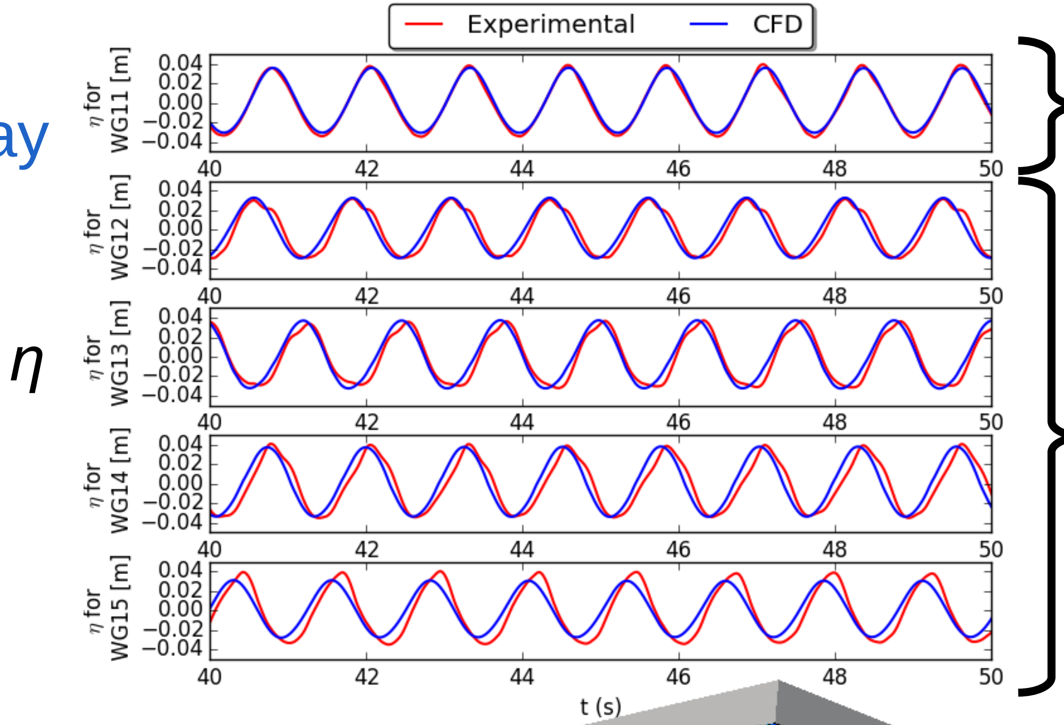
z_{WEC}

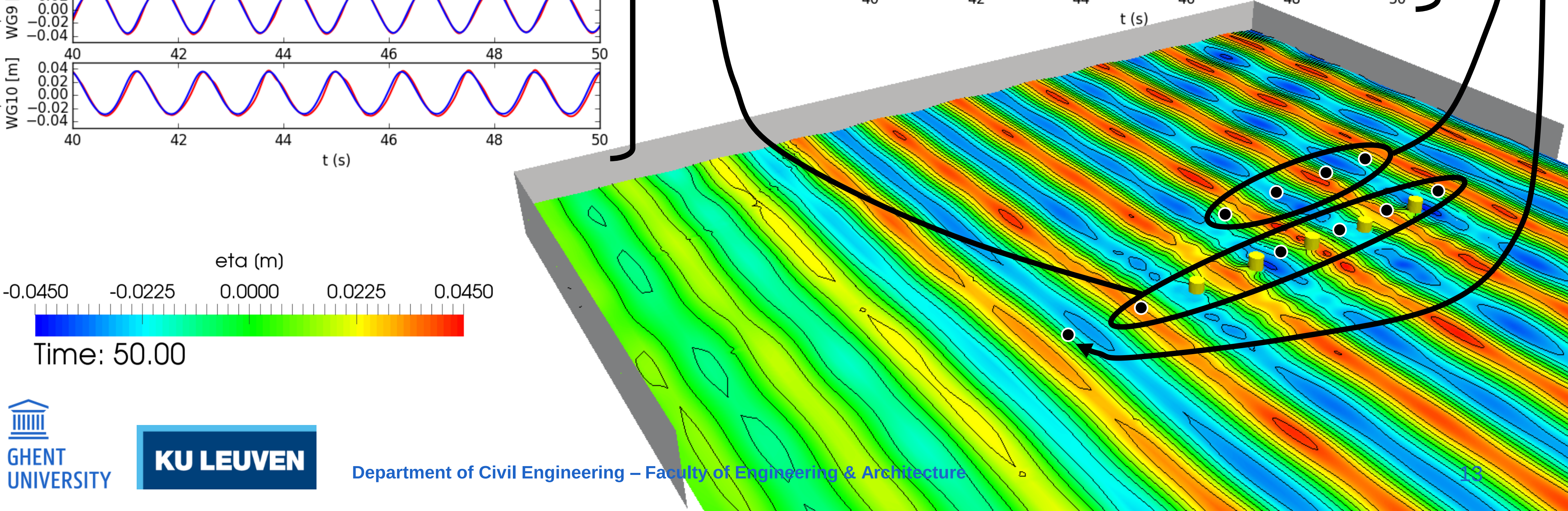




