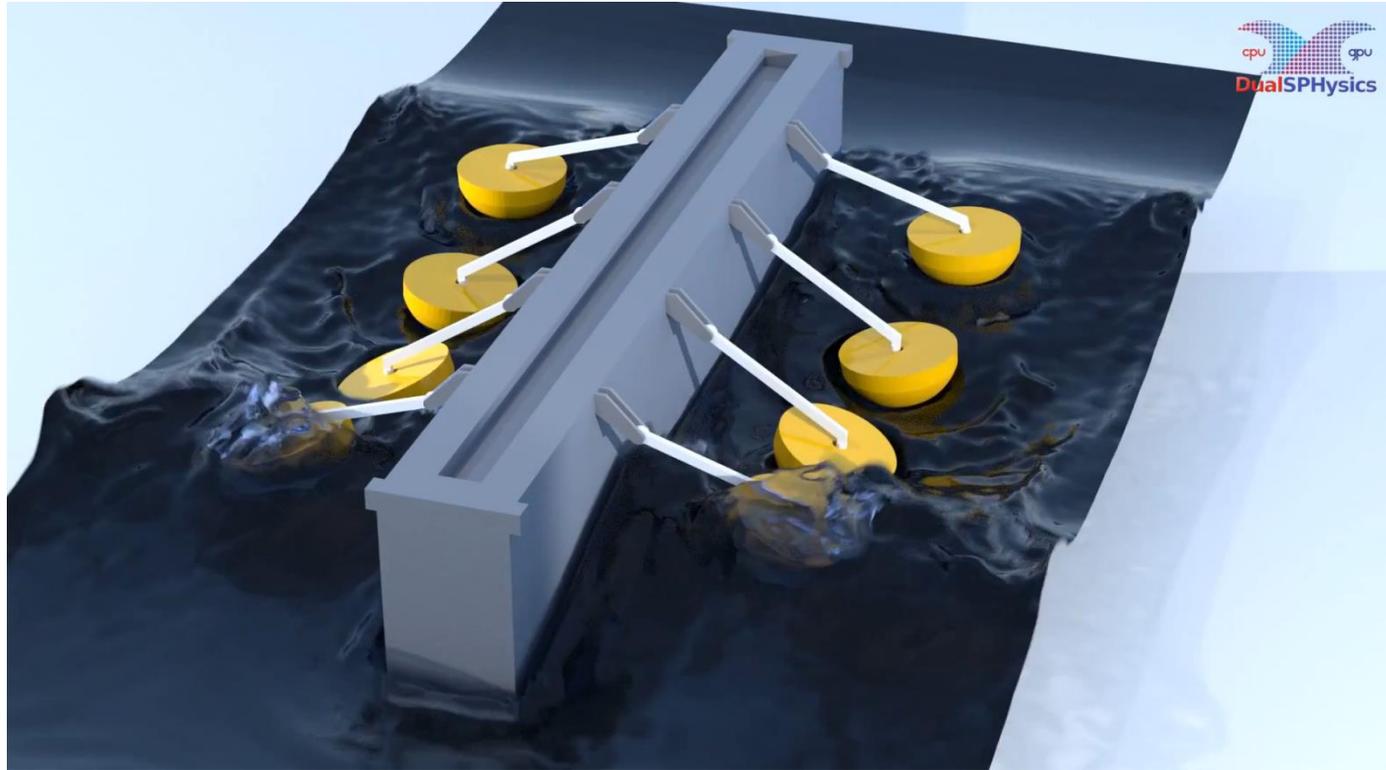


Numerical simulation of the full non-linear behaviour of Wave Energy Converters



Alejandro J. C. Crespo, M. Brito, J.M. Domínguez, R.B. Canelas, M. Hall, C. Altomare,
M. Wu, V. Stratigaki, P. Troch, L. Cappiotti, R.M. Ferreira, M. Gómez-Gesteira

Universidade de Vigo



OUTLINE

Objective: Numerical modelling of WECs

SPH modelling: DualSPHysics software

- Wave generation, propagation and absorption
- Wave-structure interaction
- Coupling with MoorDyn
- Coupling with Project Chrono

Application to different WECs

- Oscillating Water Column (OWC)
- Oscillating Wave Surge Converter (OWSC)
- Point absorber
- Others (WaveStar, M4)

Conclusions & Future work

OUTLINE

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Conclusions & Future work

OBJECTIVE

MAIN OBJECTIVE:

To develop a numerical tool that helps in the design and testing of WECs
(not only the efficiency but also the survivability)

CHALLENGES:

NWT (Numerical Wave Tank):

How to mimic wave flumes and basins and real sea state?

FSI (Wave-structure interaction):

How to solve large deformations of fixed and floating devices under extreme wave conditions?

PTO (POWER TAKE-OFF):

How to solve numerically the mechanical constraints?

Smoothed Particle Hydrodynamics (SPH)

Hydrodynamic interaction between WECs and ocean waves
is a complex high order non-linear process



FAST AND EFFICIENT
LOW AMPLITUDE MOTIONS

Linear approach

Time or frequency domain models

WAMIT, WADAM
Nemoh, WEC-SIM



TIME CONSUMING
VIOLENT FLOWS, VISCOUS FLOWS

CFD models

Approximate Navier–Stokes



**Meshbased
methods**

VOF, OpenFoam, IH-Foam,
Fluent, Fluinco, REEF3D



**Meshless
methods**

SPH

OUTLINE

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Conclusions & Future work

Smoothed Particle Hydrodynamics (SPH)

Navier-Stokes equations

**Mass
conservation**

$$\frac{d\rho}{dt} = -\rho \nabla \cdot \mathbf{v}$$

$$\left\langle \frac{d\rho}{dt} \right\rangle = \sum_j m_j (\mathbf{v}_i - \mathbf{v}_j) \cdot \nabla_i W_{ij}$$

**Momentum
conservation**

$$\frac{d\mathbf{v}}{dt} = -\frac{1}{\rho} \nabla p + \mathbf{F}$$

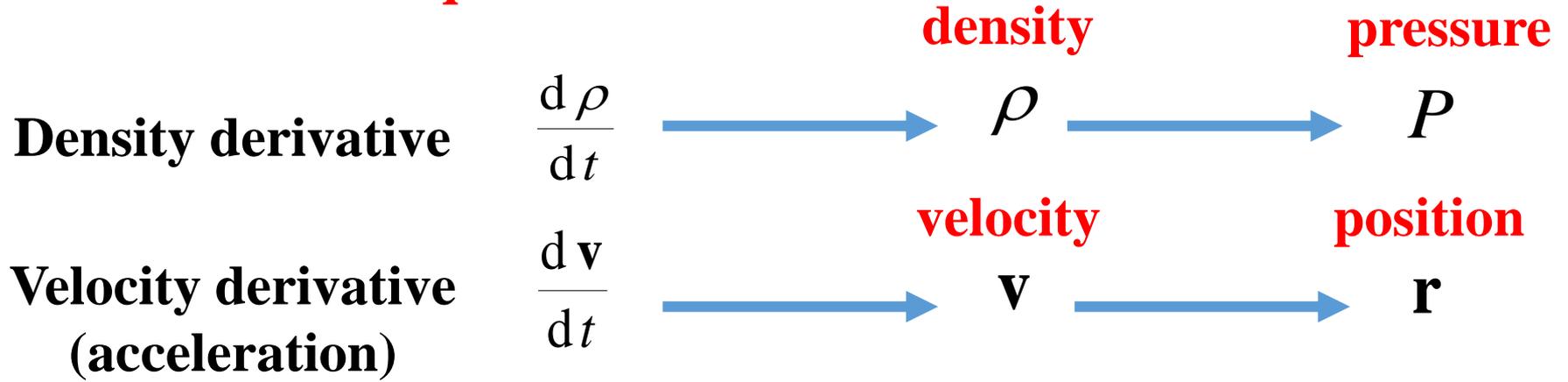
$$\left\langle \frac{d\mathbf{v}}{dt} \right\rangle = \sum_j m_j \left(\frac{p_j}{\rho_j^2} + \frac{p_i}{\rho_i^2} \right) \nabla_i W_{ij}$$

**Continuous notation
(INTEGRALS)**

**Discrete notation
(SUMMATIONS)**

Smoothed Particle Hydrodynamics (SPH)

Navier-Stokes equations

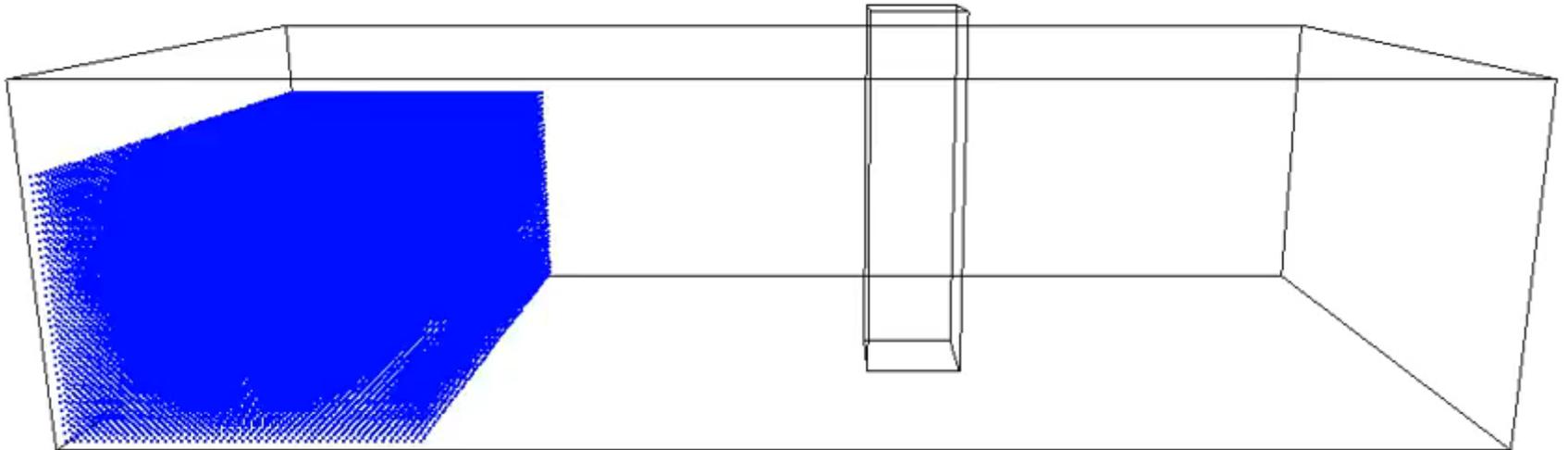
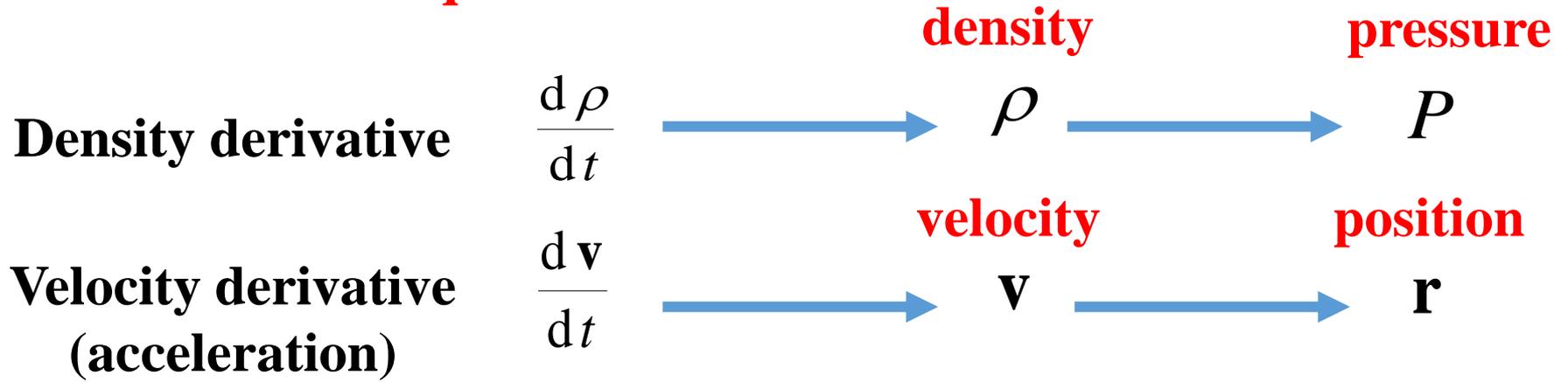


State equation for barotropic fluids

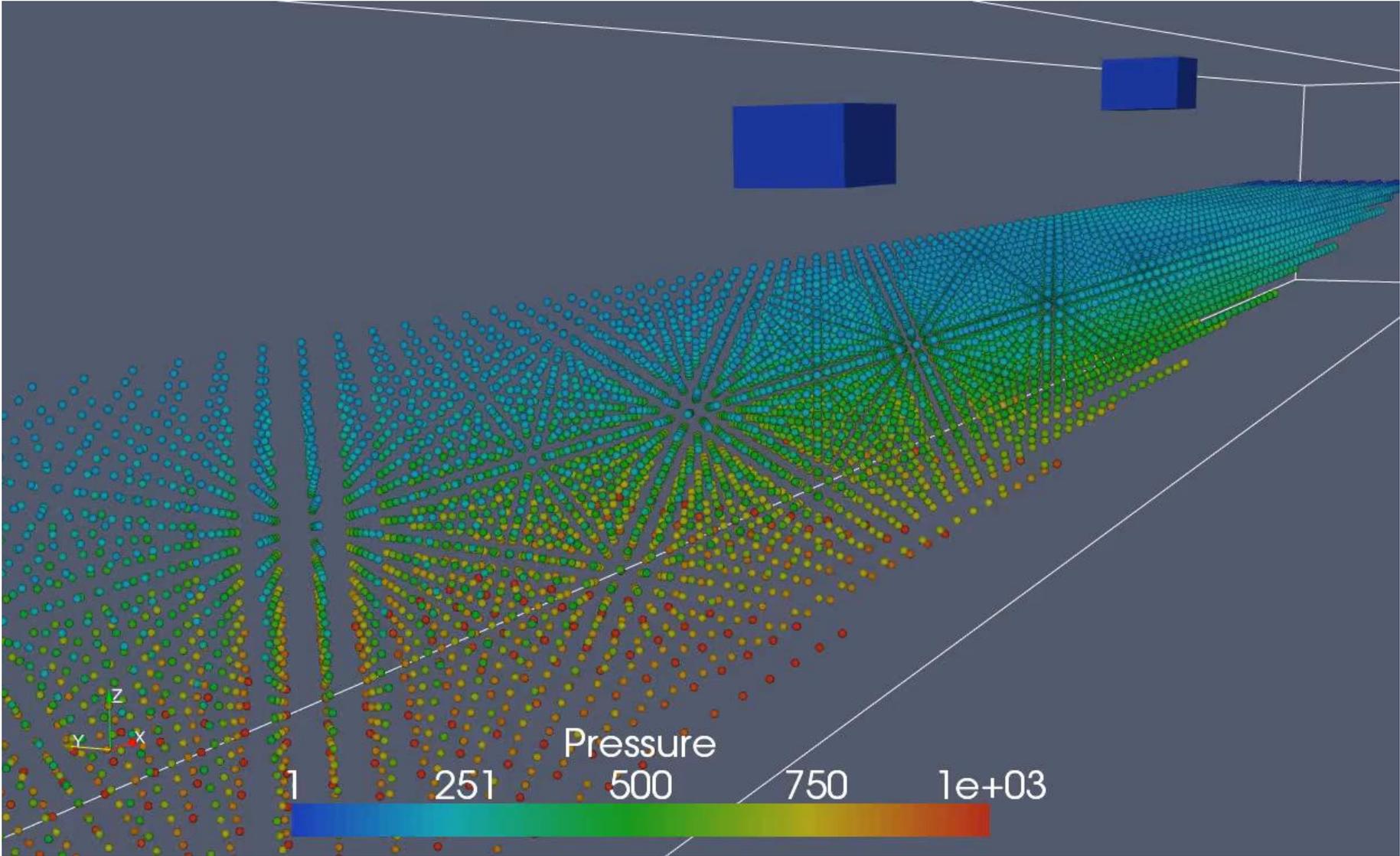
$$P = F(\rho) \quad \text{nearly incompressible fluids (small density variations)!}$$

Smoothed Particle Hydrodynamics (SPH)

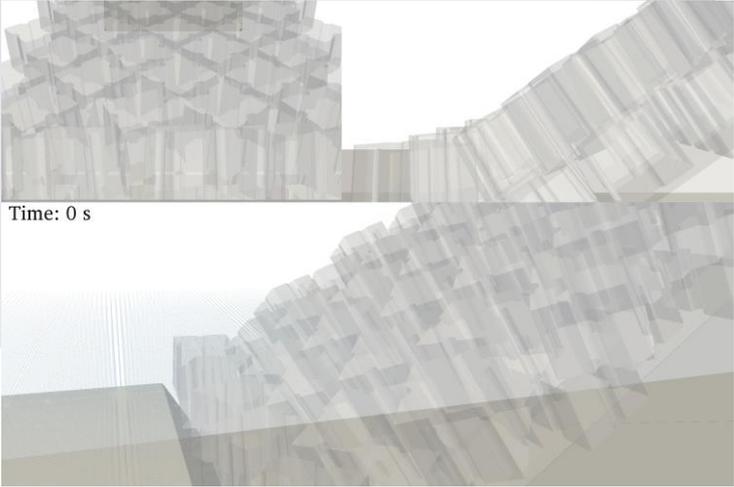
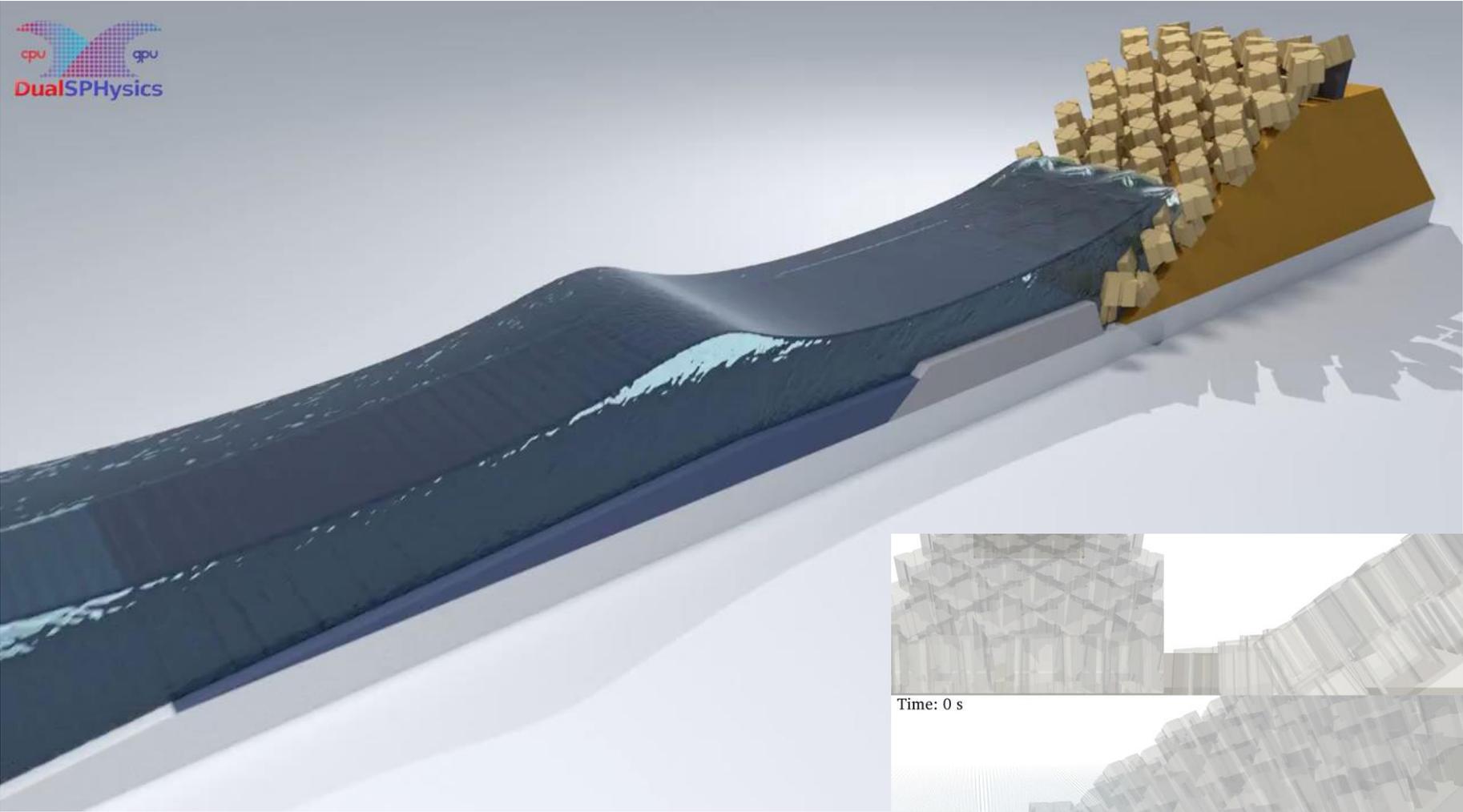
Navier-Stokes equations



Smoothed Particle Hydrodynamics (SPH)



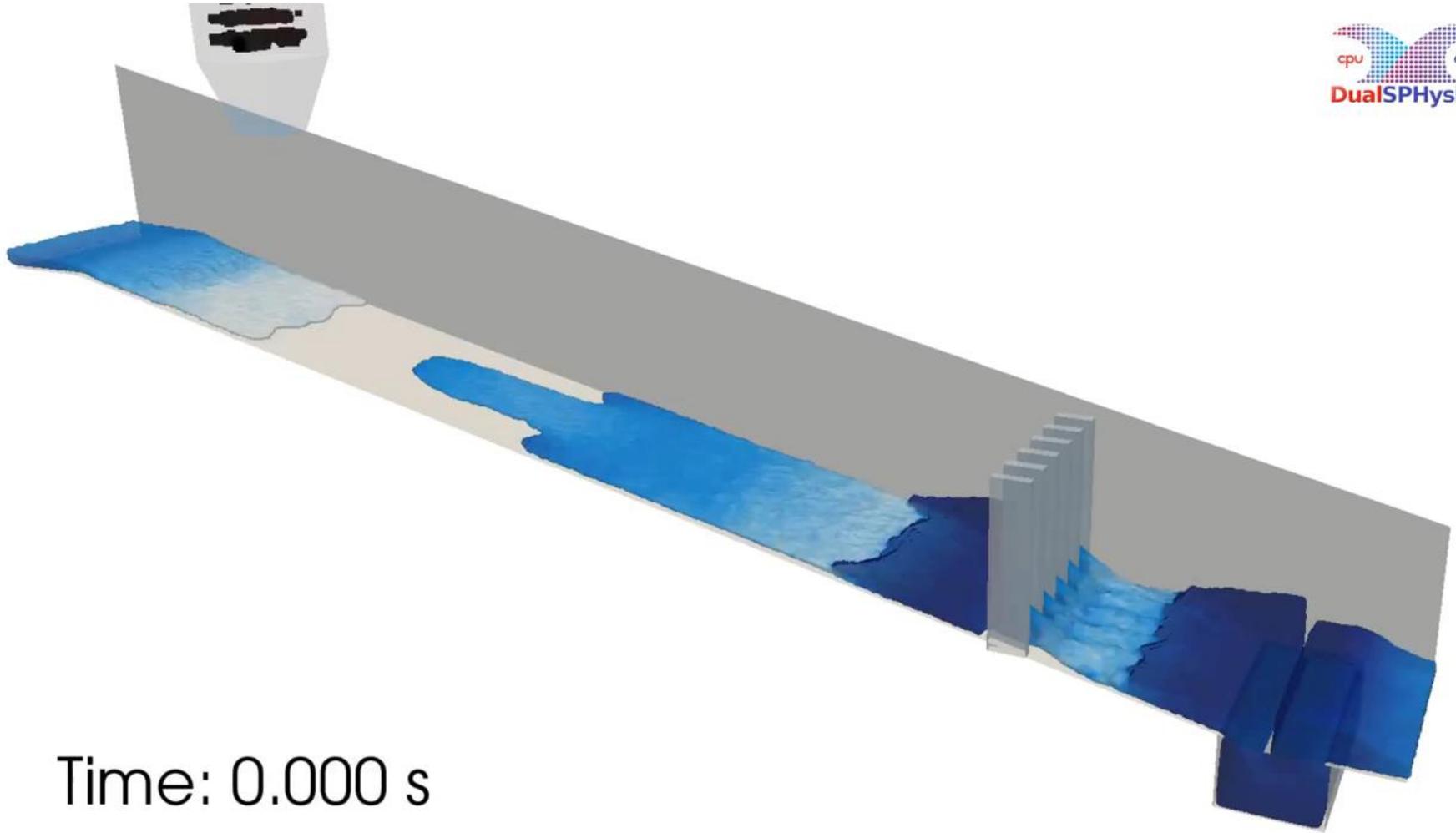
Smoothed Particle Hydrodynamics (SPH)



Smoothed Particle Hydrodynamics (SPH)



Smoothed Particle Hydrodynamics (SPH)



Time: 0.000 s

Smoothed Particle Hydrodynamics (SPH)

ADVANTAGES comparing with mesh-based CFD codes:

- ✓ Efficient treatment of the **large deformation** of free surfaces since there is no mesh distortion and **no need for a special treatment of the surface**
- ✓ Handling **complex geometries** and **high deformation**
- ✓ Distinguishing **between phases** due to holding material properties at each particle
- ✓ Natural incorporation of coefficient discontinuities and **singular forces**

DISADVANTAGES comparing with mesh-based CFD codes:

- ✓ There is still no unanimity to choose the best solid **boundary conditions**.
- ✓ **Turbulence treatment** is still an open field and more research is needed.
- ✓ **Time computation is expensive** comparing with other methods

DualSPHysics software

OPEN-SOURCE CODE

AVAILABLE FOR FREE

COLLABORATIVE PROJECT

LGPL LICENSE

HIGHLY PARALLELISED

PRE- & POST-PROCESSING

APPLIED TO REAL PROBLEMS

OPEN PROJECT

DualSPHysics

[FAQ](#) [References](#) [Downloads](#) [Validation](#) [Animations](#) [SPHysics](#) [GPU Computing](#)
[Features](#) [WIKI](#) [GUI](#) [Visualization](#) [Developers](#) [Contact](#) [Forum](#) [News](#)



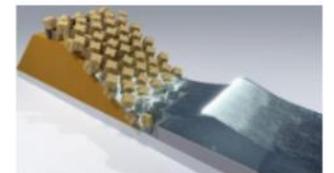
DualSPHysics is based on the Smoothed Particle Hydrodynamics model named SPHysics (www.sphysics.org).

