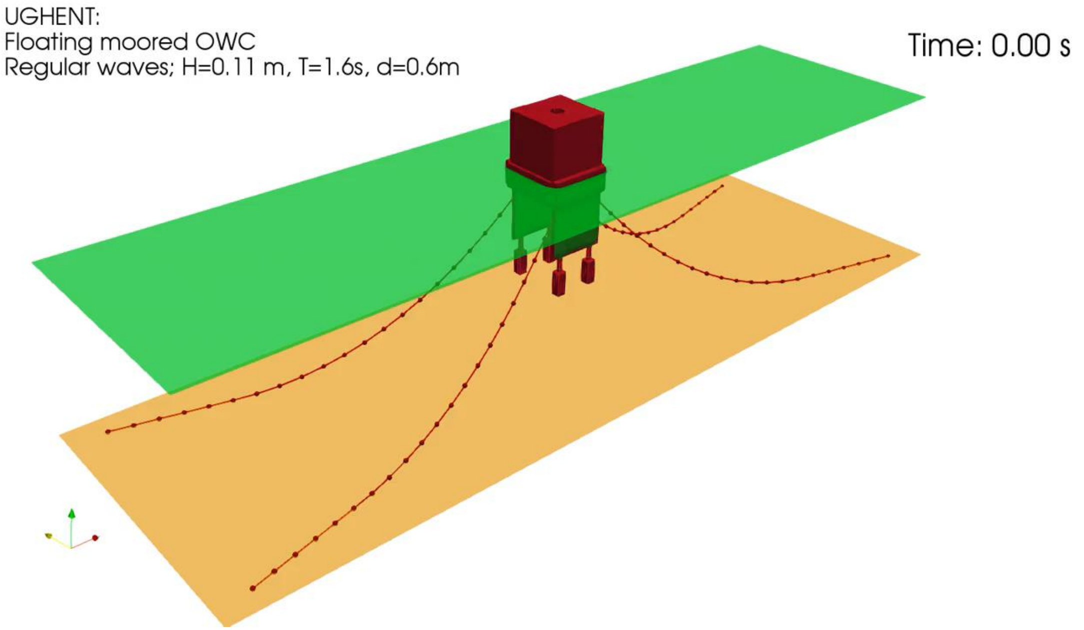
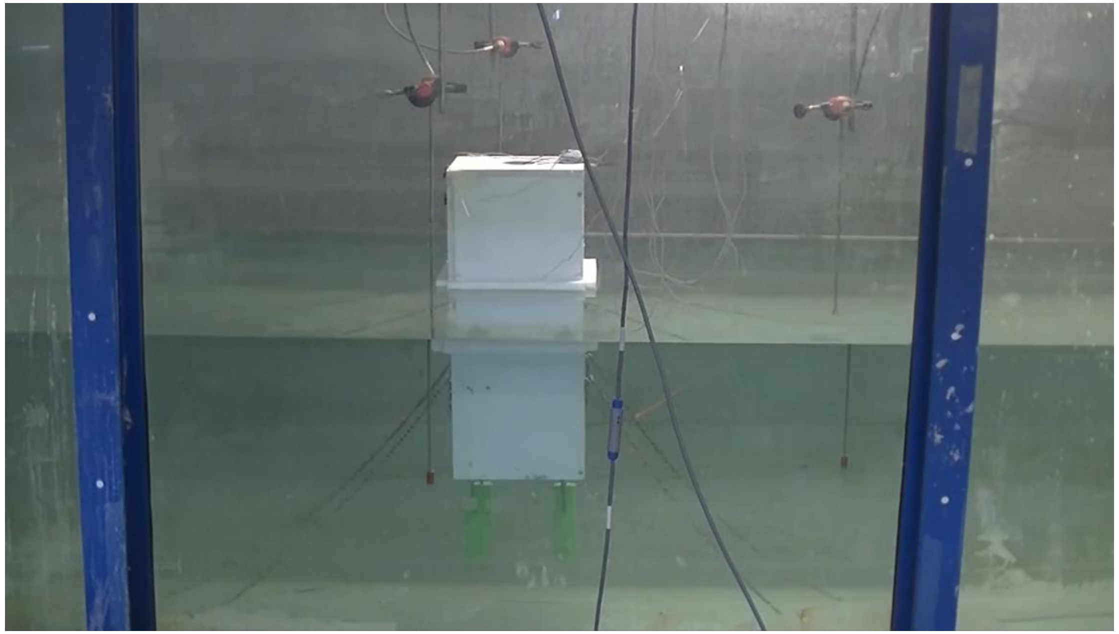
Floating Oscillating Water Column (OWC) with meshless SPH method





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UNIVERSITEIT GENT

flanders HYDRAULICS RESEARCH

OBJECTIVES

1) Develop and validate the numerical tool to simulate floating WECs

2) Design more efficient floating WECs

3) Study survivability under extreme conditions

NUMERICAL MODELLING

Wave Energy Converters (WECs)

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

CFD models
Approximate Navier–Stokes

Meshbased methods

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

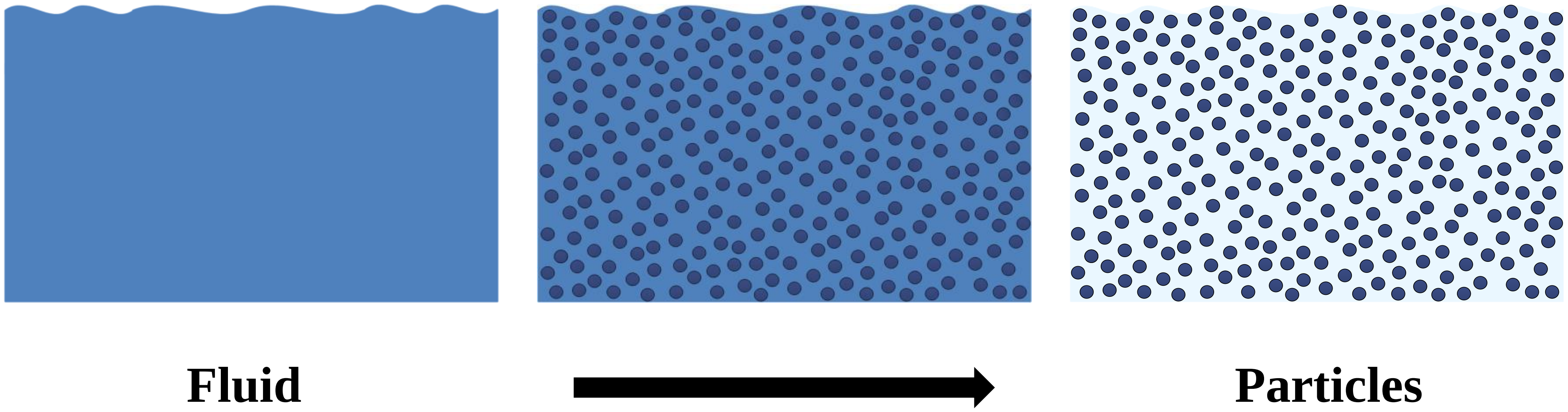
Meshless methods

SPH

SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

SPH method was invented for astrophysics during the seventies, but now it is applied in many different fields including fluid dynamics and solid mechanics.

Fluid is represented using particles which move according to the governing dynamics.



SPH interactions are carried out between a given particle and its moving neighbours.

SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

SPH is based on integral interpolants

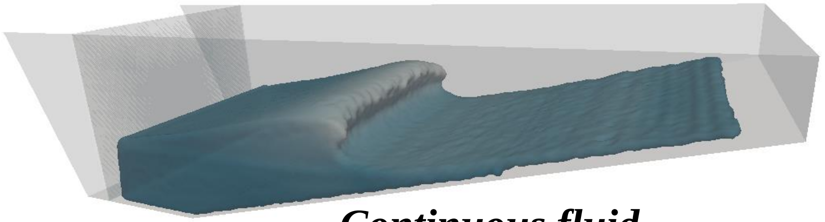
The fundamental principle is to approximate any function *F*(r) by (kernel approximation)

$$F(\mathbf{r}) = \int_\Omega F(\mathbf{r}')W(\mathbf{r}-\mathbf{r}',2h)\,d\mathbf{r}'$$

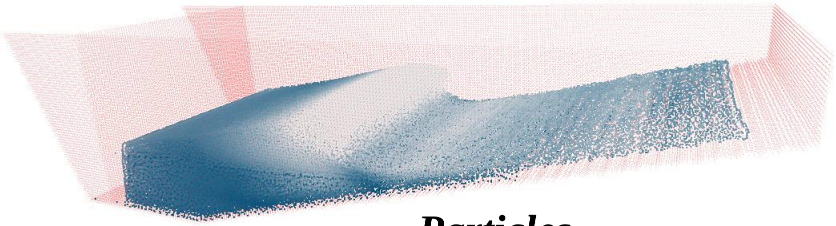
From **continuous notation** (INTEGRALS)

To **discrete notation** (SUMMATION)

$$F(\mathbf{r}) \approx \sum_{j=1}^{N} F(\mathbf{r}_j)\, W(\mathbf{r}-\mathbf{r}_j,2h)\,\frac{m_j}{\rho_j}$$

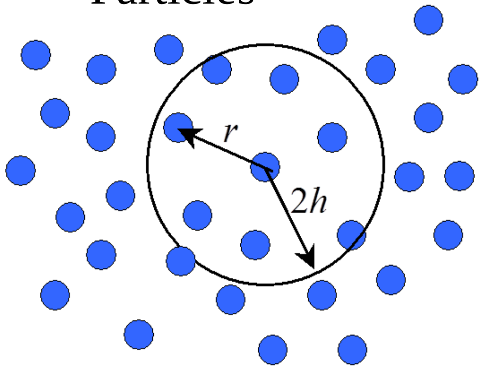


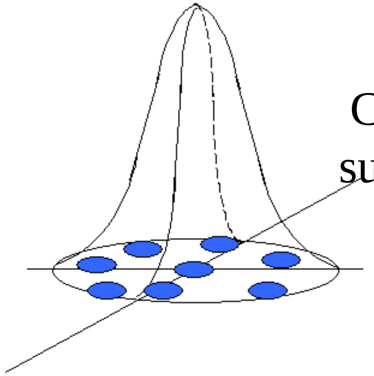
Continuous fluid



Particles

Particles





Compact support of kernel

SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

Navier-Stokes equations

Continuous notation (INTEGRALS)

Discrete notation (SUMMATIONS) in SPH form

Conservation of Mass

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

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

Conservation of Momentum

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

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

Density derivative $\frac{d\rho}{dt} \rightarrow \rho \rightarrow P$

density pressure

Velocity derivative (acceleration) $\frac{d\mathbf{v}}{dt} \rightarrow \mathbf{v} \rightarrow \mathbf{r}$

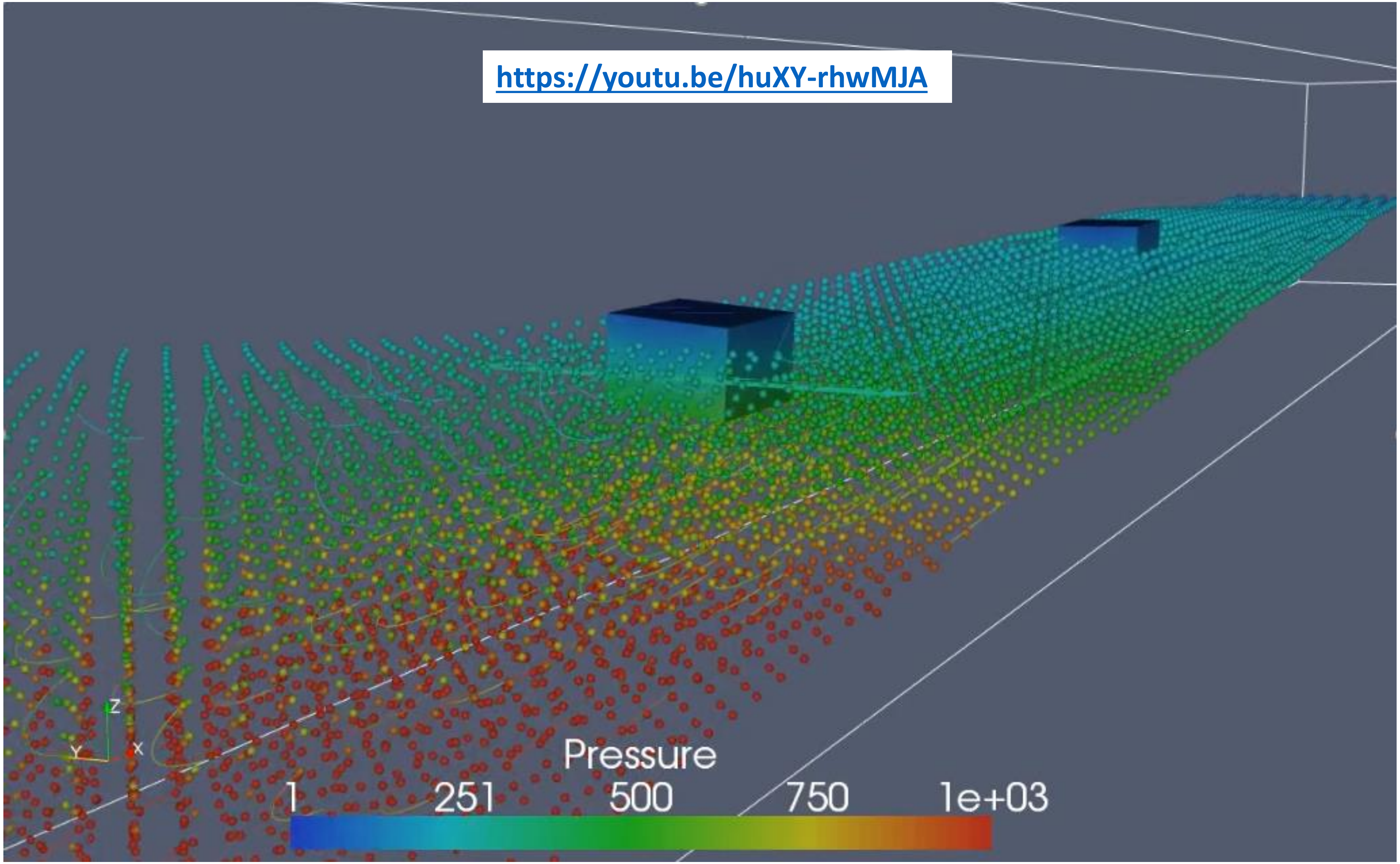
velocity position

SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

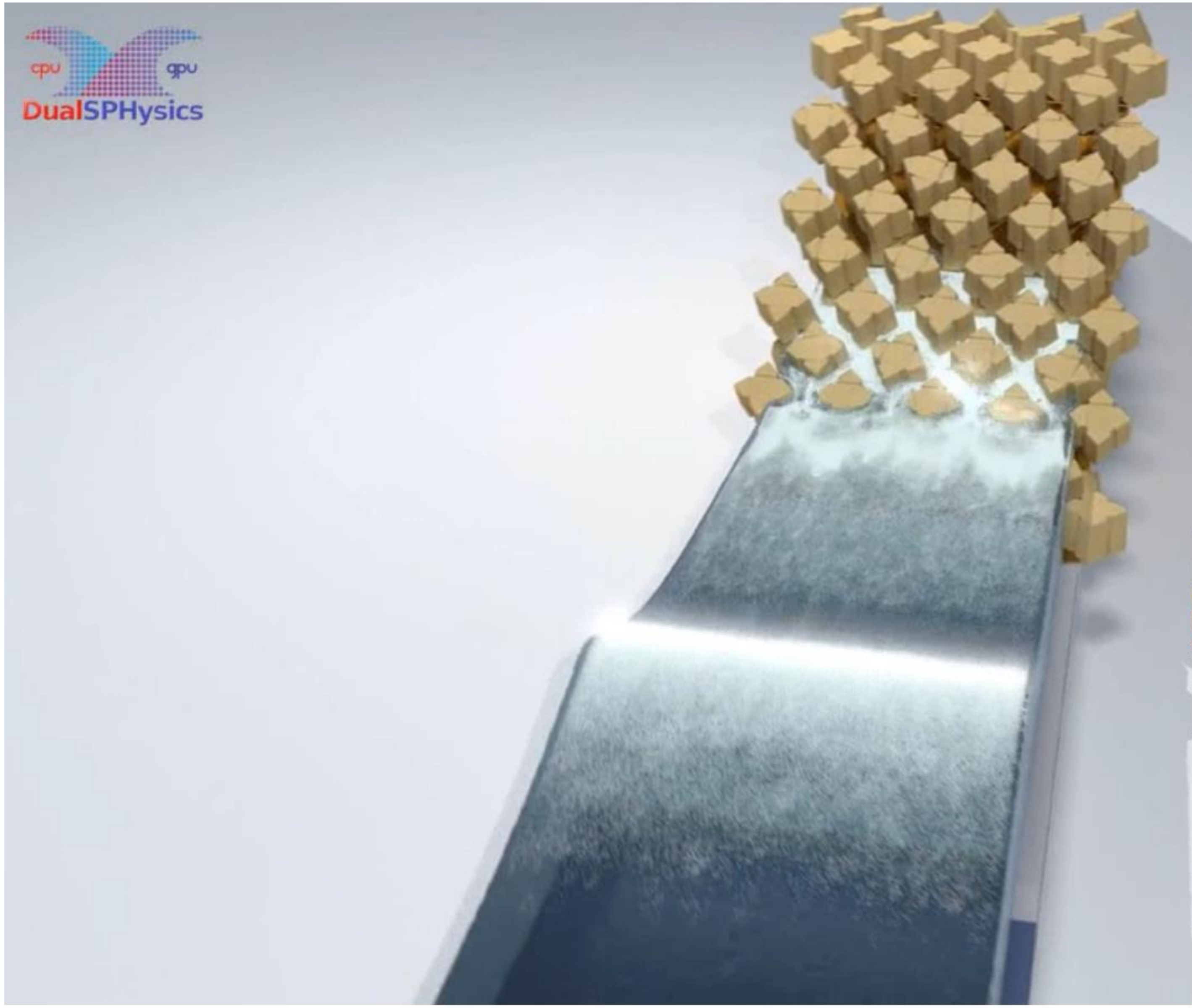
ADVANTAGES comparing with mesh-based CFD codes:

- ✓ 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 boundary** evolution
- ✓ Distinguishing **between phases** due to holding material properties at each individual particle
- ✓ Natural incorporation of coefficient discontinuities and **singular forces** into the numerical scheme
- ✓ Capable of being **coupled with other** mesh dependent and meshless techniques

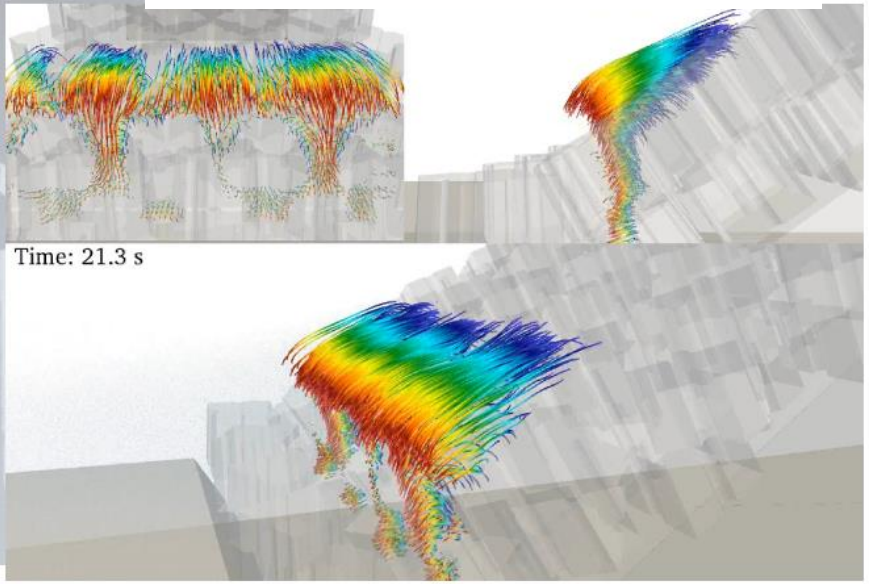
SMOOTHED PARTICLE HYDRODYNAMICS (SPH)