Results: regular wave test 5WEC-array

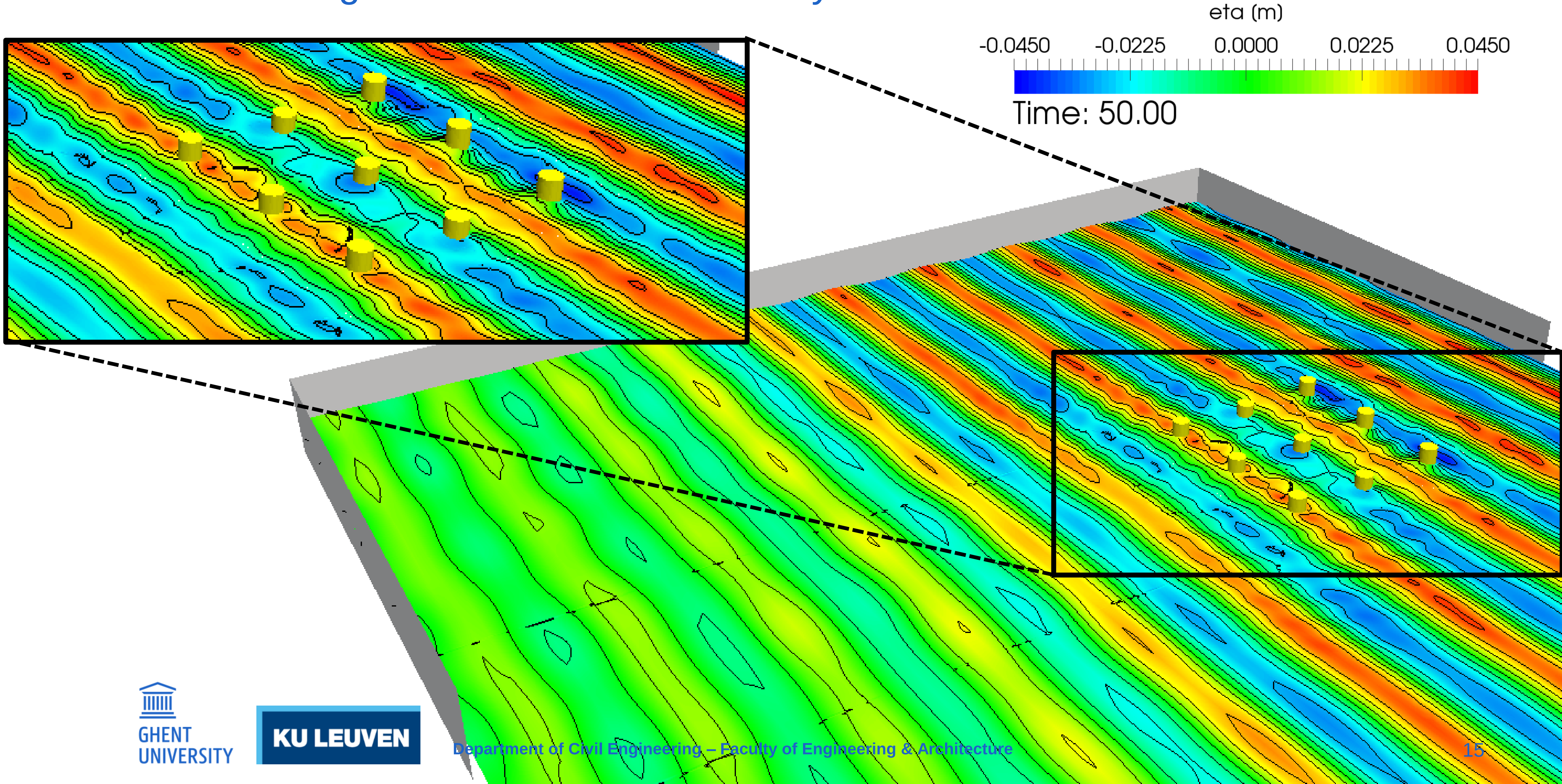






OUTLOOK:
REGULAR WAVES
9WEC-ARRAY