The code is developed to study free-surface flow phenomena where Eulerian methods can be difficult to apply, such as waves or impact of dam-breaks on off-shore structures. DualSPHysics is a set of C++, CUDA and Java codes designed to deal with real-life engineering problems.

Contact E-Mail: dualsphysics@gmail.com

Youtube Channel: www.youtube.com/user/DualSPHysics

Twitter Account: [@DualSPHysics](https://twitter.com/DualSPHysics)



www.dual.sphysics.org

DualSPHysics software

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Industrial interest:

NASA JSC, BAE Systems, Volkswagen AG, McLaren Racing Ltd, Forum NOKIA, NVIDIA, AECOM, HDR Engineering, ABPmer, DLR, CFD-NUMERICS, BMT Group, Oak Ridge National Laboratory, Rainpower Norway, Shell Company, ABB, FEMTO Engineering ...

Wave energy companies:

American Wave Machines, Carnegie Clean Energy Ltd, Maine Marine Composites, National Renewable Energy Laboratory in U.S.A., Atria Power Corporation Ltd., Global Hydro Energy, WavePower

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OPEN PROJECT

DEVELOPERS:

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The University of Manchester, UK

Instituto Superior Tecnico, Lisbon, Portugal

Università degli studi di Parma, Italy

Flanders Hydraulics Research, Belgium

New Jersey Institute of Technology, USA



COLLABORATORS:

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TECNALIA. Inspiring Business, Spain

Universitat Politècnica de Catalunya

Imperial College London, UK

Universiteit Gent, Belgium

University of Salerno, Italy

New Jersey Institute of Technology, USA

Universidad de Guanajuato, Mexico

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LGPL (Lesser General Public License)
can be used in **commercial** applications

Software can be incorporated into both:

- free software and
- proprietary software



DualSPHysics software

OPEN-SOURCE CODE

AVAILABLE FOR FREE

COLLABORATIVE PROJECT

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PRE- & POST-PROCESSING

APPLIED TO REAL PROBLEMS

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GPU  CPU
x100

DualSPHysics software

Graphical User Interface  **FreeCAD**
Open Source parametric 3D CAD modeler

OPEN-SOURCE CODE

AVAILABLE FOR FREE

COLLABORATIVE PROJECT

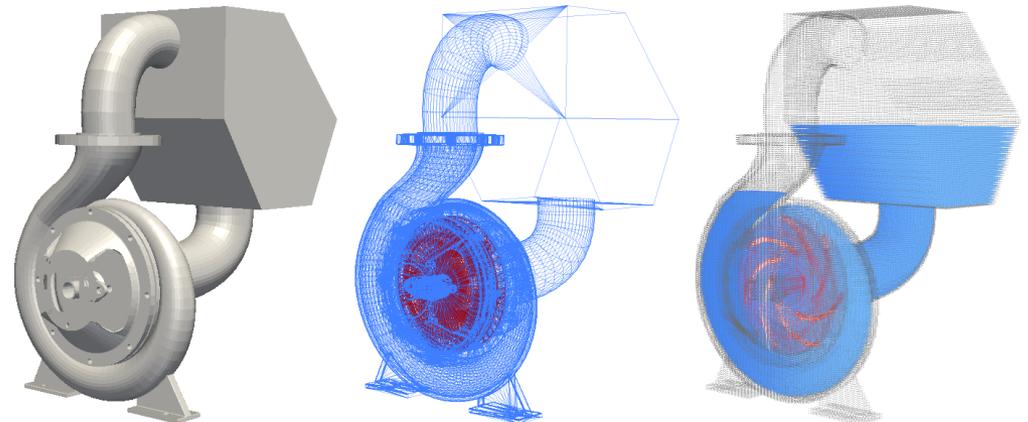
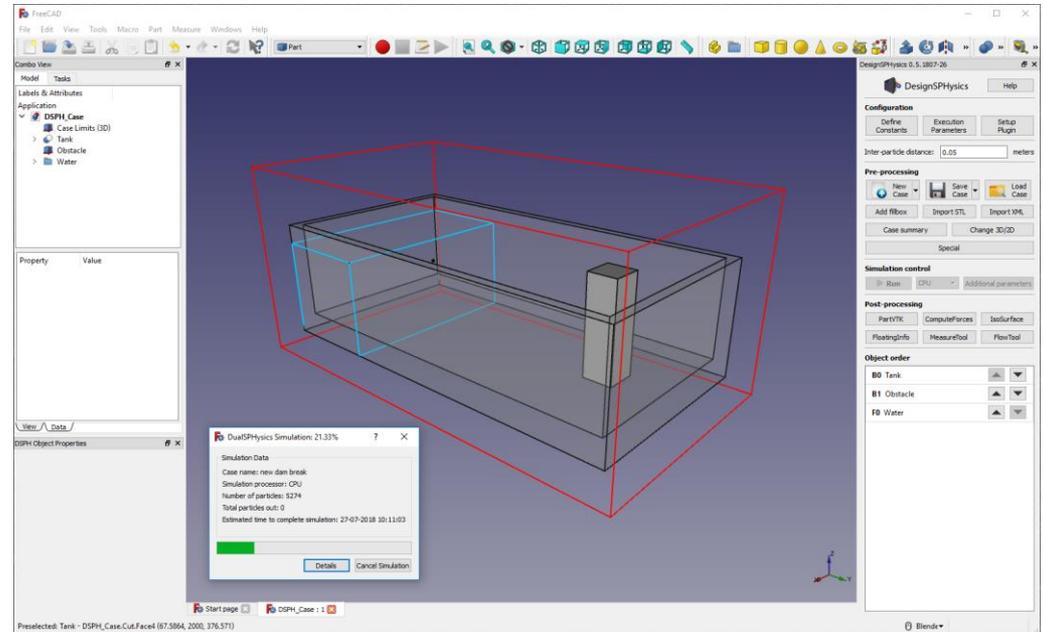
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APPLIED TO REAL PROBLEMS

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DualSPHysics software

Advanced visualisation



OPEN-SOURCE CODE

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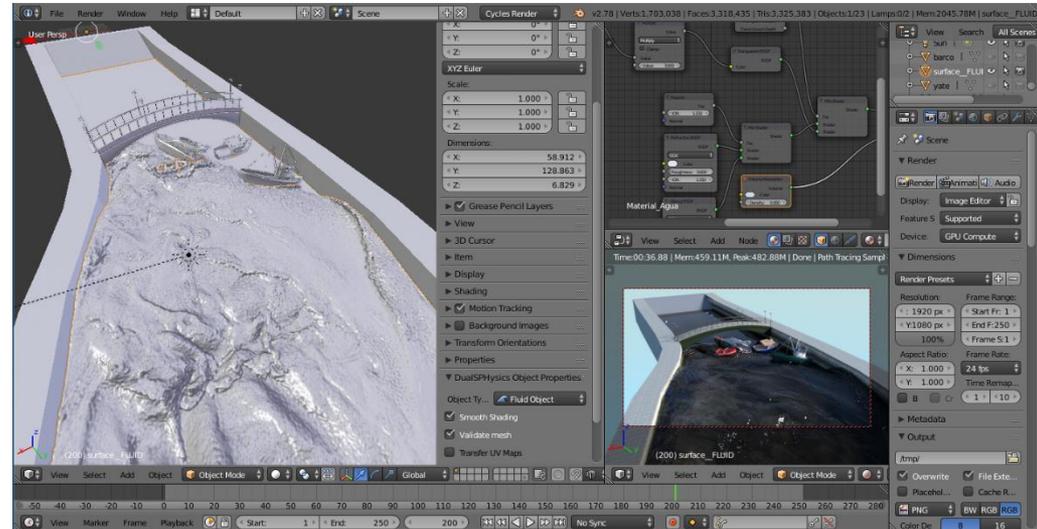
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DualSPHysics software

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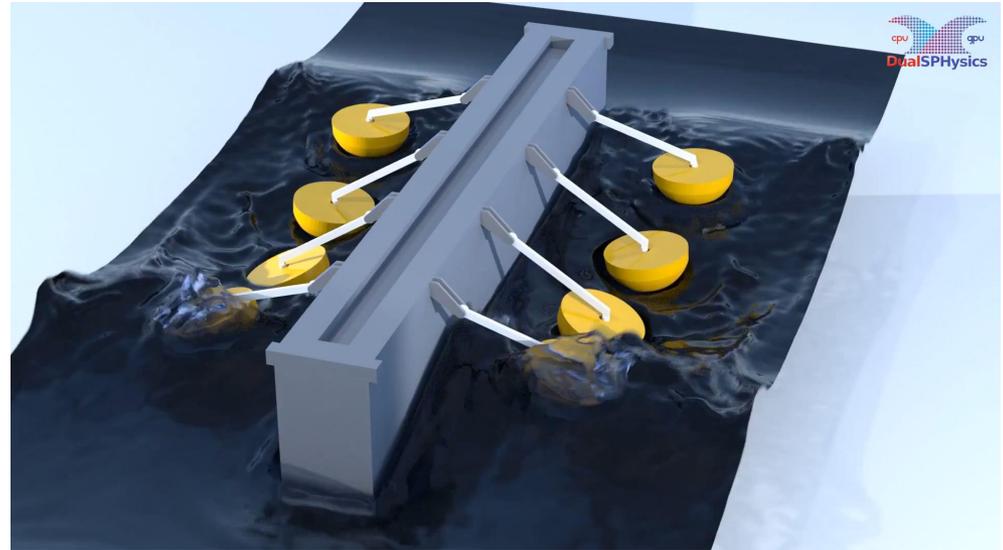
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APPLIED TO REAL PROBLEMS

OPEN PROJECT



DualSPHysics software

DualSPHysics Package
<http://dual.sphysics.org>

OPEN-SOURCE CODE

AVAILABLE FOR FREE

COLLABORATIVE PROJECT

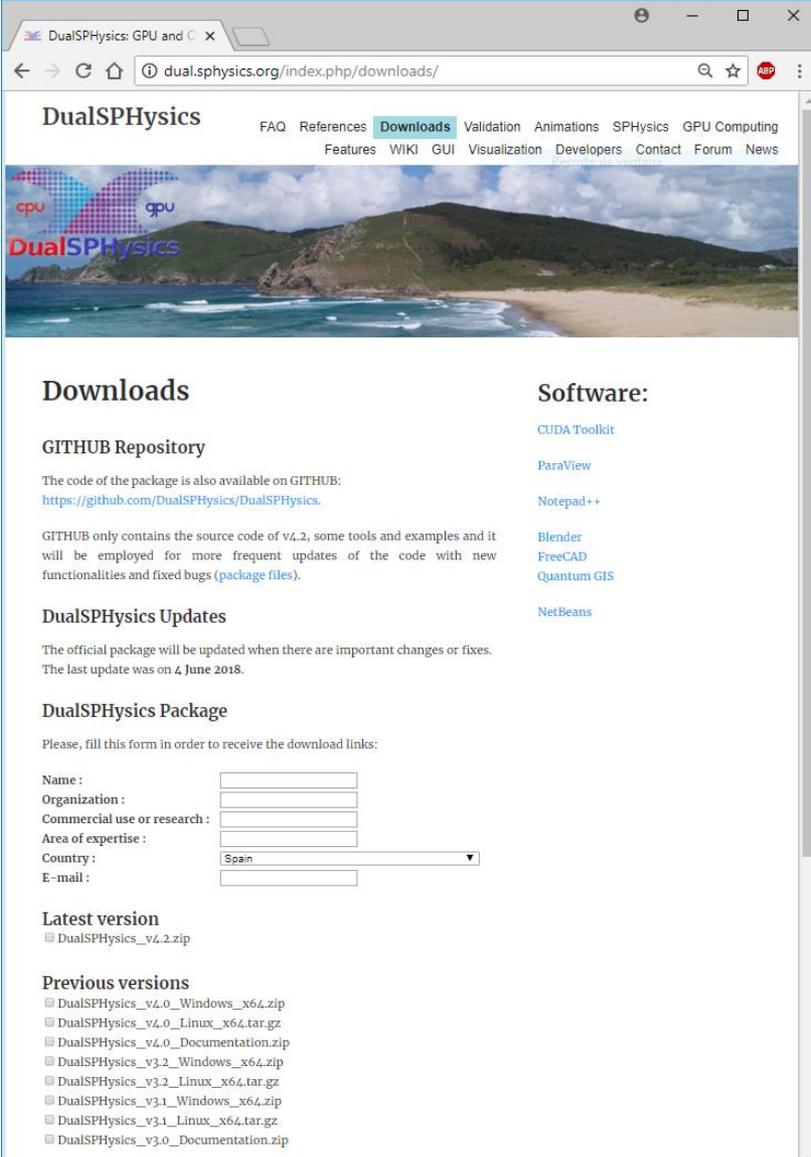
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PRE- & POST-PROCESSING

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OPEN PROJECT



The screenshot shows a web browser window displaying the 'Downloads' page of the DualSPHysics website. The browser's address bar shows the URL 'dual.sphysics.org/index.php/downloads/'. The website header includes navigation links for 'FAQ', 'References', 'Downloads', 'Validation', 'Animations', 'SPHysics', 'GPU Computing', 'Features', 'WIKI', 'GUI', 'Visualization', 'Developers', 'Contact', 'Forum', and 'News'. Below the header is a banner image of a beach with the DualSPHysics logo and 'cpu' and 'gpu' icons. The main content area is divided into two columns. The left column contains sections for 'Downloads', 'GITHUB Repository' (with a link to the GitHub repository), 'DualSPHysics Updates' (stating the last update was on 4 June 2018), and 'DualSPHysics Package' (with a form to request download links). The right column contains a 'Software:' section with links to 'CUDA Toolkit', 'ParaView', 'Notepad++', 'Blender', 'FreeCAD', 'Quantum GIS', and 'NetBeans'. At the bottom, there are sections for 'Latest version' (DualSPHysics_v4.2.zip) and 'Previous versions' (listing various zip and tar.gz files for versions 4.0, 3.2, and 3.1).

DualSPHysics software

OPEN-SOURCE CODE

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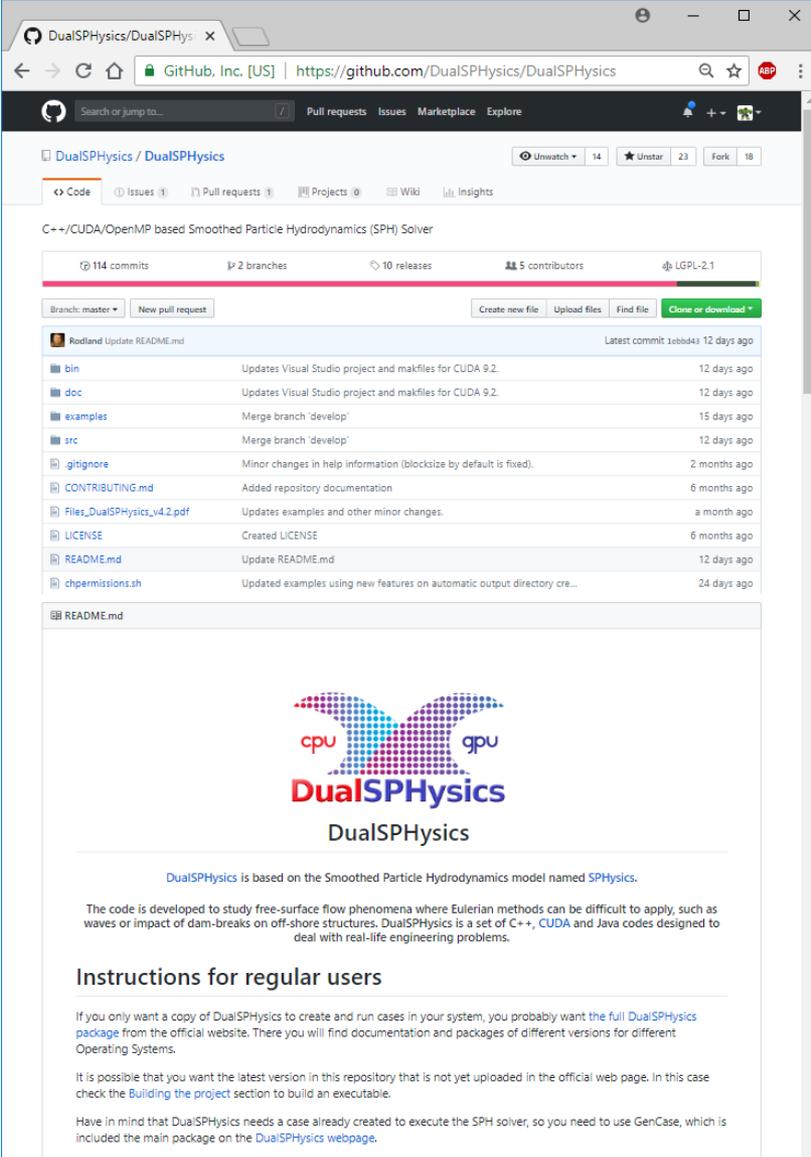
PRE- & POST-PROCESSING

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OPEN PROJECT

DualSPHysics Code on GitHub

<https://github.com/DualSPHysics/DualSPHysics>



C++/CUDA/OpenMP based Smoothed Particle Hydrodynamics (SPH) Solver

114 commits 2 branches 10 releases 5 contributors LGPL-2.1

Branch: master New pull request Create new file Upload files Find file Clone or download

Commit	Message	Time
Rodland Update README.md	Latest commit 1ebbd43	12 days ago
bin	Updates Visual Studio project and makfiles for CUDA 9.2.	12 days ago
doc	Updates Visual Studio project and makfiles for CUDA 9.2.	12 days ago
examples	Merge branch 'develop'	15 days ago
src	Merge branch 'develop'	12 days ago
.gitignore	Minor changes in help information (blocksize by default is fixed).	2 months ago
CONTRIBUTING.md	Added repository documentation	6 months ago
Files_DualSPHysics_v4.2.pdf	Updates examples and other minor changes.	a month ago
LICENSE	Created LICENSE	6 months ago
README.md	Update README.md	12 days ago
chpermissions.sh	Updated examples using new features on automatic output directory cre...	24 days ago

README.md



DualSPHysics

DualSPHysics is based on the Smoothed Particle Hydrodynamics model named SPHysics.

The code is developed to study free-surface flow phenomena where Eulerian methods can be difficult to apply, such as waves or impact of dam-breaks on off-shore structures. DualSPHysics is a set of C++, CUDA and Java codes designed to deal with real-life engineering problems.

Instructions for regular users

If you only want a copy of DualSPHysics to create and run cases in your system, you probably want the full DualSPHysics package from the official website. There you will find documentation and packages of different versions for different Operating Systems.

It is possible that you want the latest version in this repository that is not yet uploaded in the official web page. In this case check the [Building the project](#) section to build an executable.

Have in mind that DualSPHysics needs a case already created to execute the SPH solver, so you need to use GenCase, which is included in the main package on the [DualSPHysics webpage](#).

If you need help check out the [wiki](#) for this project.

Wave propagation and absorption

Regular waves (H=0.1m;T=1.3s)

Time: 0.00s



INCIDENT WAVE
+ REFLECTED WAVE
+ RE-REFLECTED WAVE

Regular waves with Passive Absorption (BEACH)



Regular waves with Passive Absorption (SPONGE)



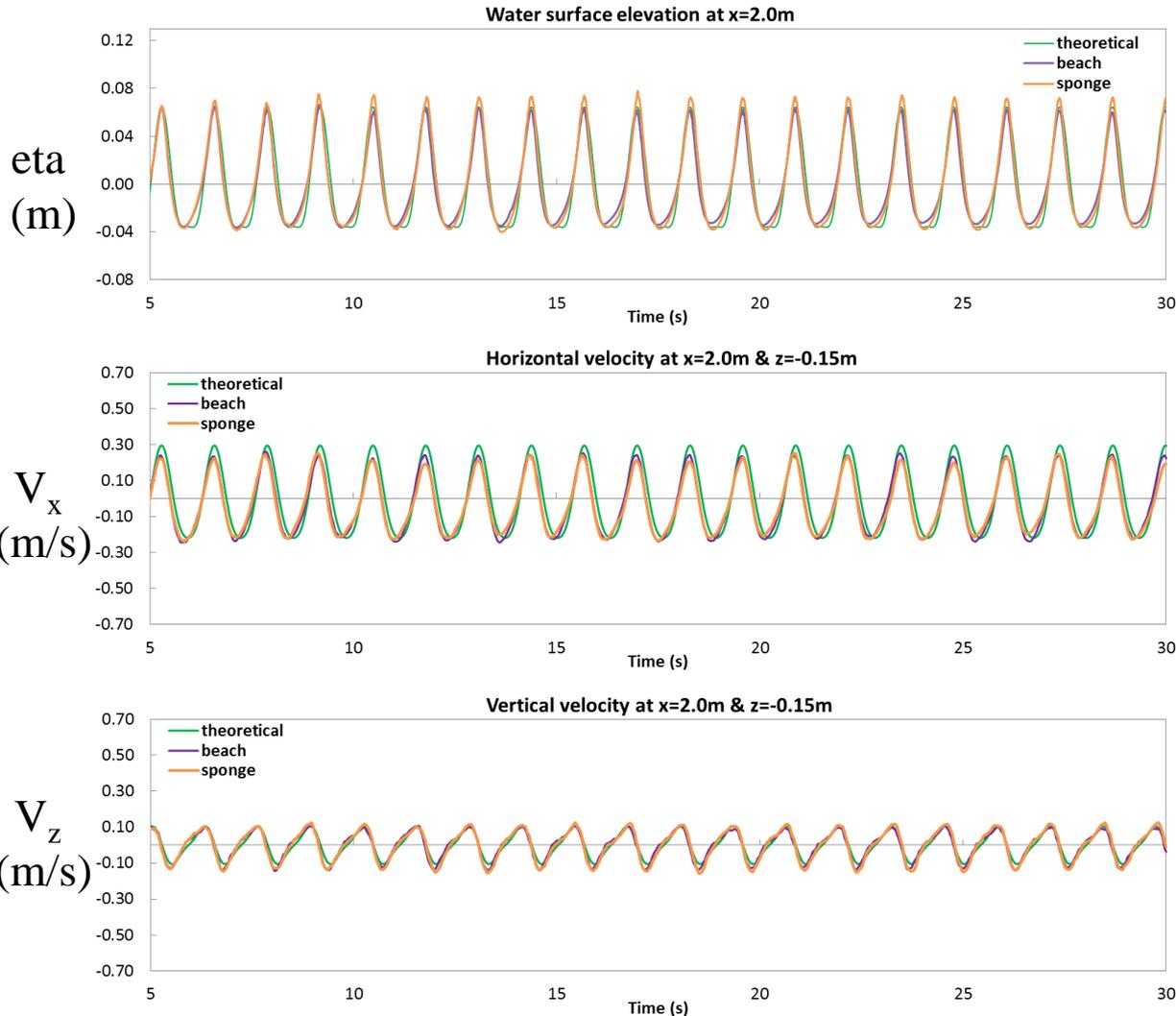
Regular waves with Active Absorption (AWAS)



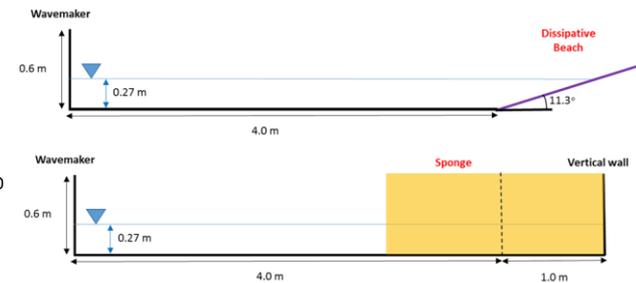
INCIDENT WAVE
+ REFLECTED WAVE

Wave propagation and absorption

Regular waves: $H=0.1\text{m}$, $T=1.3\text{s}$



THEORY
2nd Stokes
VS
SPH



Wave-structure interaction

Interaction between waves and fixed structures: RUN-UP

DualSPHysics was validated using **TIME SERIES** of Run-up!!!