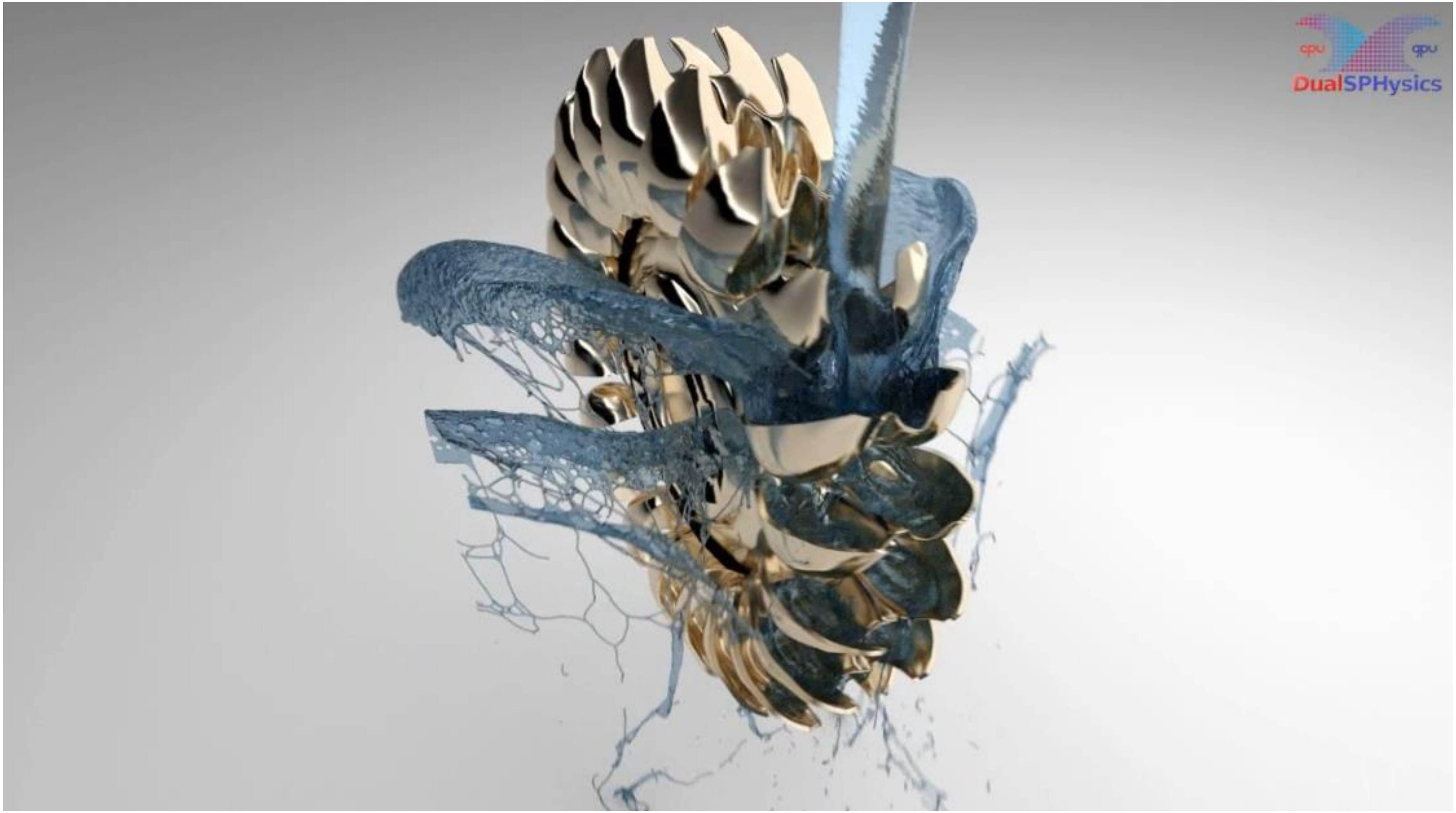
SMOOTHED PARTICLE HYDRODYNAMICS (SPH)



https://youtu.be/uMJEQKiJgP4

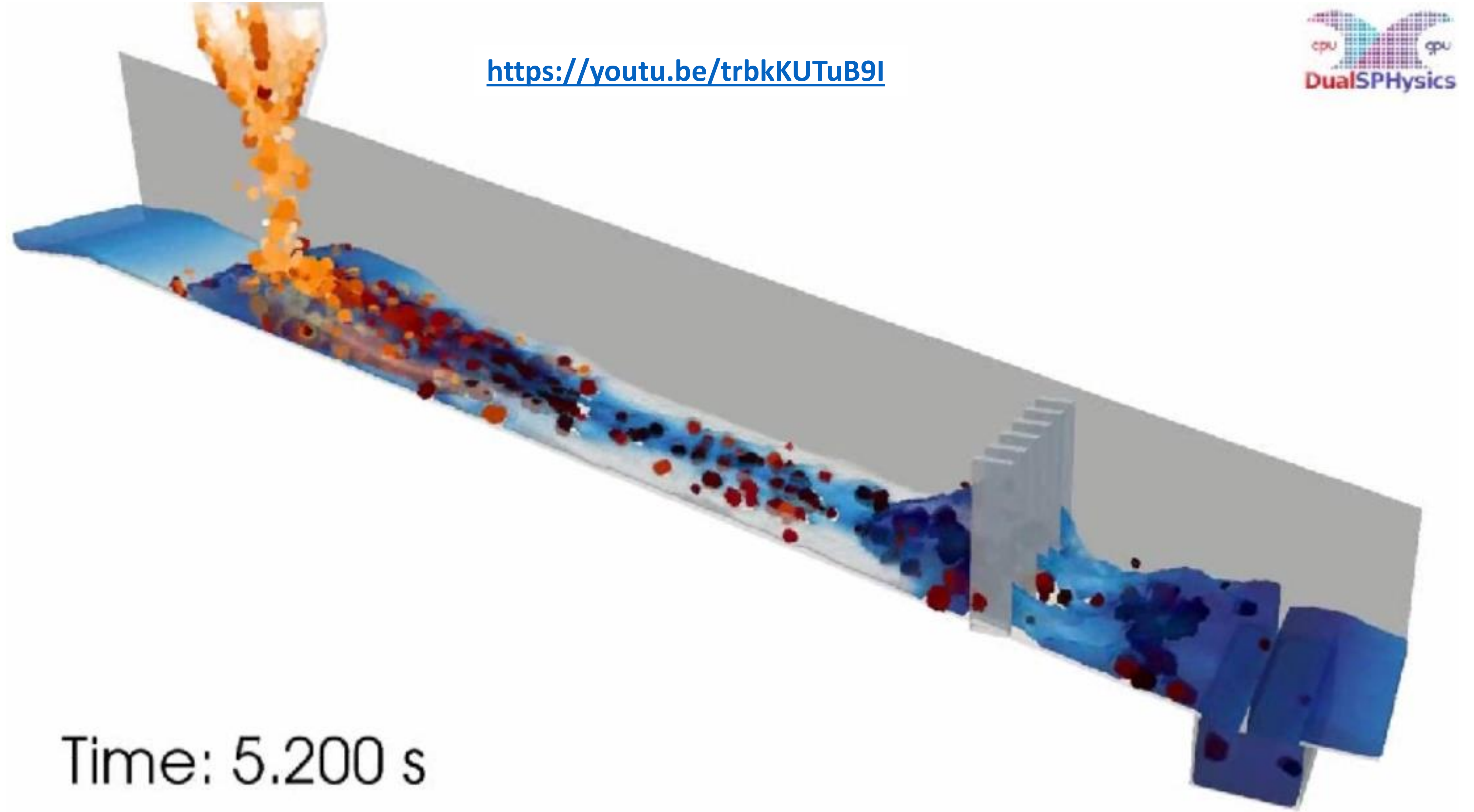


SMOOTHED PARTICLE HYDRODYNAMICS (SPH)



SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

https://youtu.be/trbkKUTuB9I



SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

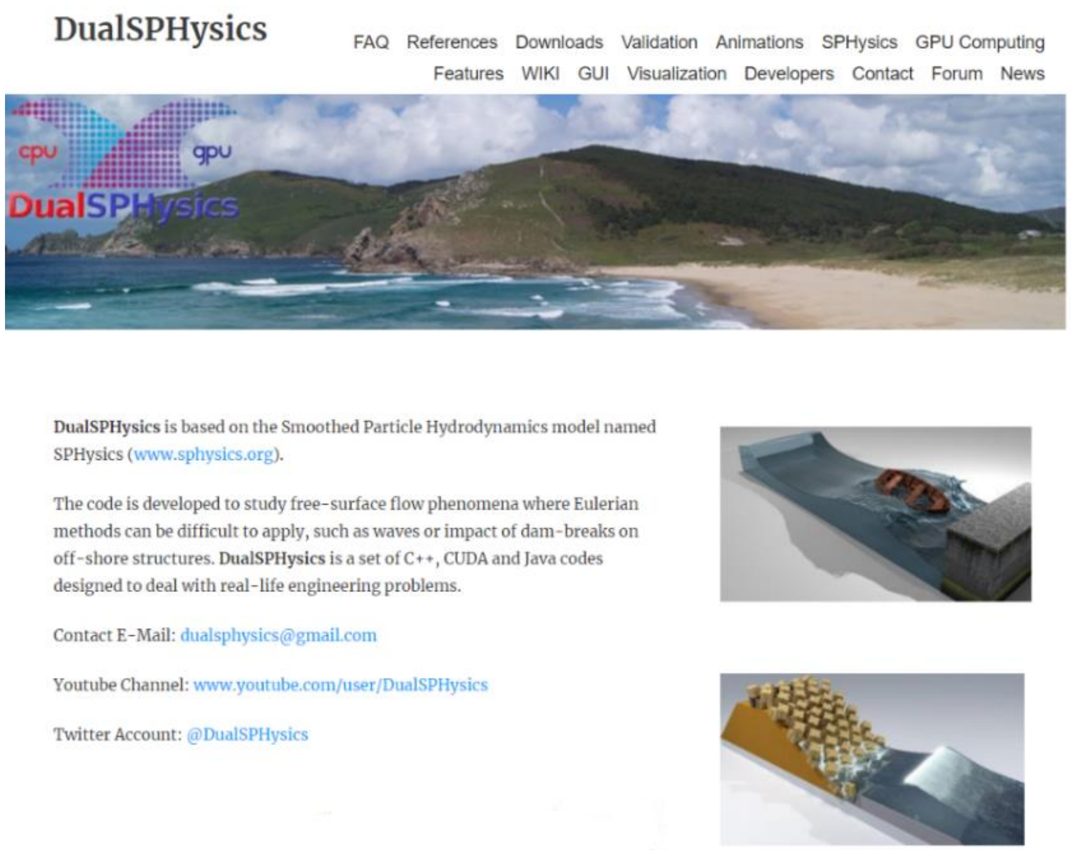
DISADVANTAGES comparing with mesh-based CFD codes:

- ✓ The **interpolation method** used in SPH is very simple and it will be strongly affected by **particle disorder**. SPH gives reasonable results for the first order gradients, but they can be worse for higher order derivatives.
- ✓ **Turbulence treatment** is still an open field and more research is needed.
- ✓ **Boundary condition** implementation is a hard task and fluid particles penetration into boundaries must be avoided. There is no unanimity to choose the best boundary conditions approach.
- ✓ **Time computation is expensive** comparing with other meshbased methods or CFD software.

SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

DualSPHysics

DualSPHysics CODE



www.dual.sphysics.org

- **OPEN-SOURCE CODE**
- AVAILABLE FOR FREE
- COLLABORATIVE PROJECT
- LGPL LICENSE
- HIGHLY PARALLELISED
- PRE- & POST-PROCESSING
- APPLIED TO REAL PROBLEMS
- JOURNAL PUBLICATIONS

SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

DualSPHysics

DualSPHysics CODE

Version	# downloads
v1	701
v2	6472
v3	6982
v4	7827

TOTAL ~ 22,000 downloads

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SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

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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

SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

DualSPHysics

DualSPHysics CODE

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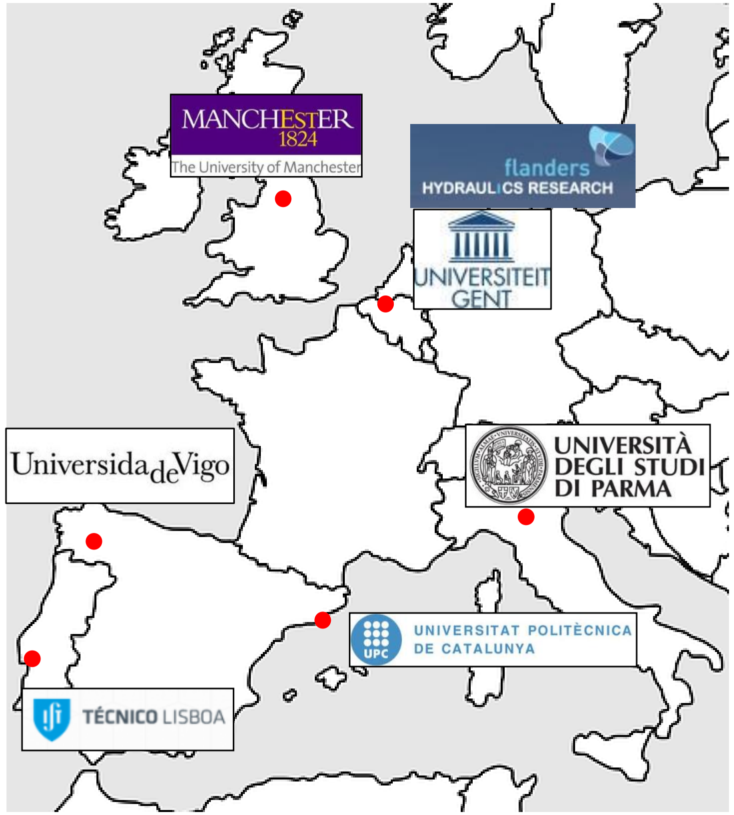
Dr Athanasios Mokos
Dr Georgios Fourtakas
Prof. Peter Stansby
Alex Chow
Annelie Baines

Prof. Moncho Gómez Gesteira
Dr Alejandro J.C. Crespo
Dr Jose M. Domínguez
Dr José González Cao
Orlando G. Feal
Andrés Vieira

Prof. Rui Ferreira
Dr Ricardo Canelas
Moisés Brito



Dr Corrado Altomare
Dr Tomohiro Suzuki
Tim Verbrugghe

Dr Renato Vacondio
Prof. Paolo Mignosa

Dr Xavier Gironella
Dr Andrea Marzeddu

SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

DualSPHysics CODE

LGPL can be used in **commercial** applications
Software can be incorporated into both:
- free software and
- proprietary software

- OPEN-SOURCE CODE
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SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

DualSPHysics CODE

GPU CPU

x100

- OPEN-SOURCE CODE
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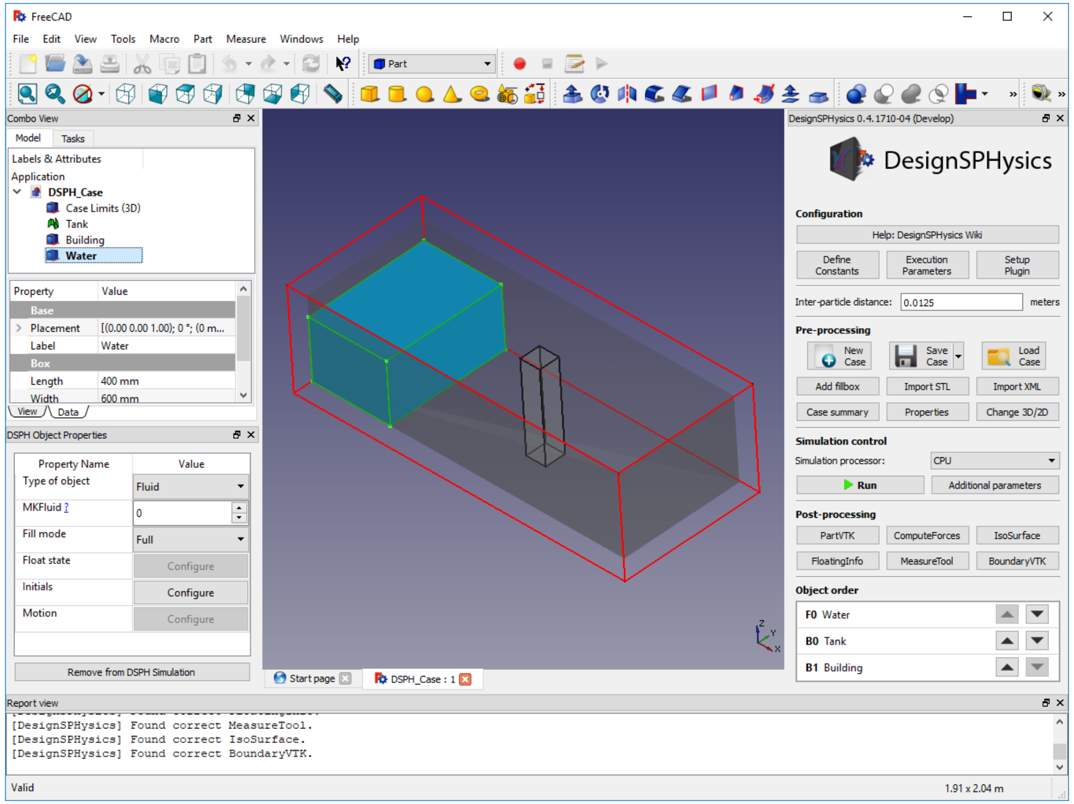
SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

cpu gpu
DualSPHysics

DualSPHysics CODE



FreeCAD
Open Source parametric 3D CAD modeler

Graphical User Interface

- OPEN-SOURCE CODE
- AVAILABLE FOR FREE
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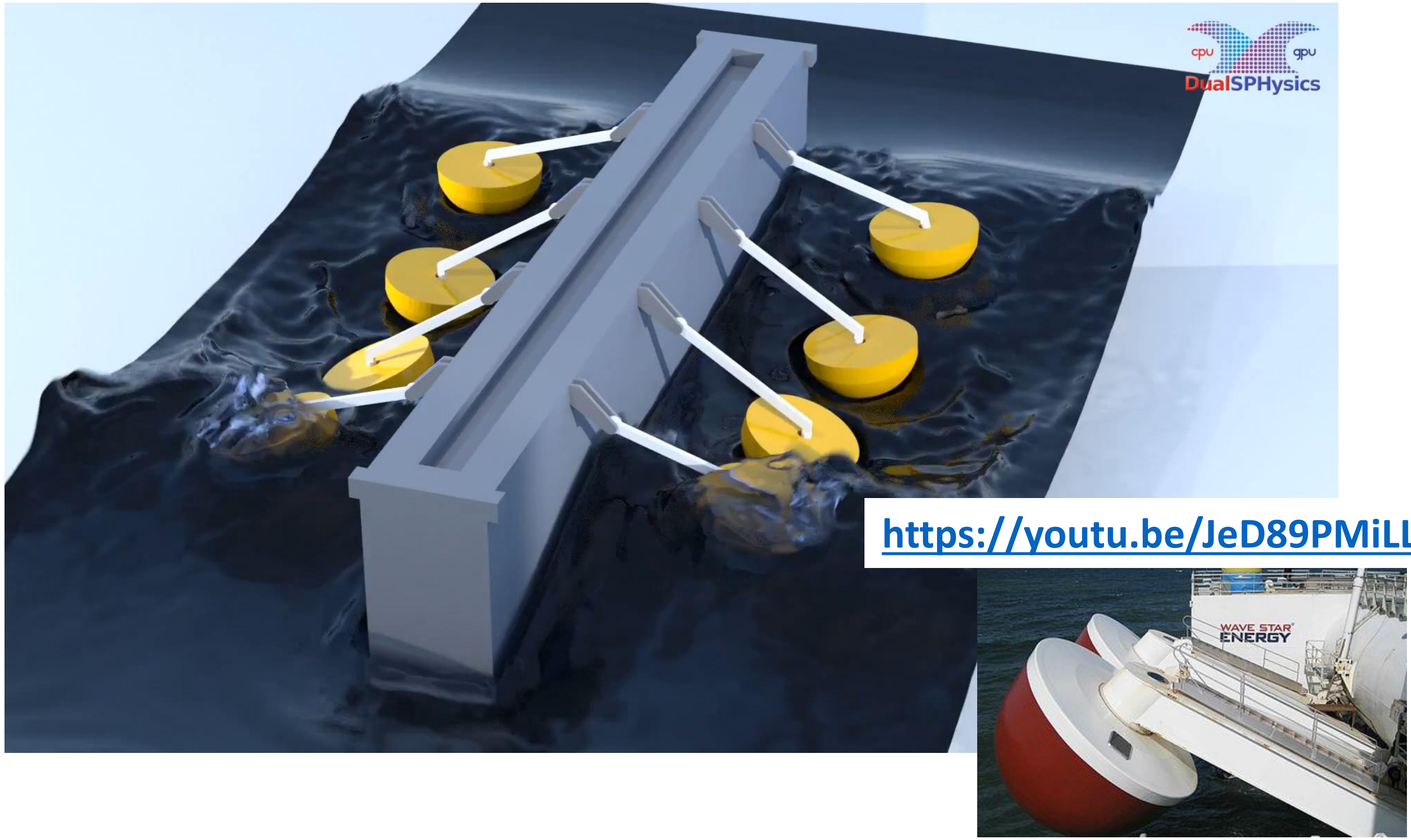
SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

