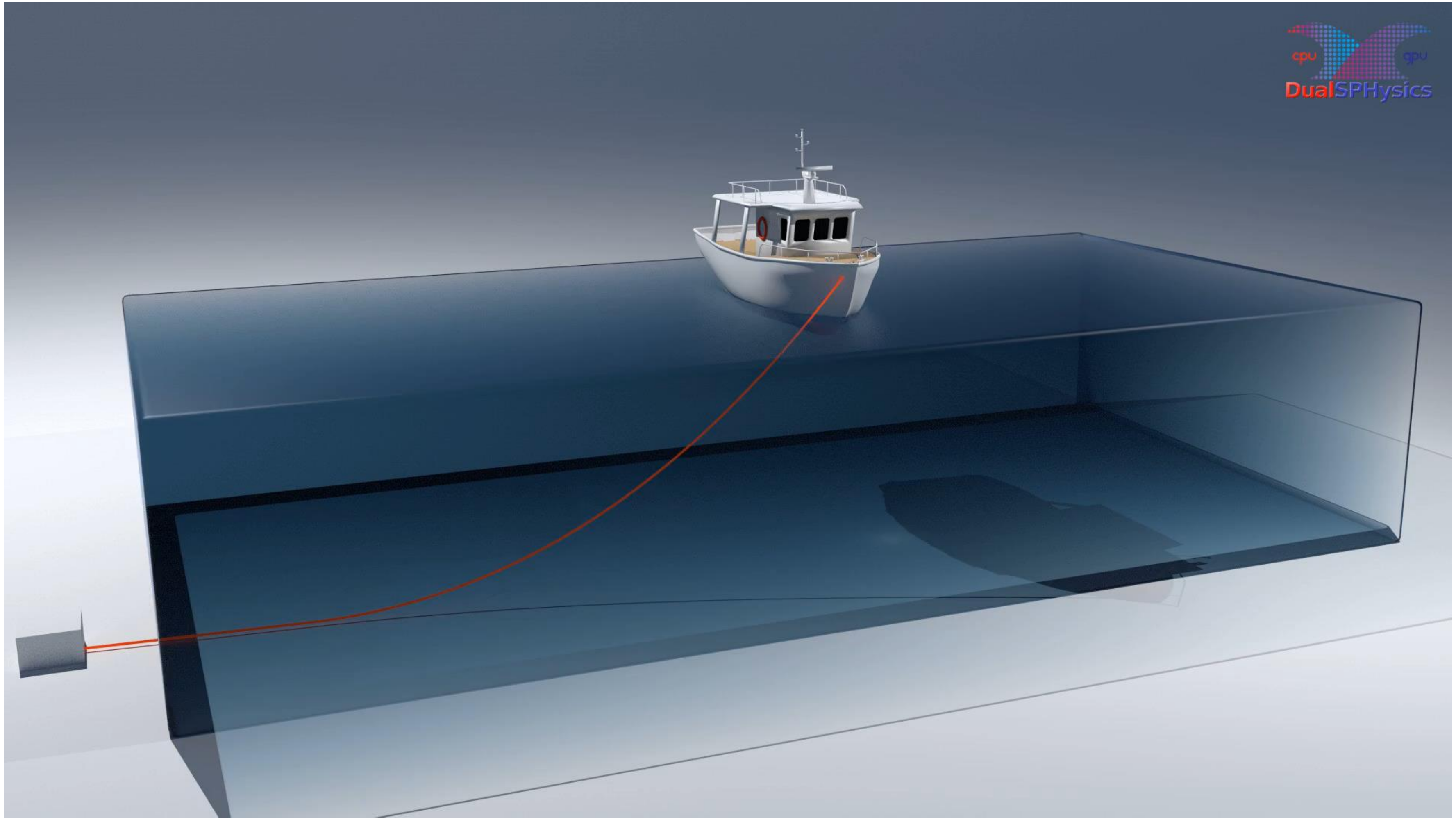
Survivability of floating moored offshore structures studied with DualSPHysics