Experiments performed in the CIEMito wave flume at LIM-UPC (Barcelona)

Web: <http://ciemlab.upc.edu/>



UNIVERSITAT POLITÈCNICA
DE CATALUNYA
BARCELONATECH

Wave-structure interaction

Interaction between waves and fixed structures: RUN-UP

AMOUR BLOCK DIKE



Wave-structure interaction

Interaction between waves and fixed structures: RUN-UP

AMOUR BLOCK DIKE

Initial particle distance: $dp=0.008$ m with $h/dp=2.6$

Wendland kernel with interaction distance of $2h$

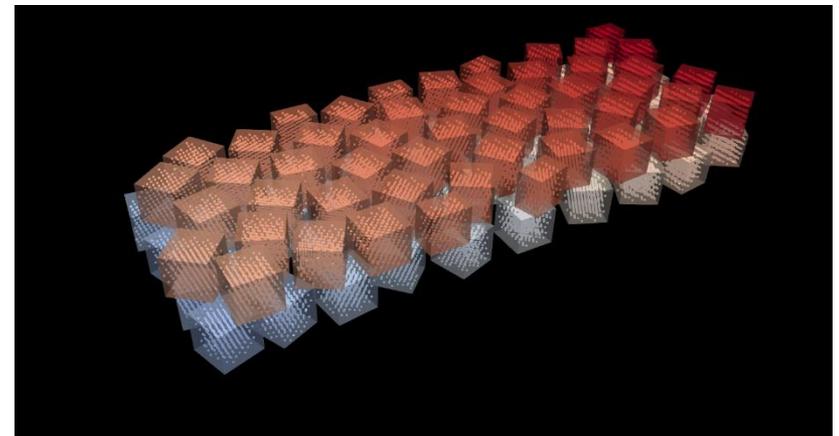
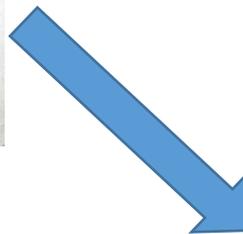
Total number of particles with depth= 0.25 leads to **1,133,955**

Physical time to be simulated: 20 seconds

Computational time using **GeForce RTX 2080 Ti** GPU card was **15.4h (160,130 steps)**

Piston motion following external file (time and x-position)

Exact position of the blocks in STL file

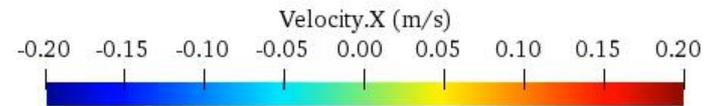
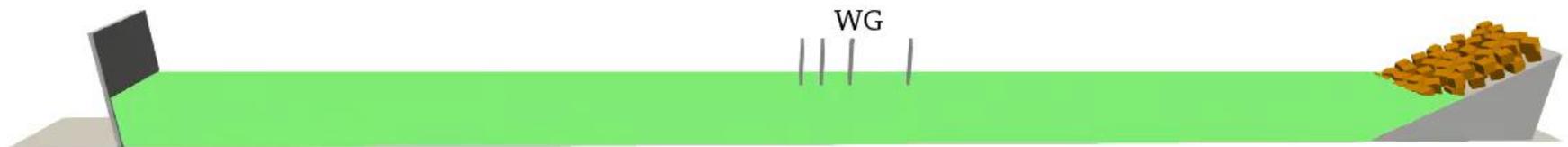


Wave-structure interaction

Interaction between waves and fixed structures: RUN-UP



CIEMito experiment: Run-up over breakwater



Time: 0.00 s

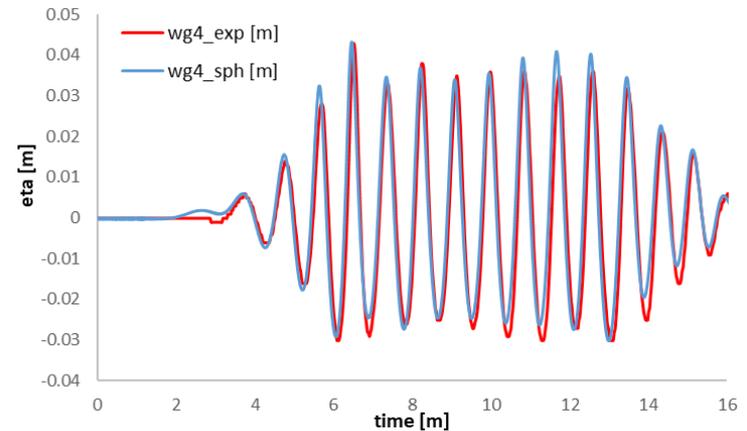
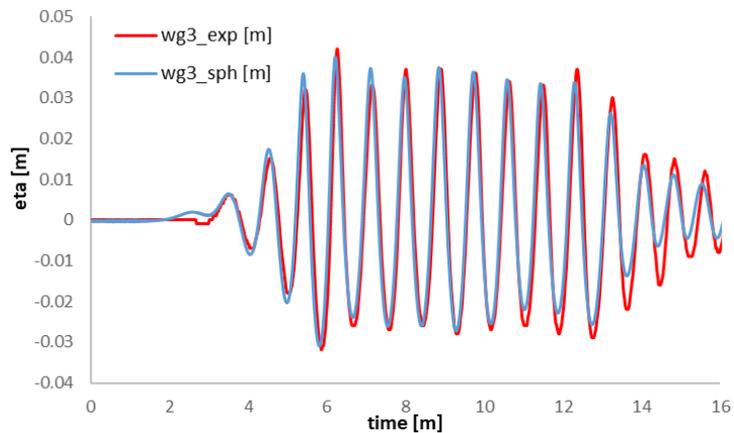
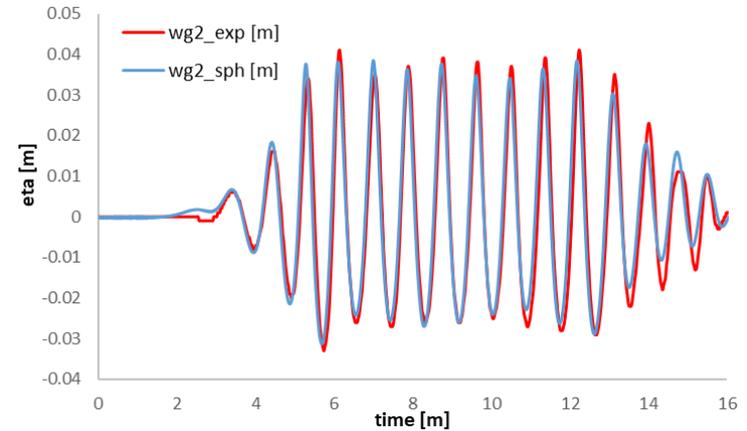
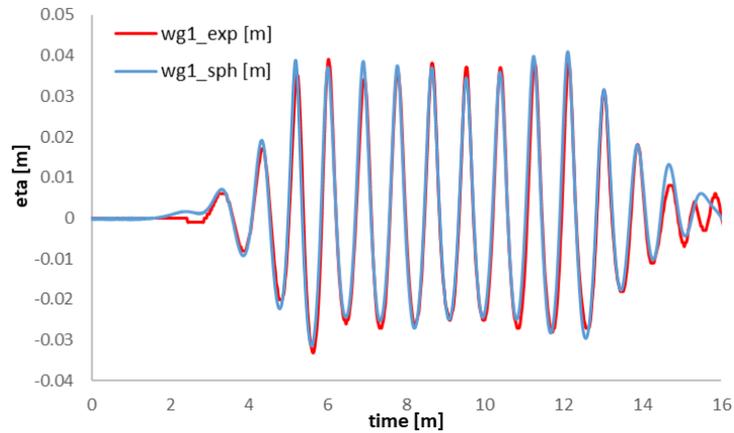


Wave-structure interaction

Interaction between waves and fixed structures: RUN-UP

AMOUR BLOCK DIKE

Case#7: $H=0.08$ m, $T=0.87$ s, $d=0.25$ m



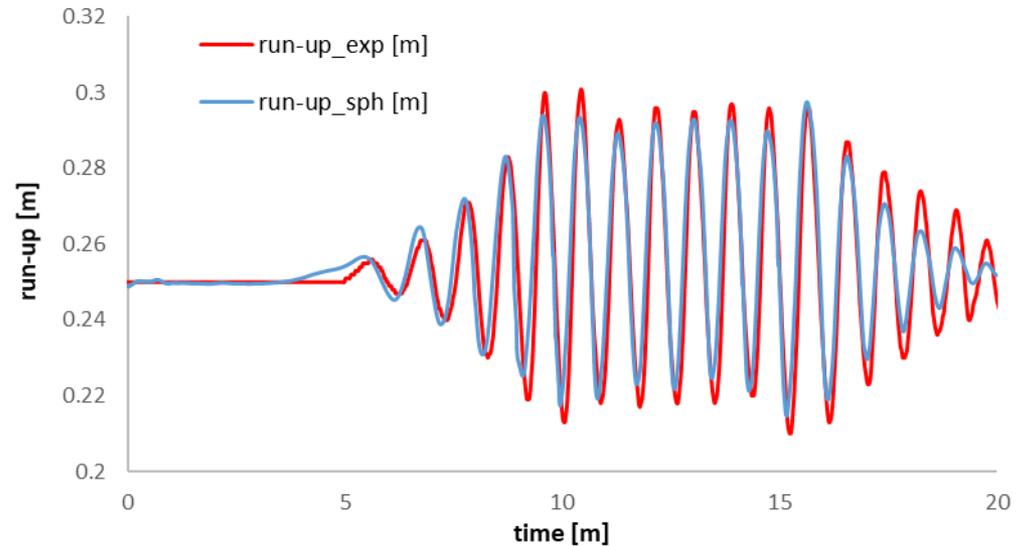
Time series of the experimental and numerical surface elevation

Wave-structure interaction

Interaction between waves and fixed structures: RUN-UP

AMOUR BLOCK DIKE

Case#7: $H=0.08$ m, $T=0.87$ s, $d=0.25$ m

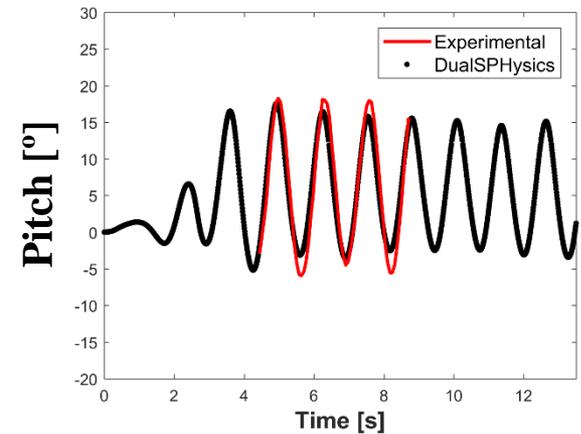
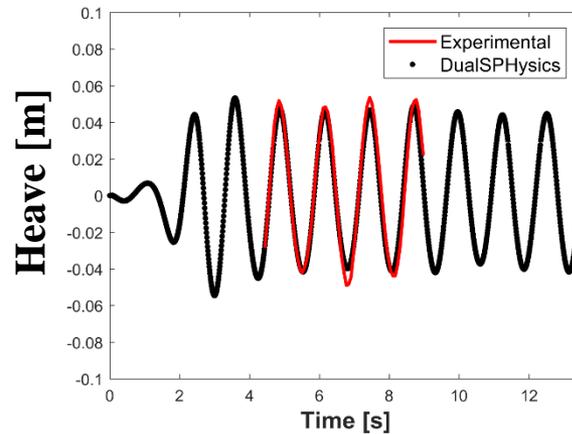
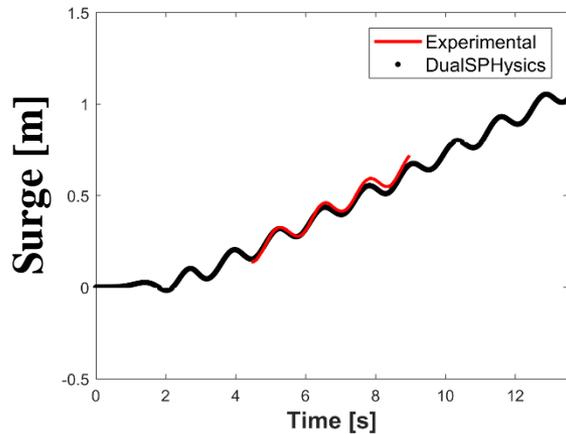
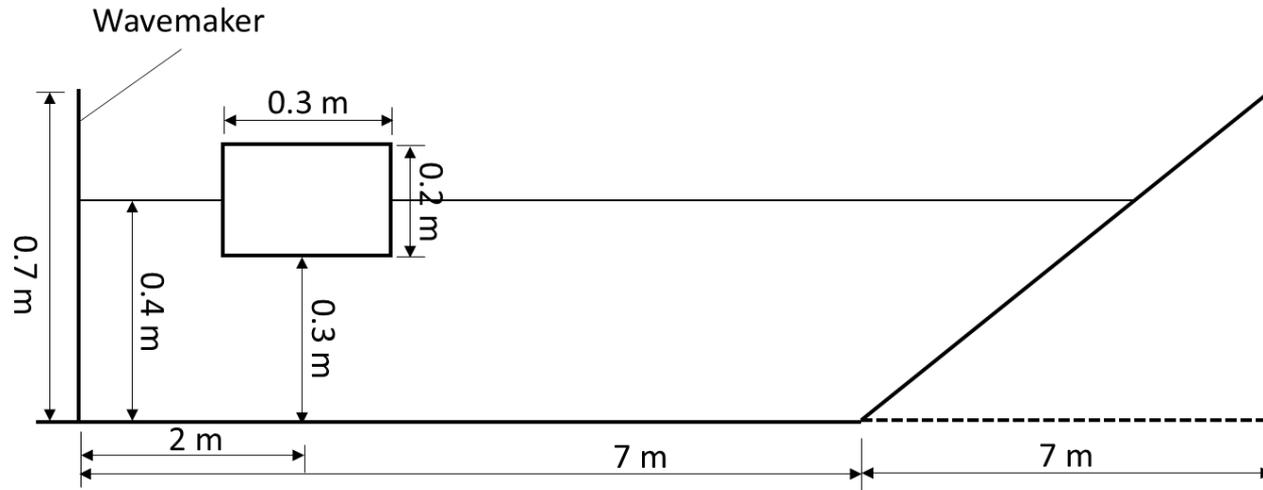


Time series of the experimental and numerical RUNUP

Wave-structure interaction II

Interaction between waves and floating structures

Floating BOX subjected to REGULAR WAVES



Wave-structure interaction II

Interaction between waves and floating structures

Validation of a floating box interacting with waves



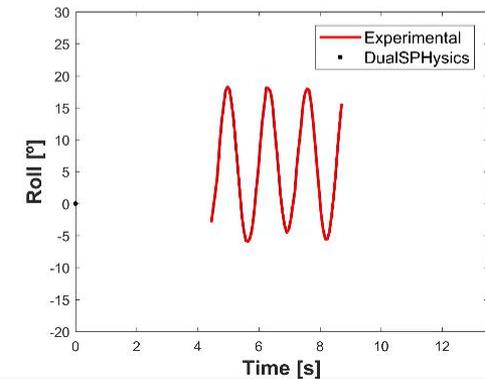
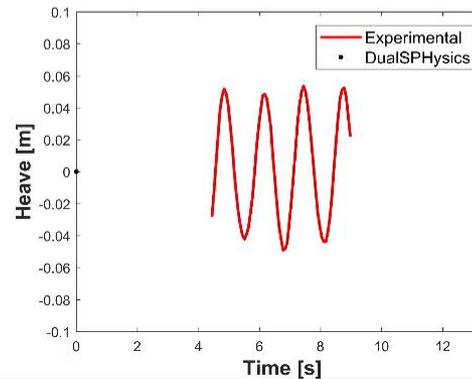
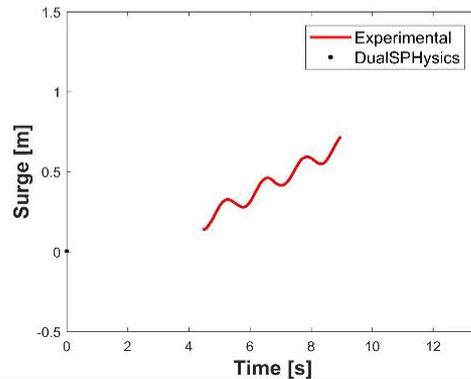
Regular waves:
 $H=0.1\text{m}$, $T=1.2\text{s}$, $d=0.4\text{m}$

Box dimensions:
 $0.3\text{m} \times 0.2\text{m}$

Wave absorption

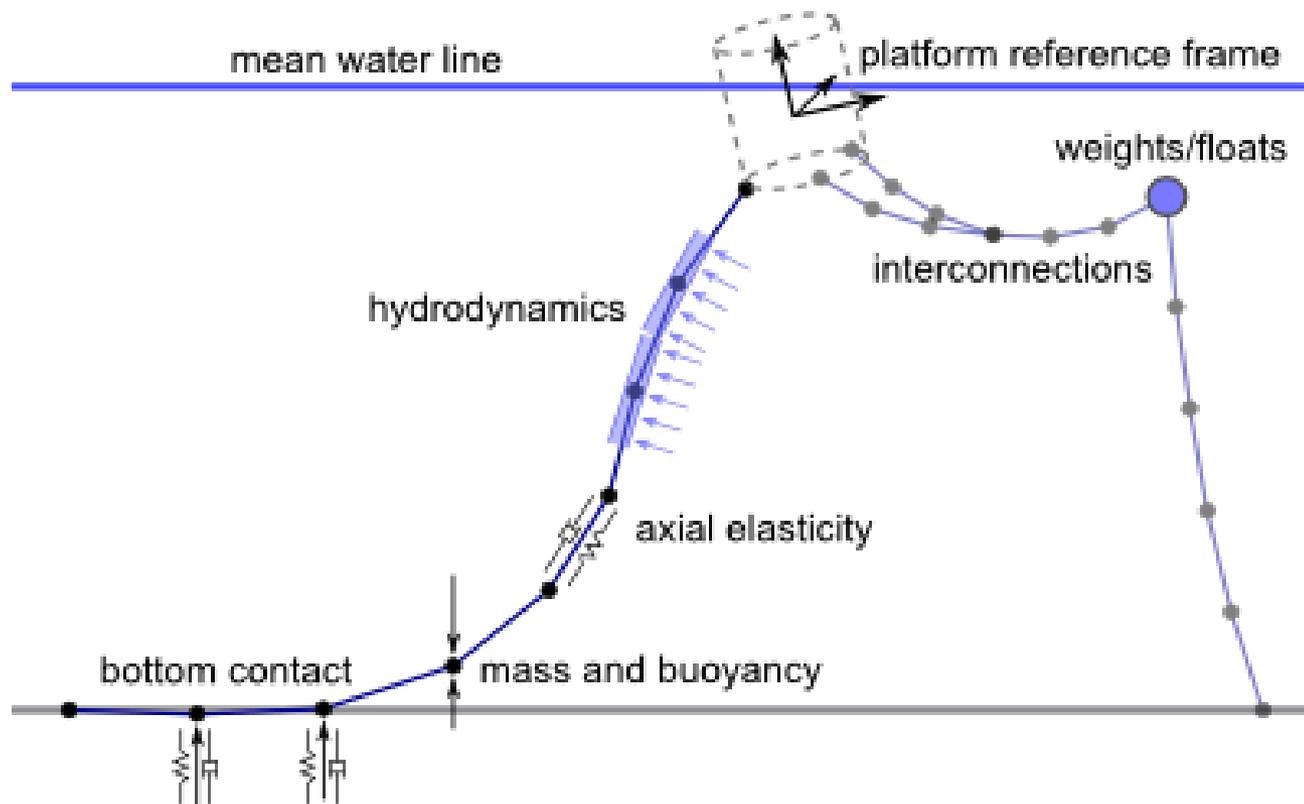


Time: 0.00 s



Coupling with MoorDyn

MoorDyn is an open-source dynamic **mooring** line model that uses a lumped-mass formulation for modelling axial elasticity, hydrodynamics, and bottom contact.

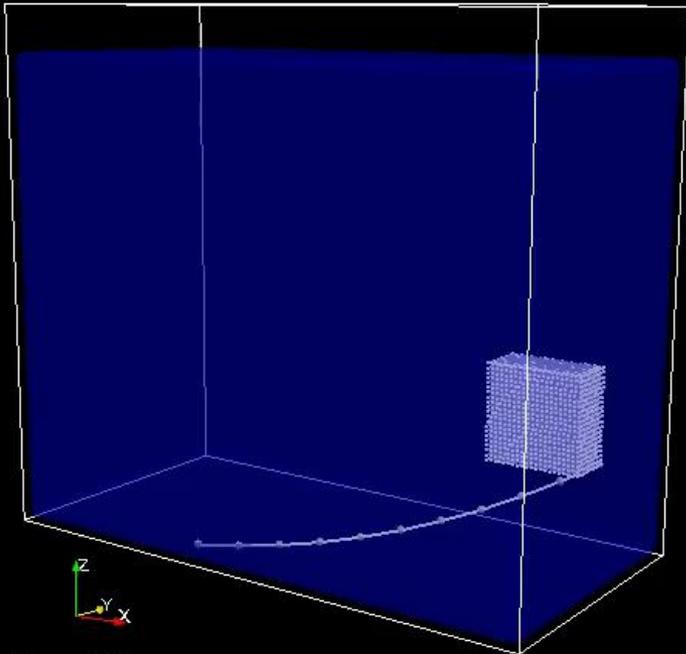


<http://www.matt-hall.ca/moordyn/>

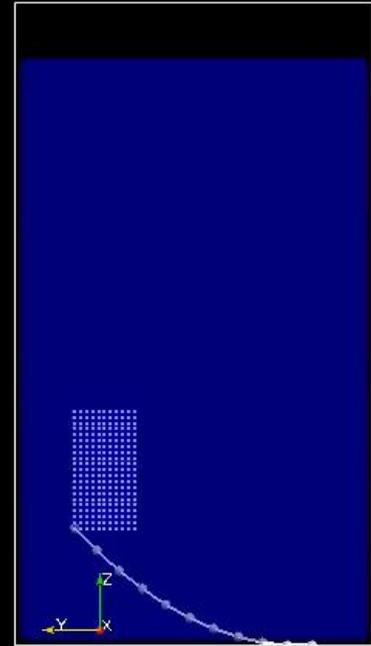
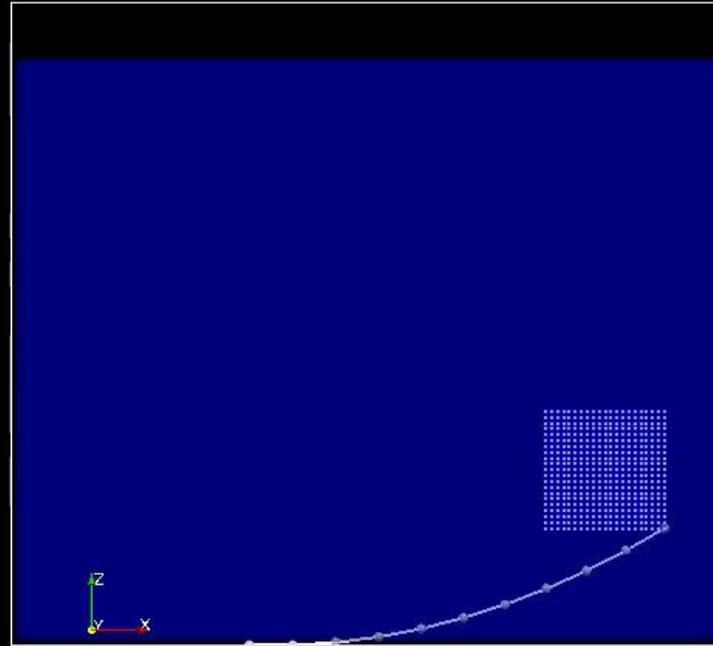
Coupling with MoorDyn

MoorDyn is an open-source dynamic **mooring** line model that uses a lumped-mass formulation for modelling axial elasticity, hydrodynamics, and bottom contact.