DualSPHysics CODE



https://youtu.be/JeD89PMiLLQ

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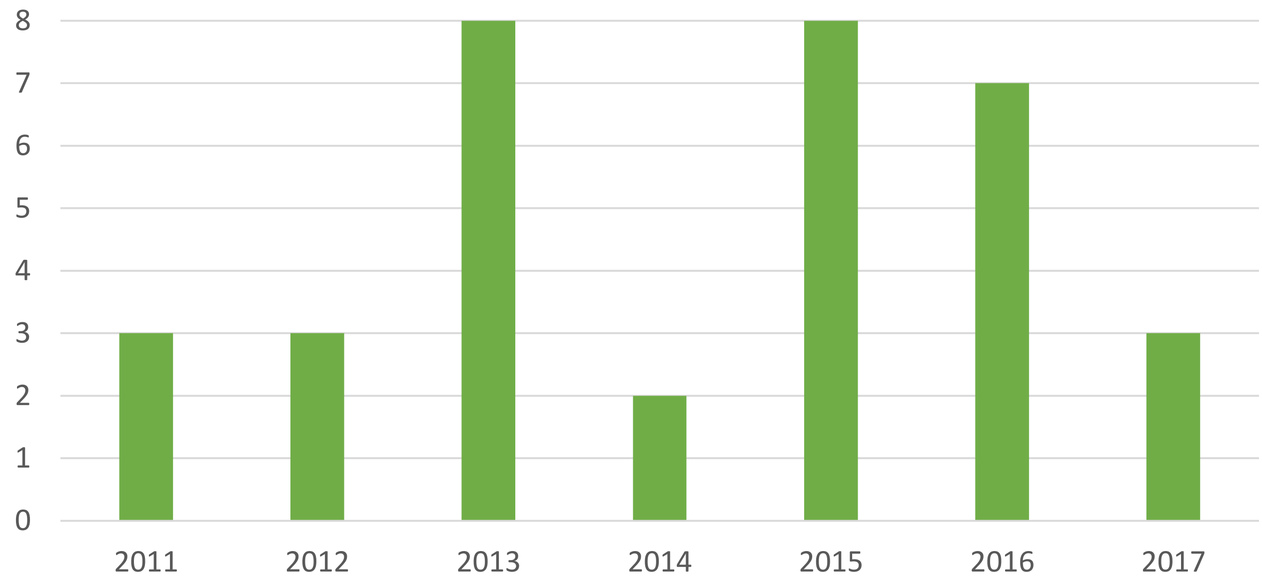
SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

cpu gpu DualSPHysics

DualSPHysics CODE

Papers by DSPH team 2011-2017

http://dual.sphysics.org/index.php/references/



34 papers in peer-reviewed SCI journals that have been cited 1055 times (>30 cites/paper) (SCOPUS 12/06/2018)

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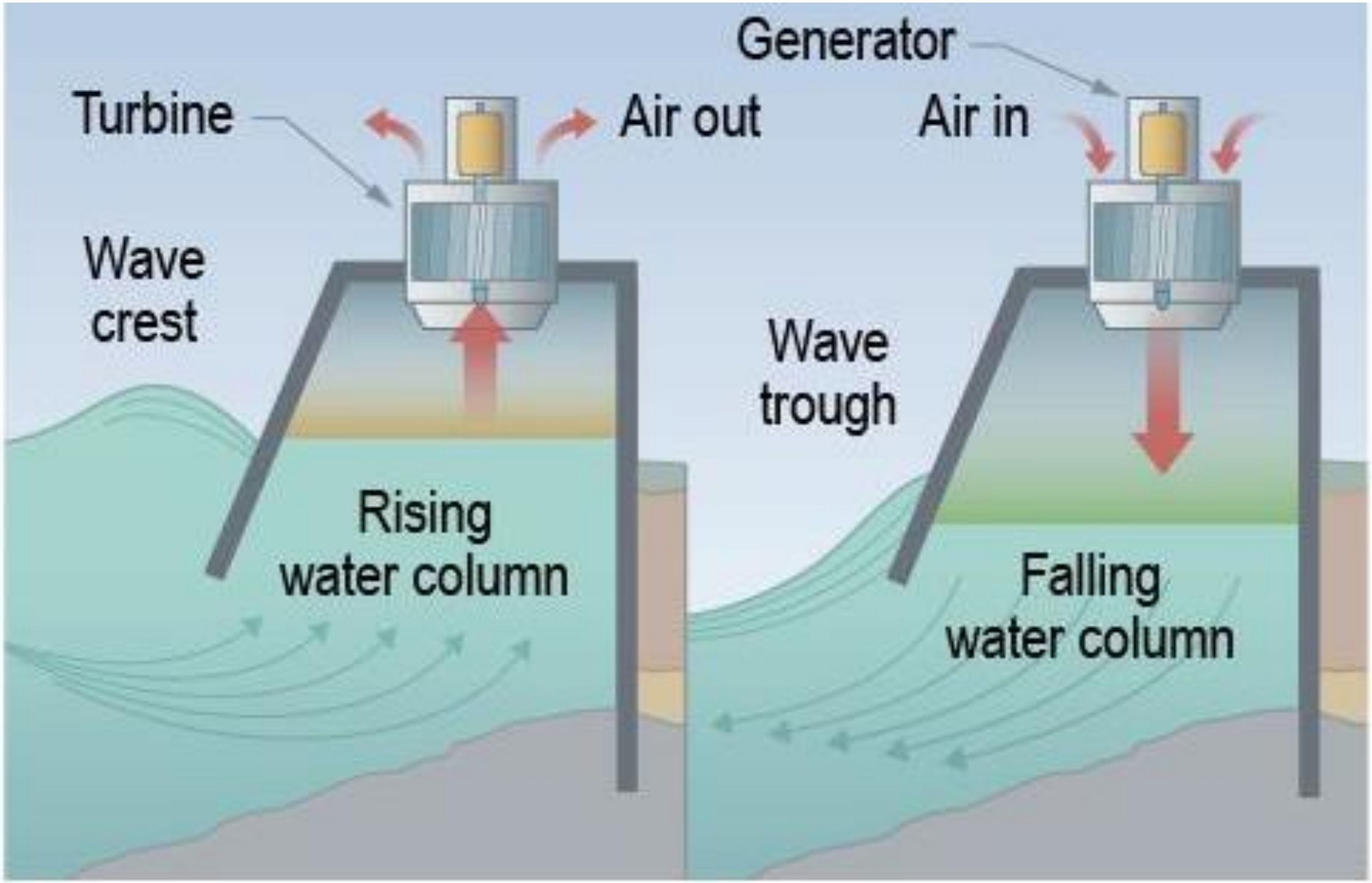
- **JOURNAL PUBLICATIONS**

OSCILLATING WATER COLUMN (OWC)

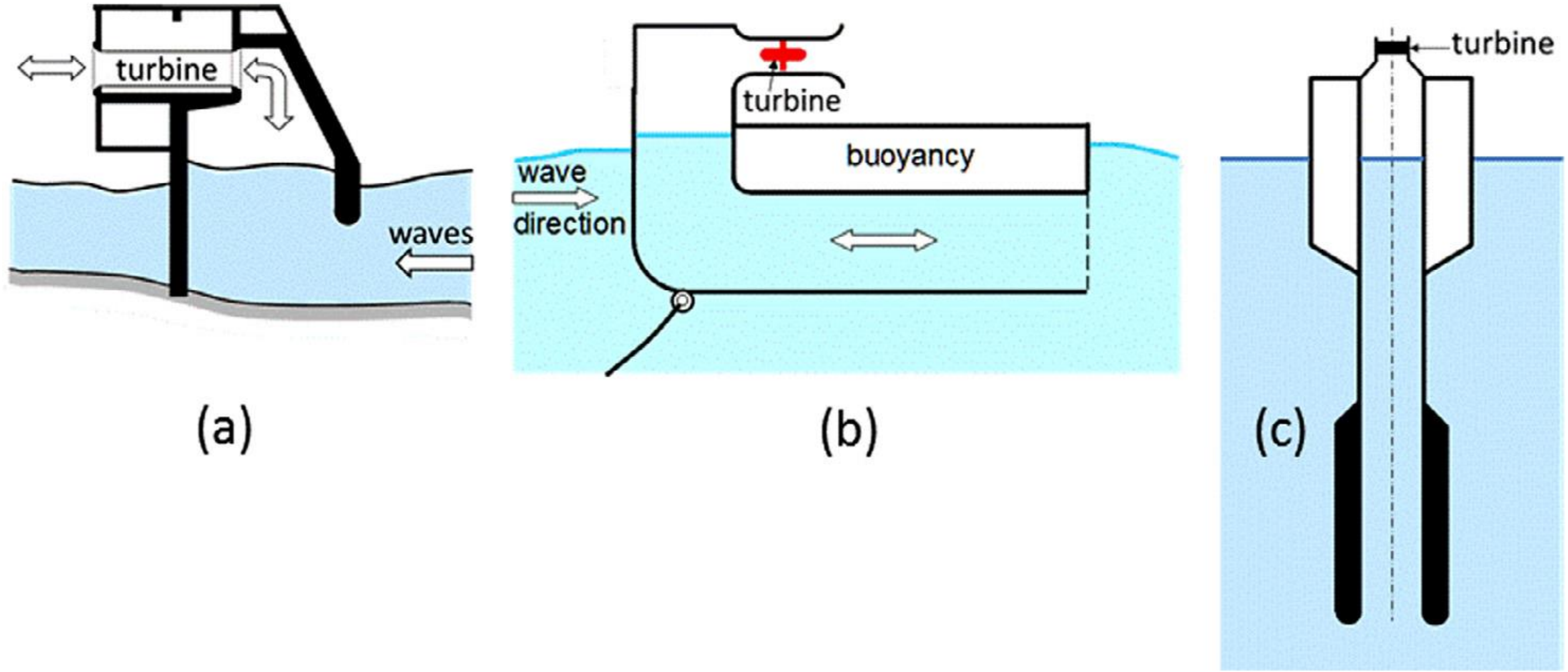


http://en.openei.org/

OSCILLATING WATER COLUMN (OWC)

OFFSHORE OWC

Falcao, A.F. de O. (2010). Wave energy utilization: A review of the technologies. Renewable and Sustainable Energy Reviews 14, 899–918.



OSCILLATING WATER COLUMN (OWC)

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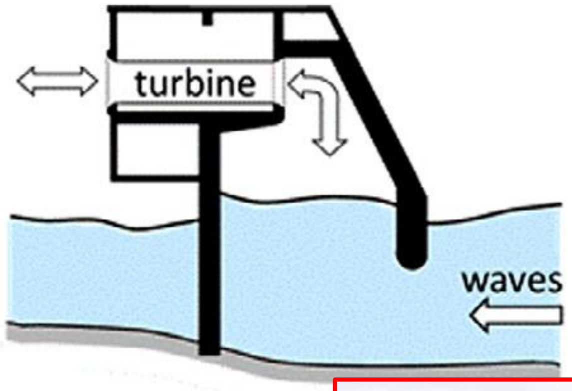
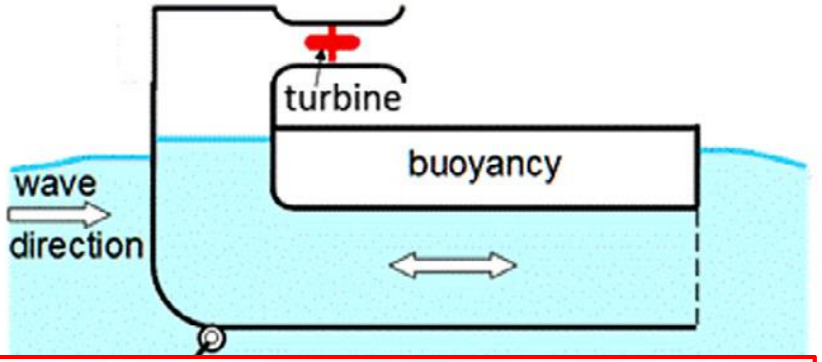
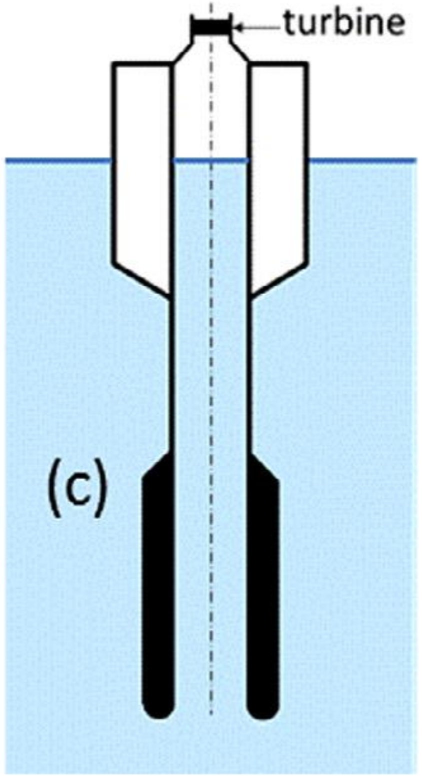


(a)





SPAR-BUOY

Backward Bend Duck Buoy (BBDB):
Ocean Energy Buoy

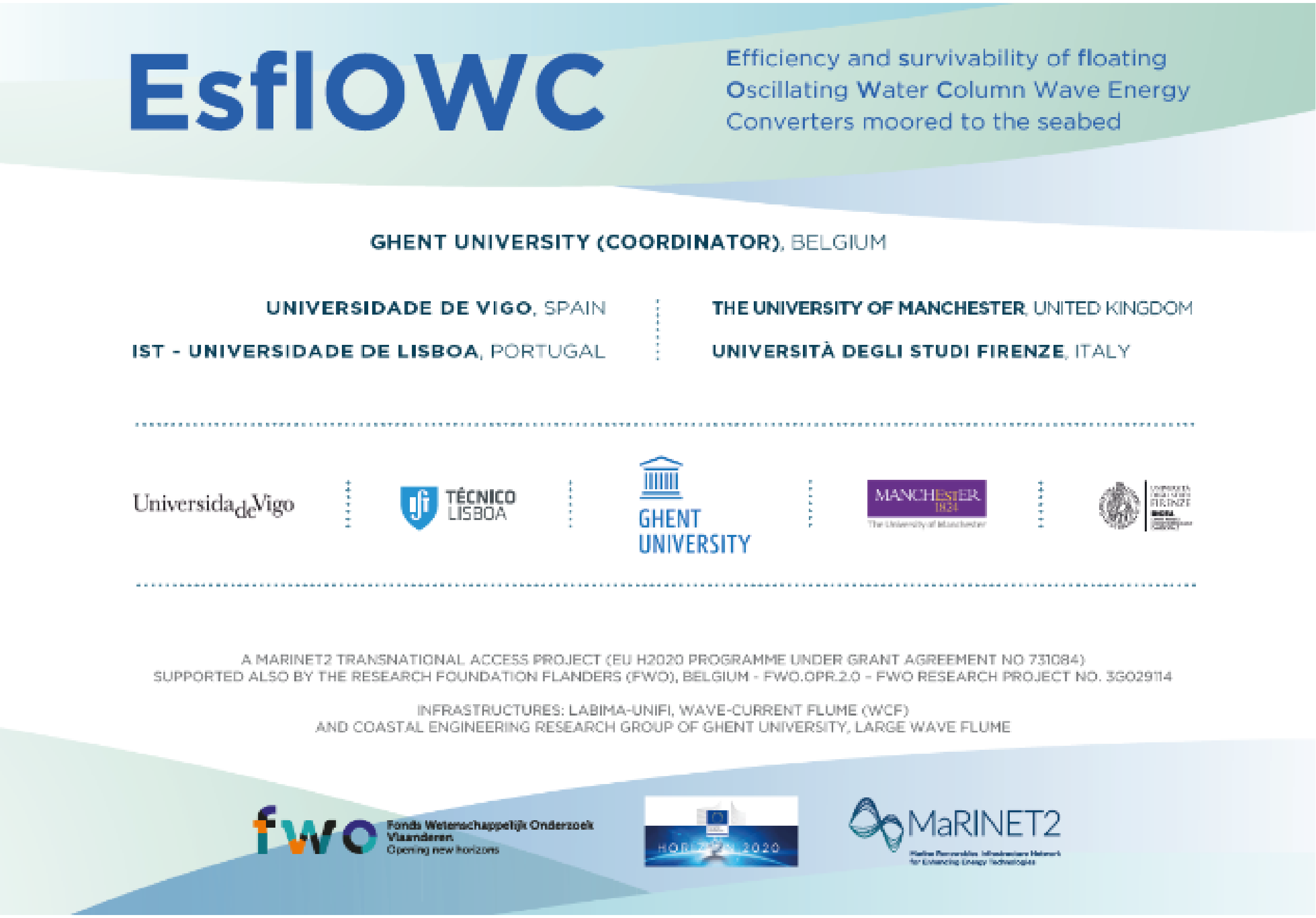
OCEANENERGY
A WORLD OF POWER

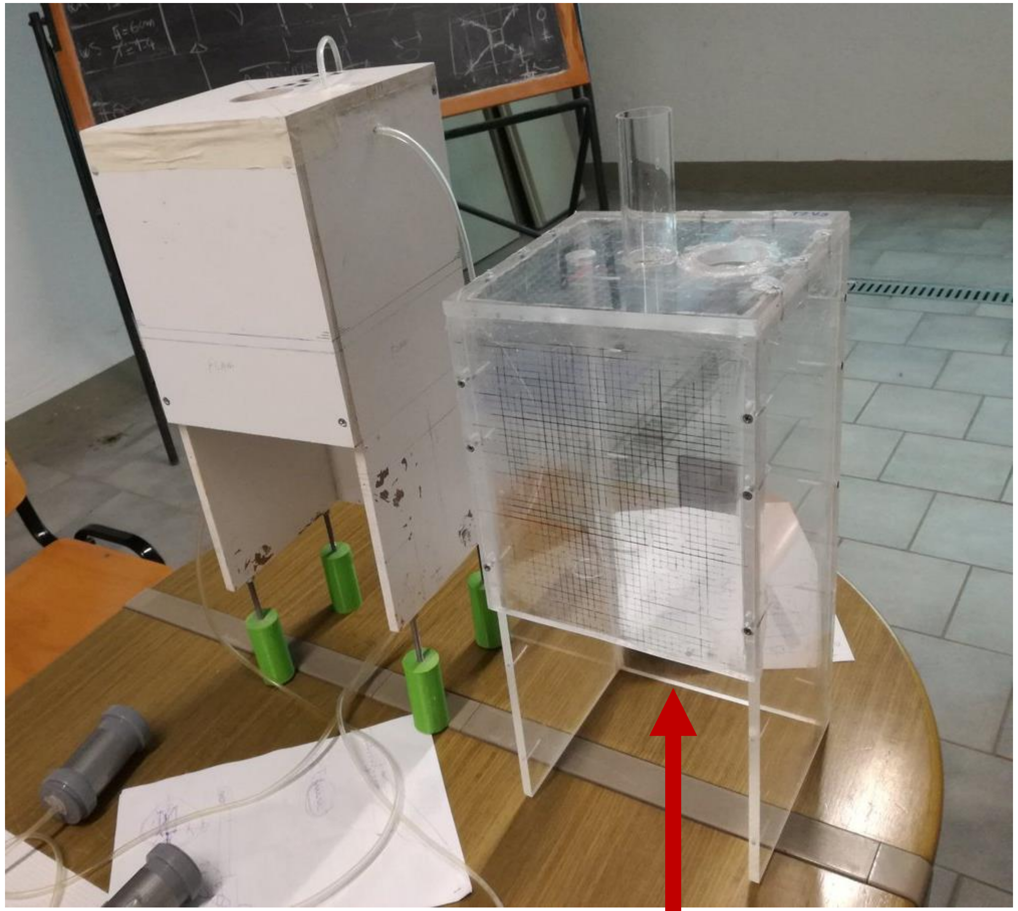
TÉCNICO LISBOA

OSCILLATING WATER COLUMN (OWC)