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Universidade de Vigo, Spain

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Instituto Superior Tecnico, Portugal

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University of Manchester, United Kingdom

Efficiency and survivability of floating Oscillating Water Column Wave Energy 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

IST - UNIVERSIDADE DE LISBOA, PORTUGAL

THE UNIVERSITY OF MANCHESTER, UNITED KINGDOM

UNIVERSITÀ DEGLI STUDI FIRENZE, ITALY

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. 3G029114

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

Fonds Wetenschappelijk Onderzoek Vlaanderen
Opening new horizons

HORIZON 2020

MaRINET2
Marine Renewables Infrastructure Network for Enhancing Energy Technologies

MaRINET2

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

SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

Numerical simulation of FLOATING MOORED DEVICES 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**

What SPH code can deal with these applications?

SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

cpu gpu DualSPHysics

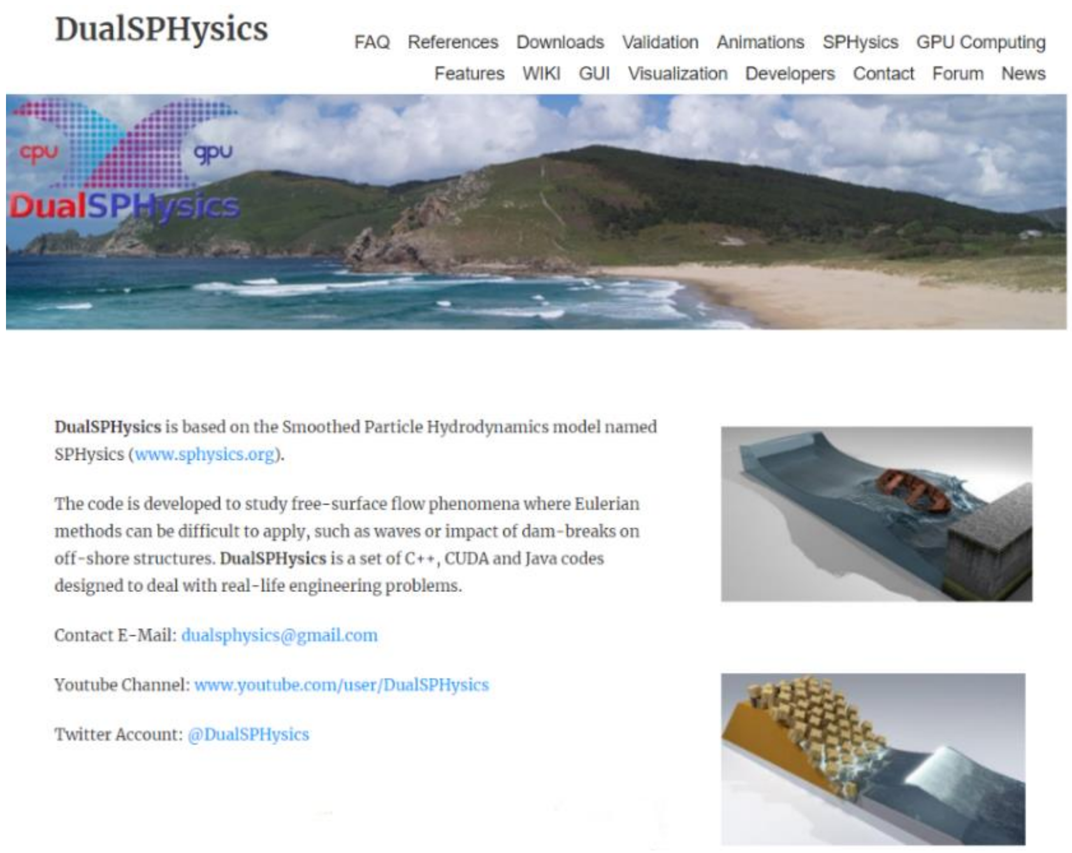
DualSPHysics CODE

- 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)

cpu gpu DualSPHysics

DualSPHysics CODE



www.dual.sphysics.org

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SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