Simulation 3D & MoorDyn

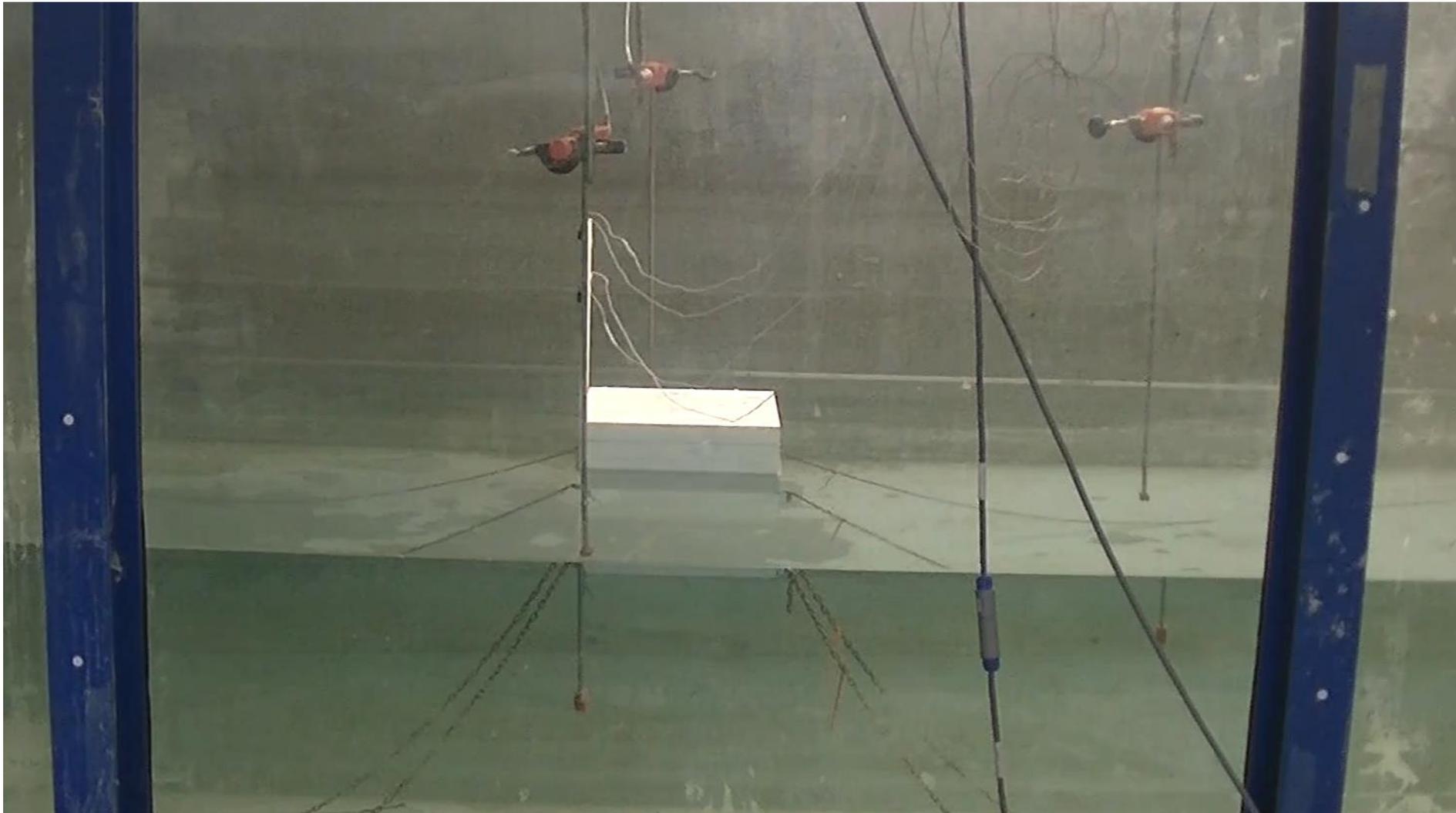


Time: 0.0 s



Coupling with MoorDyn

VALIDATION: EXPERIMENTS IN GHENT UNIVERSITY

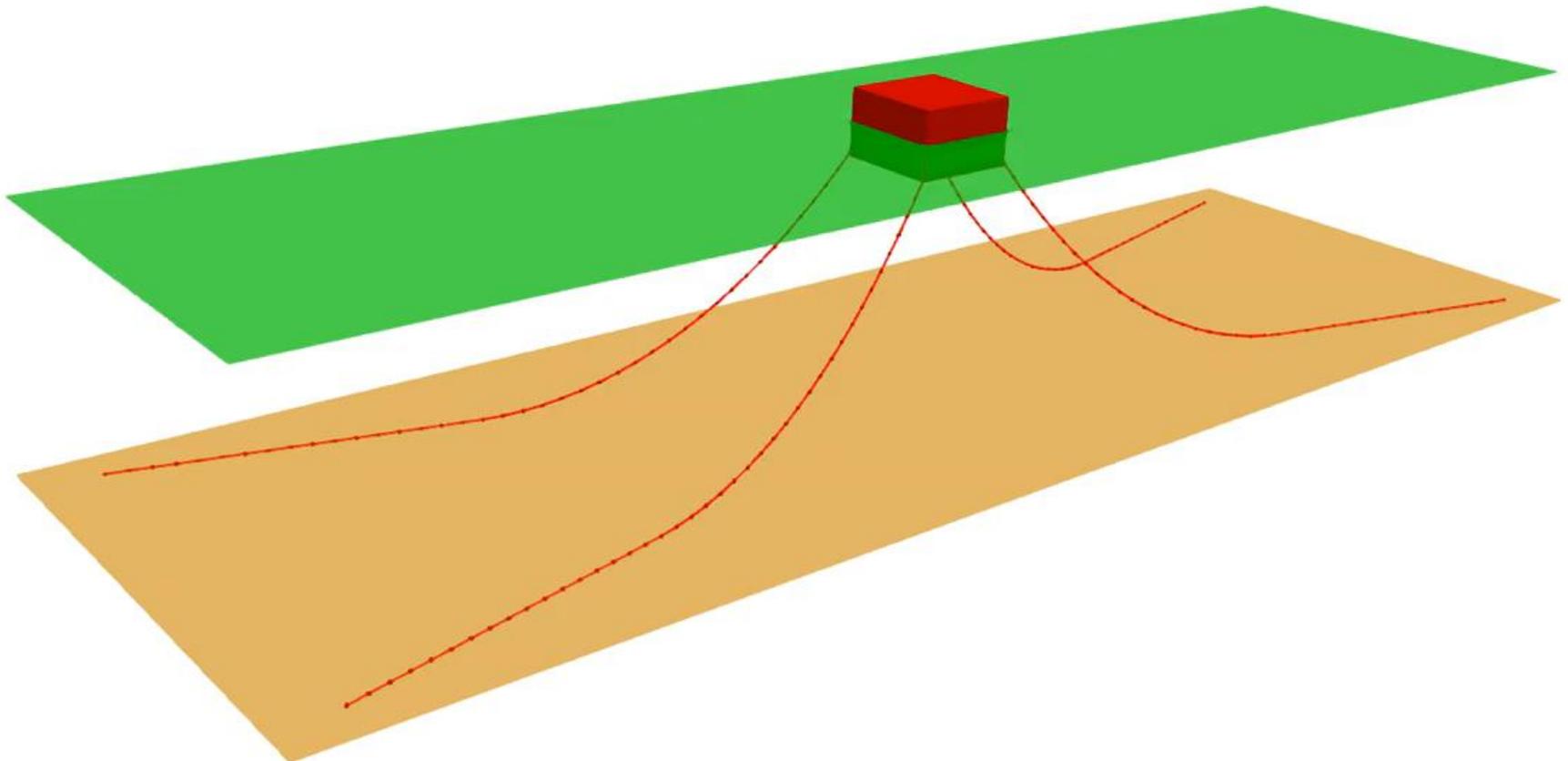


Coupling with MoorDyn

VALIDATION: EXPERIMENTS IN GHENT UNIVERSITY

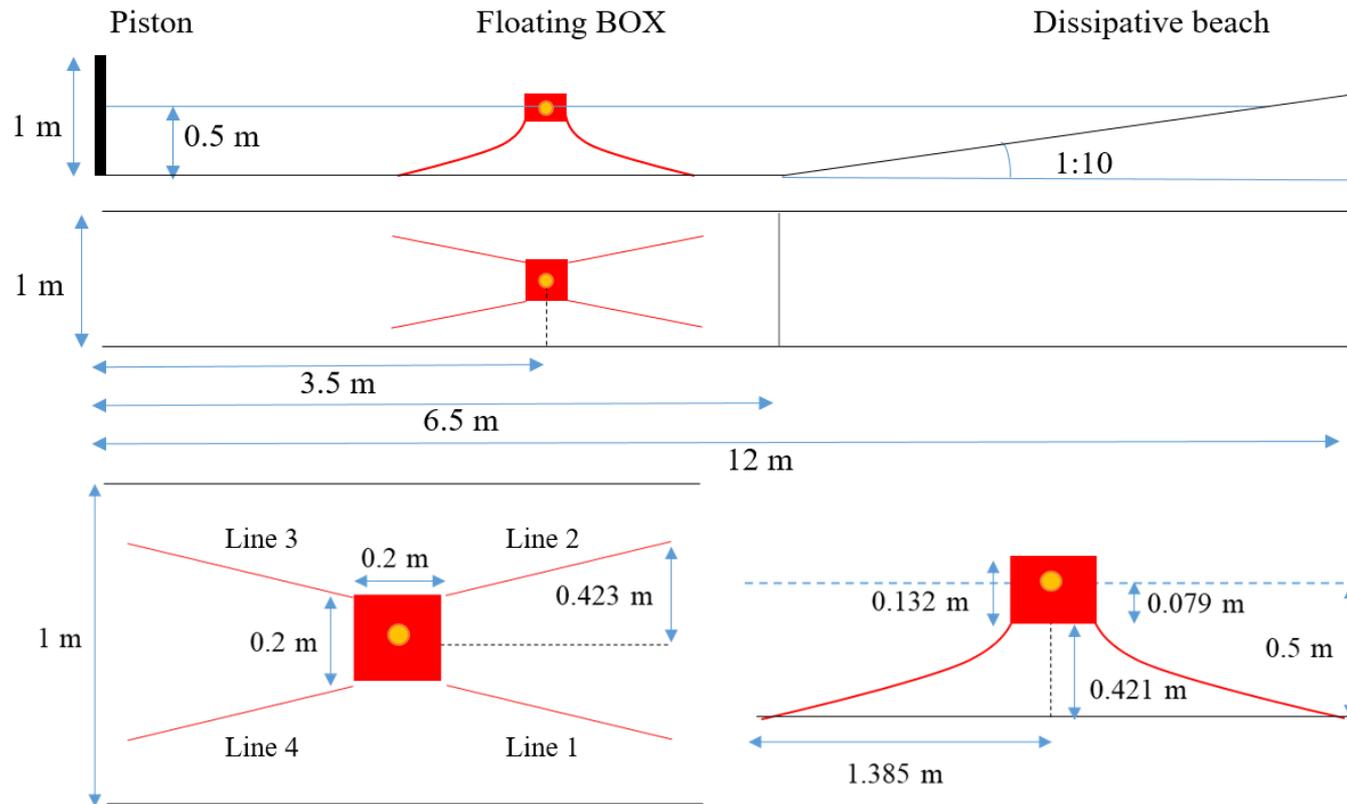
Floating moored BOX
Regular waves; $H=0.12$ m, $T=1.6$ s, $d=0.5$ m

Time: 0.00 s



Coupling with MoorDyn

VALIDATION: EXPERIMENTS IN GHENT UNIVERSITY



Regular waves

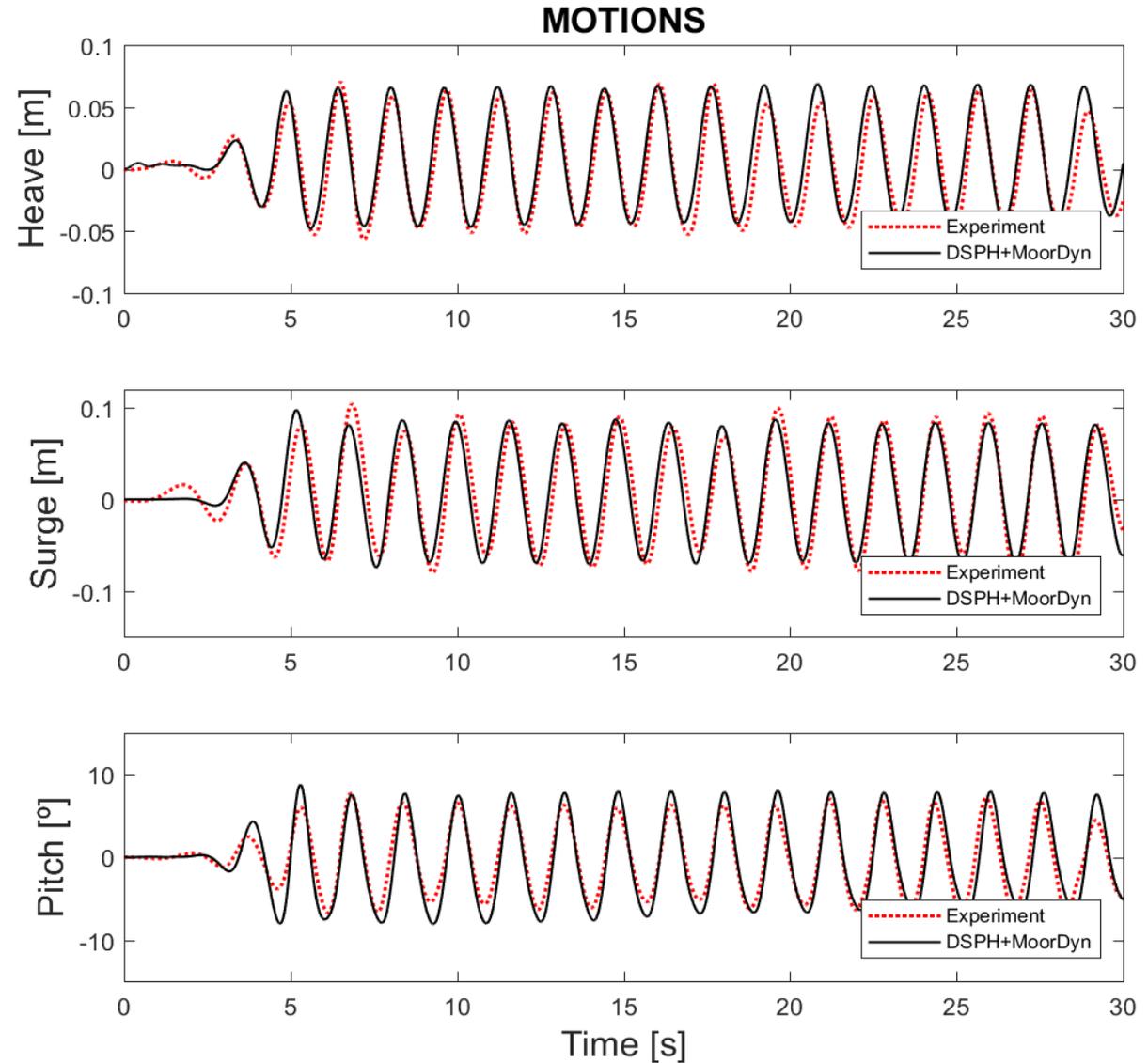
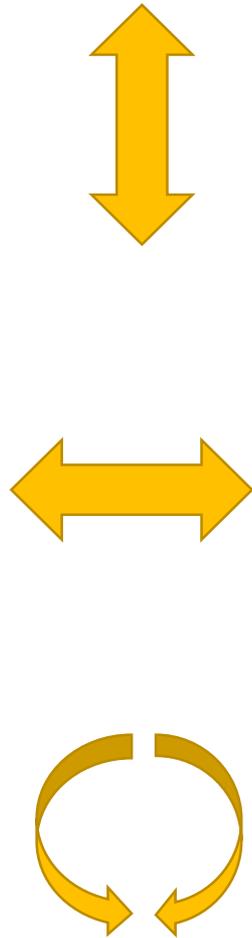
- $H=0.12$ m
- $T=1.6$ s
- $d=0.5$ m
- $L=3$ m

DualSPHysics	
BOX Dimensions	20 x 20 x 13.2 cm ³
BOX Weight	3 kg + 0.6 kg(extra)
BOX Centre of gravity	(0, 0, -1.26) cm
BOX Lip draught	7.86 cm

MoorDyn	
MOORING Diameter	3.656 mm
MOORING Weight	0.607 g/cm
MOORING Length	145.5 cm
Water depth	50 cm

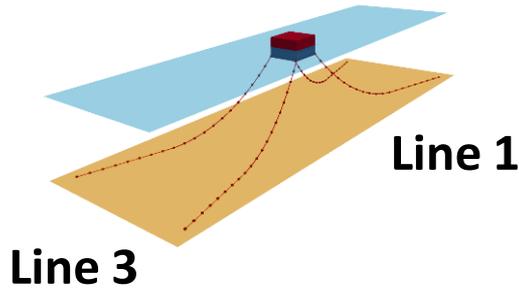
Coupling with MoorDyn

VALIDATION: EXPERIMENTS IN GHENT UNIVERSITY

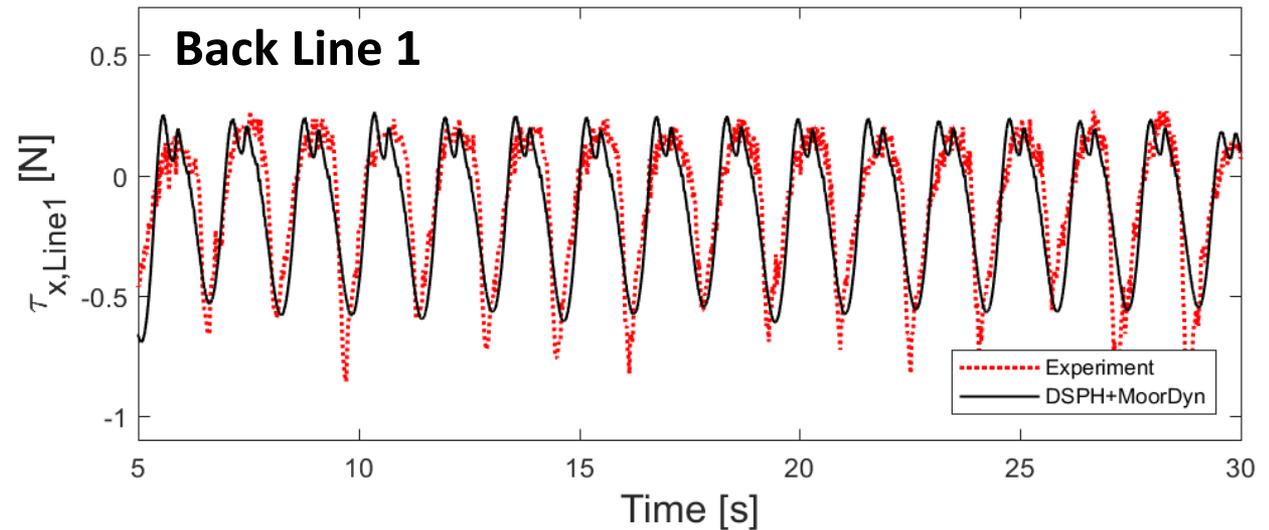
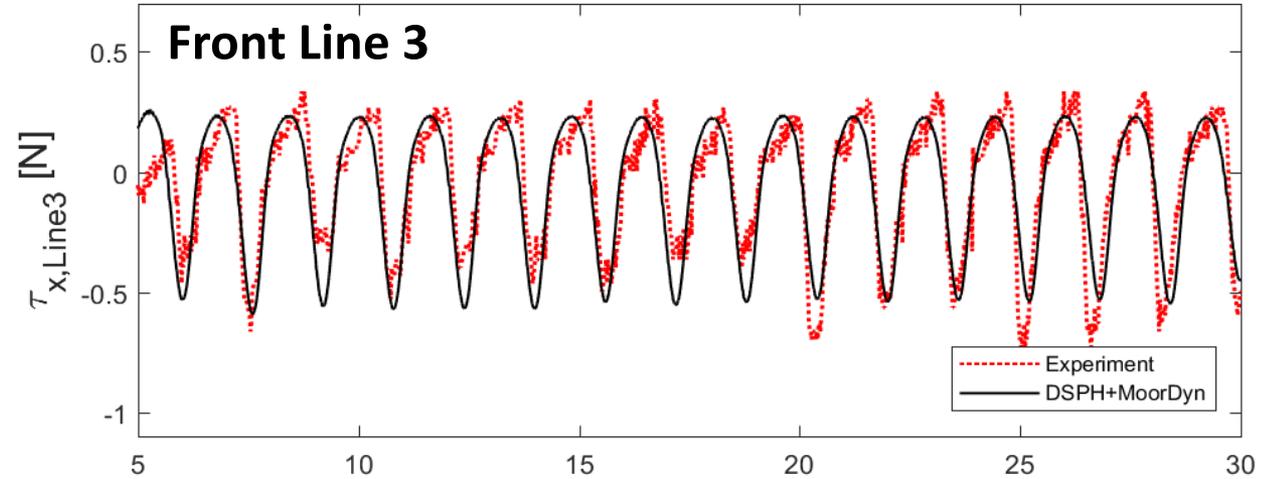


Coupling with MoorDyn

VALIDATION: EXPERIMENTS IN GHENT UNIVERSITY

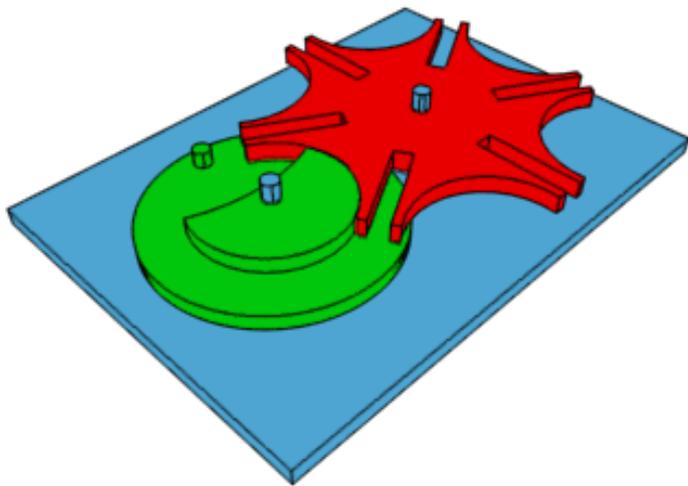


MOORING TENSION



Coupling with Project Chrono

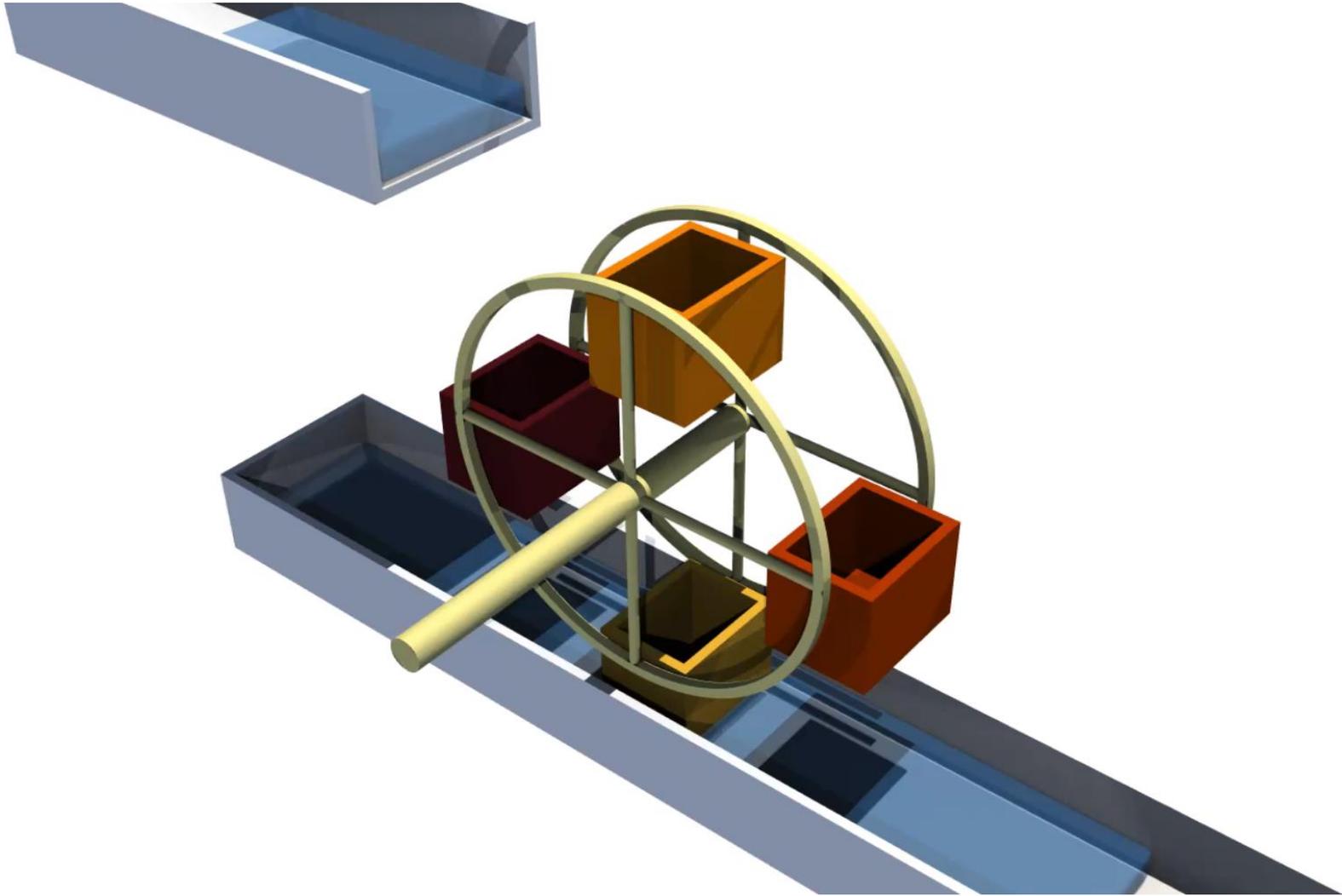
Project Chrono is an open-source **multi-physics** simulation engine



- Wide set of joints: spherical, revolute joint, prismatic, glyph, etc.
- Unilateral constraints
- Exact Coulomb friction model, for precise stick-slip of bodies
- **Springs and dampers, even with non-linear features**