MaRINET2

OFFSHORE **FLOATING MOORED** OWC



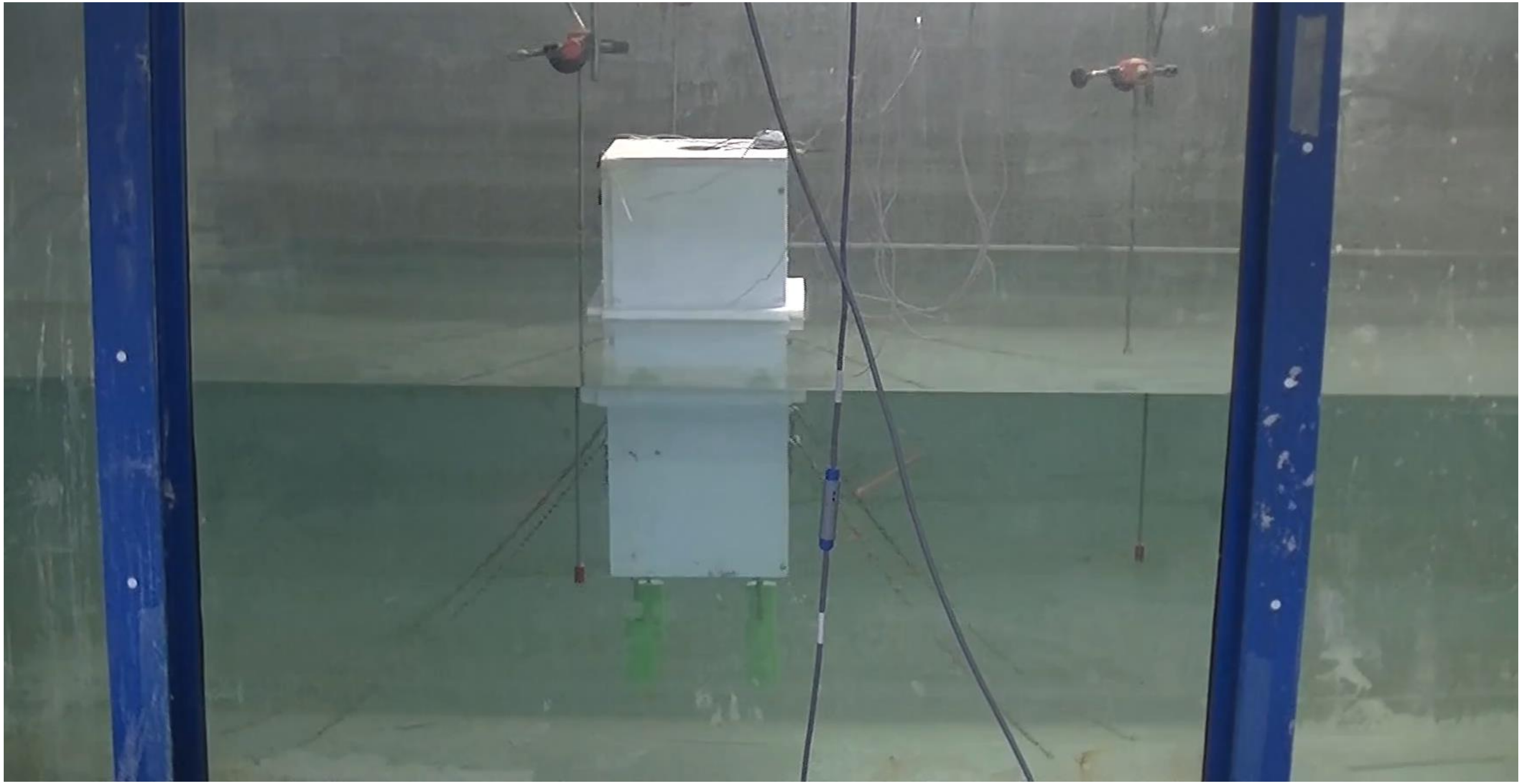


Simonetti et al., 2017

OSCILLATING WATER COLUMN (OWC)

UNIVERSITEIT GENT

EXPERIMENT IN **GENT UNIVERSITY**: FLOATING MOORED OWC



DUALSPHYSICS CODE

Numerical simulation of floating moored OWC needs:

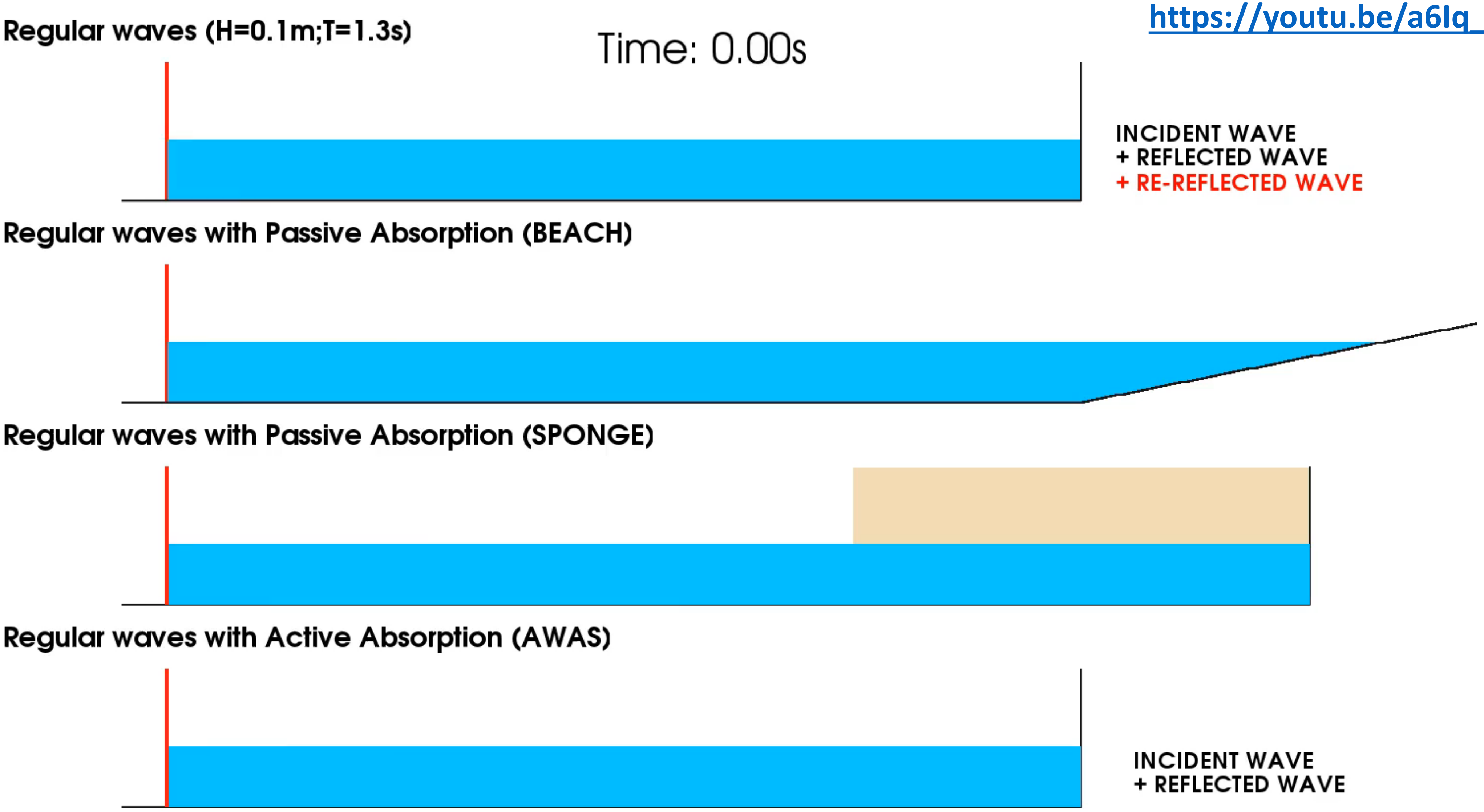
- **Wave generation, wave propagation and wave absorption**
- **Interaction between waves and fixed structures**
- **Interaction between waves and floating structures**
- **Interaction between waves and floating moored structures**

DUALSPHYSICS CODE

Altomare et al., 2017

Wave generation, wave propagation and wave absorption

https://youtu.be/a6Iq_FjU2_I



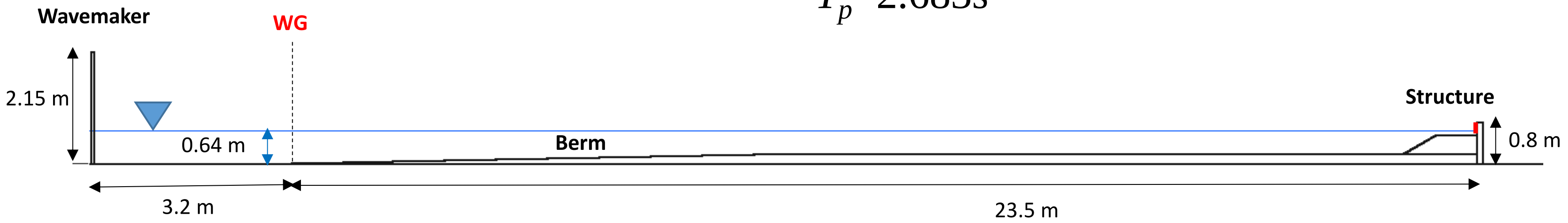
DUALSPHYSICS CODE

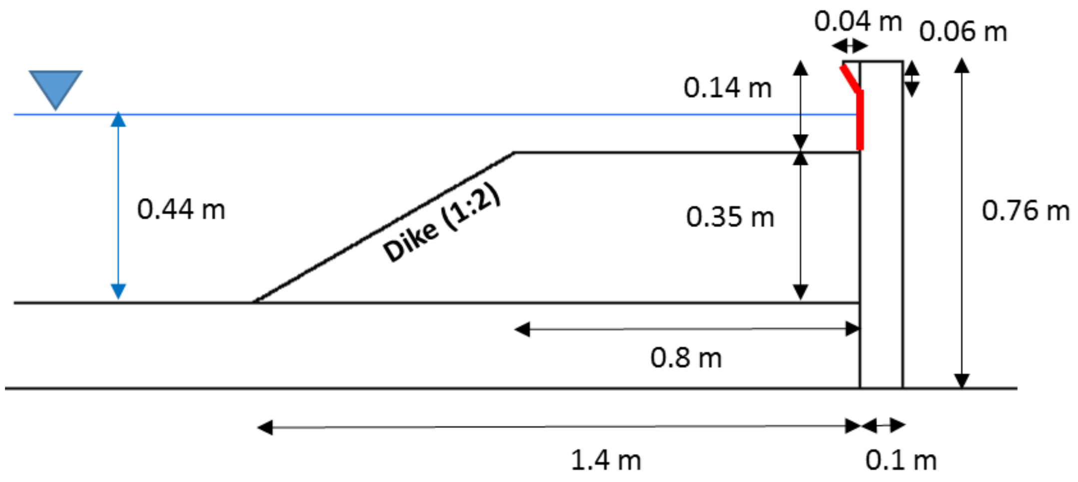
Altomare et al., 2015

Interaction between waves and fixed structures

Assessment of wave loadings on the dikes and storm return walls in the Blankenberge Marina (Belgium)

H_{m0}=0.101m
T_p=2.683s





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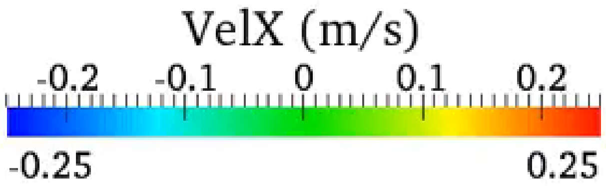
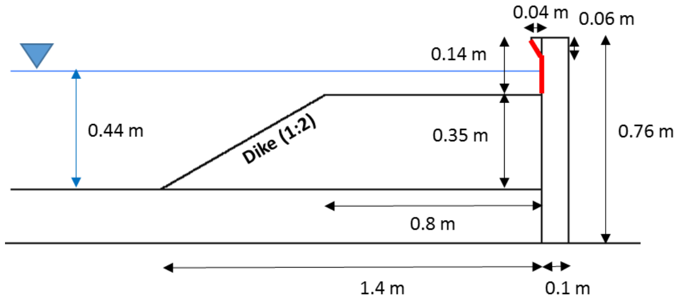
Altomare et al., 2015

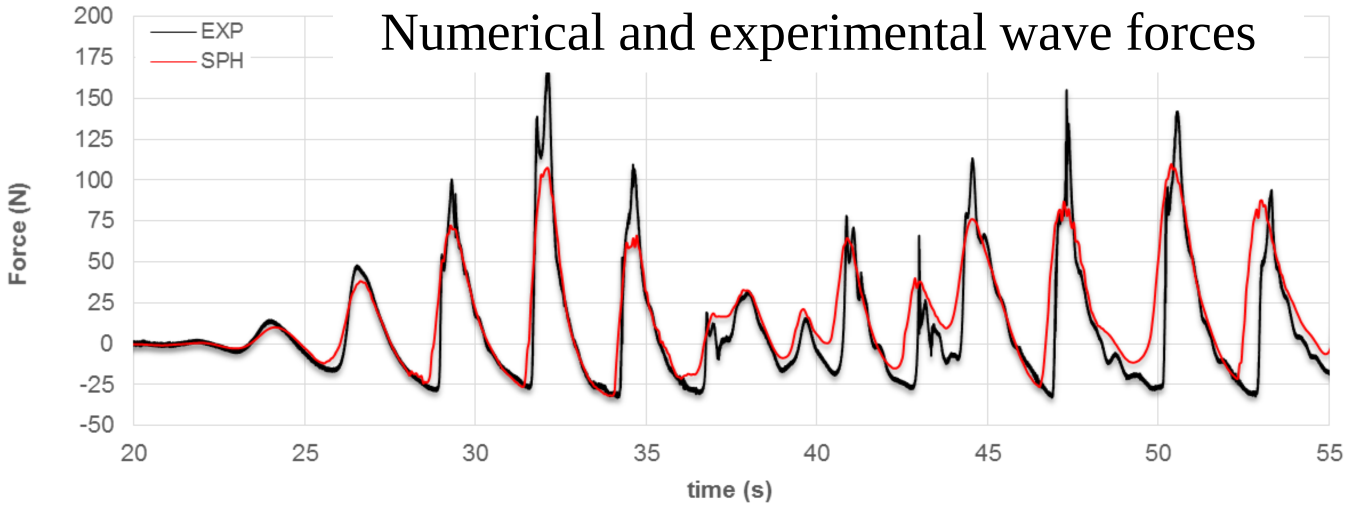
Interaction between waves and fixed structures





Time: 0.000 s

FORCE

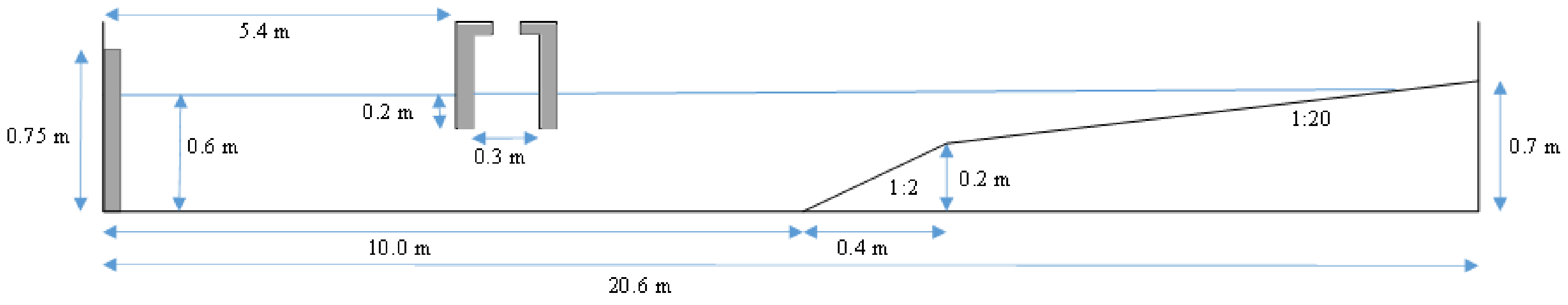


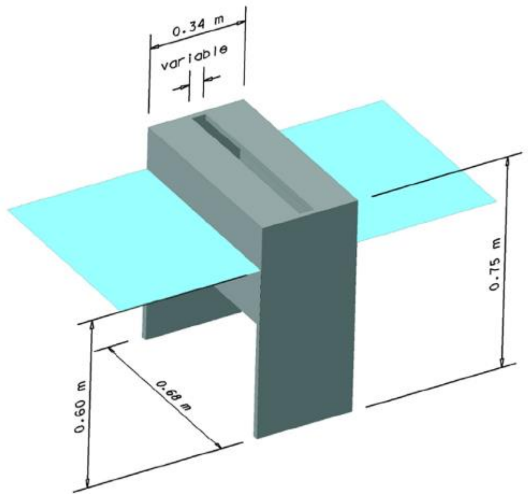
DUALSPHYSICS CODE

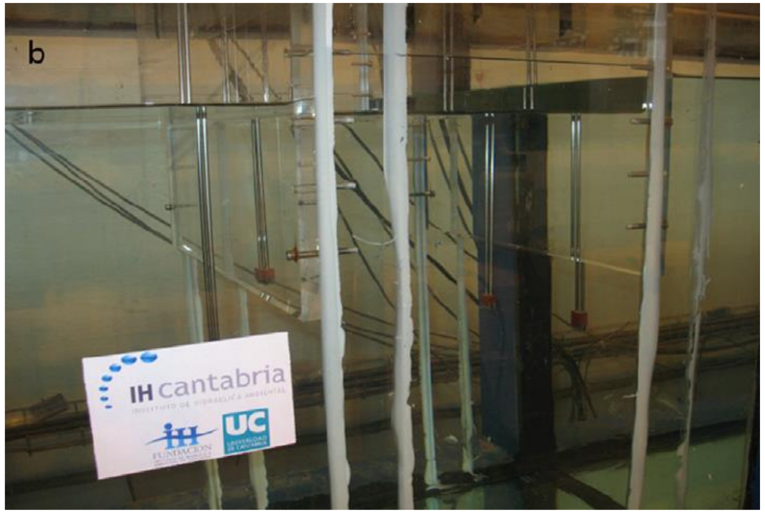
Crespo et al., 2017

Interaction between waves and **fixed** structures

Experiment carried out in the IH-Cantabria of regular waves impacting with a fixed OWC







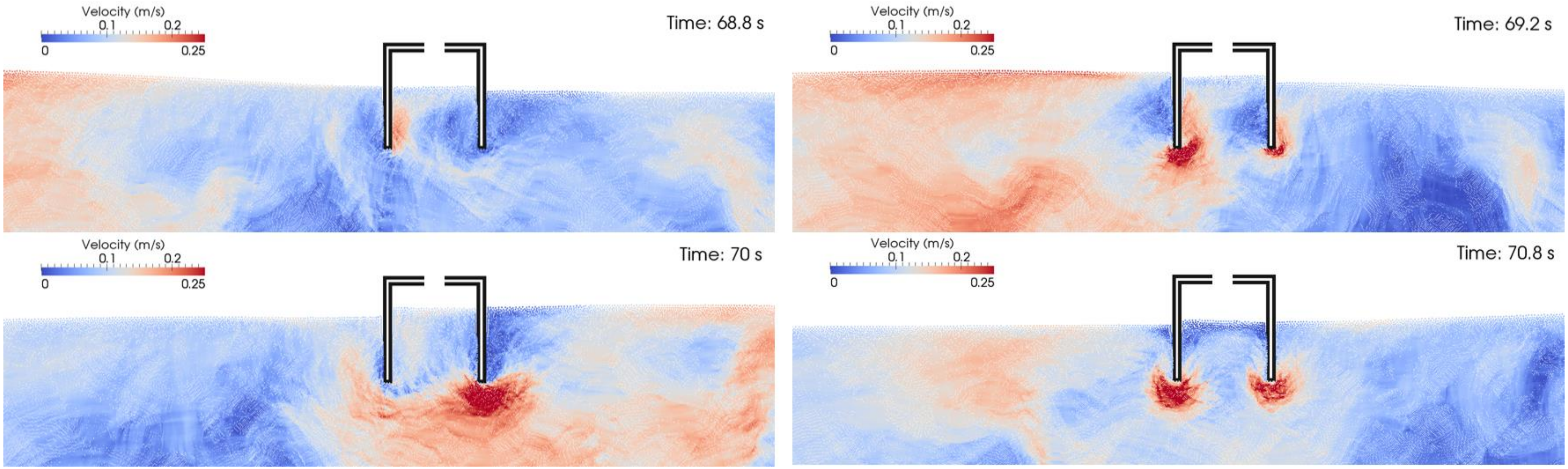
Regular waves
- H=0.08 m
- T=3.2 s
- d=0.6 m
- L=7.46 m

DUALSPHYSICS CODE

Crespo et al., 2017

Interaction between waves and fixed structures

Experiment carried out in the IH-Cantabria of regular waves impacting with a fixed OWC