Outlook: regular wave test 9WEC-array



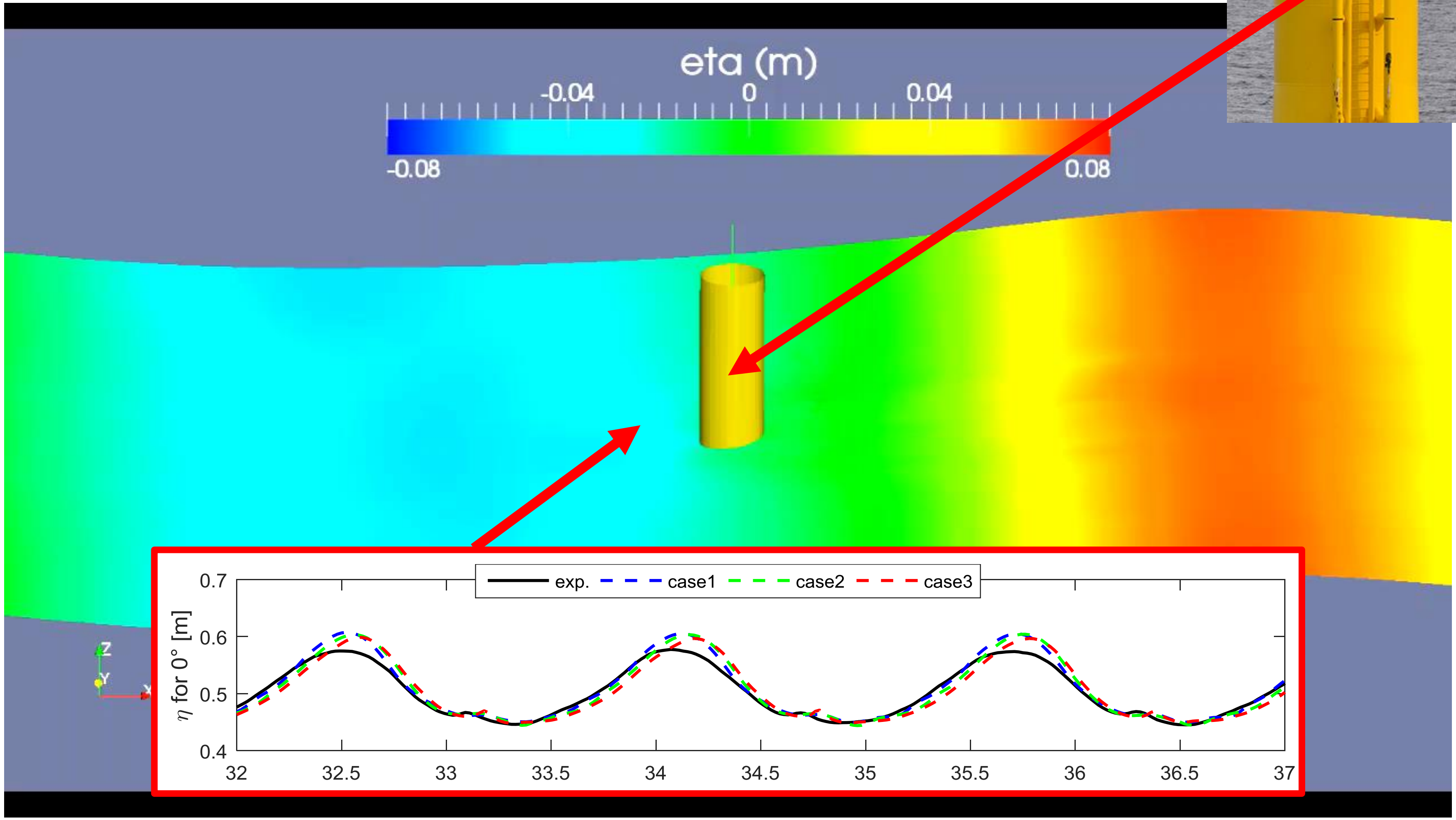
Conclusions (part I)