DualSPHysics CODE

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 Wave 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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SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

DualSPHysics CODE

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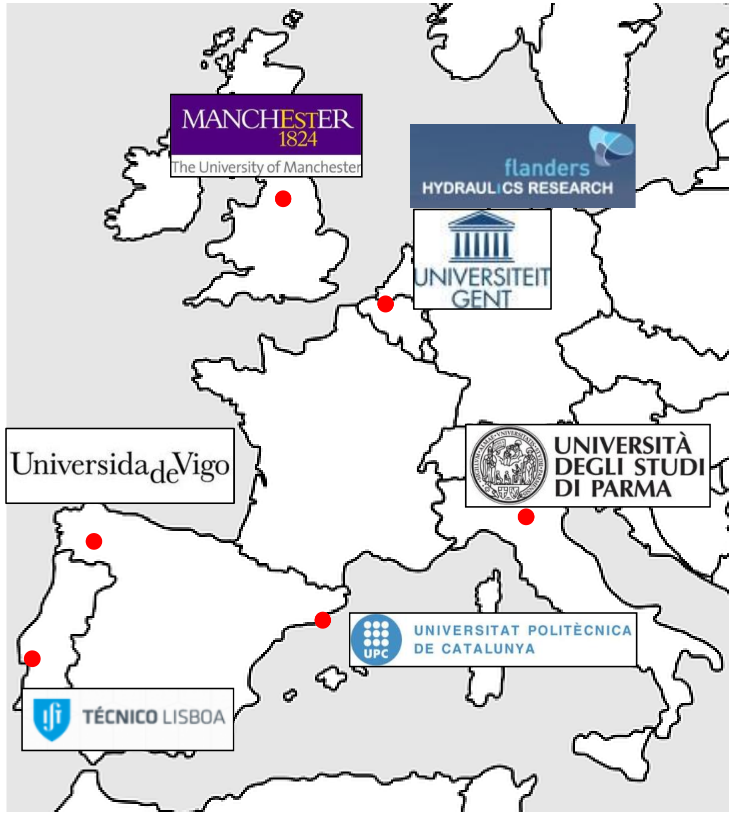

Dr Corrado Altomare
Dr Tomohiro Suzuki
Tim Verbrugghe

Dr Renato Vacondio
Prof. Paolo Mignosa

Dr Xavier Gironella
Dr Andrea Marzeddu

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SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