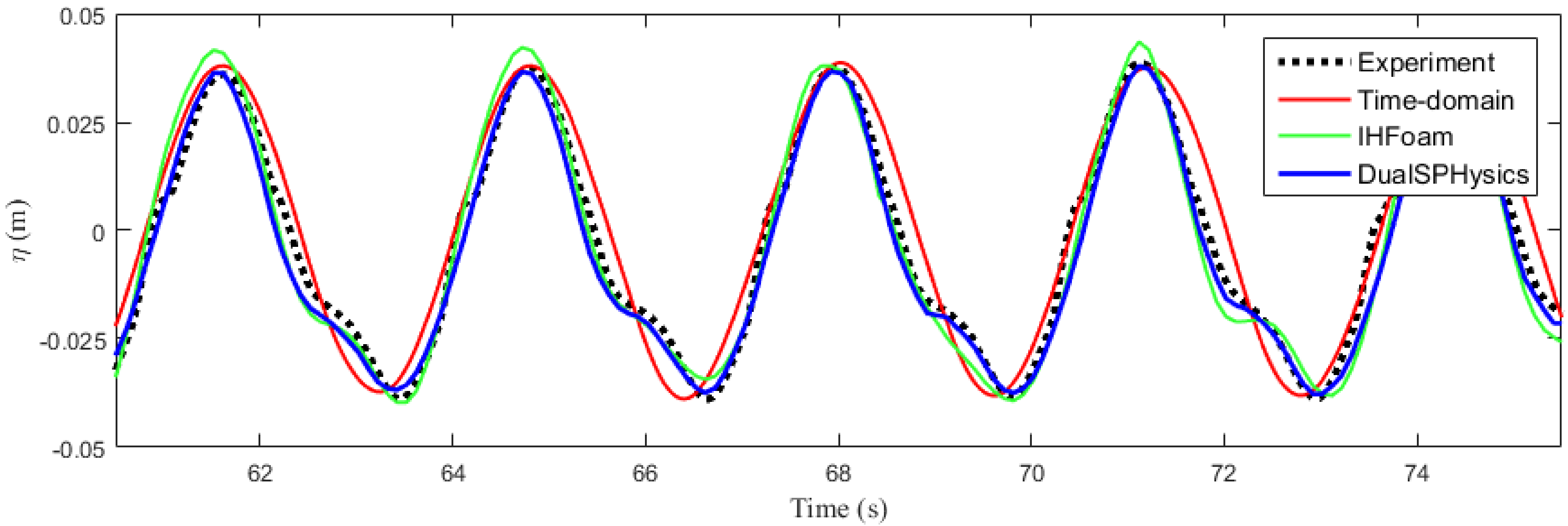


DUALSPHYSICS CODE

Crespo et al., 2017

Interaction between waves and fixed structures

Experiment carried out in the IH-Cantabria of regular waves impacting with a fixed OWC



Elevation inside the chamber:

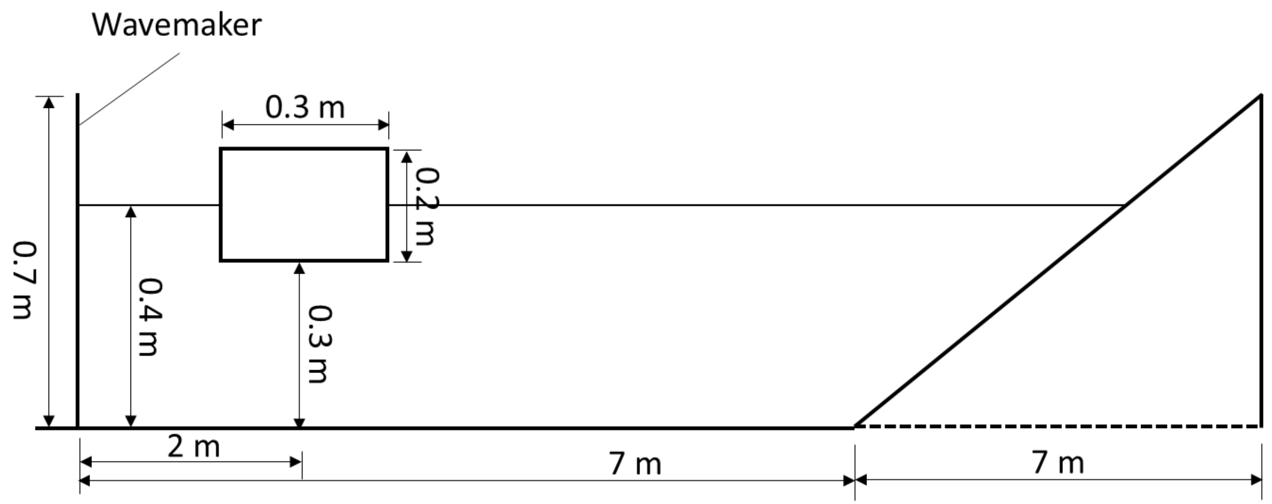
Experiment vs Time-domain vs IHFoam vs DualSPHysics

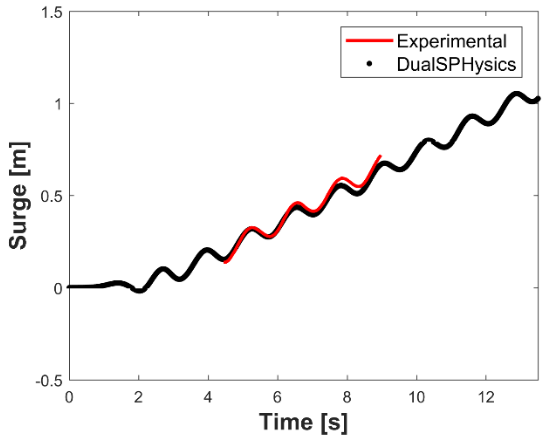
DUALSPHYSICS CODE

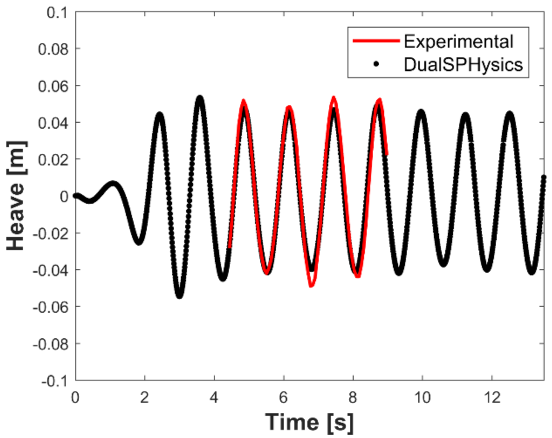
Ren et al., 2015

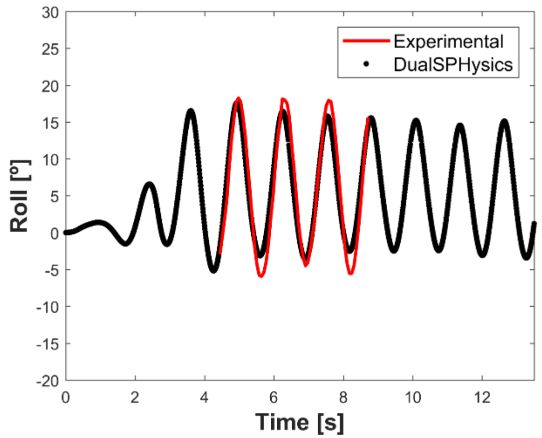
Interaction between waves and floating structures