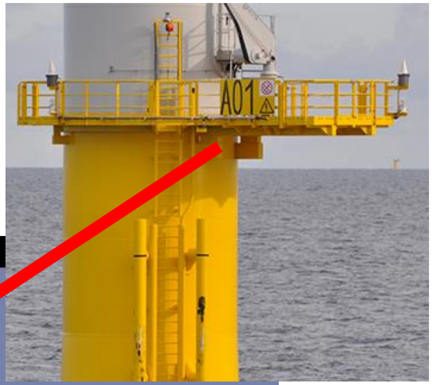
- CFD modelling of WEC-arrays in a numerical wave tank (OpenFOAM)
- Numerical model is validated with experimental data (WECwakes)
  - 2WEC-array
  - 5WEC-array

- 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…

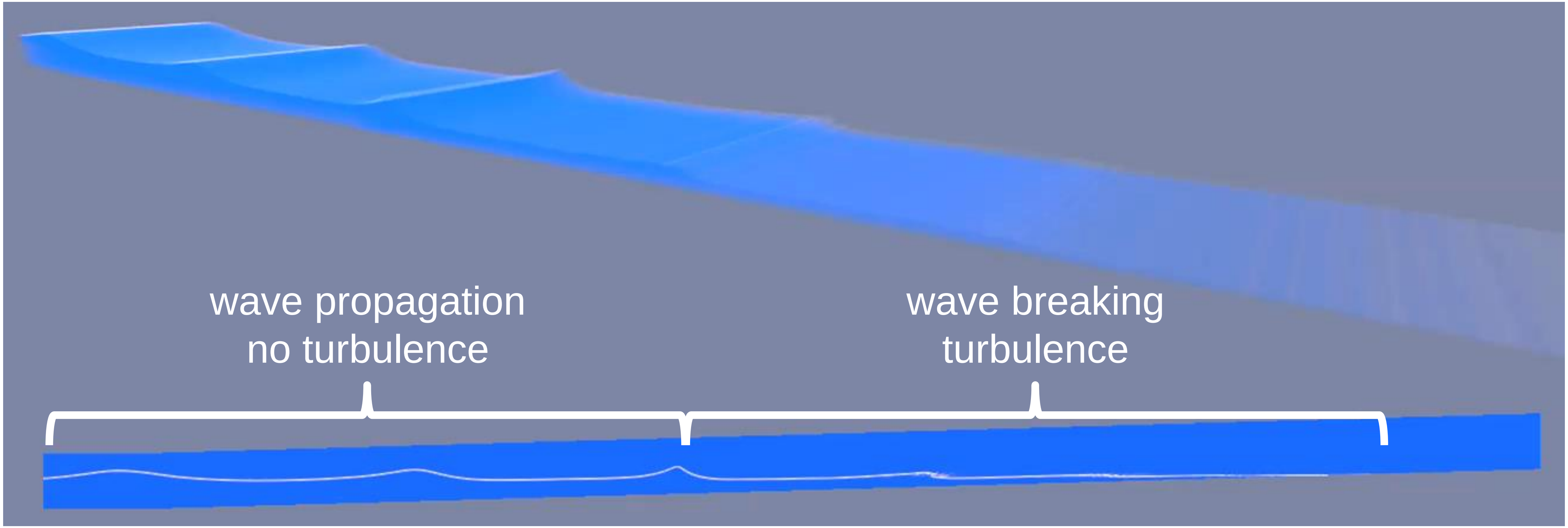
Wave run-up around a monopile





B. Devolder, P. Rauwoens, P. Troch, Application of a buoyancy-modified *k-ω SST* turbulence model to simulate wave run-up around a monopile subjected to regular waves using OpenFOAM®, Coast. Eng. 125 (2017) 81–94. doi:10.1016/j.coastaleng.2017.04.004.

Wave breaking: turbulence modelling



Experiments: F.C.K. Ting, J.T. Kirby, Observation of undertow and turbulence in a laboratory surf zone, Coast. Eng. 24 (1994) 51–80. doi:10.1016/0378-3839(94)90026-4.