cpu gpu DualSPHysics

DualSPHysics CODE

LGPL Free Software
Free as in Freedom

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

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NVIDIA CUDA

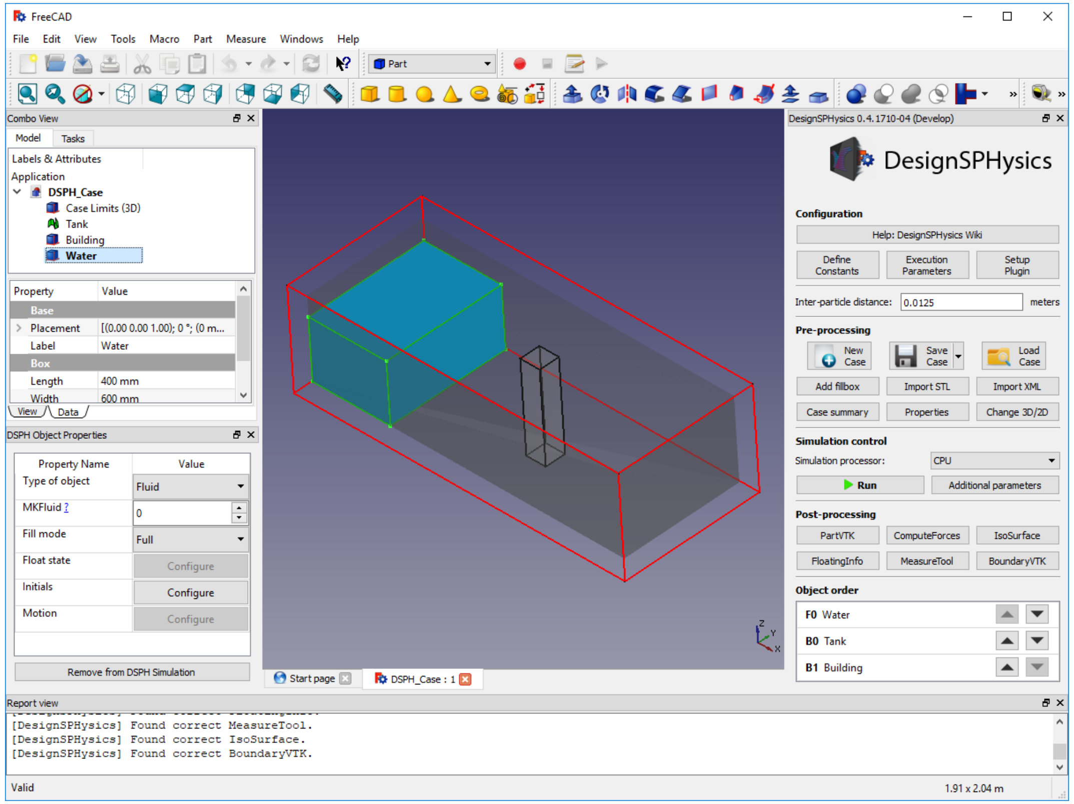
GPU CPU

x100

SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

cpu gpu DualSPHysics

DualSPHysics CODE



FreeCAD
Open Source parametric 3D CAD modeler

Graphical User Interface

http://design.sphysics.org/

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SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

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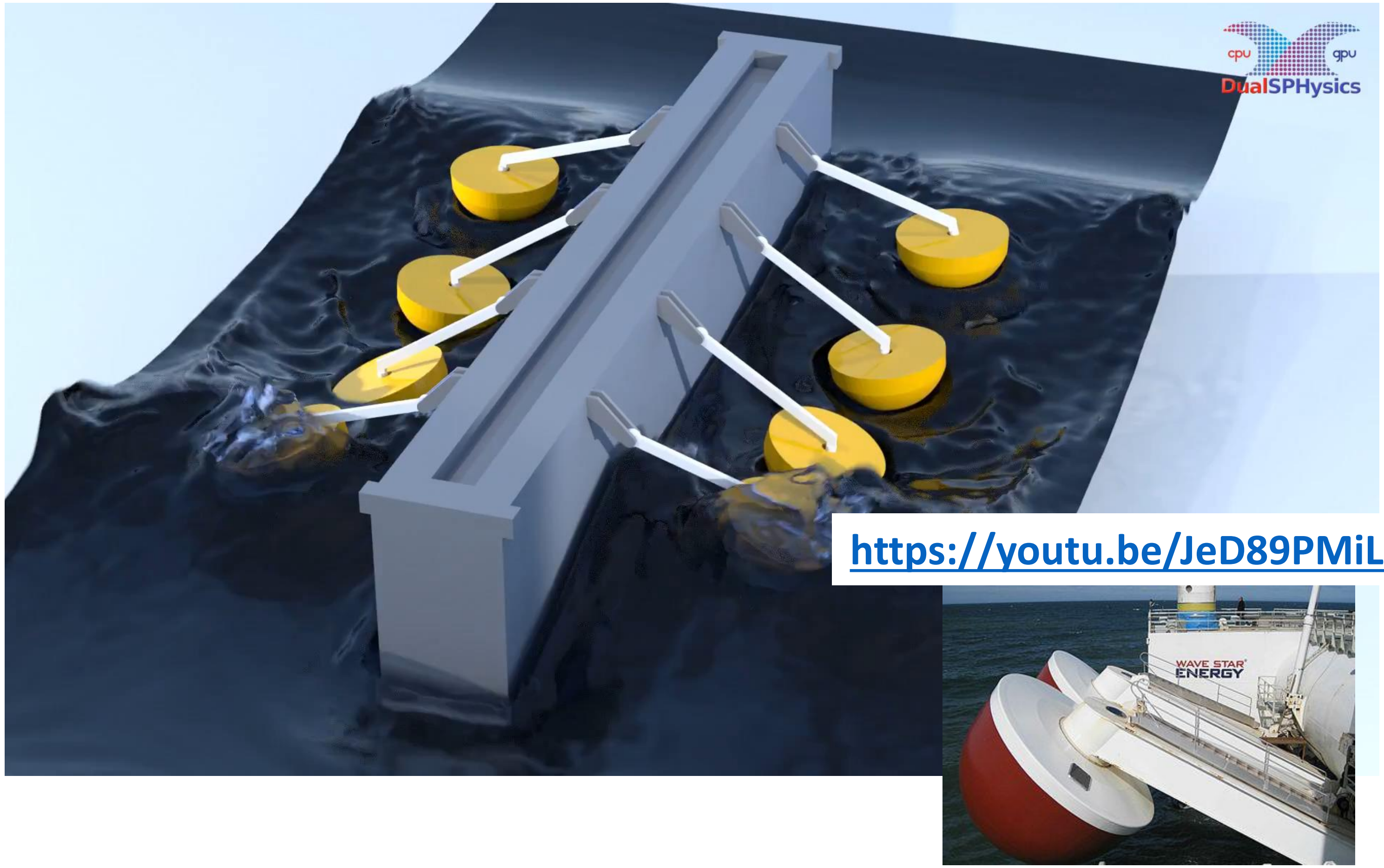