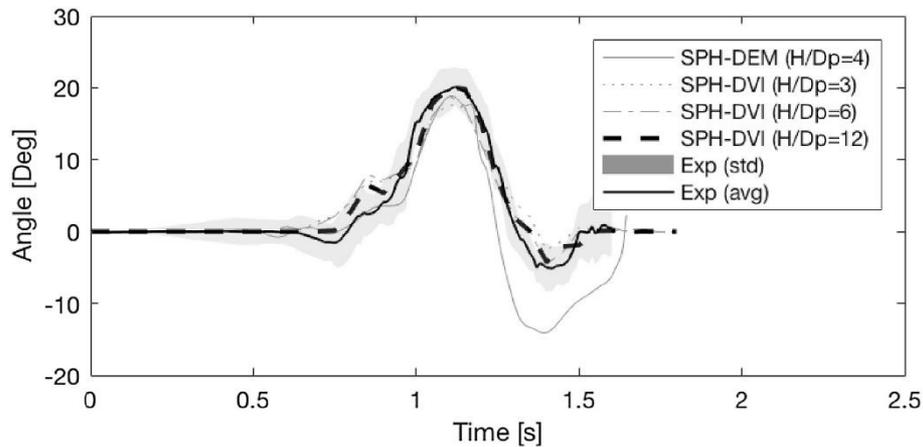
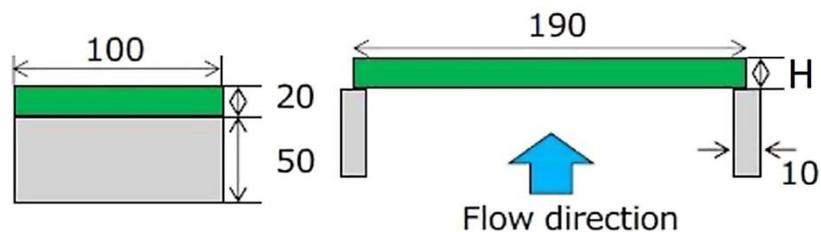
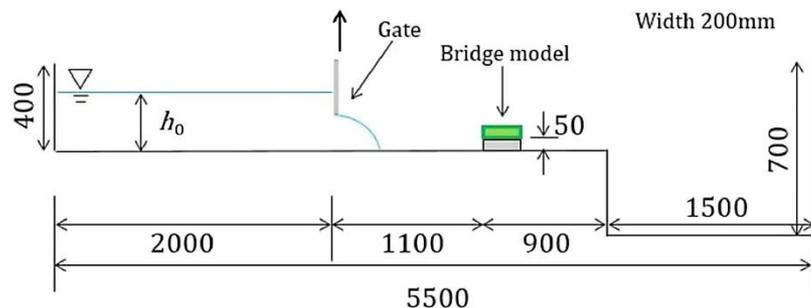
<http://projectchrono.org>

Coupling with Project Chrono

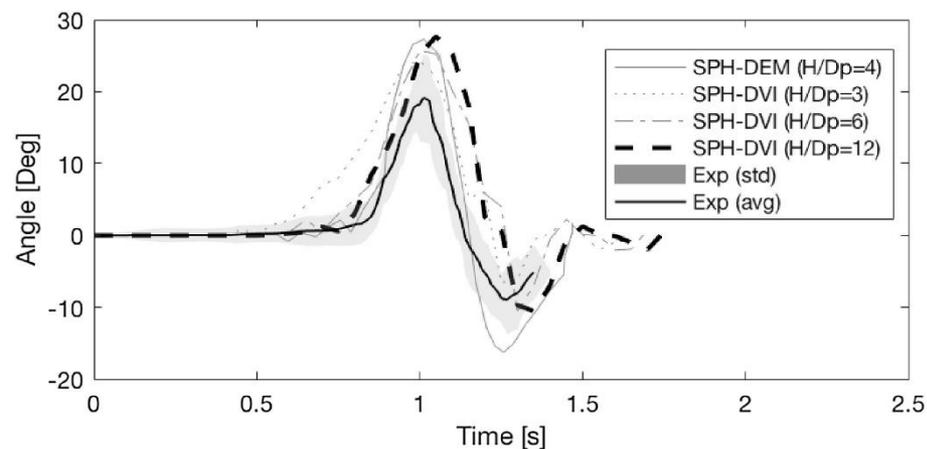


Coupling with Project Chrono

VALIDATION: Chandra and Asai, 2016



Rotation angle for $h_0=300\text{mm}$

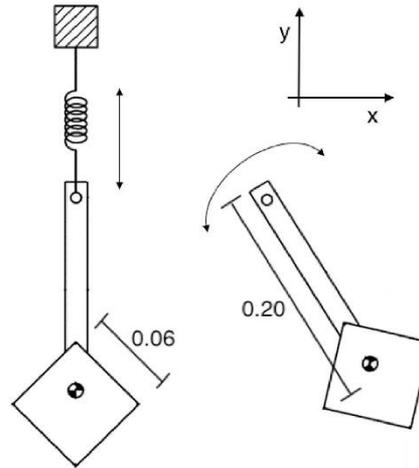


Rotation angle for $h_0=350\text{mm}$

Coupling with Project Chrono

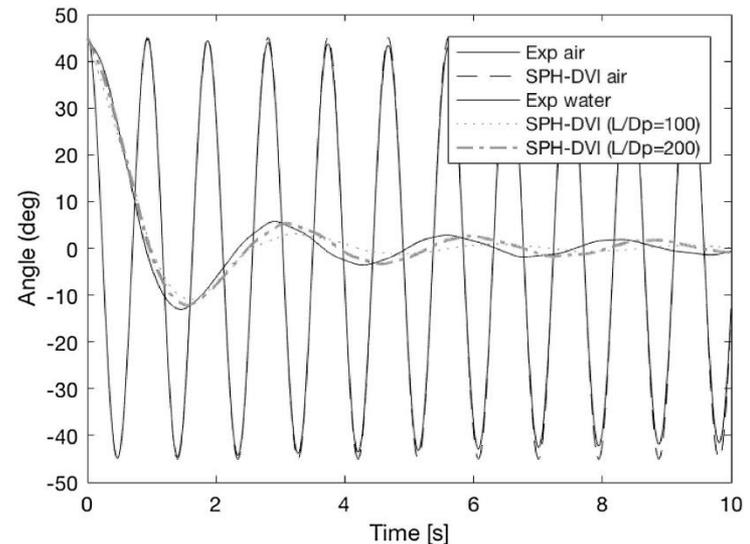
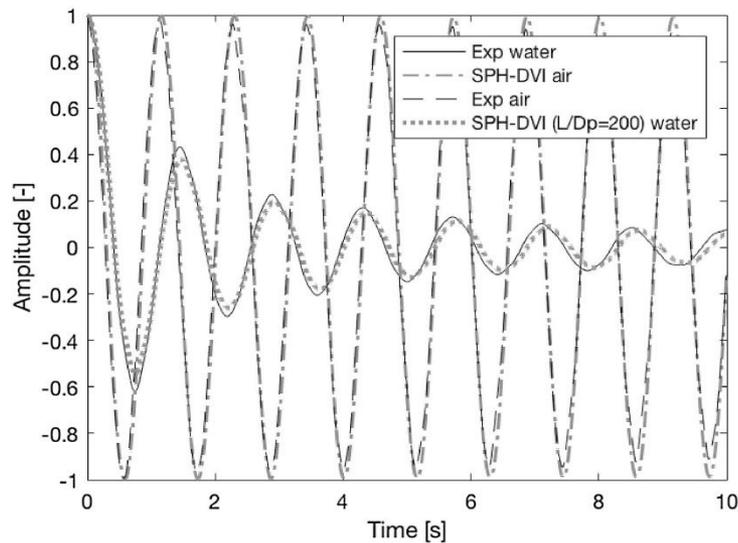
VALIDATION

Spring pendulum



Gravity pendulum

Comparison between numerical and experimental rotation angle of **spring pendulum** in air and water and **gravity pendulum** in air and water



OUTLINE

Objective: Numerical modelling of WECs

SPH modelling: DualSPHysics software

- Wave generation, propagation and absorption
- Wave-structure interaction
- Coupling with MoorDyn
- Coupling with Project Chrono

Application to different WECs

- Oscillating Water Column (OWC)
- Oscillating Wave Surge Converter (OWSC)
- Point absorber
- Others (WaveStar, M4)

Conclusions & Future work

Oscillating Water Column (OWC)

OFFSHORE FLOATING MOORED OWC

Esflowc

Efficiency and survivability of floating
Oscillating Water Column Wave Energy
Converters moored to the seabed

GHENT UNIVERSITY (COORDINATOR), BELGIUM

UNIVERSIDADE DE VIGO, SPAIN

THE UNIVERSITY OF MANCHESTER, UNITED KINGDOM

IST - UNIVERSIDADE DE LISBOA, PORTUGAL

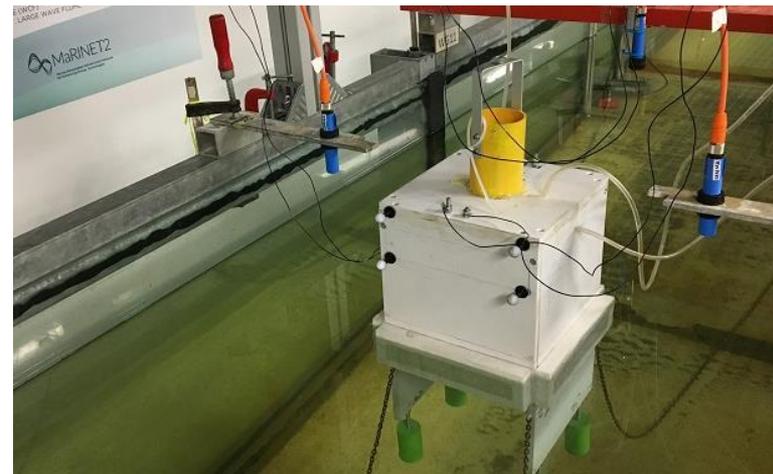
UNIVERSITÀ DEGLI STUDI FIRENZE, ITALY

Universidade de Vigo



A MARINET2 TRANSNATIONAL ACCESS PROJECT (EU H2020 PROGRAMME UNDER GRANT AGREEMENT NO 731084)
SUPPORTED ALSO BY THE RESEARCH FOUNDATION FLANDERS (FWO), BELGIUM - FWO.OPR.2.0 - FWO RESEARCH PROJECT NO. 3G02914

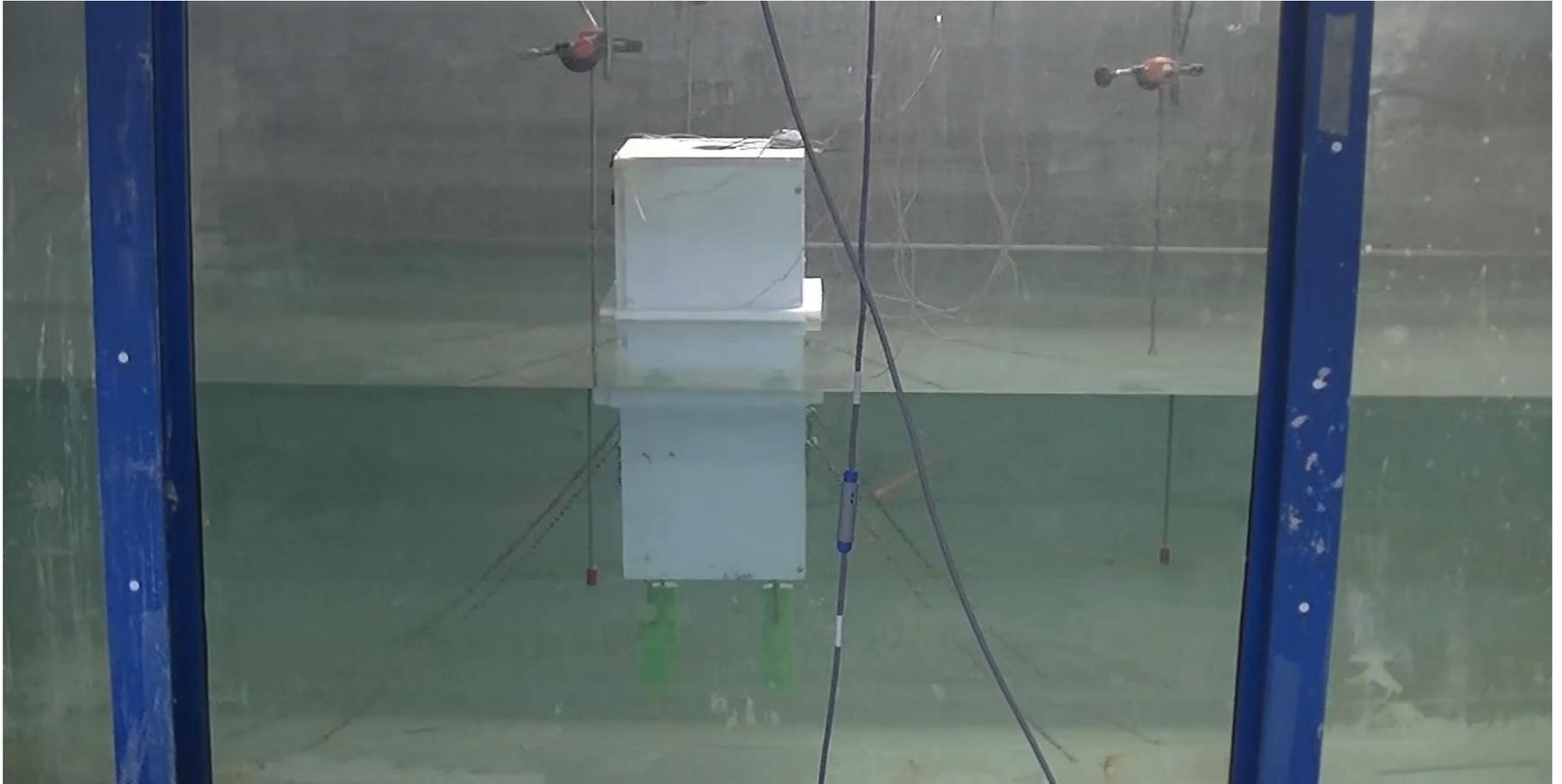
INFRASTRUCTURES: LABIMA-UNIFL WAVE-CURRENT FLUME (WCF)
AND COASTAL ENGINEERING RESEARCH GROUP OF GHENT UNIVERSITY, LARGE WAVE FLUME



Oscillating Water Column (OWC)

Floating and moored OWC

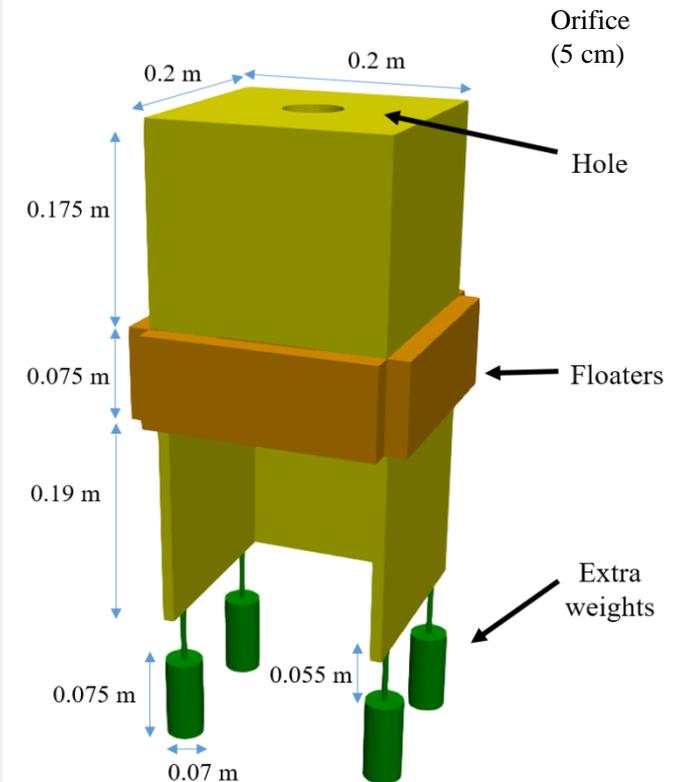
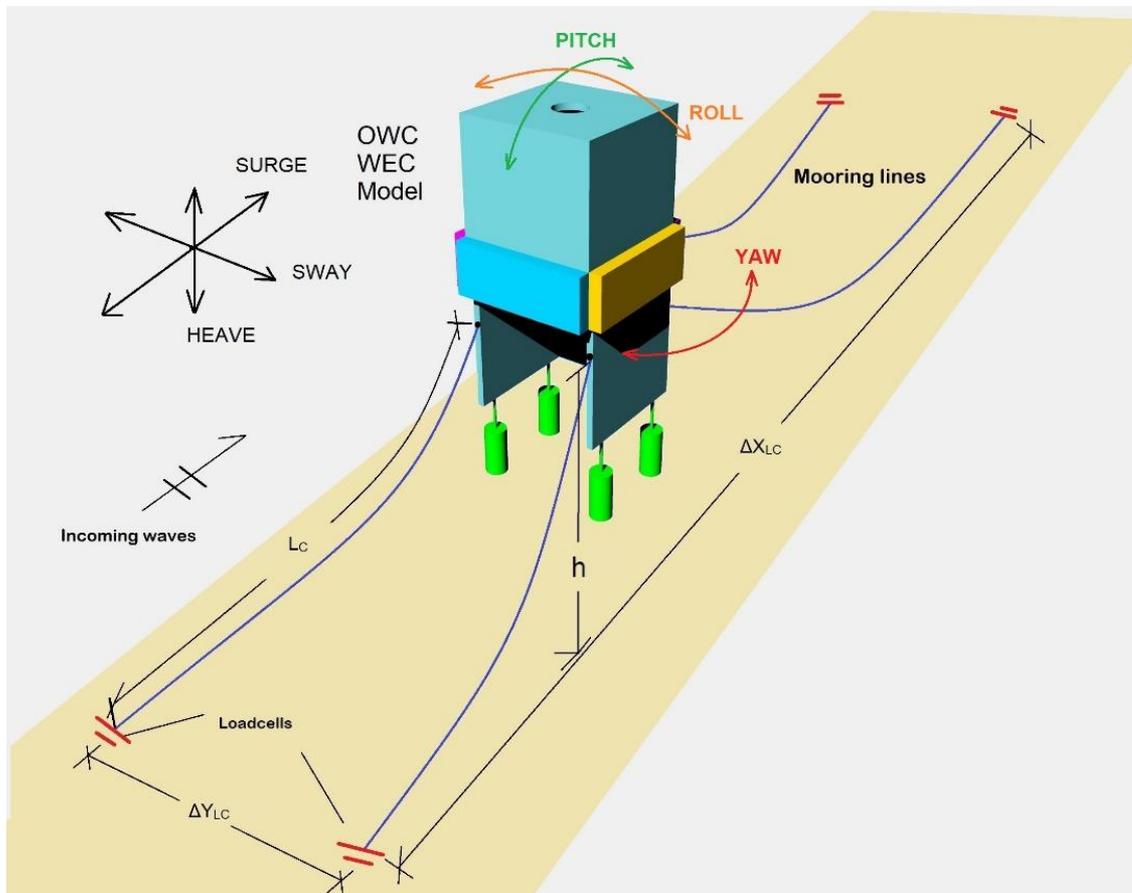
EXPERIMENT IN GENT UNIVERSITY: FLOATING MOORED OWC



Oscillating Water Column (OWC)

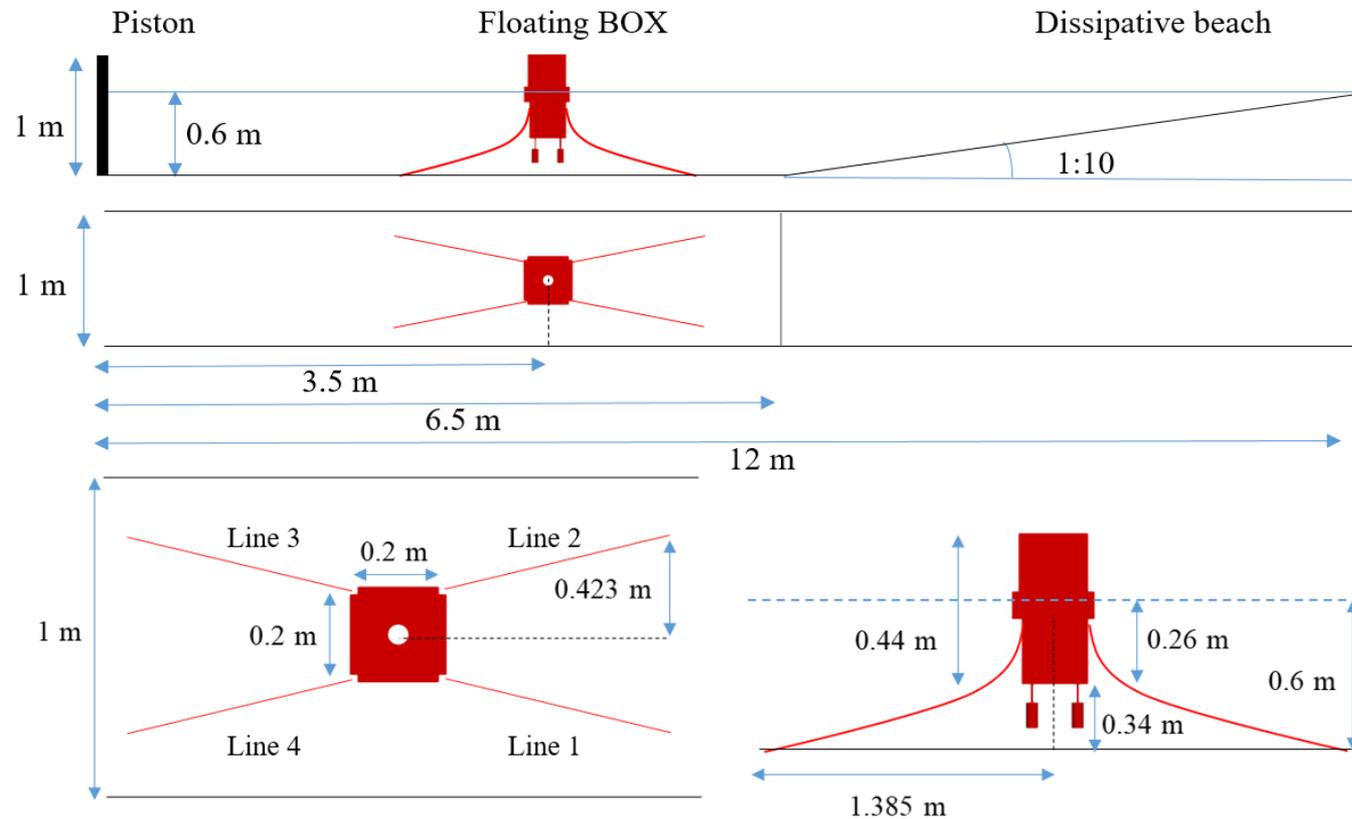
Floating and moored OWC

OWC with different materials but total MASS is 2.593 kg
 SPH particles of density 578 kg/m^3



Oscillating Water Column (OWC)

Floating and moored OWC



Regular waves

- $H=0.11$ m
- $T=1.6$ s
- $d=0.6$ m
- $L=3.27$ m

DualSPHysics

OWC Dimensions	20 x 20 x 44 cm ³
OWC Weight	2.593 kg
OWC Centre of gravity	(-0.91, 0, -10.8) cm

MoorDyn

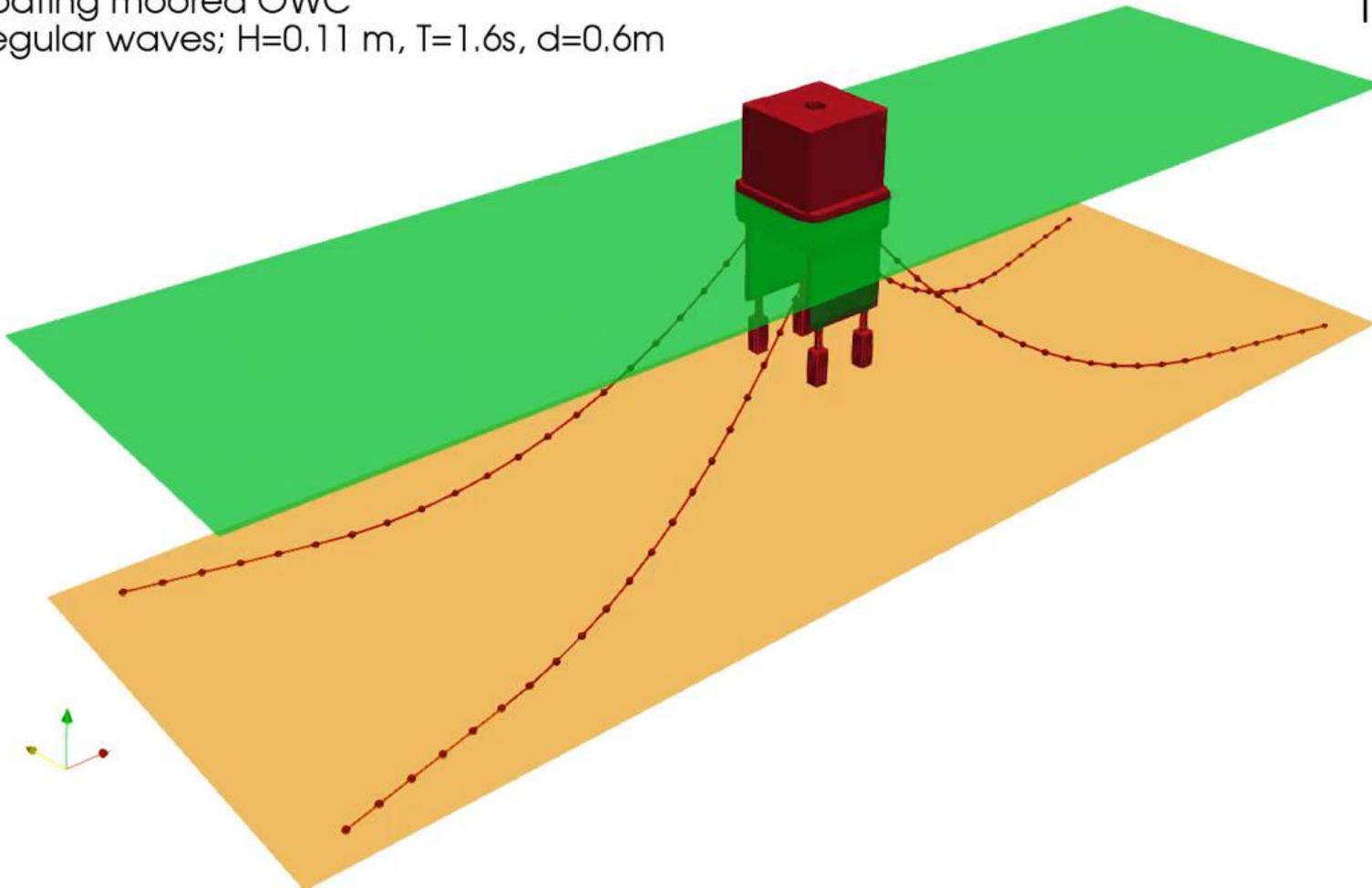
MOORING Diameter	3.656 mm
MOORING Weight	0.607 g/cm
MOORING Length	145.5 cm
Water depth	50 cm