…AND IT'S NOT ONLY ME…

PhD Vincent GRUWEZ (Ghent University, Department of Civil Engineering)

www.crestproject.be

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

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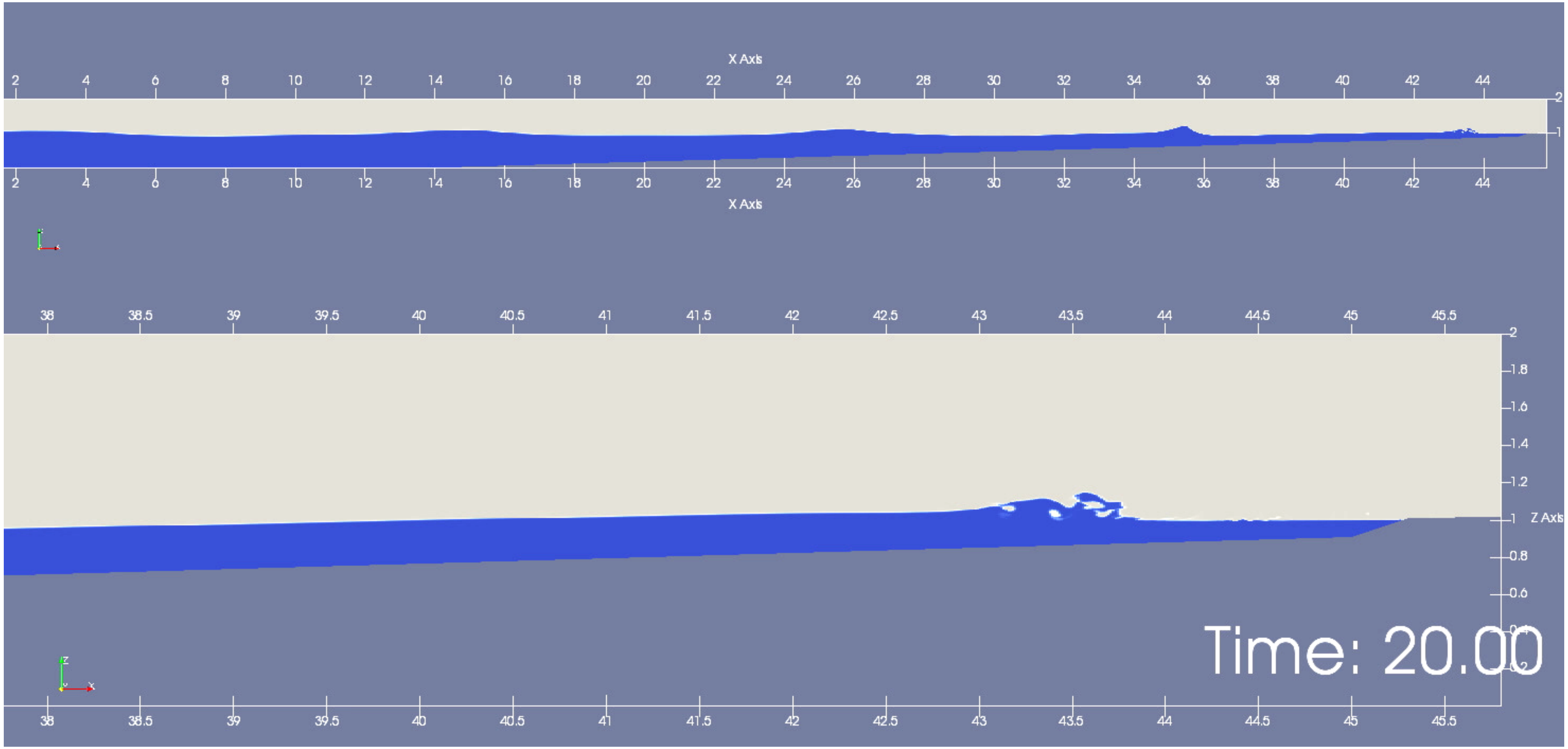