https://youtu.be/JeD89PMiLLQ

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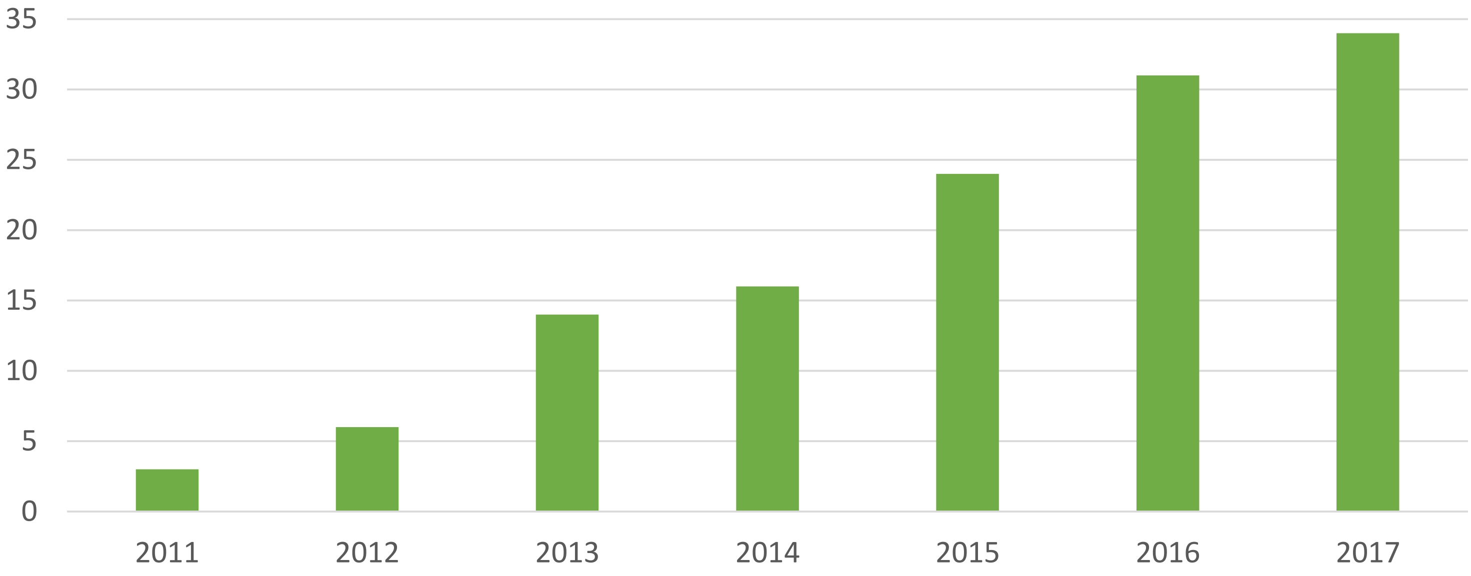
SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