Oscillating Water Column (OWC)

Floating and moored OWC

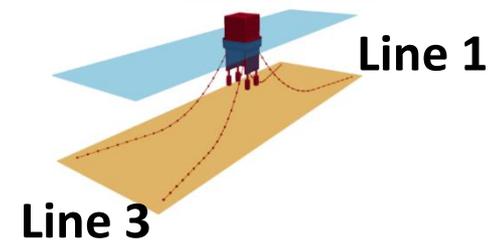
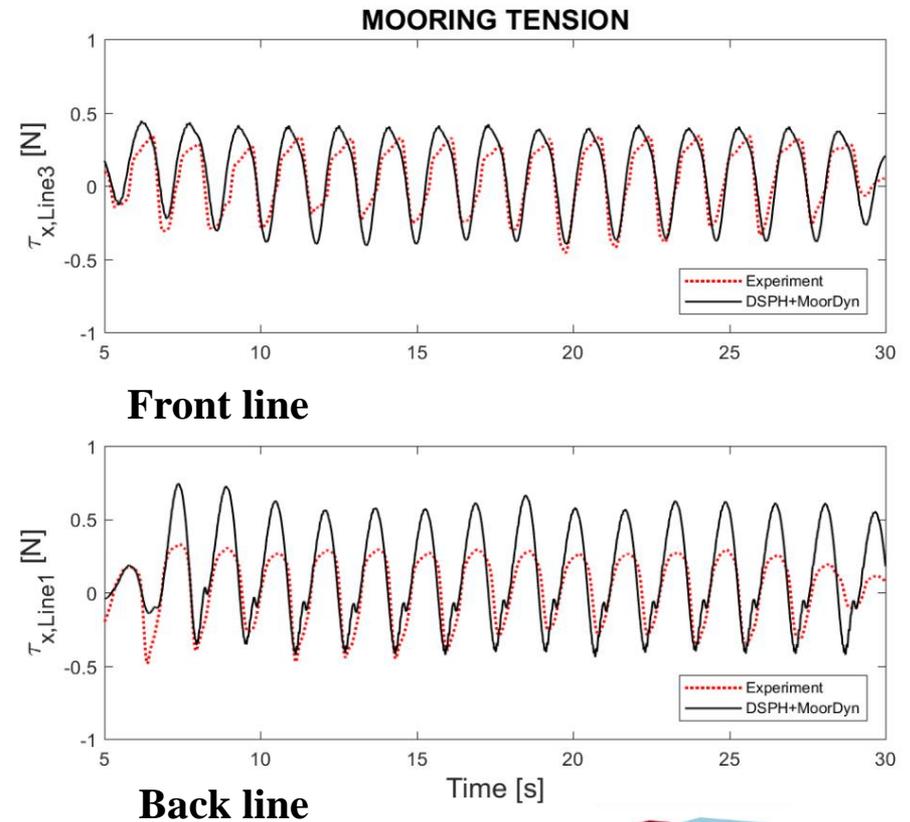
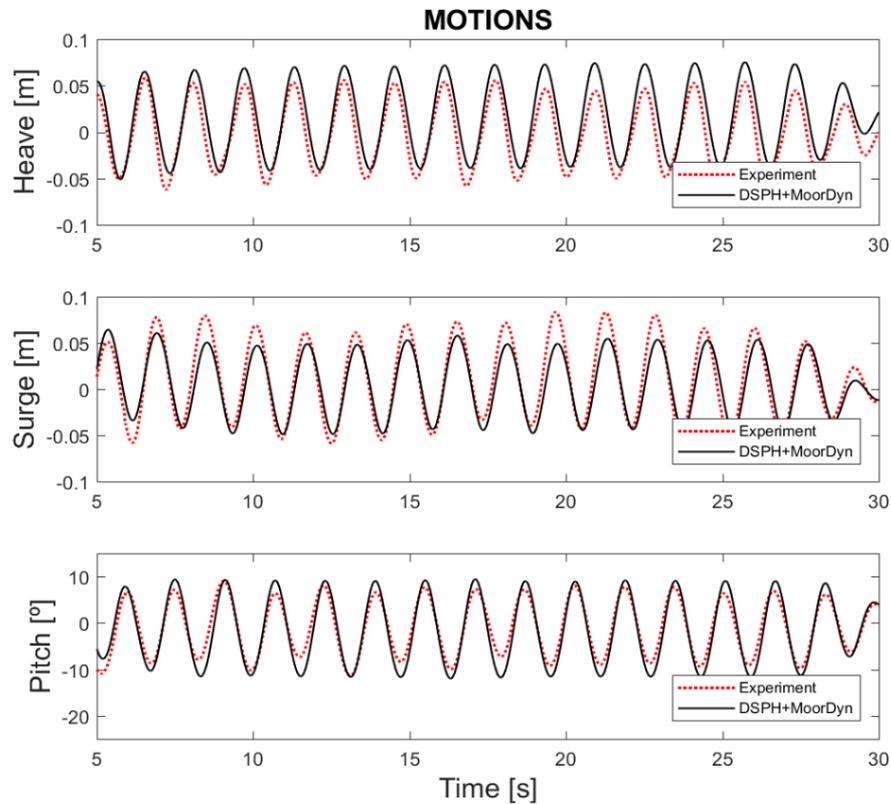
UGHENT:
Floating moored OWC
Regular waves; $H=0.11$ m, $T=1.6$ s, $d=0.6$ m

Time: 0.00 s



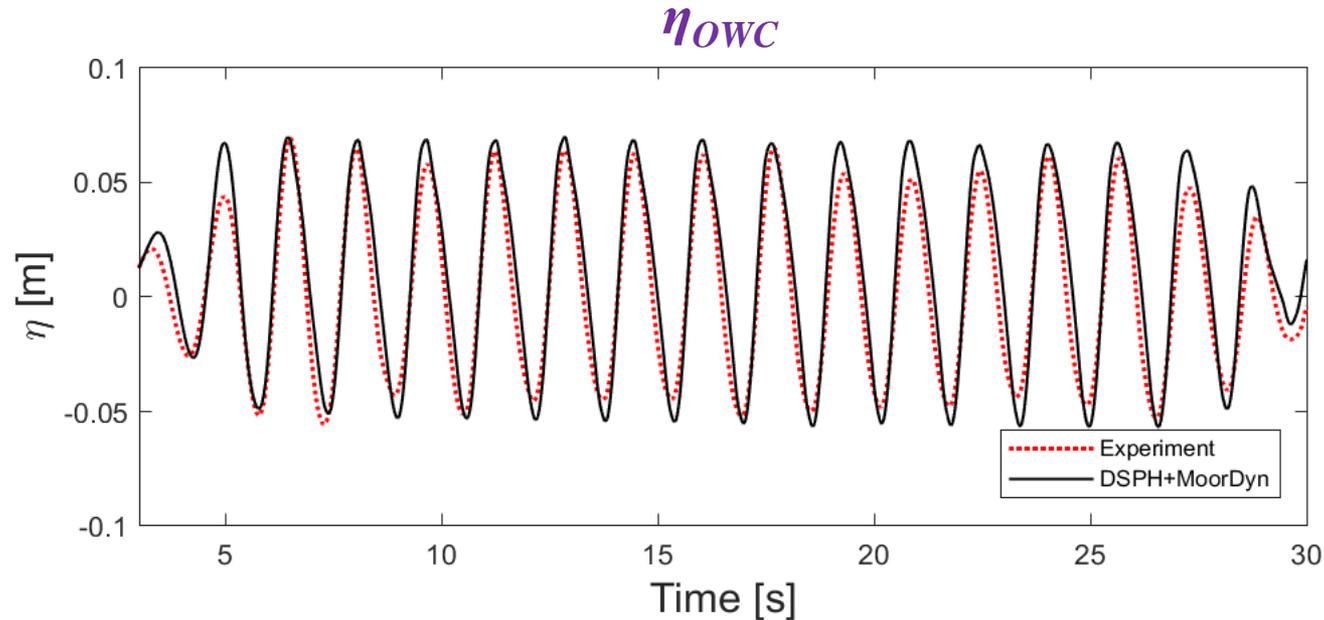
Oscillating Water Column (OWC)

Floating and moored OWC



Oscillating Water Column (OWC)

Floating and moored OWC



**RELATIVE MOTION BETWEEN HEAVE AND
WATER ELEVATION INSIDE OWC**

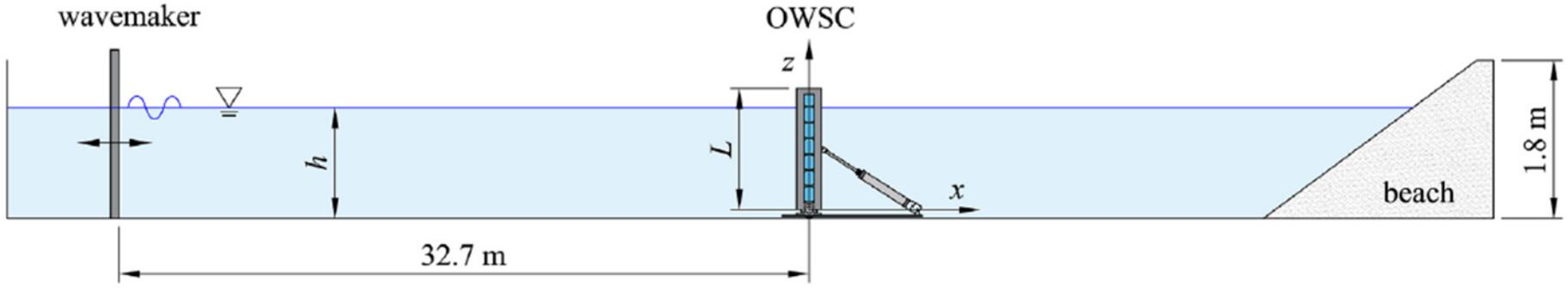
heave - η_{OWC}

Oscillating Wave Surge Converter (OWSC)

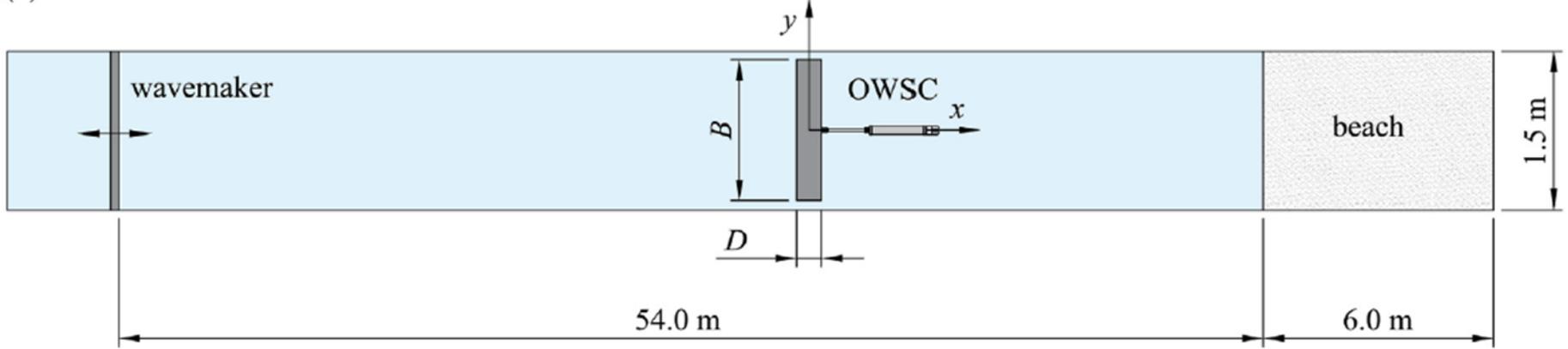
Experimental set up at the Marine Research Group's hydraulics laboratory at Queen's University Belfast.

Regular waves:
 $d=0.825$, $T=2s$, $H=0.15m$
 $d=0.825$, $T=2s$, $H=0.25m$
 $d=0.825$, $T=3s$, $H=0.20m$

(a)

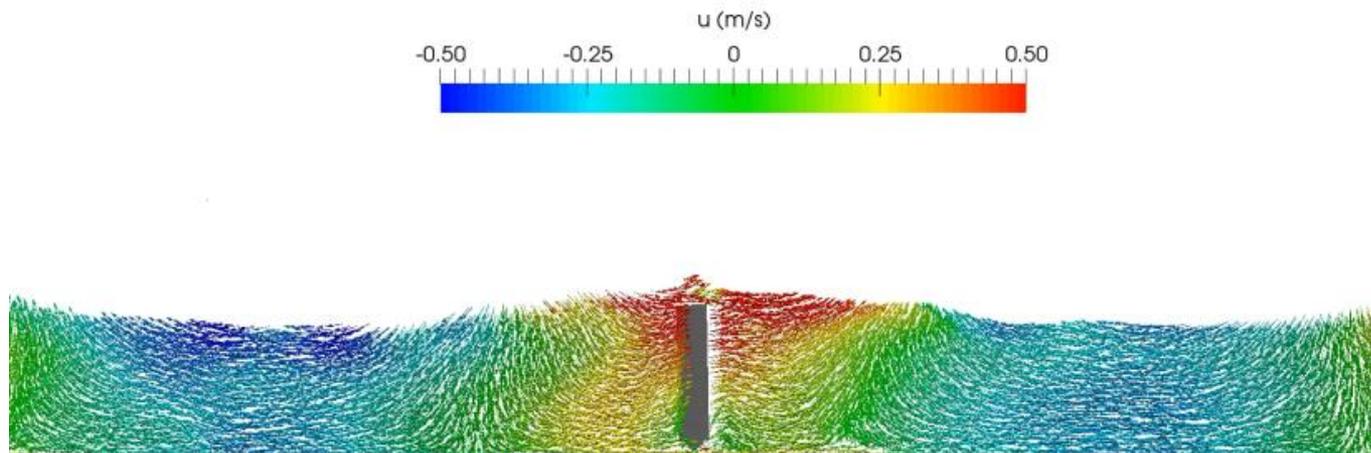
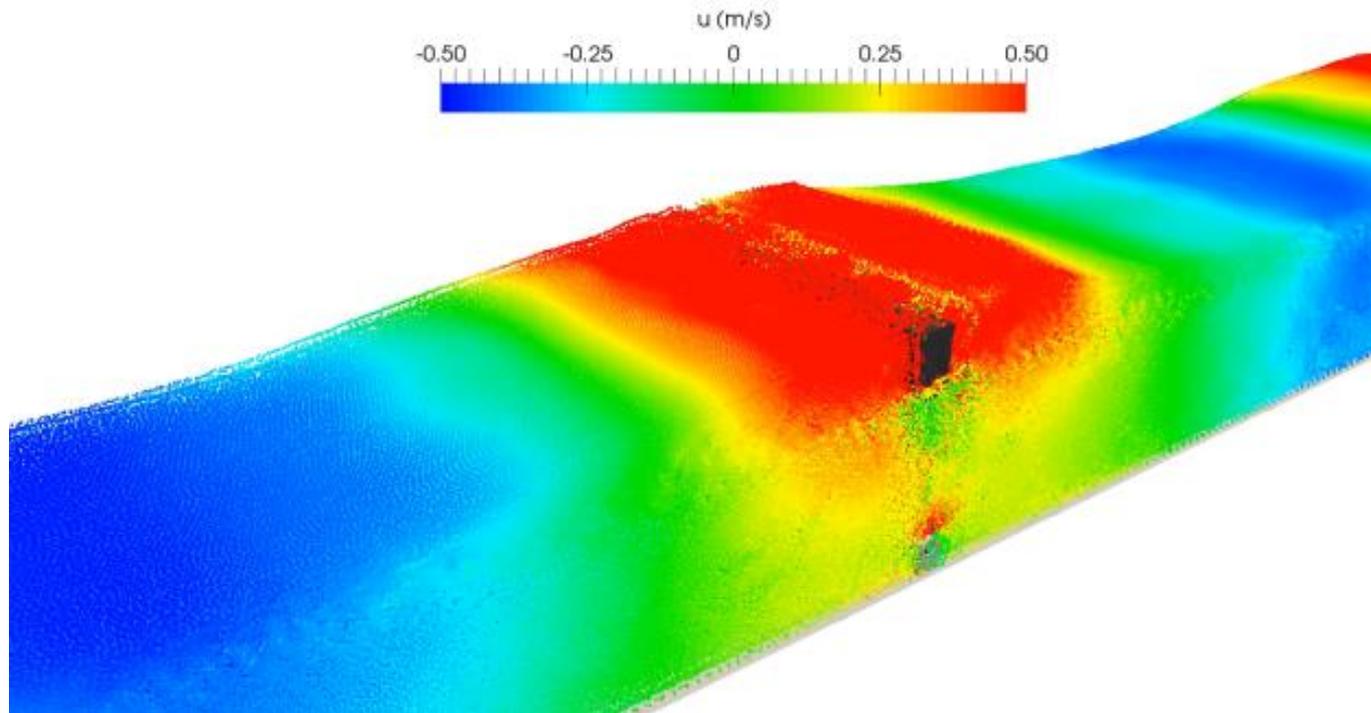


(b)



Oscillating Wave Surge Converter (OWSC)

Brito et al., 2019

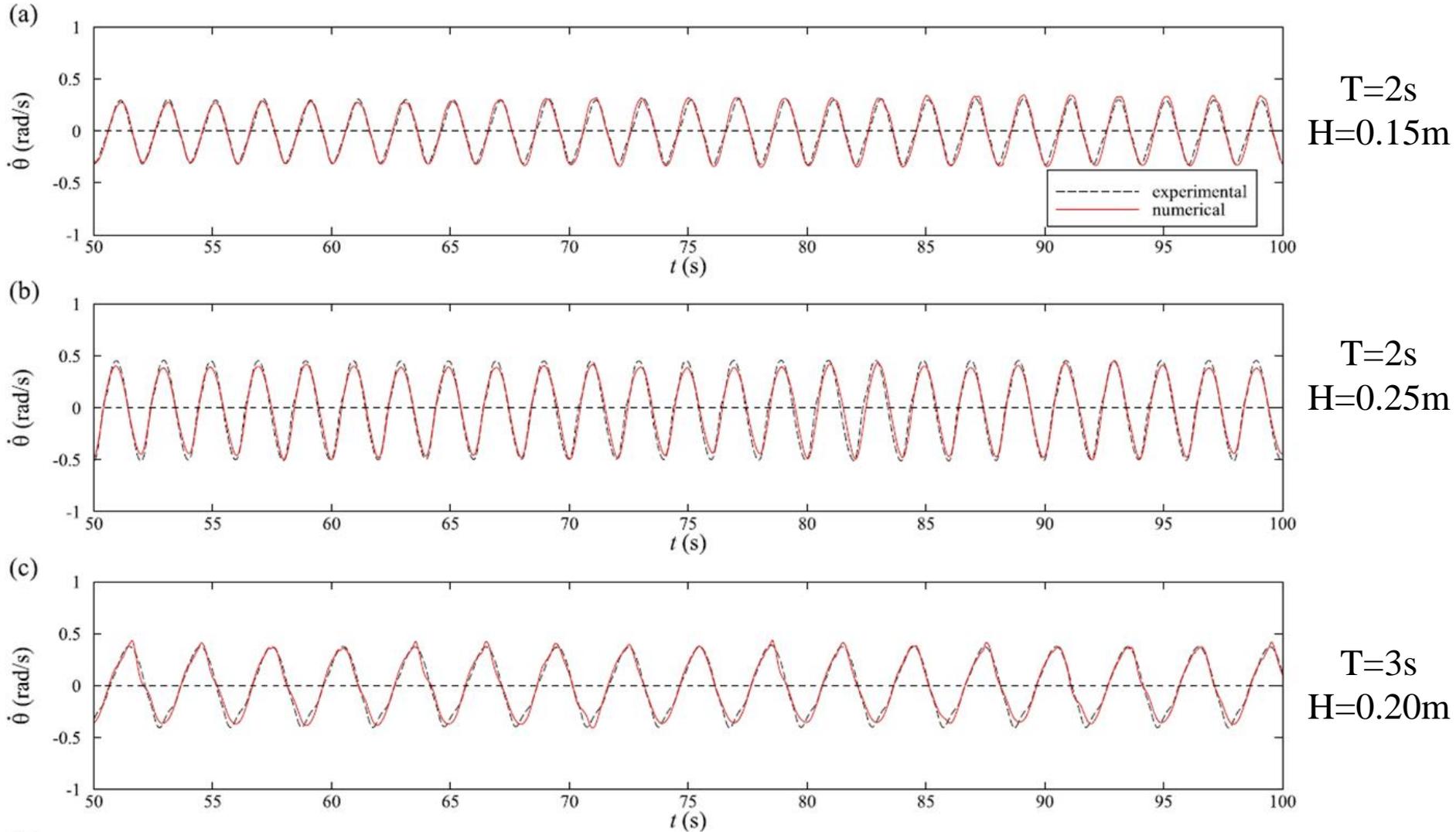


Oscillating Wave Surge Converter (OWSC)

Brito et al., 2019

VALIDATION:

Numerical and **experimental** time series of angular velocity of the flap



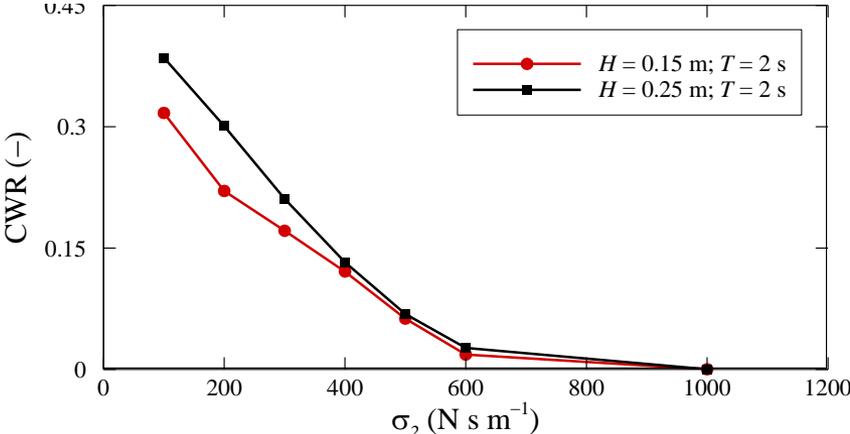
Oscillating Wave Surge Converter (OWSC)

Influence of the PTO system

CWR: capture width ratio

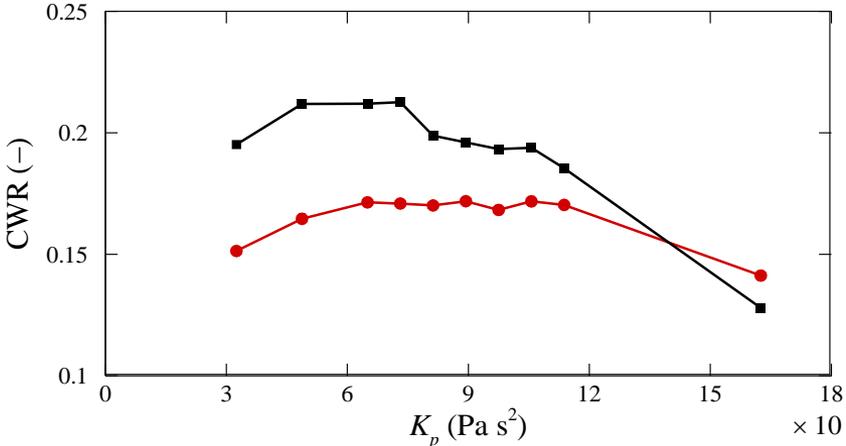
$$F_f^{smooth}(t) = \sigma_0 z_d(t) + \sigma_1 \dot{z}_d(t) + \sigma_2 \dot{x}(t)$$