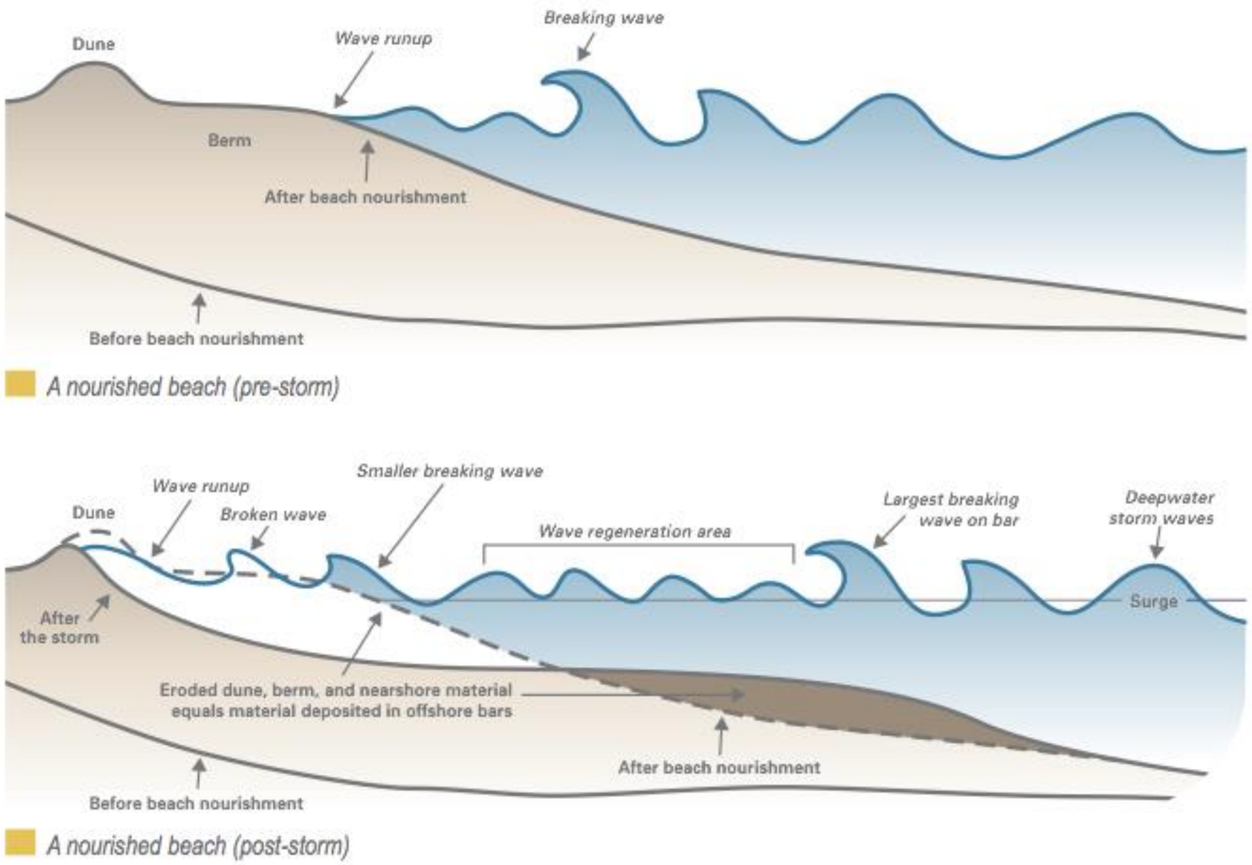
Experiments: Chen, Xuexue, Bas Hofland, Corrado Altomare, and J. S. W. Uijttewaal. “Overtopping Flow Impact on a Vertical Wall on a Dike Crest.” In ICCE 2014: Proceedings of 34th International Conference on Coastal Engineering, Seoul, Korea, 15-20 June 2014. Coastal Engineering Research Council, 2014.

PhD Ine VANDEBEEK (Ghent University and KU Leuven, Department of Civil Engineering)