Floating BOX subjected to REGULAR WAVES







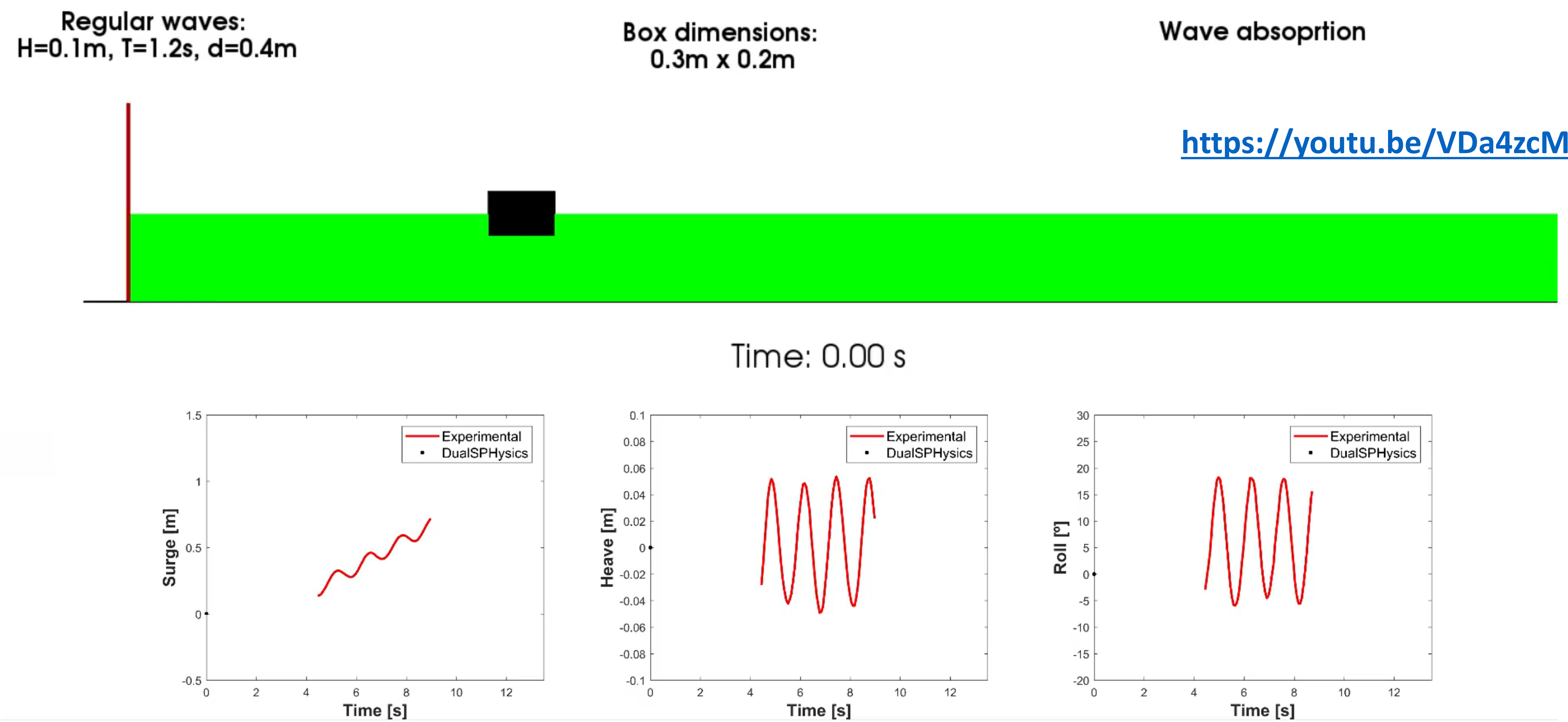


DUALSPHYSICS CODE

Ren et al., 2015

Interaction between waves and floating structures

Floating BOX subjected to REGULAR WAVES



https://youtu.be/VDa4zcMDjJA

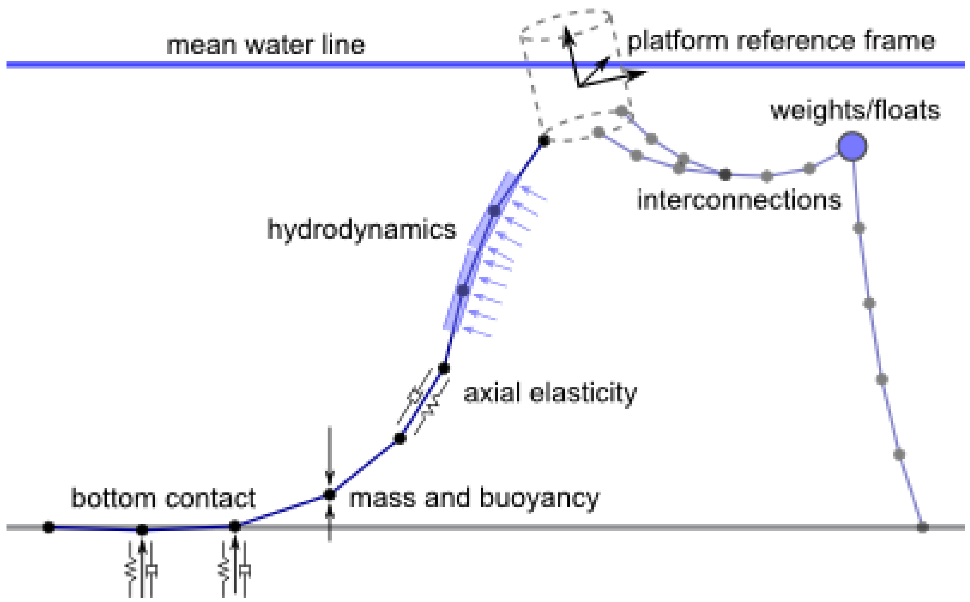
DUALSPHYSICS CODE

Interaction between waves and floating moored structures

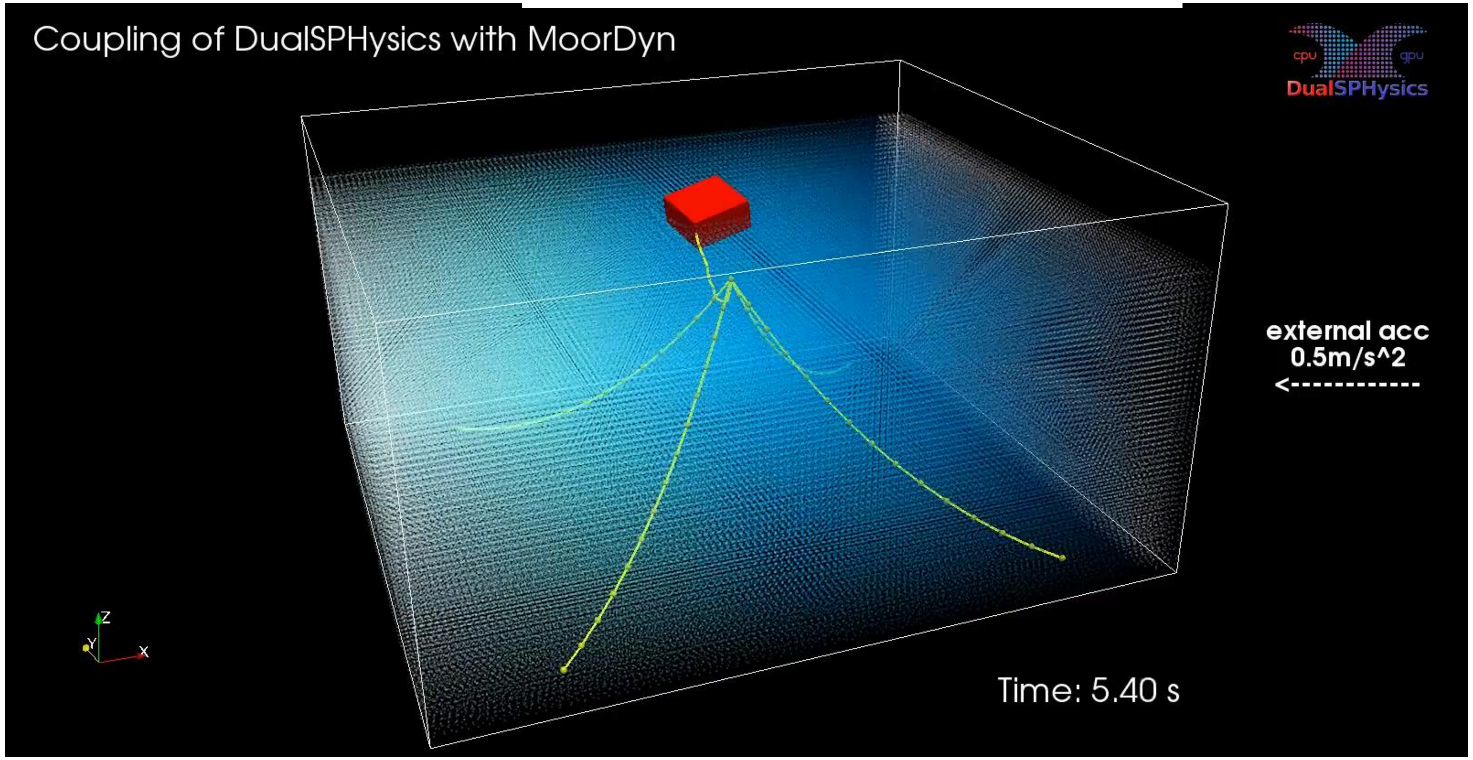
Coupling with **MoorDyn** library

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

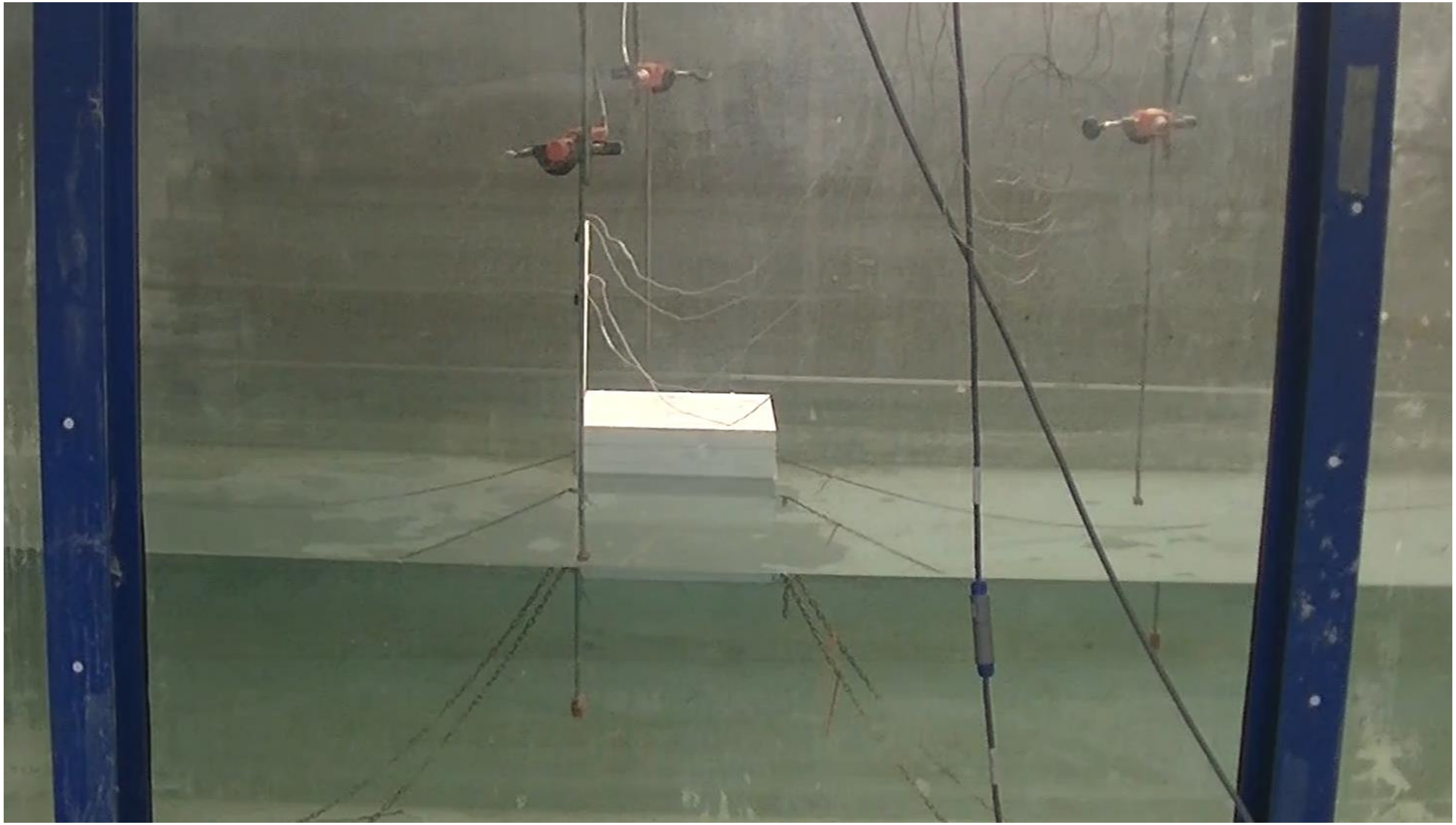
https://youtu.be/ToEsV0FDs0I



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

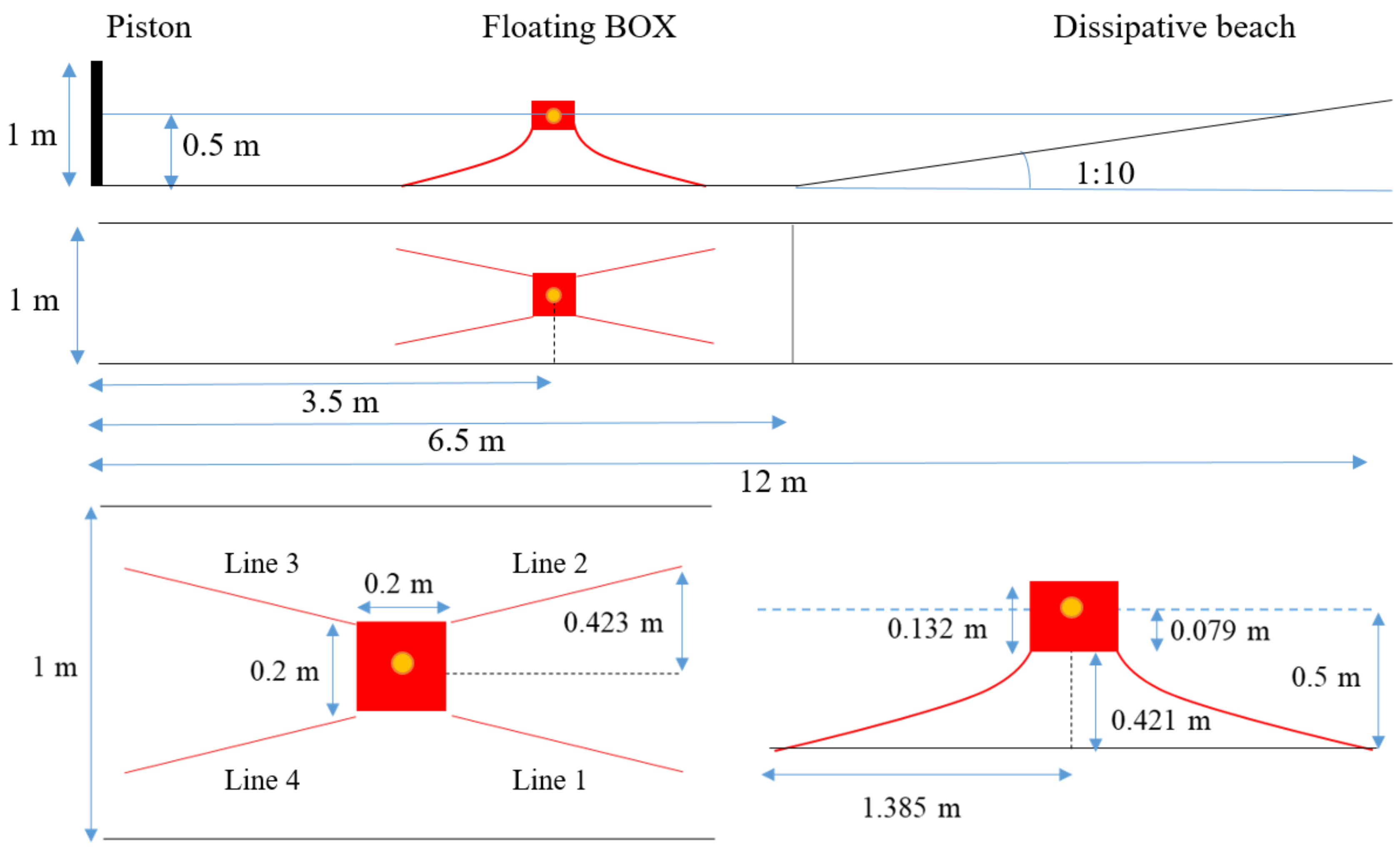


EXPERIMENT IN **GENT UNIVERSITY**: FLOATING BOX



DUALSPHYSICS CODE

Interaction between waves and floating moored structures

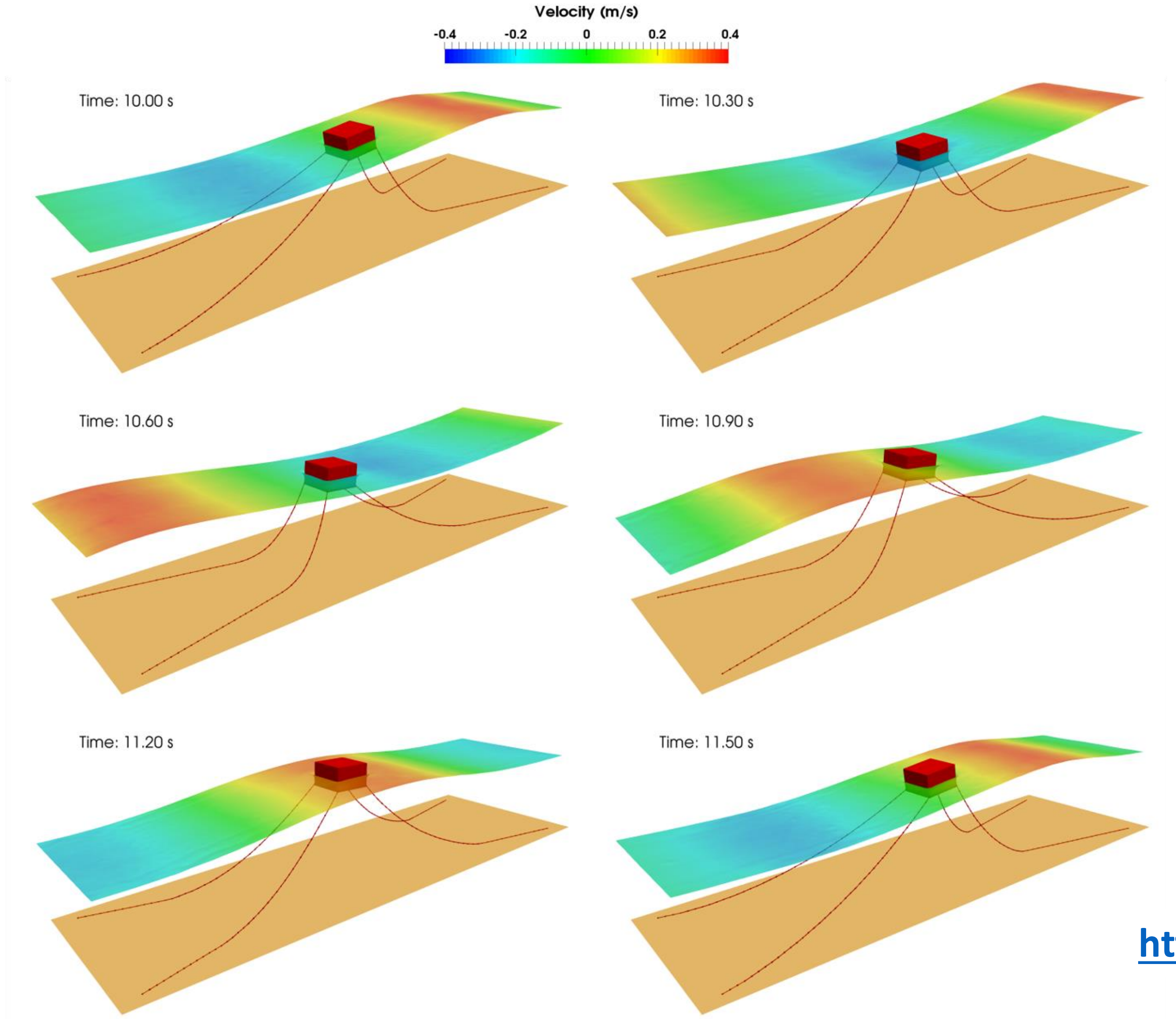


Regular waves
- H=0.12 m
- T=1.6 s
- d=0.5 m
- L=3 m

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

DUALSPHYSICS CODE

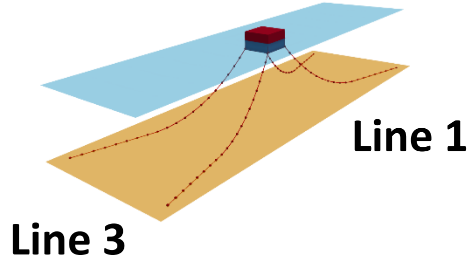
Interaction between waves and floating moored structures

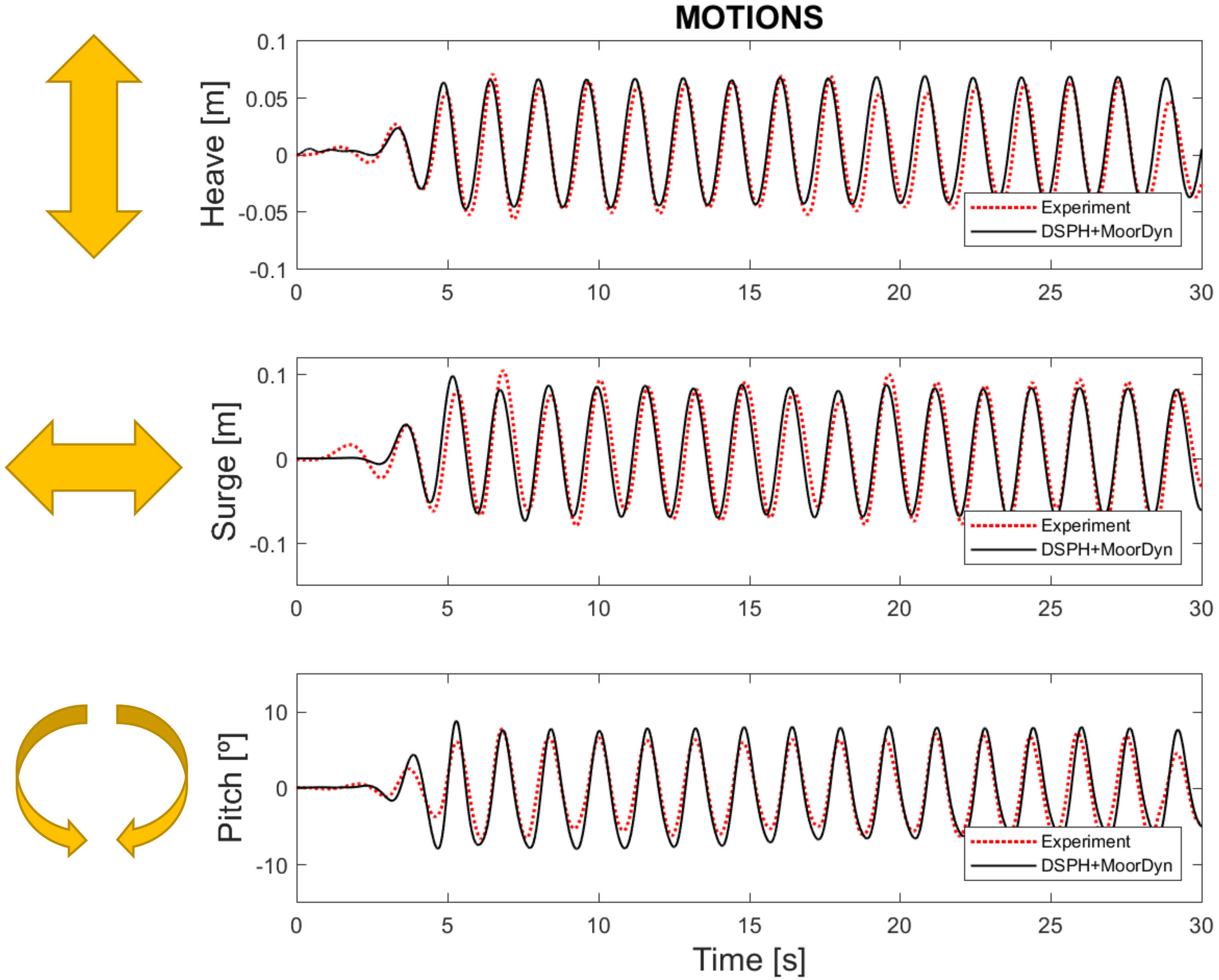


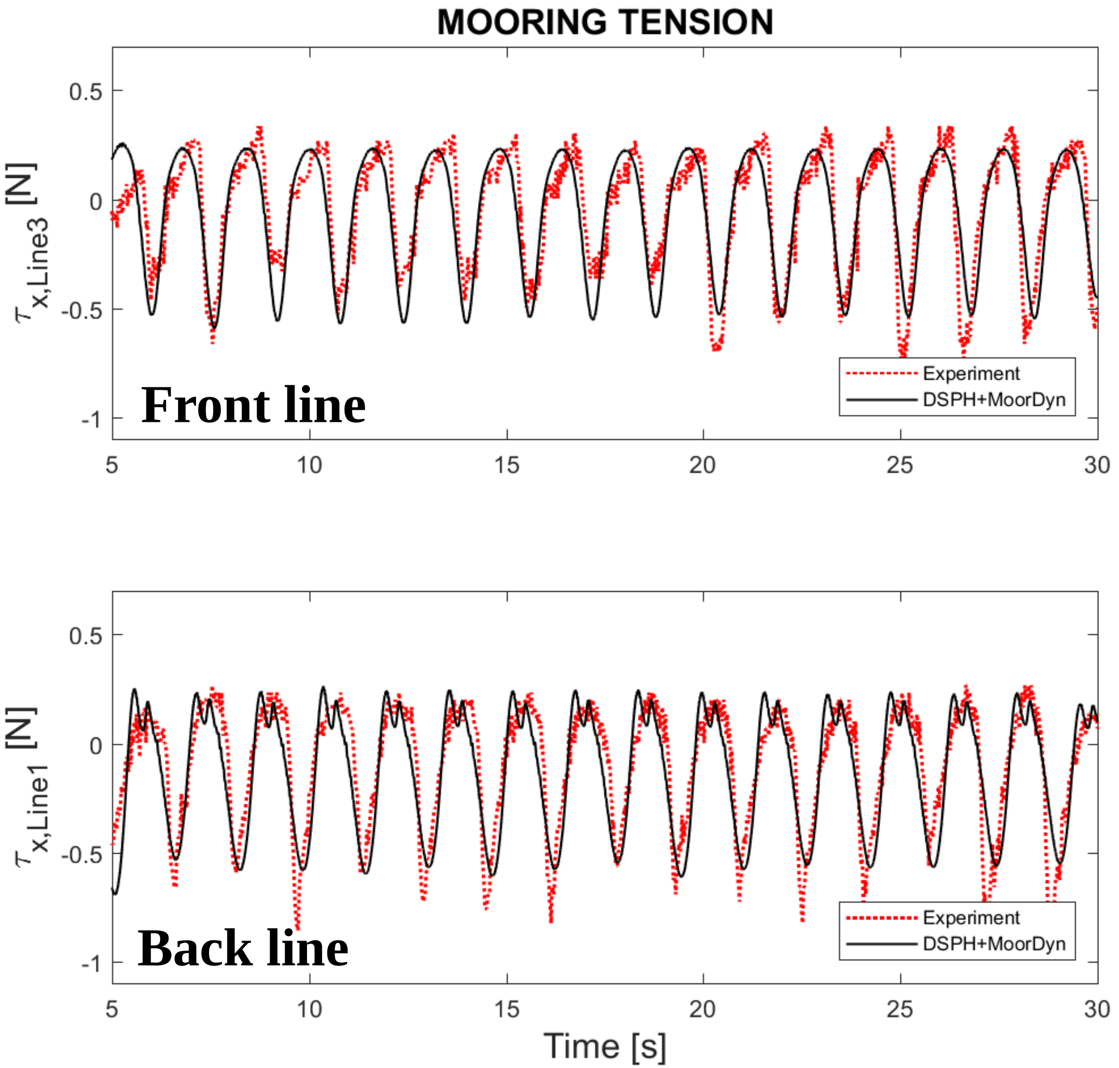
https://youtu.be/YUSxGXPkYvE

DUALSPHYSICS CODE

Interaction between waves and floating moored structures







DUALSPHYSICS CODE

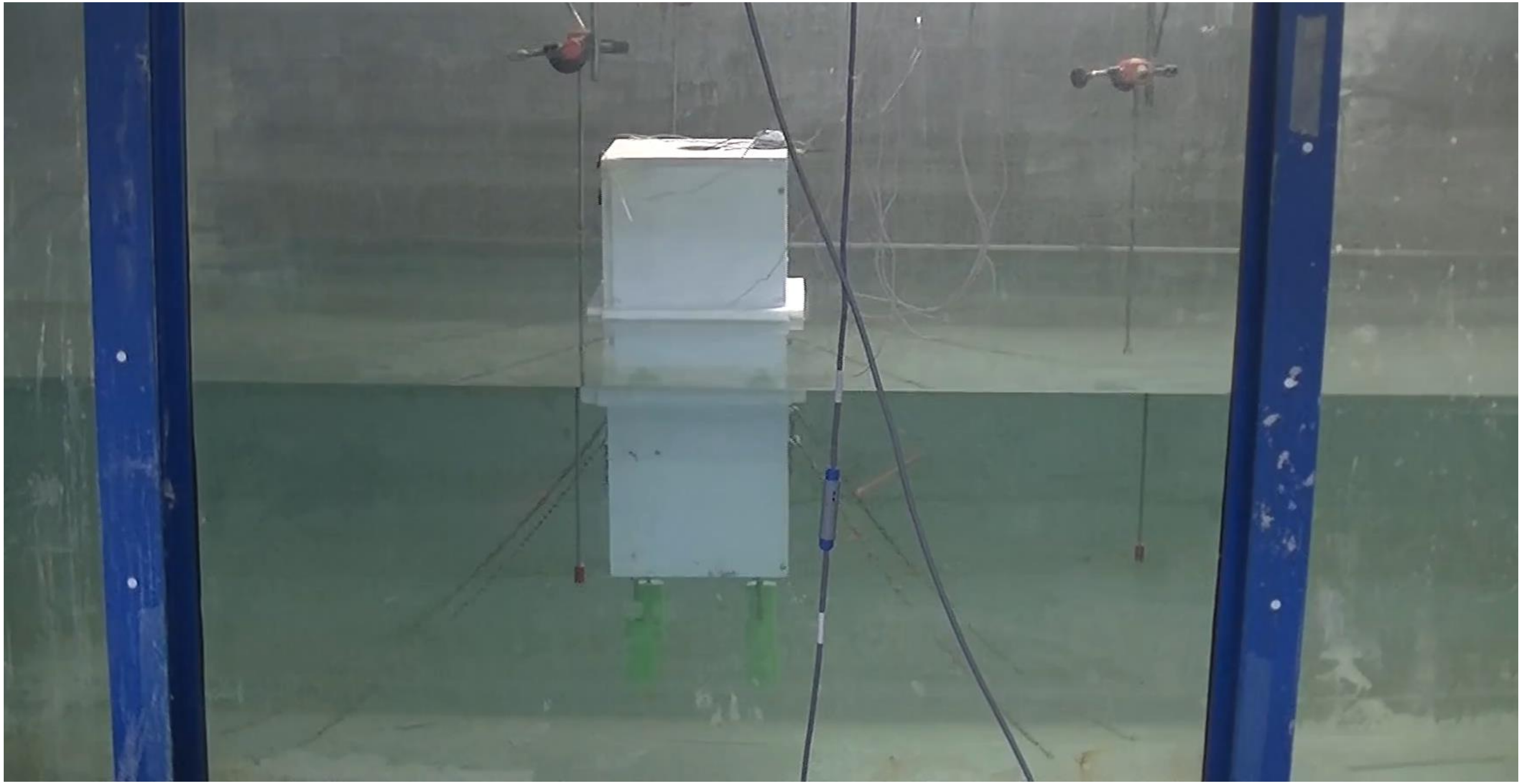
Numerical simulation of floating moored OWC needs:

- **Wave generation, wave propagation and wave absorption** ✓
- **Interaction between waves and fixed structures** ✓
- **Interaction between waves and floating structures** ✓
- **Interaction between waves and floating moored structures** ✓
- **AIR PHASE INSIDE THE CHAMBER**