Viscous friction coefficient

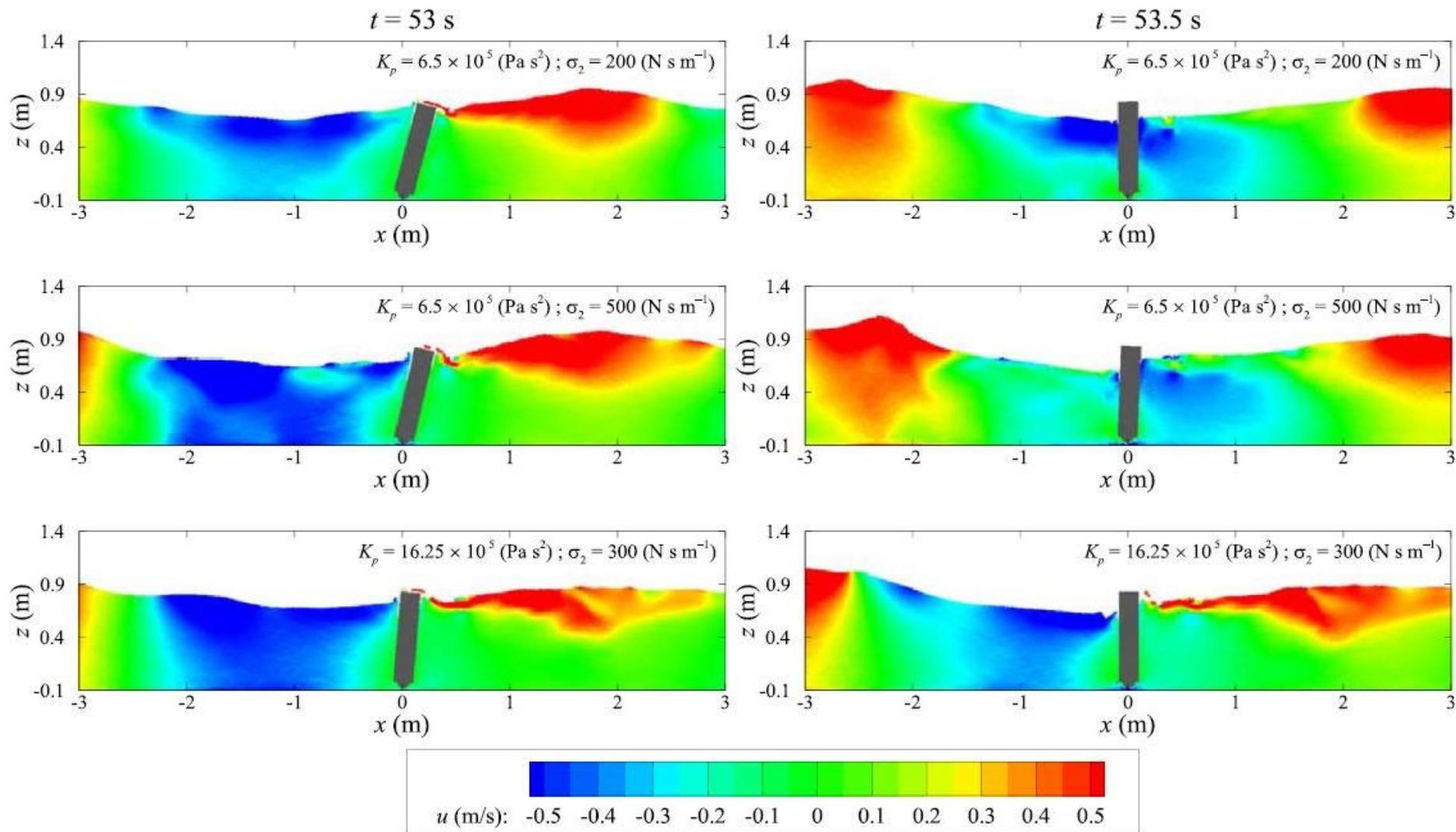


$$F_p^{smooth}(t) = [K_p \dot{x}(t)^2 + I_p \ddot{x}(t)] A$$

Pressure loss coefficient



Influence of the PTO system

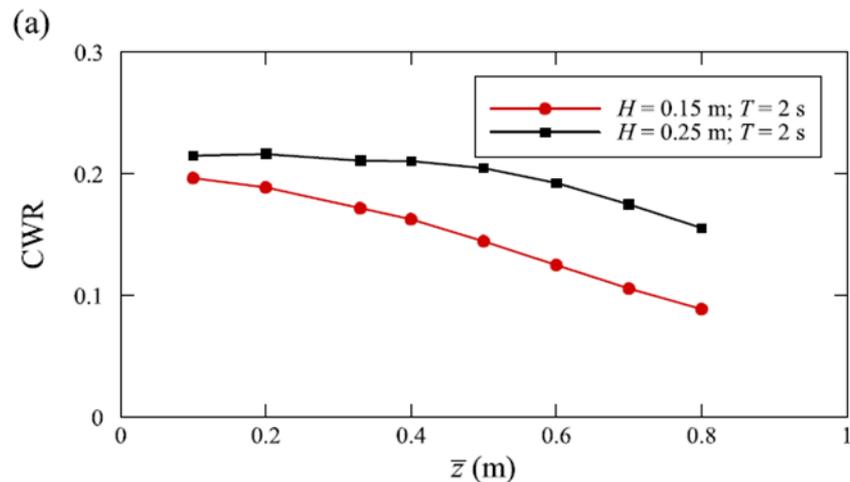


Oscillating Wave Surge Converter (OWSC)

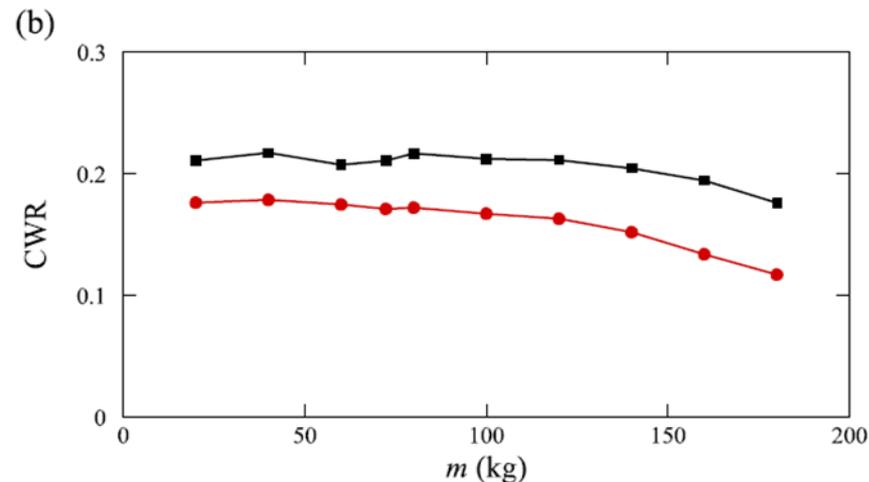
Brito et al., 2019

Influence of flap inertia

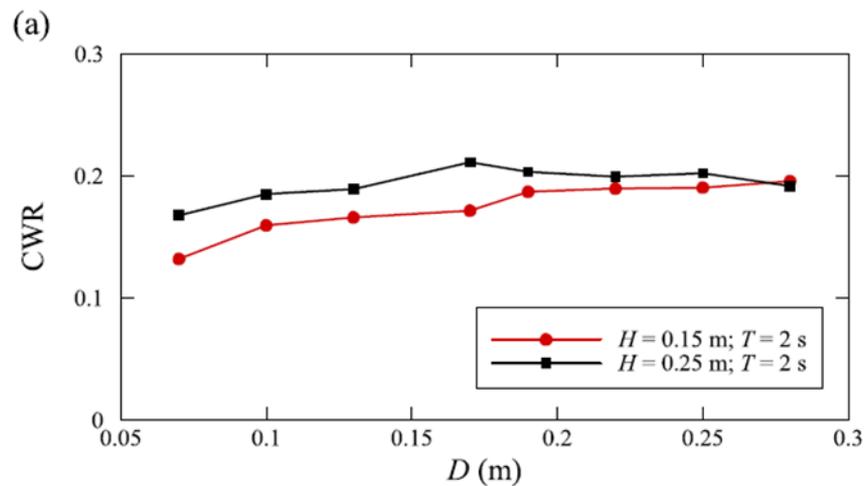
CWR: capture width ratio



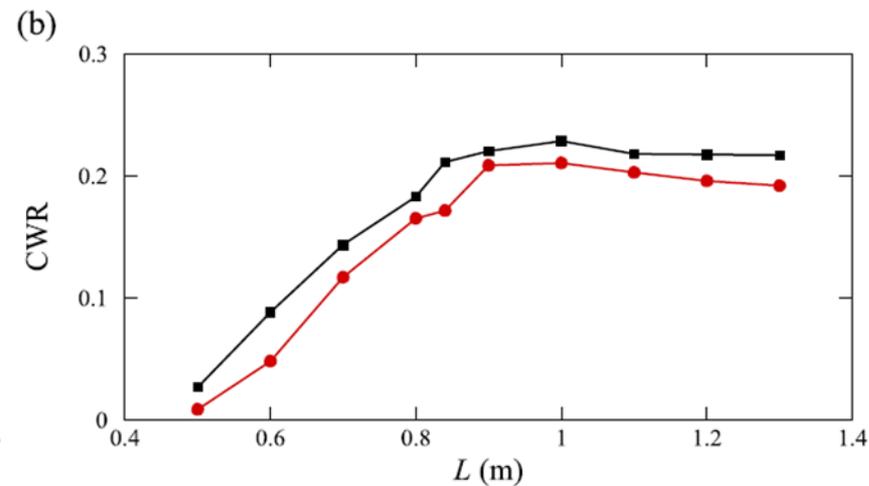
CENTER OF MASS



MASS



THICKNESS



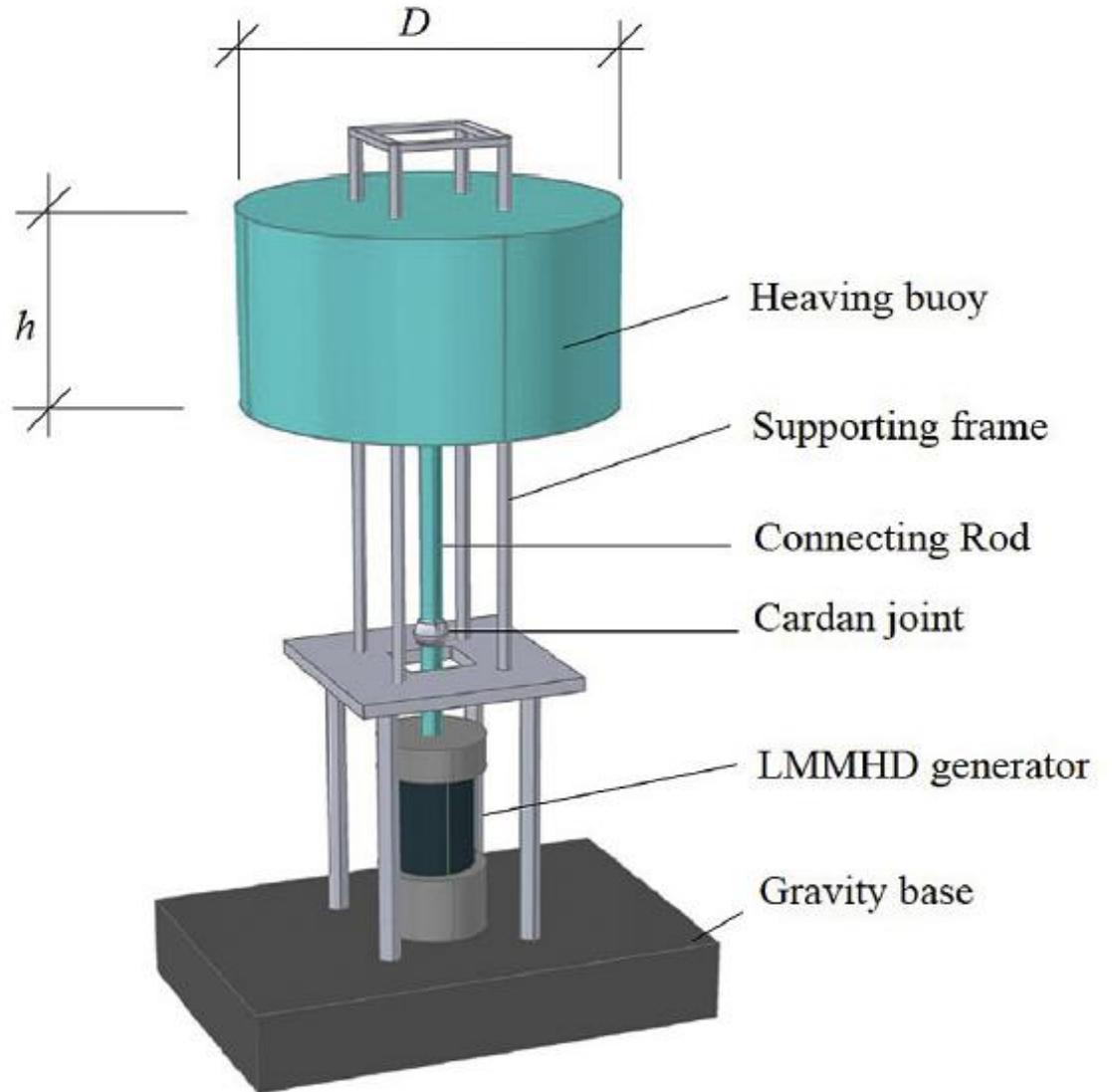
HEIGHT

Point absorber (only heave motion)

$$F_{\text{PTO}} = \mathbf{k} \cdot z + \mathbf{c} \cdot \text{vel.}z$$

k: stiffness

c: damping



Point absorber (only heave motion)

Zang Z, Zhang Q, Qi Y, Fu X, 2018. Hydrodynamic responses and efficiency analyses of a heaving-buoy wave energy converter with PTO damping in regular and irregular waves. Renewable Energy, 116: 527-542

PTO is modelled as a linear damper

$$F_{\text{PTO}} = c \cdot \text{vel.}z$$

Buoy: cylinder with only-heave motion:

Diameter $D=0.5$ m

Mass $M=21.6$ kg

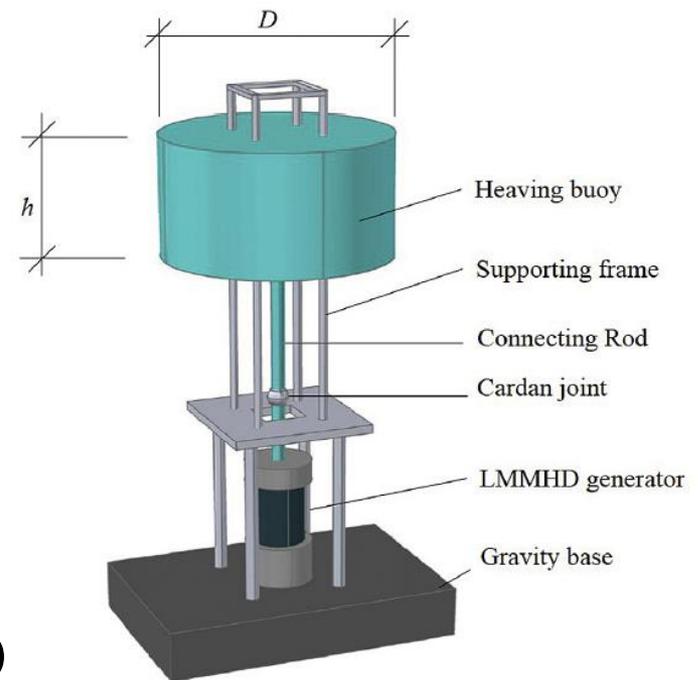
Draft $B=0.11$ m

Regular waves:

$H=0.16$ m, $T=1.5$ s, $d=1.1$ m

Linear damper with CHRONO:

$\text{rest_length}=0.99$ m, $k(\text{stiffness})=0$



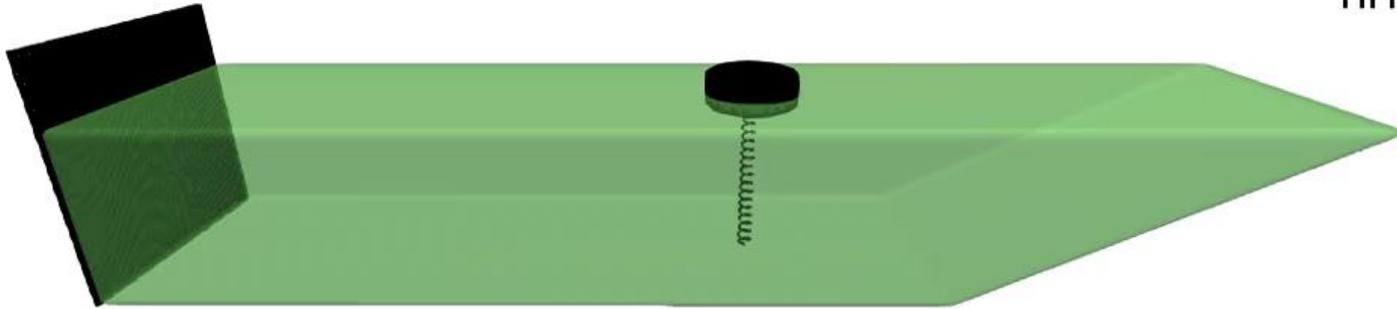
Point absorber (only heave motion)

Regular waves: $H=0.16$ m, $T=1.5$ s, $d=1.1$ m

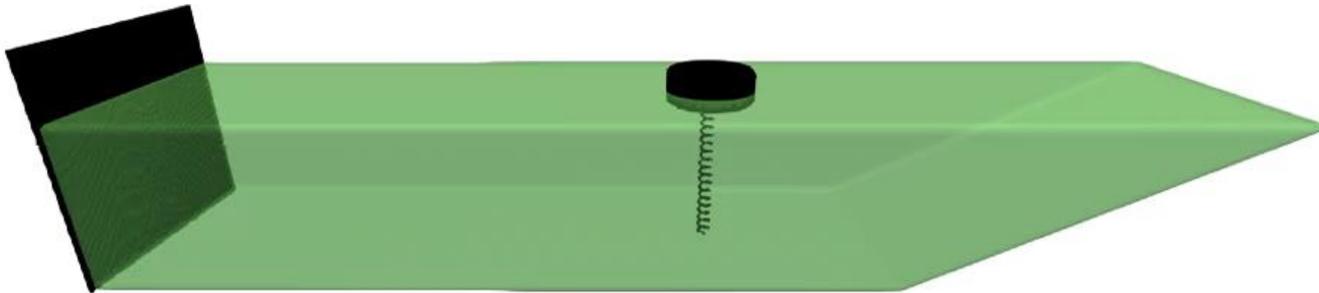
Spring-damper with CHRONO: $\text{rest_length}=0.99$ m, $k=0$

c=0

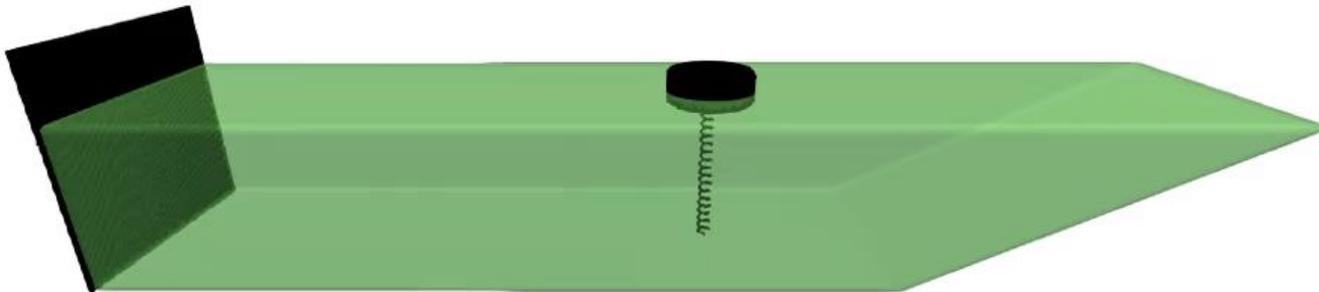
Time: 0.00 s



c=240



c=1100



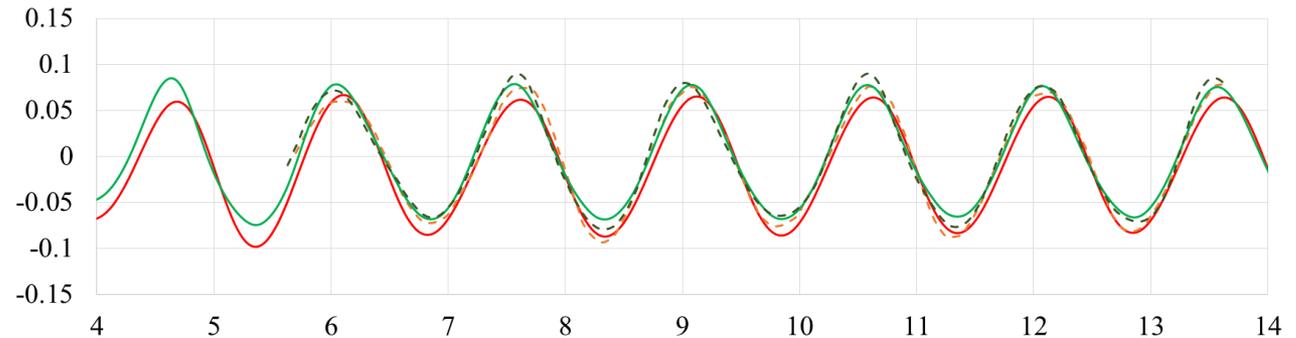
Point absorber (only heave motion)

VALIDATION

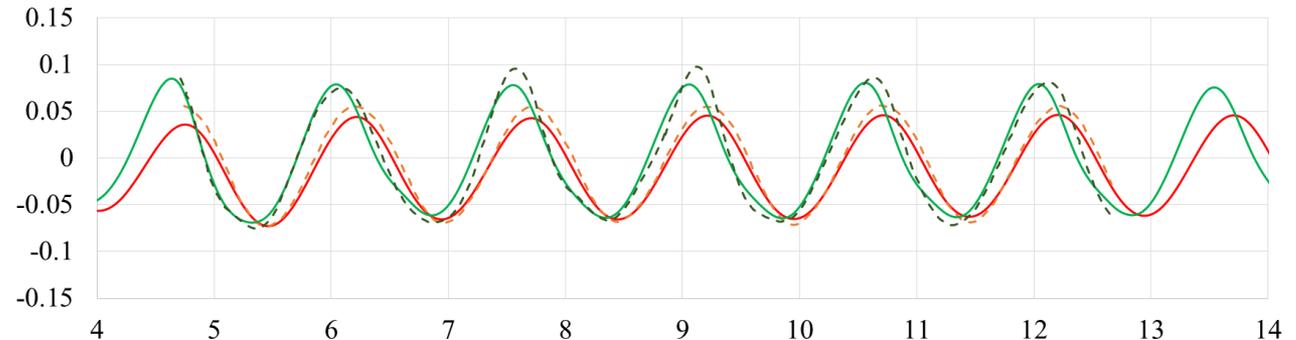
Regular waves: $H=0.16$ m, $T=1.5$ s, $d=1.1$ m

Spring-damper with CHRONO: $\text{rest_length}=0.99$ m, $k=0$

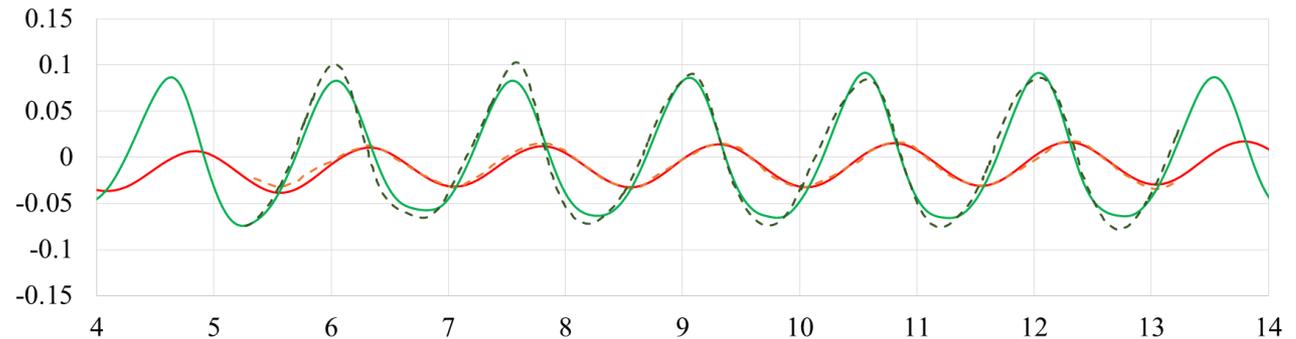
c=0



c=240



c=1100



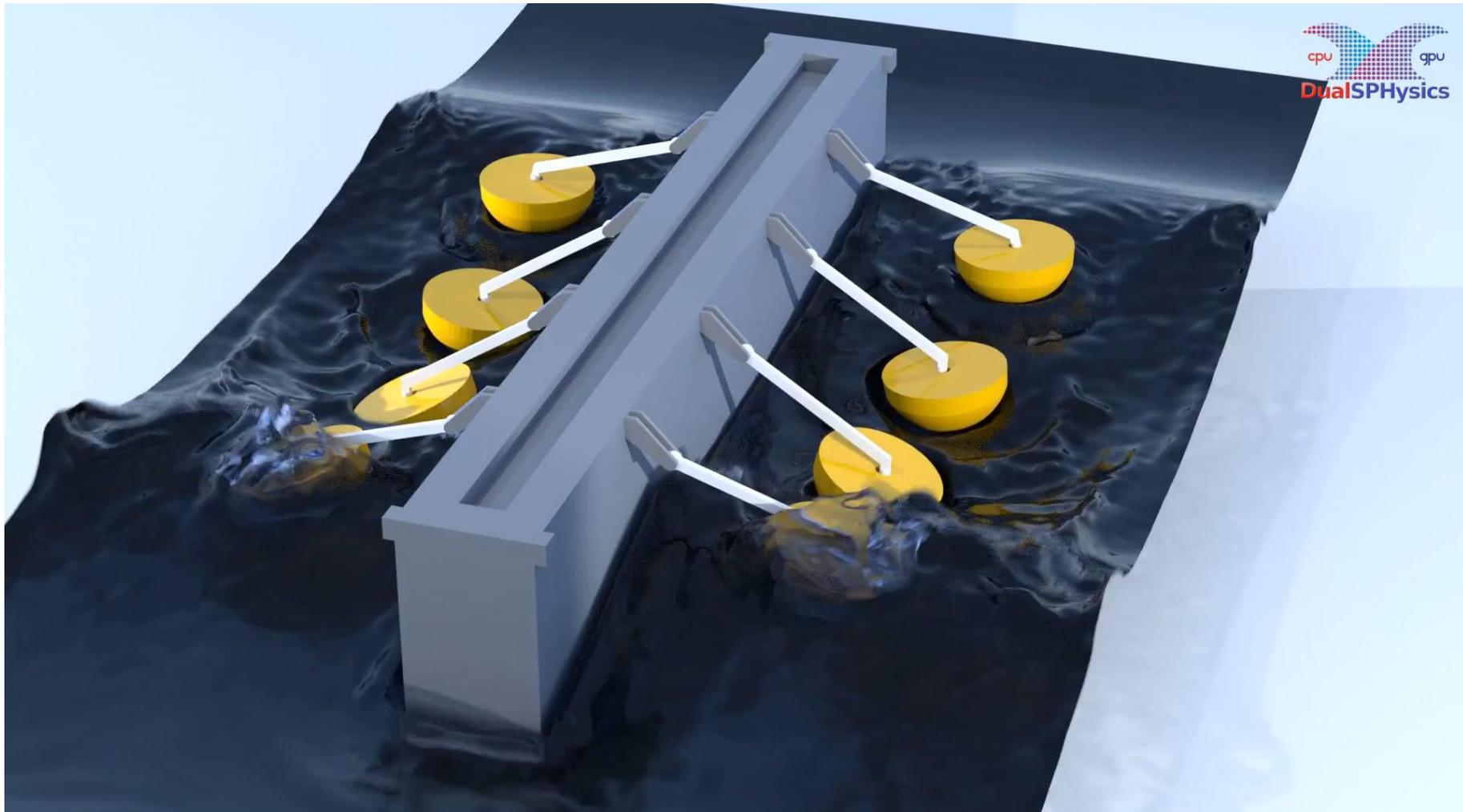
— heave [m] - - - EXP z [m/s] — eta [m] - - - EXP eta [m]

WaveStar

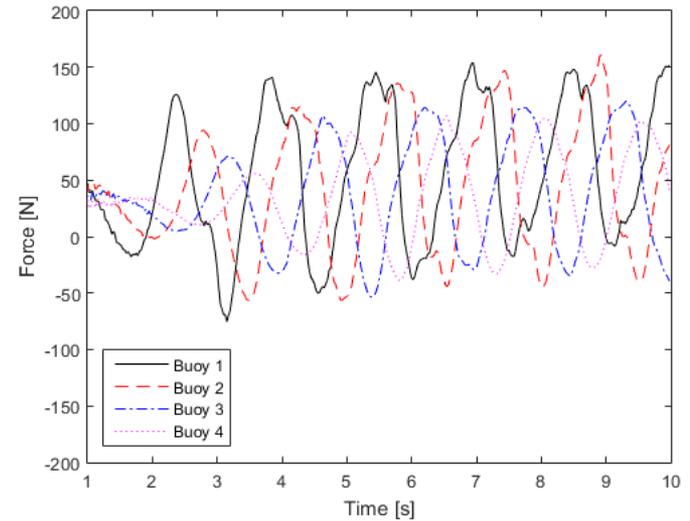
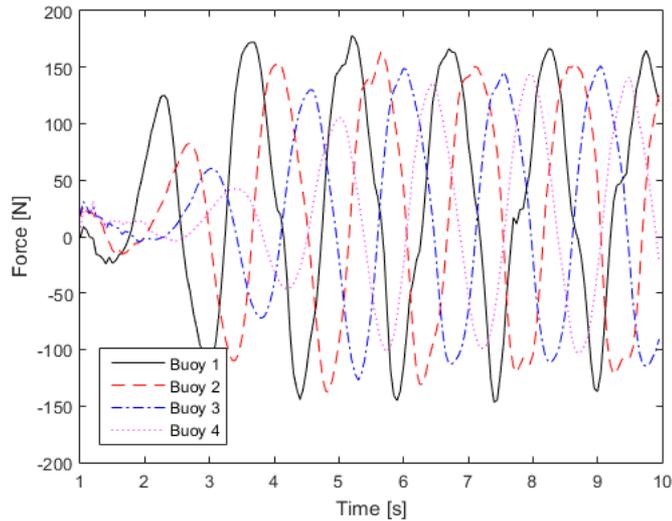
Revolute and spherical joints on the articulated arms and buoys.