www.crestproject.be

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

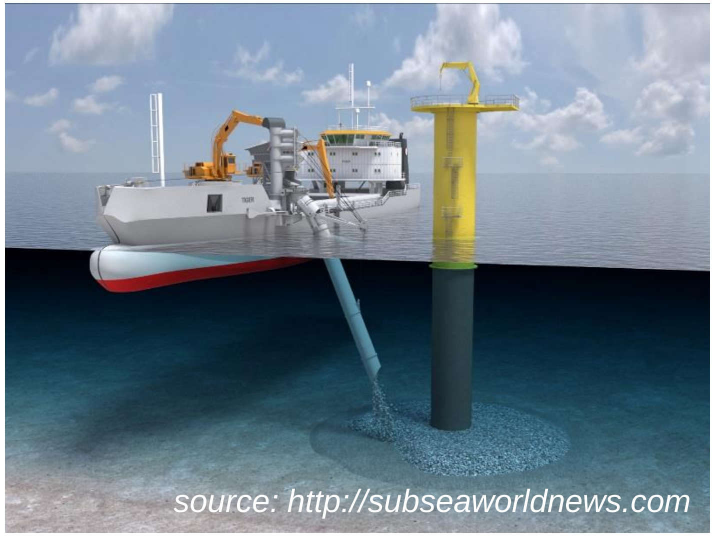


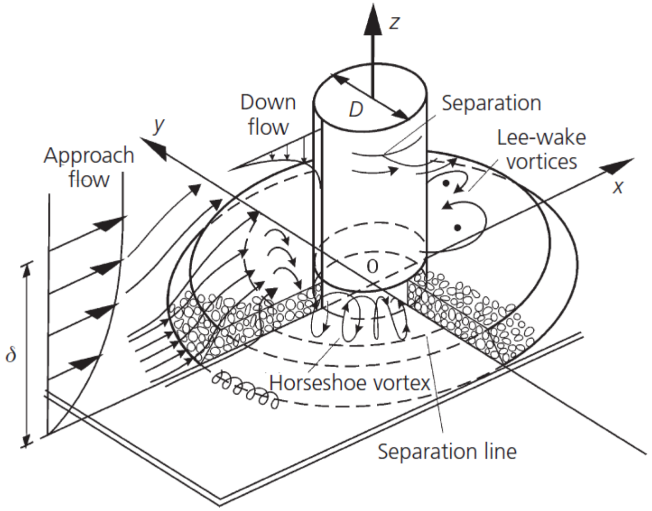
source: ASBPA and U.S. Army Corps of Engineers

PhD Carlos ARBOLEDA CHAVEZ (Ghent University, Department of Civil Engineering)

Scour protection around wind turbine monopile foundations in a combined wave and current condition

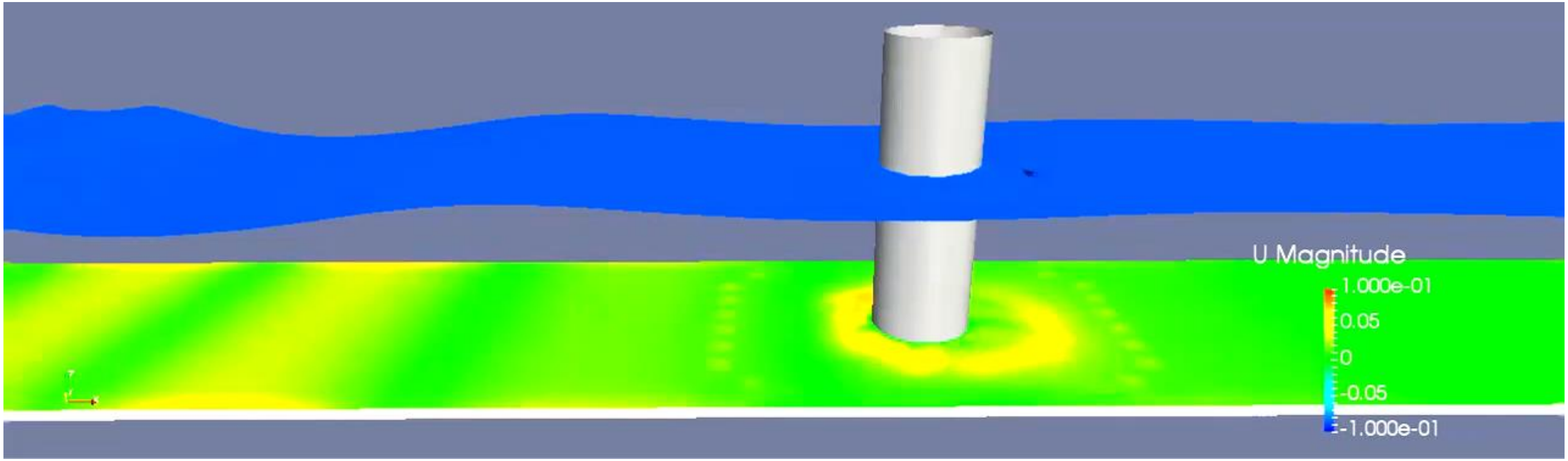
- Goal:
  - CFD modelling of combined waves and current
  - CFD modelling of the flow field inside porous media
- Methods
  - CFD modelling with OpenFOAM using the VoF method
  - Validation by using experimental data
- Status
  - Wave propagation towards the monopile


source: http://subseaworldnews.com



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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