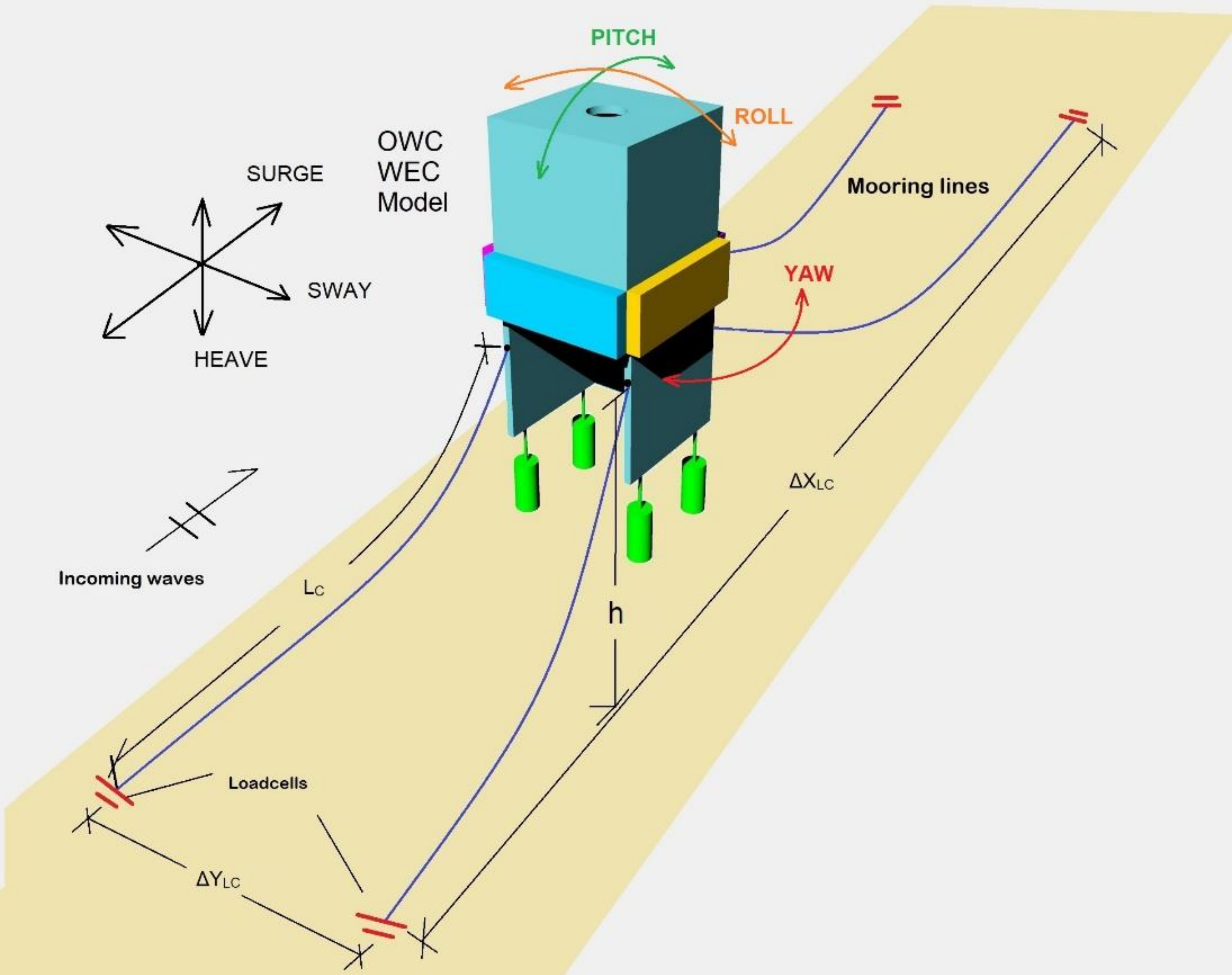
SPH SIMULATION OF FLOATING MOORED OWC

UNIVERSITEIT GENT

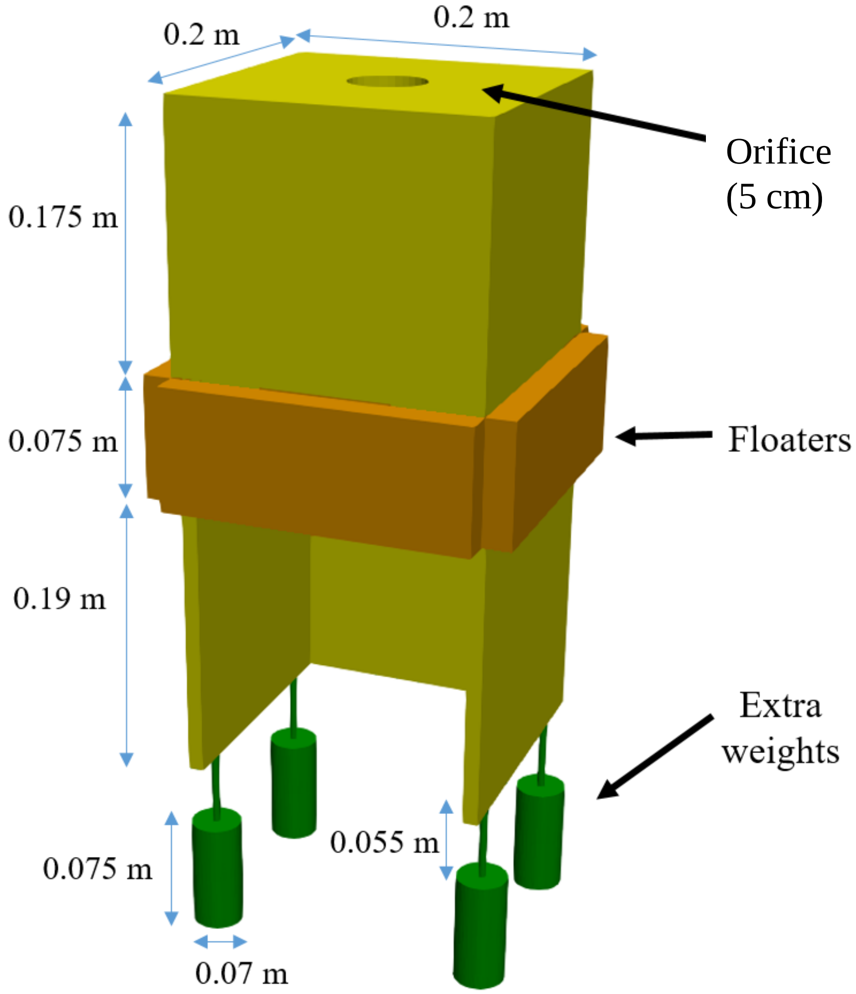
EXPERIMENT IN **GENT UNIVERSITY**: OWC



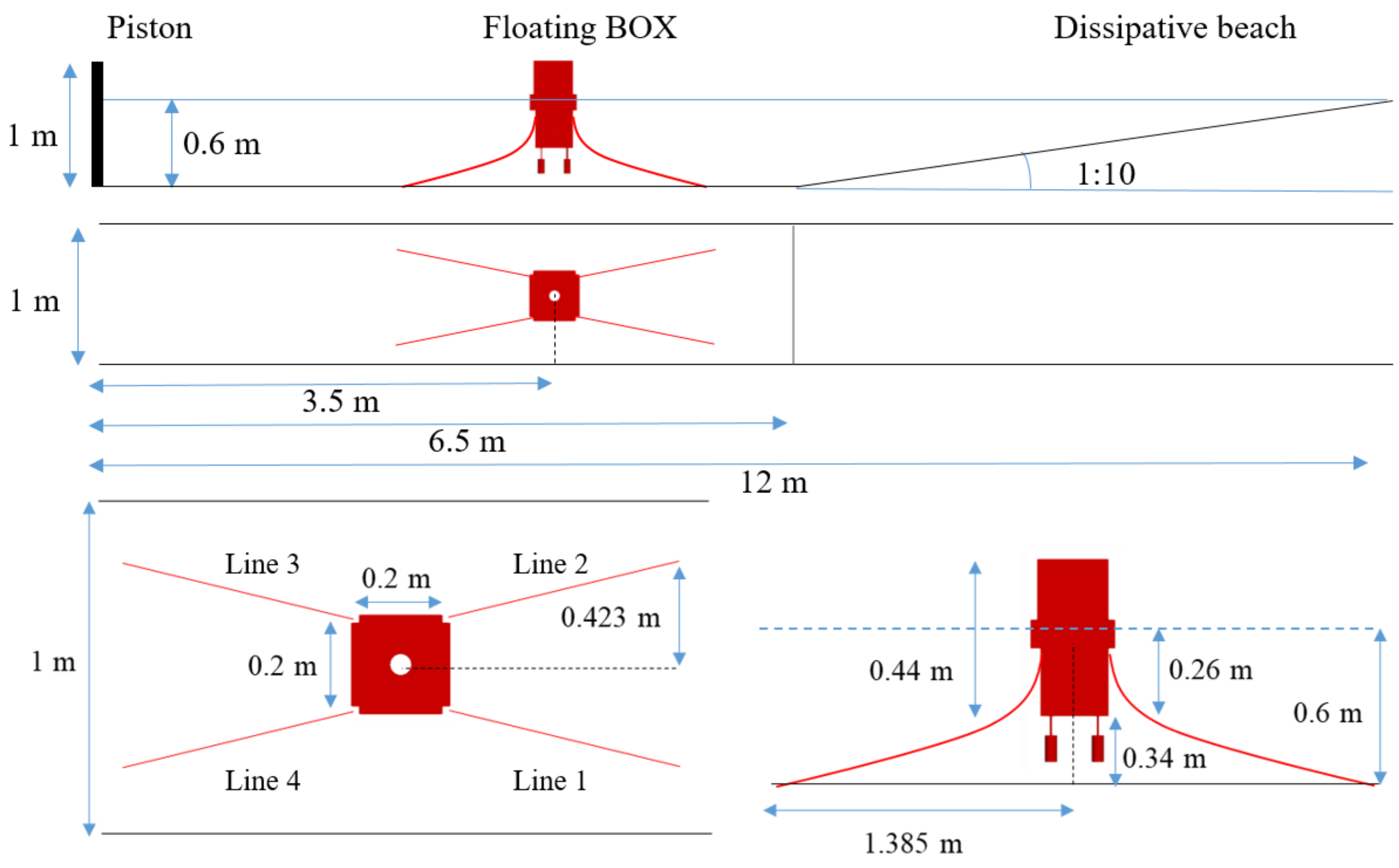
SPH SIMULATION OF FLOATING MOORED OWC



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



SPH SIMULATION OF FLOATING MOORED OWC



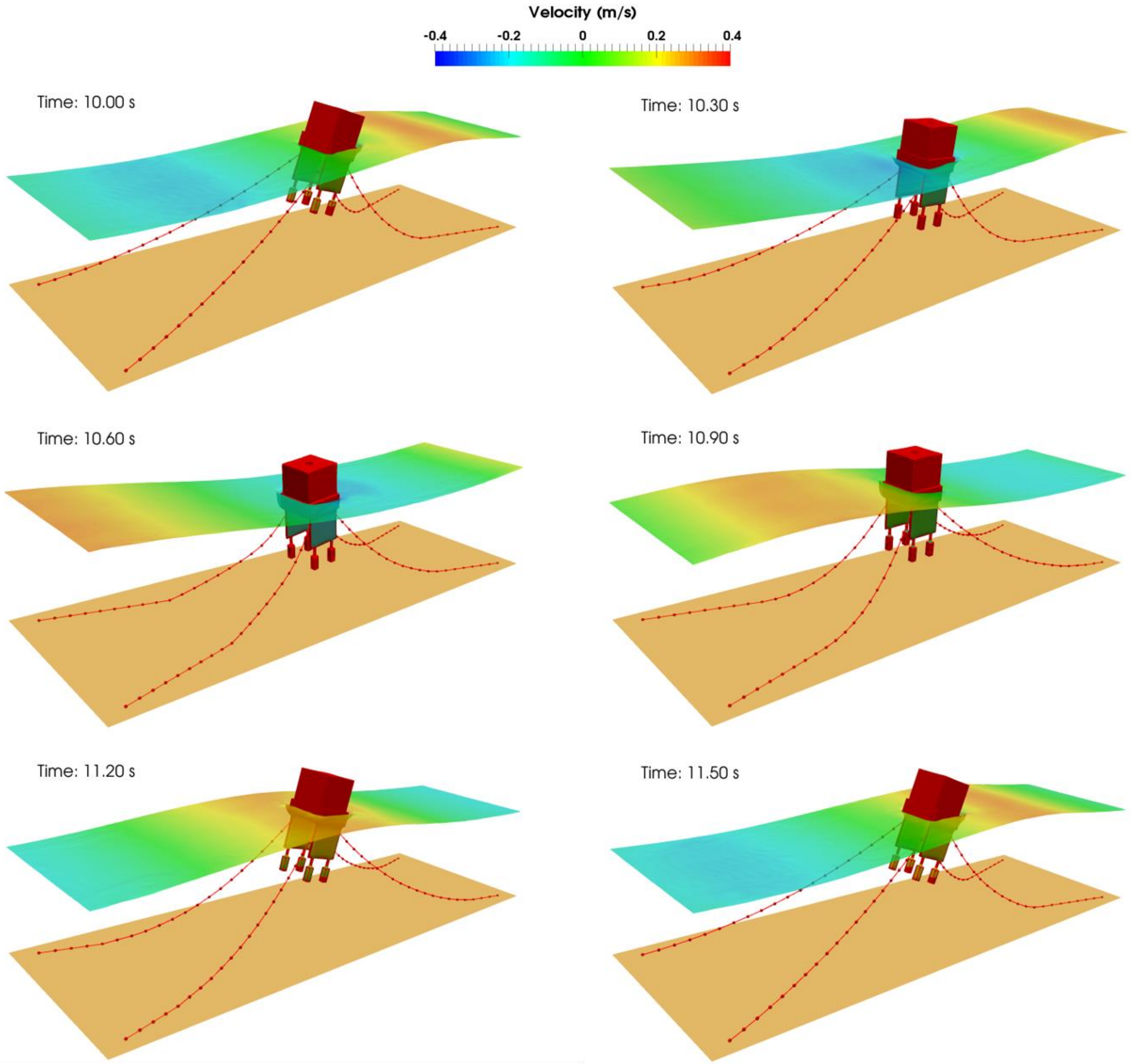
OWC with different materials but total MASS is 2.593 kg
SPH particles of density 578 kg/m^3

Regular waves

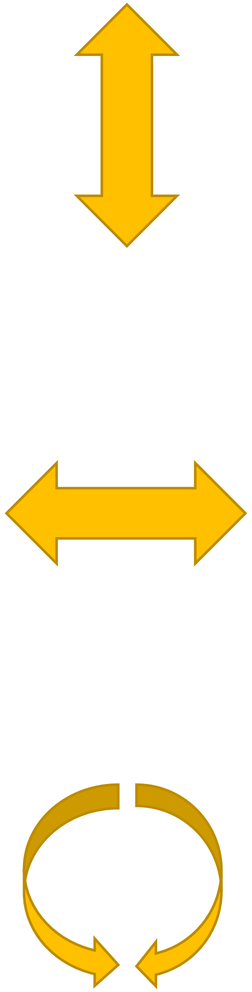
- H=0.11 m
- T=1.6 s
- d=0.6 m
- L=3.27 m

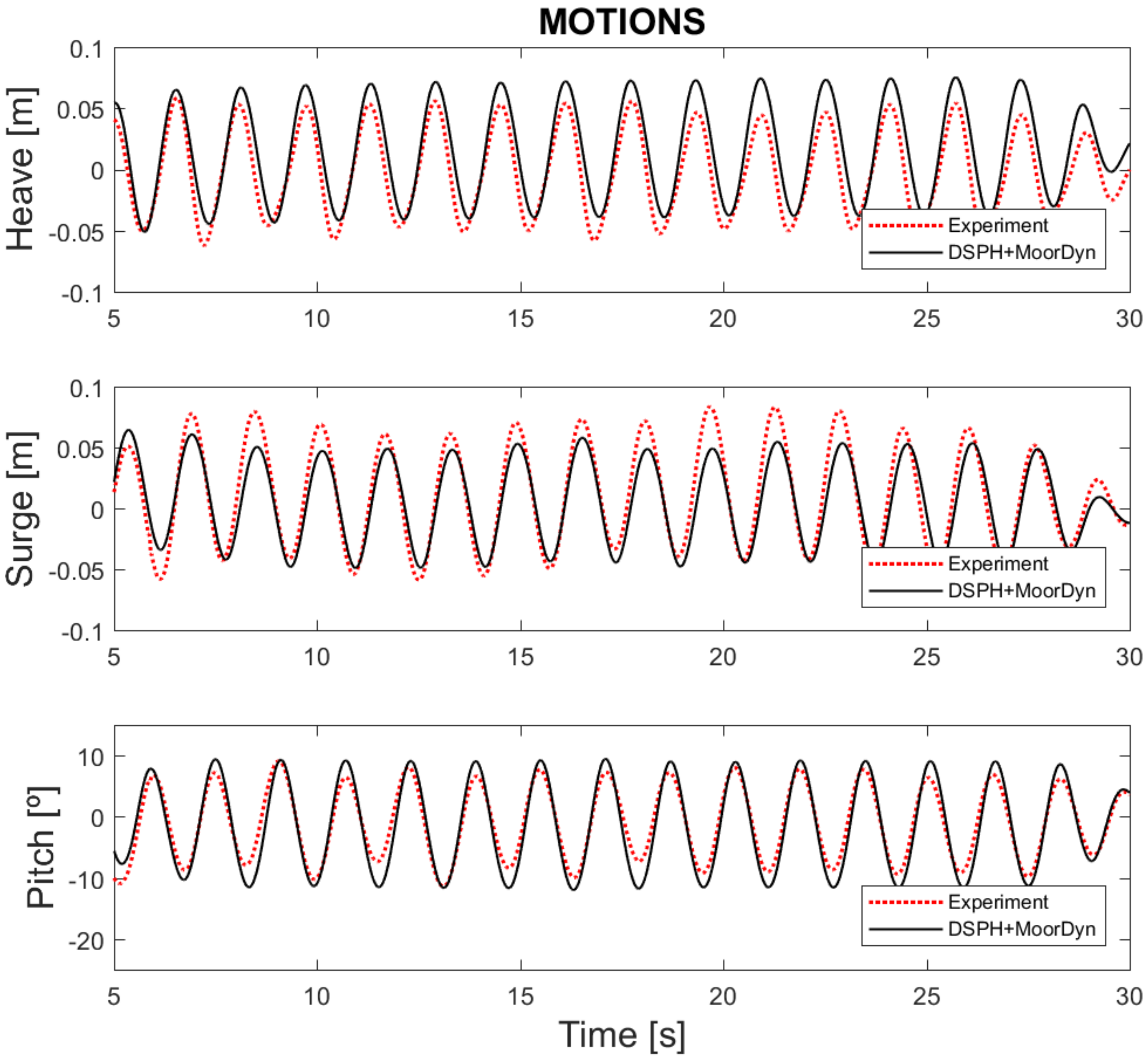
DualSPHysics	
OWC Dimensions	20 x 20 x 44 cm^3
OWC Weight	2.593 kg
OWC Centre of gravity	(-0.91, 0, -10.8) cm
MoorDyn	
MOORING Diameter	3.656 mm
MOORING Weight	0.607 g/cm
MOORING Length	145.5 cm
Water depth	50 cm