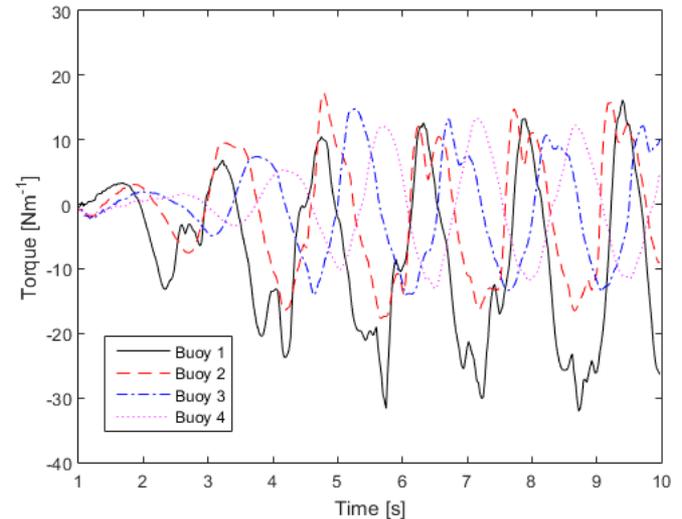
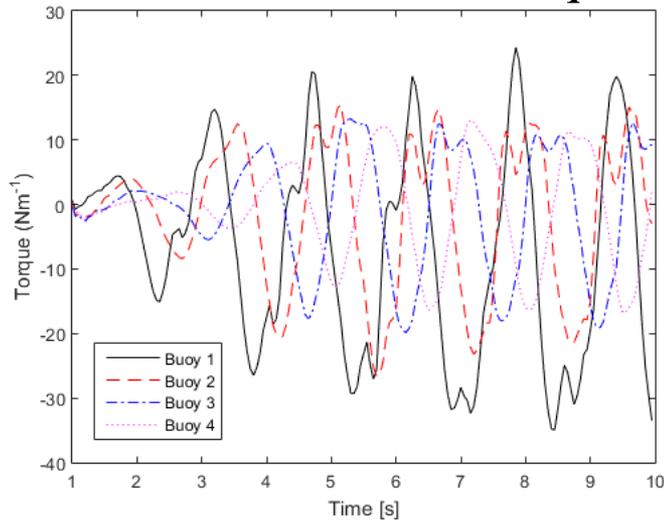
Revolute and spherical joints on the articulated arms and buoys.



Forces on the buoy link



Torque on the buoy link



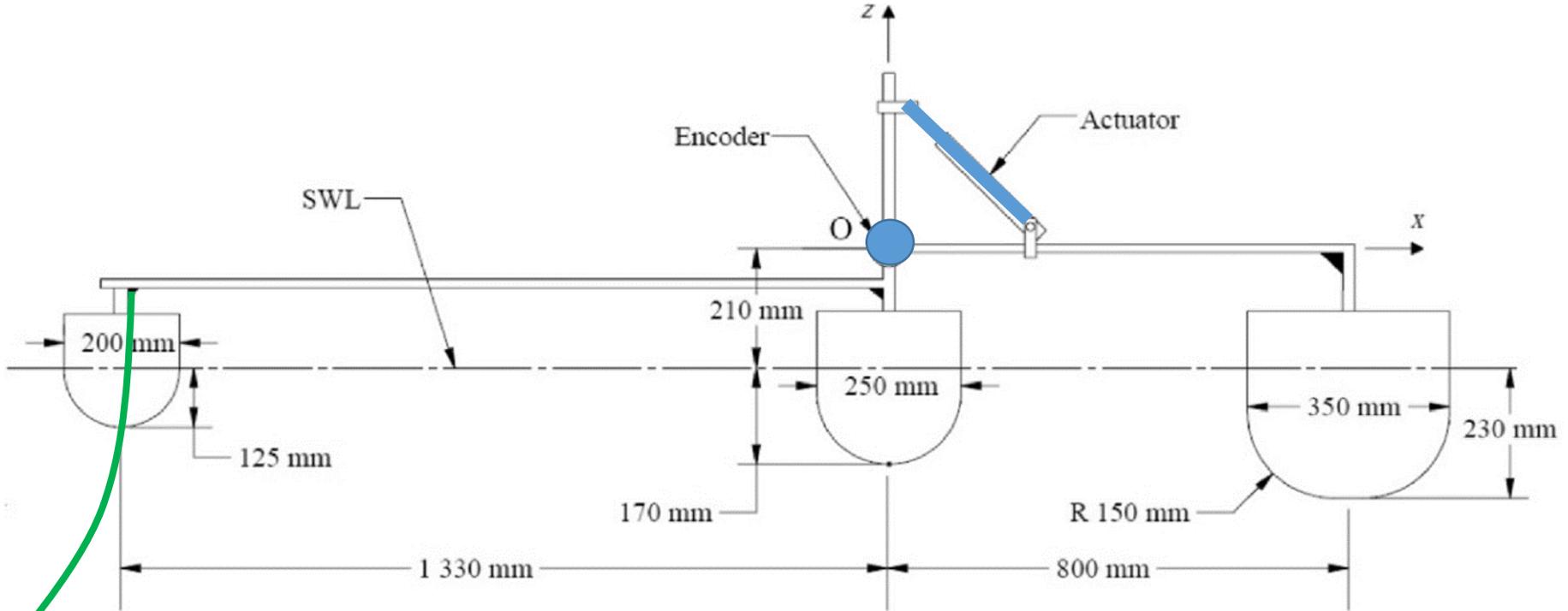
Without PTO
 $k=0, c=0$

With PTO
 $k=2500, c=500$

Multi-floater M4

M4 is a moored three-float line absorber WEC

Stansby P, Carpintero-Moreno E, Stallard T, 2017. Large capacity multi-float configurations for the wave energyconverter M4 using a time-domain linear diffraction model. Applied Ocean Research, 68: 53-64.



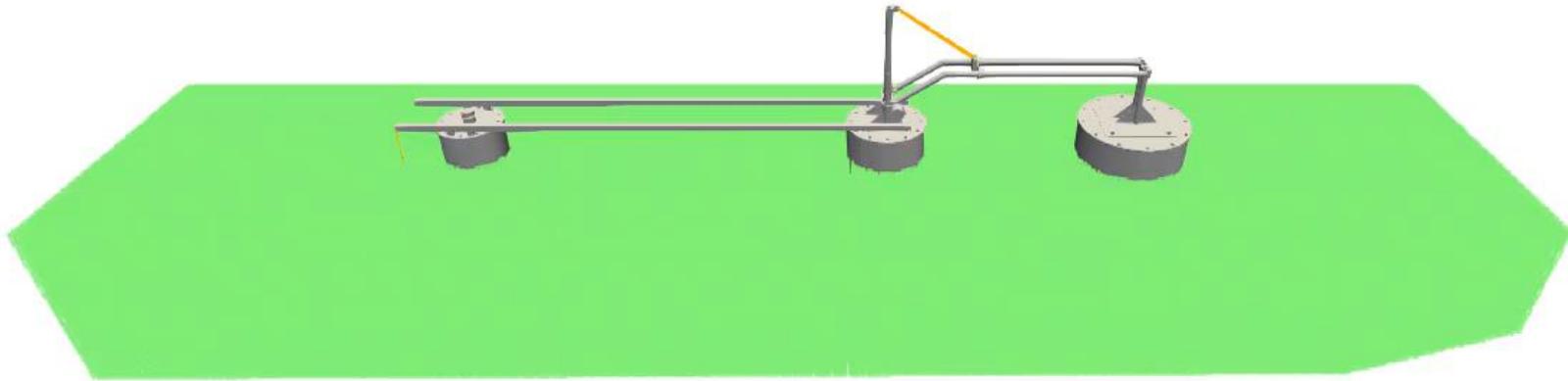
Interaction waves-structure
Mechanical constraint “hinge”
Pneumatic actuator or damper
Mooring line

SPH
CHRONO
CHRONO
MOORDYN

Multi-floater M4

M4 is patented and has been supported by:

- EPSRC Supergen Marine Challenge grant Step WEC (EP/K012487/1) provided by the UK government
- The Energy Sustainability Conacyt-SENER fund provided by the Mexican government
- The EU Marinet2 Transnational Access programme (project M4WW)



OUTLINE

Objective: Numerical modelling of WECs

SPH modelling: DualSPHysics software

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- Oscillating Wave Surge Converter (OWSC)
- Point absorber
- Others (WaveStar, M4)

Conclusions & Future work

Conclusions & Future work

- ✓ DualSPHysics code has been **validated with experimental data** to prove the capability to simulate wave-structure interactions (fixed and floating structures).
- ✓ DualSPHysics is **successfully coupled with the other models:**
 - ✓ MoorDyn to simulate mooring lines
 - ✓ Project Chrono to simulate the behaviour of PTO
- ✓ It can be used to study not only the **efficiency** of WECs but also **the survivability under extreme waves** (high energetic sea states).
- ✓ Source code and examples are **available in DualSPHysics v4.4**

Conclusions & Future work

SOURCE CODE AND EXAMPLE IN **DUALSPHYSICS V4.4**

CaseBoxOnlyHeave



Particles: 17,491
Physical time: 10 s
Runtime (GTX Titan Black): 500 s



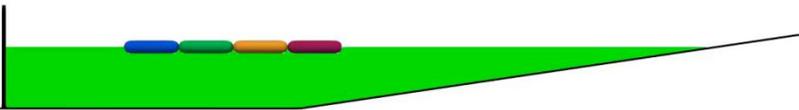
CaseBoxOnlyHeaveCHRONO



Particles: 17,491
Physical time: 10 s
Runtime (GTX Titan Black): 560 s

Time: 0.00 s

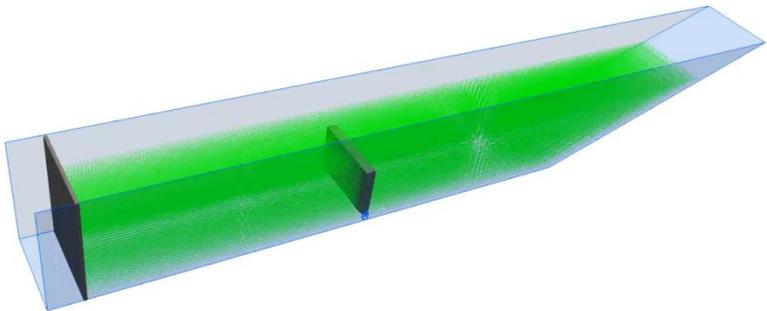
CasePelamis



Particles: 30,801
Physical time: 10 s
Runtime (GTX Titan Black): 342 s

Time: 0.00 s

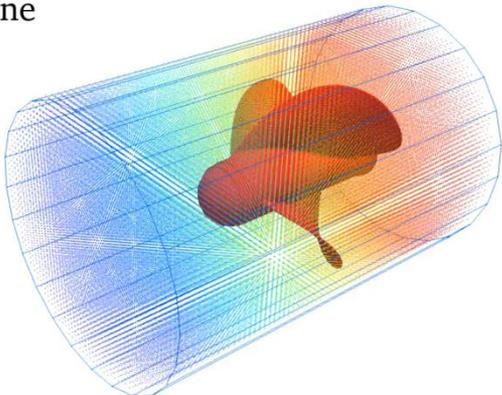
CaseOWSC3D



Particles: 173,388
Physical time: 10 s
Runtime (GTX Titan Black): 20 min

Time: 0.00 s

CaseTurbine



Particles: 127,331
Physical time: 5 s
Runtime (GTX TITAN Black): 208 s

Time: 0.00 s

<https://dual.sphysics.org/>

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- Altomare C, Domínguez JM, Crespo AJC, González-Cao J, Suzuki T, Gómez-Gesteira M, Troch P. 2017. Long-crested wave generation and absorption for SPH-based DualSPHysics model. *Coastal Engineering*, 127: 37-54.
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- Crespo AJC, Hall M, Domínguez JM, Altomare C, Wu M, Verbrugge T, Stratigaki V, Troch P, Gómez-Gesteira M. 2018. Floating moored oscillating water column with meshless SPH method. In: 37th International Conference on Ocean, Offshore and Arctic Engineering, Madrid, Spain, OMAE2018-77313
- Brito M, Canelas RB, García-Feal O, Domínguez JM, Crespo AJC, Ferreira RML, Neves MG, Teixeira L. 2019. A numerical tool for modelling oscillating wave surge converter with nonlinear mechanical constraints. *Renewable Energy*, 146: 2024-2043.

ACKNOWLEDGEMENTS

COST Action CA17105, COST Association
WECANet: A pan-European Network for Marine
Renewable Energy



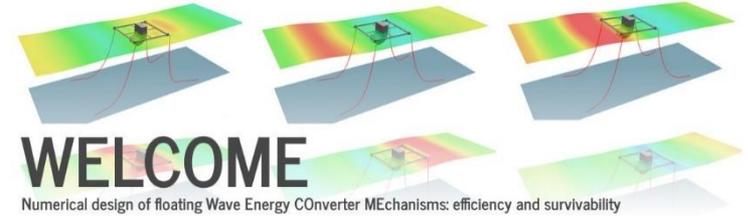
SPANISH GOVERNMENT. RETOS 2016

WELCOME: Numerical design of floating Wave Energy
CONverter MEchanisms: efficiency and survivability



MARINET2

Esflowc: Efficiency and survivability of floating
OWC moored to the seabed



Esflowc Efficiency and survivability of floating Oscillating Water Column Wave Energy Converters moored to the seabed

GHENT UNIVERSITY (COORDINATOR), BELGIUM

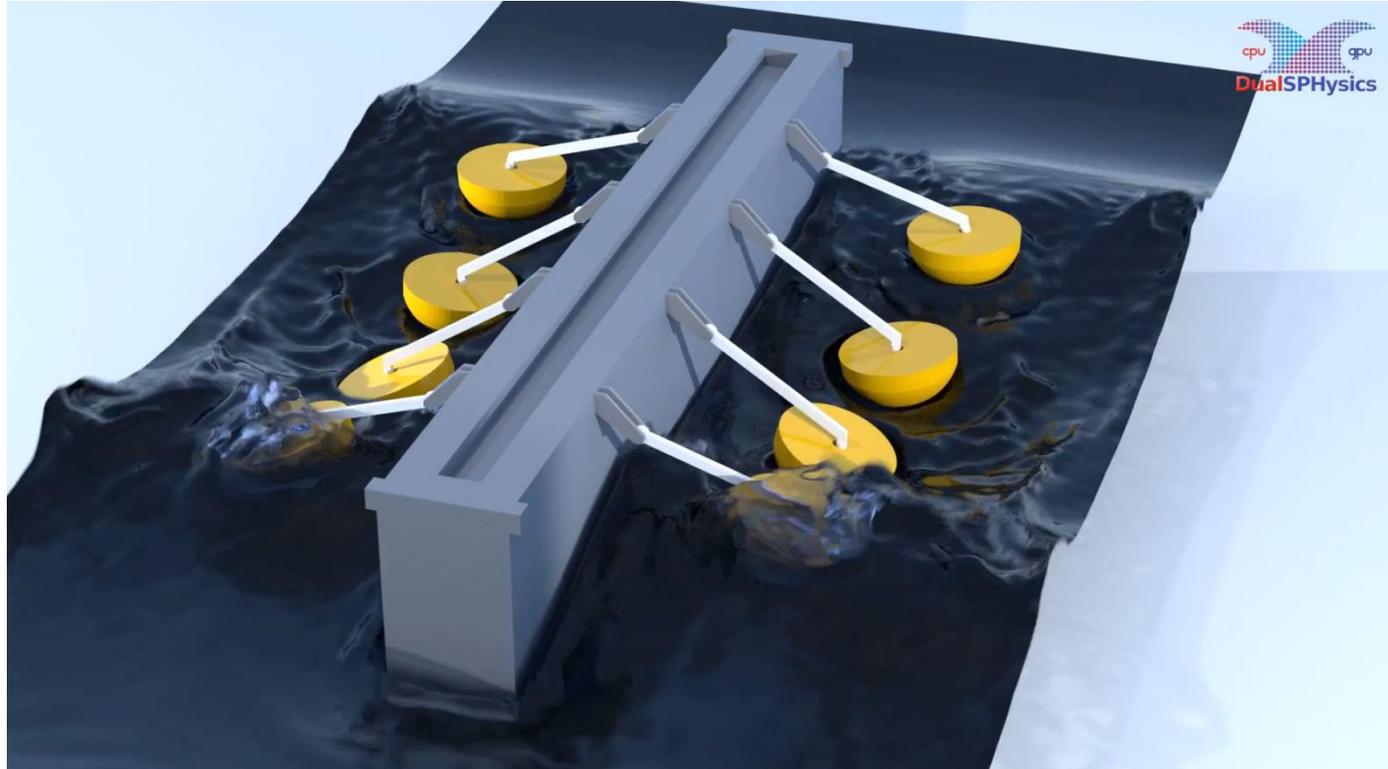
UNIVERSIDADE DE VIGO, SPAIN | THE UNIVERSITY OF MANCHESTER, UNITED KINGDOM
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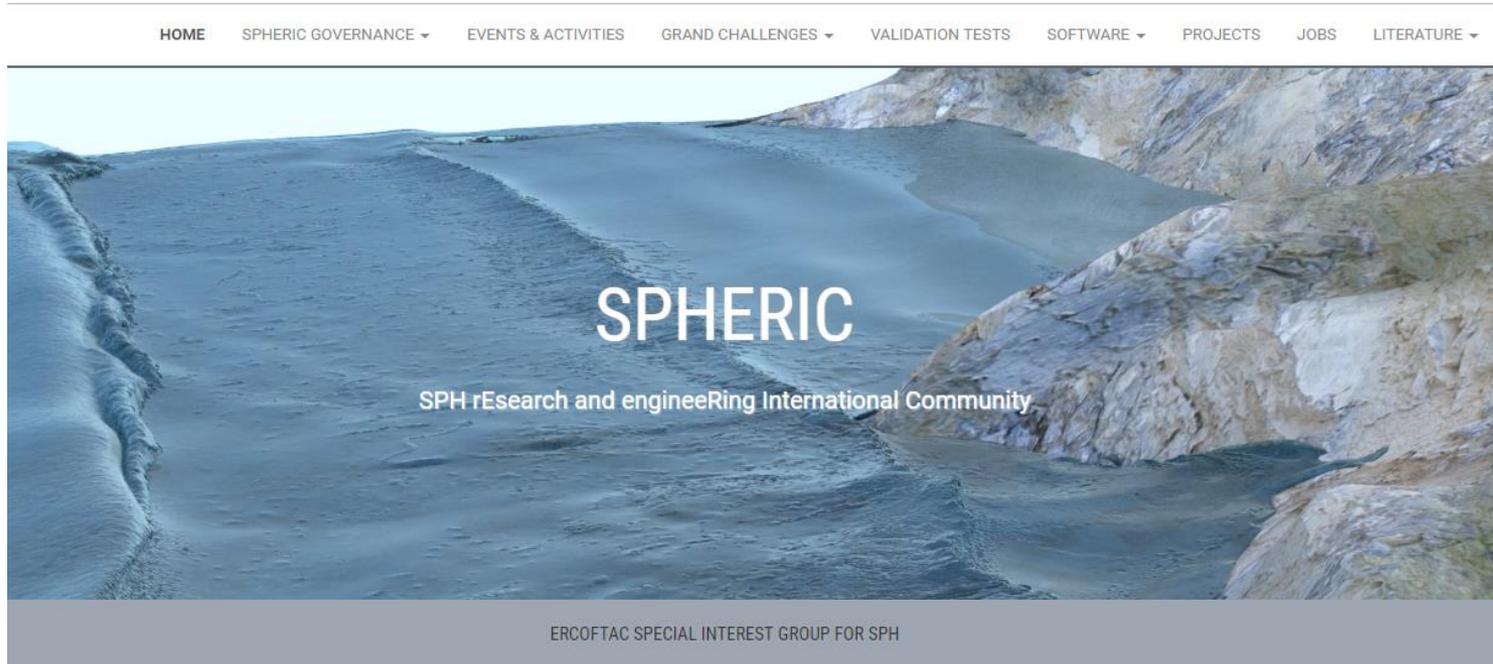
Thanks a lot for your attention



Grazie per la vostra attenzione

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SPHERIC organisation



Welcome to SPHERIC

SPHERIC is the international organisation representing the community of researchers and industrial users of Smoothed Particle Hydrodynamics (SPH).

As a purely Lagrangian technique, SPH enables the simulation of highly distorting fluids and solids. Fields including free-surface flows, solid mechanics, multi-phase, fluid-structure interaction and astrophysics where Eulerian methods can be difficult to apply represent ideal applications of this meshless method.



Annual Workshops

<http://spheric-sph.org/>

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SPHERIC organisation

SPHERIC is the international organisation representing the community of researchers and industrial users of Smoothed Particle Hydrodynamics (SPH)

UNIVERSIDADE DE VIGO is member of SPHERIC since 2006

Objectives of SPHERIC

To develop the fundamental basis of SPH.

To discuss current and new concepts.

To foster communication between industry and academia.

To communicate experience in the application of the technology.

To investigate accelerating simulations and visualisation.

To provide access to existing software and methods.

To define benchmark test cases.

To identify future needs of SPH.



SPHERIC STEERING COMMITTEE:

Prof. Moncho Gómez Gesteira (2006-2013)

Dr Alejandro J. C. Crespo (2014-TODAY) WEBMASTER

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DualSPHysics Users Workshop

1st DualSPHysics Users Workshop, University of Manchester, U.K., 8-9 September 2015

2nd DualSPHysics Users Workshop, University of Manchester, U.K., 6-7 December 2016

3rd DualSPHysics Users Workshop, University of Parma, Italy, 13-15 November 2017

4th DualSPHysics Users Workshop, Instituto Superior Técnico, Lisboa, 22-24 October 2018

5th DualSPHysics Users Workshop, Universitat Politècnica de Catalunya, Barcelona, 2020