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**

DUALSPHYSICS CODE

DualSPHysics v4.2

- Parallelisation with OpenMP and CUDA (one GPU card) (Domínguez et al., 2013)
- Time integration scheme: Verlet (Verlet, 1967) & Symplectic (Leimkhuler, 1996)
- Variable time step (Monaghan and Kos, 1999)
- Kernel functions: Cubic Spline (Monaghan and Lattanzio, 1985) & Quintic Wendland (Wendland, 1995)
- Density treatment: Delta-SPH formulation (Molteni and Colagrossi, 2009)
- Viscosity: Artificial (Monaghan, 1992) & Laminar + SPS turbulence model (Dalrymple and Rogers, 2006)
- Weakly compressible approach using Tait's equation of state (Batchelor, 1974)
- Shifting algorithm (Lind et al., 2012)
- Dynamic boundary conditions (Crespo et al., 2007)

DUALSPHYSICS CODE

DualSPHysics v4.2

- Floating objects (Monaghan et al., 2003)
- Periodic open boundaries (Gómez-Gesteira et al., 2012)
- Coupling with Discrete Element Method (Canelas et al., 2016)
- External body forces (Longshaw and Rogers, 2015)
- Double precision (Domínguez et al., 2013)
- Multi-phase (soil-water) (Fourtakas and Rogers, 2016)
- Multi-phase (gas-liquid) (Mokos et al., 2015)
- Piston- and flap-type long-crested second-order wave generation (Altomare et al., 2017)
- Passive and Active Wave Absorption System (Altomare et al., 2017)

DUALSPHYSICS CODE

Future releases

•Inlet/outlet flow conditions	Tafuni et al. SPHERIC 2016 & SPHERIC 2017
•Coupling with Project Chrono	Canelas et al. SPHERIC 2016, Canelas et al. 2018
•Coupling with wave propagation models	Altomare et al. CEJ 2015, Suzuki et al SPHERIC 2017
•Incompressible SPH	Chow et al. 2018

Under developmment

Variable particle resolution

Other BCs

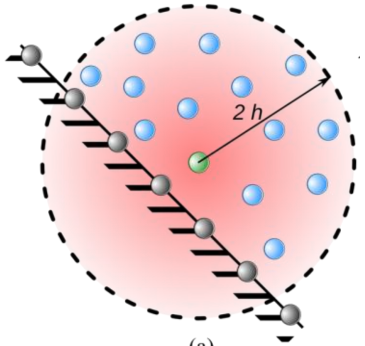
Multi-GPU implementation

Domínguez et al. SPHERIC 2015
SPHERIC Benchmark Test Case #2

DUALSPHYSICS CODE

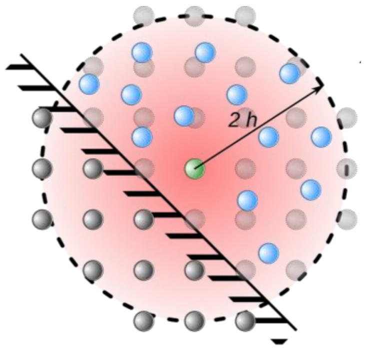
DYNAMIC BOUNDARY CONDITIONS

DBC
Dynamic boundaries (DBC)
Boundary repulsive forces



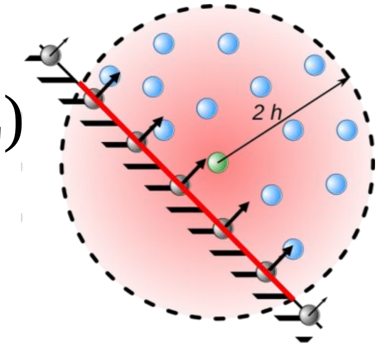
(a)