SPH SIMULATION OF FLOATING MOORED OWC

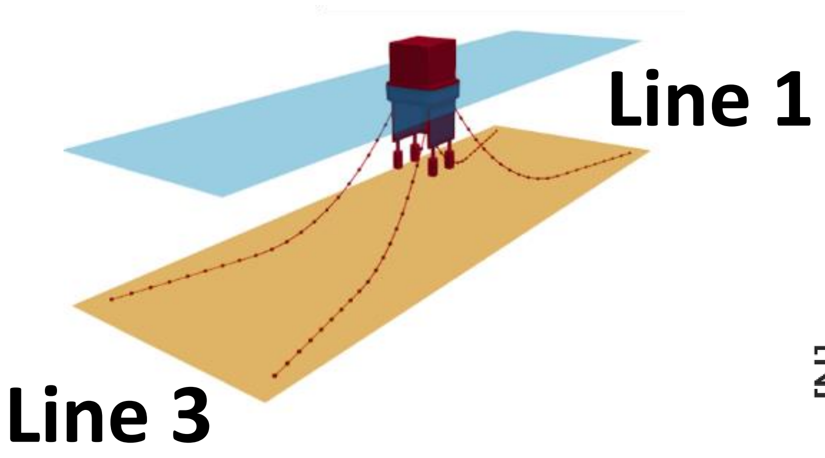


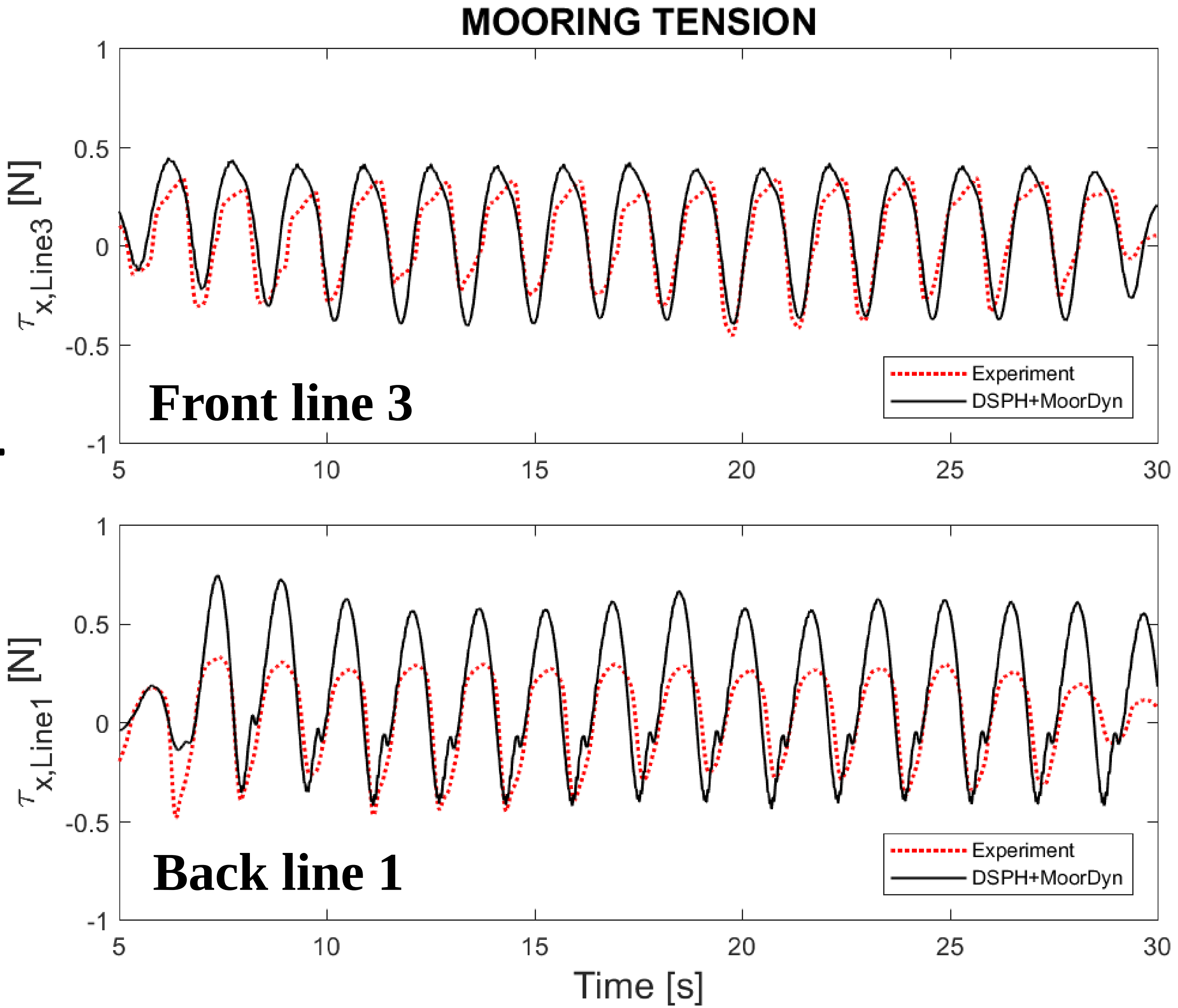
SPH SIMULATION OF FLOATING MOORED OWC





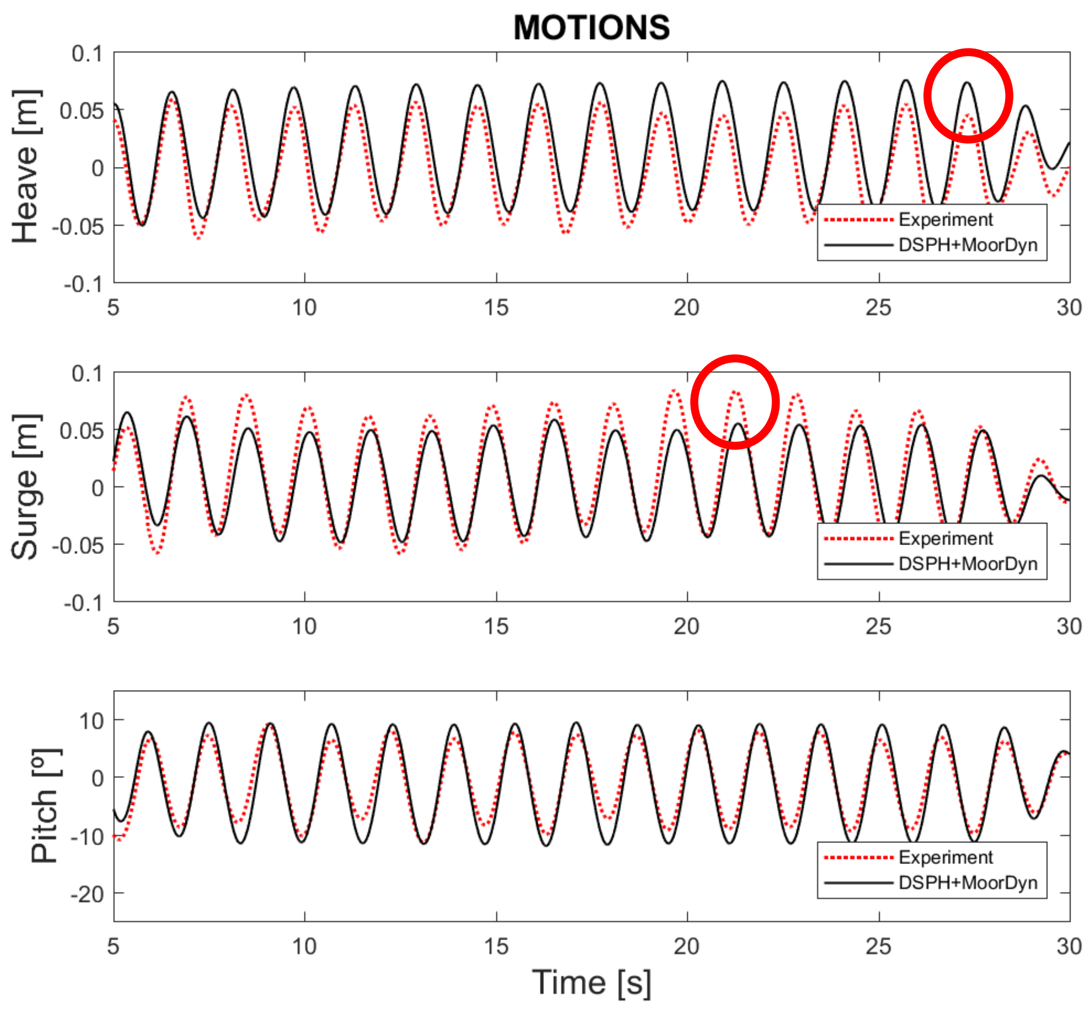
SPH SIMULATION OF FLOATING MOORED OWC

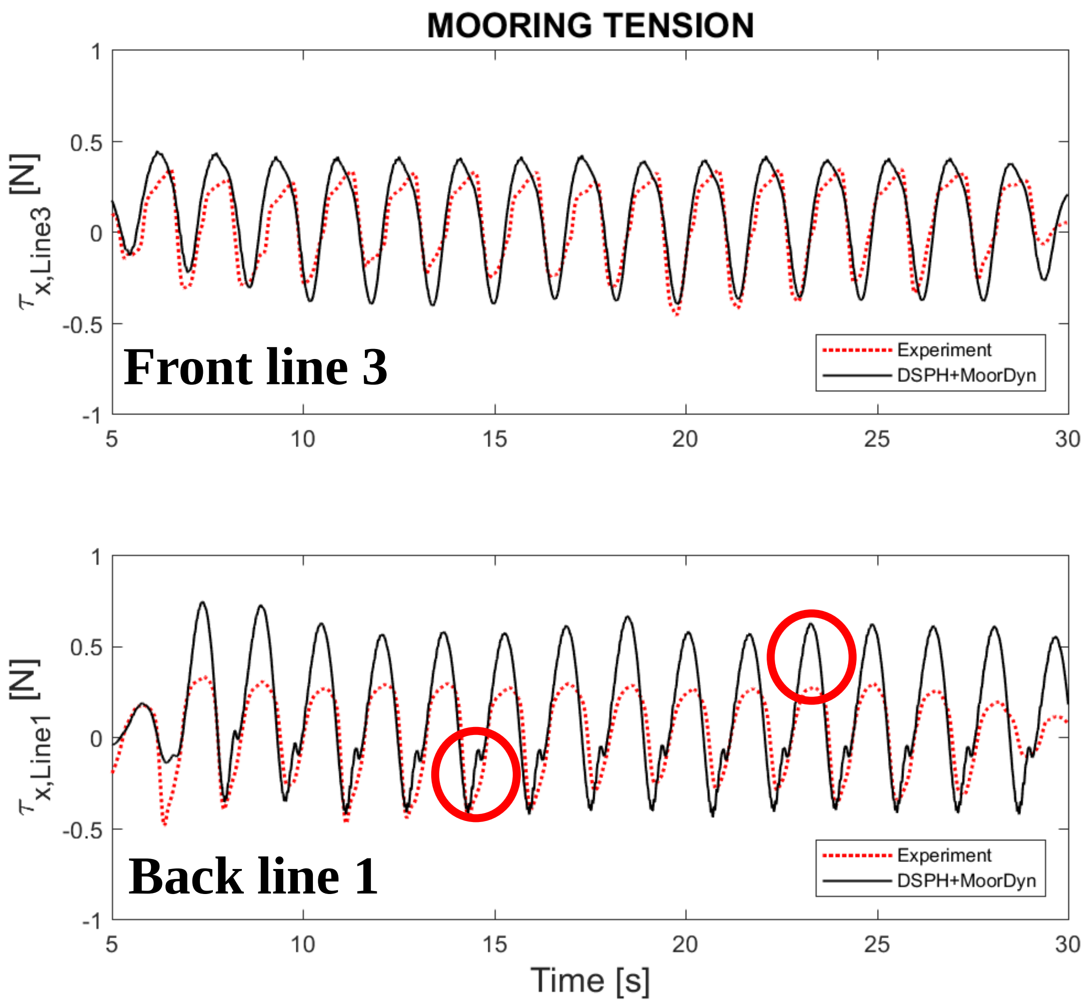




SPH SIMULATION OF FLOATING MOORED OWC

VALIDATION WITH EXPERIMENT IN GENT UNIVERSITY





Experimental Moment of Inertia of OWC ???

SPH SIMULATION OF FLOATING MOORED OWC

ENERGY CONVERSION

⇓

AIR FLUX TROUGH THE TURBINE

⇓

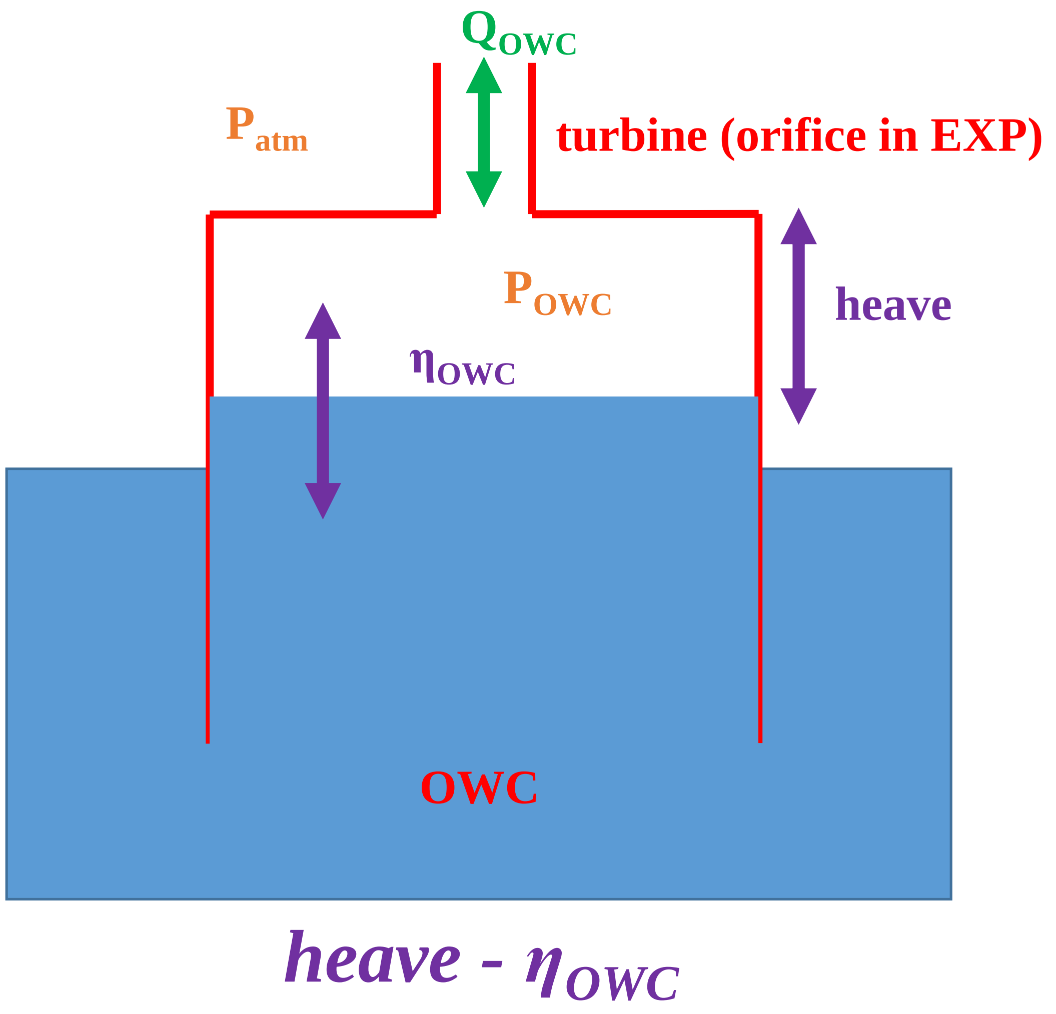
PRESSURE DIFFERENCE OF AIR INSIDE AND OUTSIDE OWC

⇓

CHANGES IN AIR VOLUME INSIDE OWC

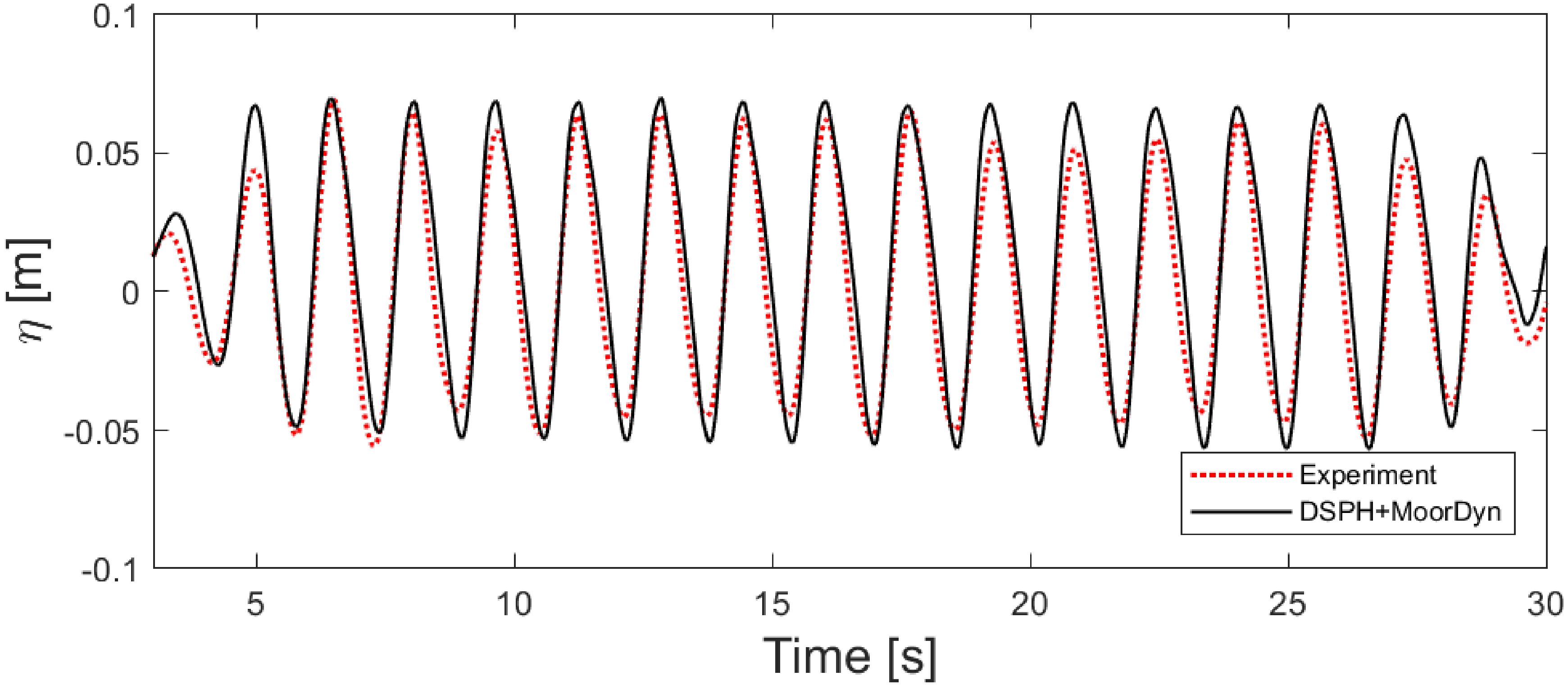
⇓

RELATIVE MOTION BETWEEN HEAVE AND
WATER ELEVATION INSIDE OWC



SPH SIMULATION OF FLOATING MOORED OWC

η_{OWC}



RELATIVE MOTION BETWEEN HEAVE AND WATER ELEVATION INSIDE OWC

$heave - \eta_{OWC}$

CONCLUSIONS & FUTURE WORK

OBJECTIVES WERE:

1) Develop and validate the numerical tool to simulate floating WECs

2) Design more efficient floating WECs

3) Study survivability under extreme conditions

CONCLUSIONS & FUTURE WORK

OBJECTIVES WERE:

1) Develop and validate the numerical tool to simulate floating WECs

2) Design more efficient floating WECs

3) Study survivability under extreme conditions

The **DualSPHysics** code is **successfully** coupled with the MoorDyn model in order to simulate floating devices/structures moored to the seabed

Validation is carried out using experimental data of a floating BOX and floating OWC

- 3D simulations
- including mooring tensions (important for **survivability**)

Future work would focus on the simulation of the **air phase** inside the OWC chamber

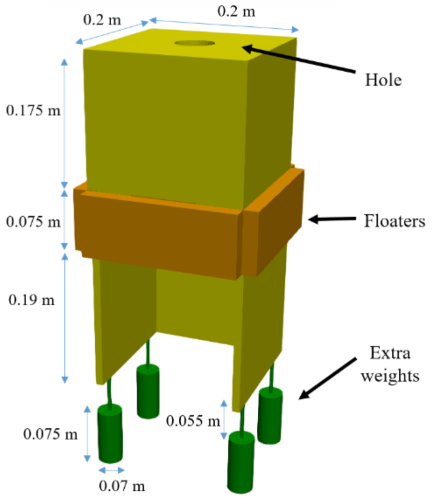
CONCLUSIONS & FUTURE WORK

OBJECTIVES WERE:

1) Develop and validate the numerical tool to simulate floating WECs

2) Design more efficient floating WECs

3) Study survivability under extreme conditions



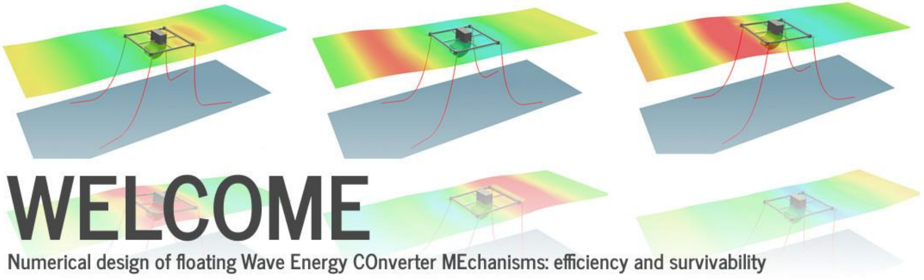
The OWC designed here was important for:
- Validation of the numerical model
- Facing problems in physical tests with floating moored structures

We want to collaborate with researchers that are designing WECs

We want to simulate your WEC!!!

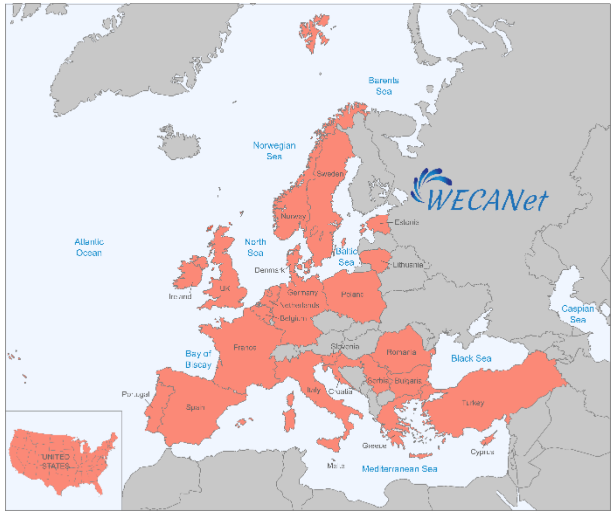
SPANISH GOVERNMENT. RETOS 2016

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



COST Action CA17105, COST Association

WECANet: A pan-European Network for Marine Renewable Energy



MARINET2

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