LUST
Local Uniform STencil (LUST)
Fluid extensions to the solid boundary

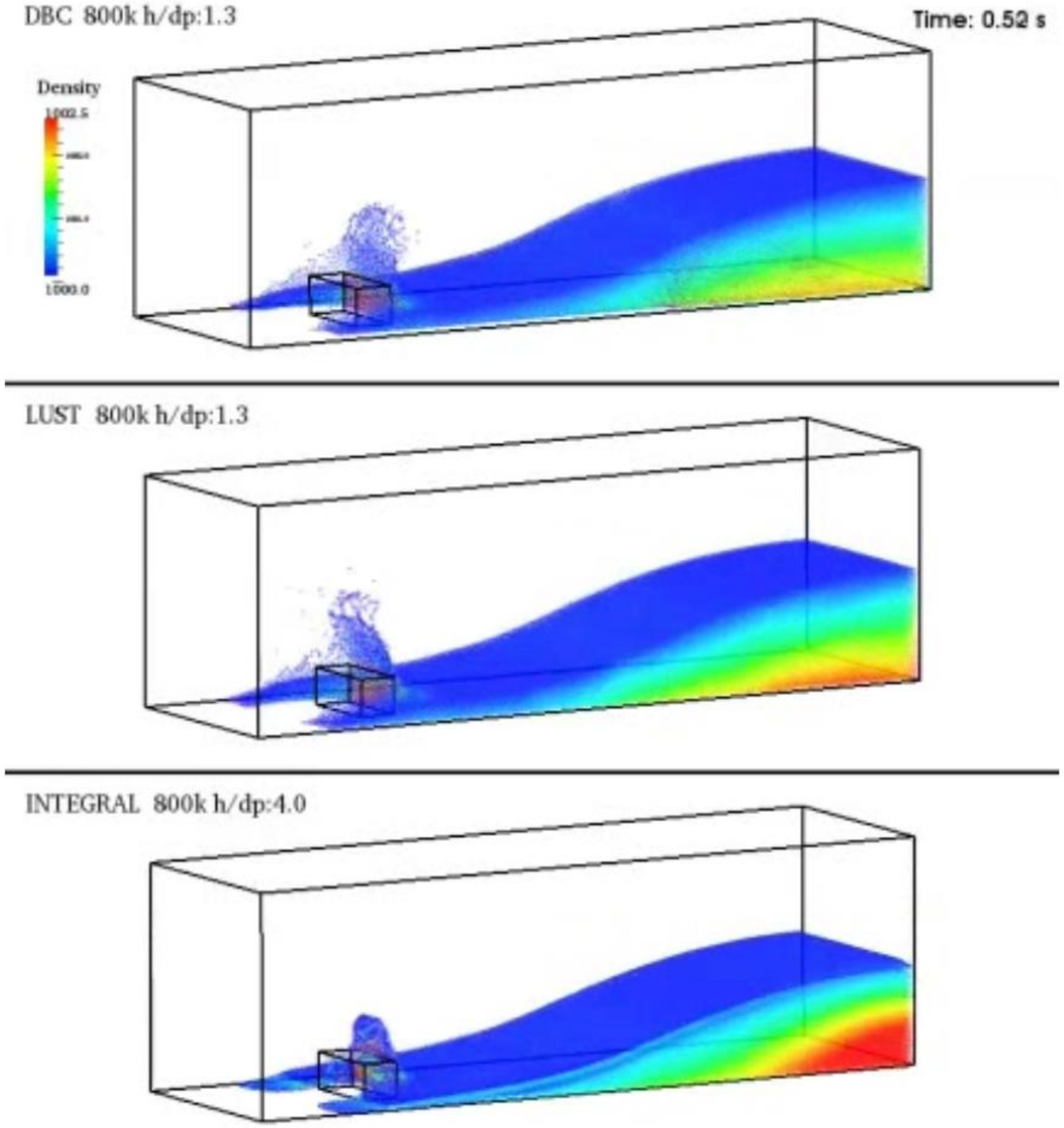


(b)

INTEGRAL
Boundary Integral (INTEGRAL)
Boundary integral representation
terms preservation



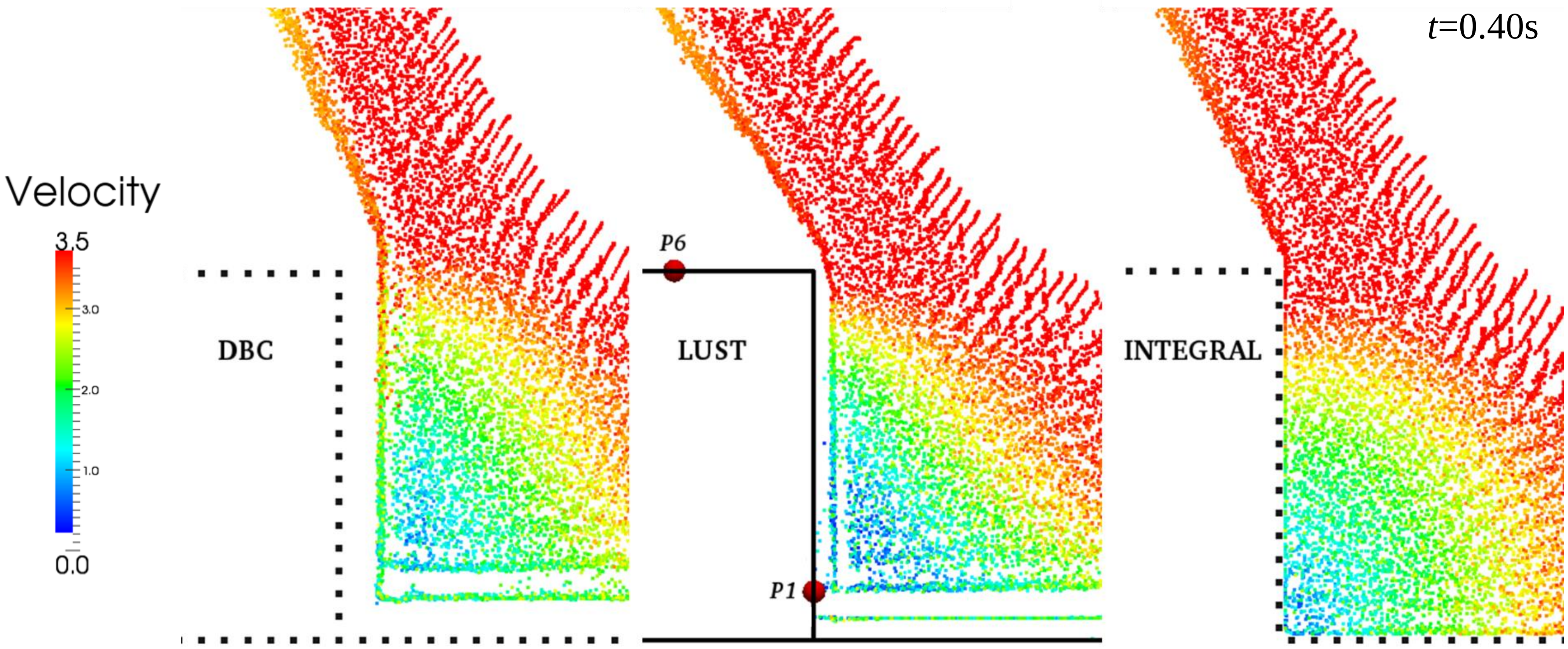
(c)



DUALSPHYSICS CODE

Domínguez et al. SPHERIC 2015
SPHERIC Benchmark Test Case #2

DYNAMIC BOUNDARY CONDITIONS



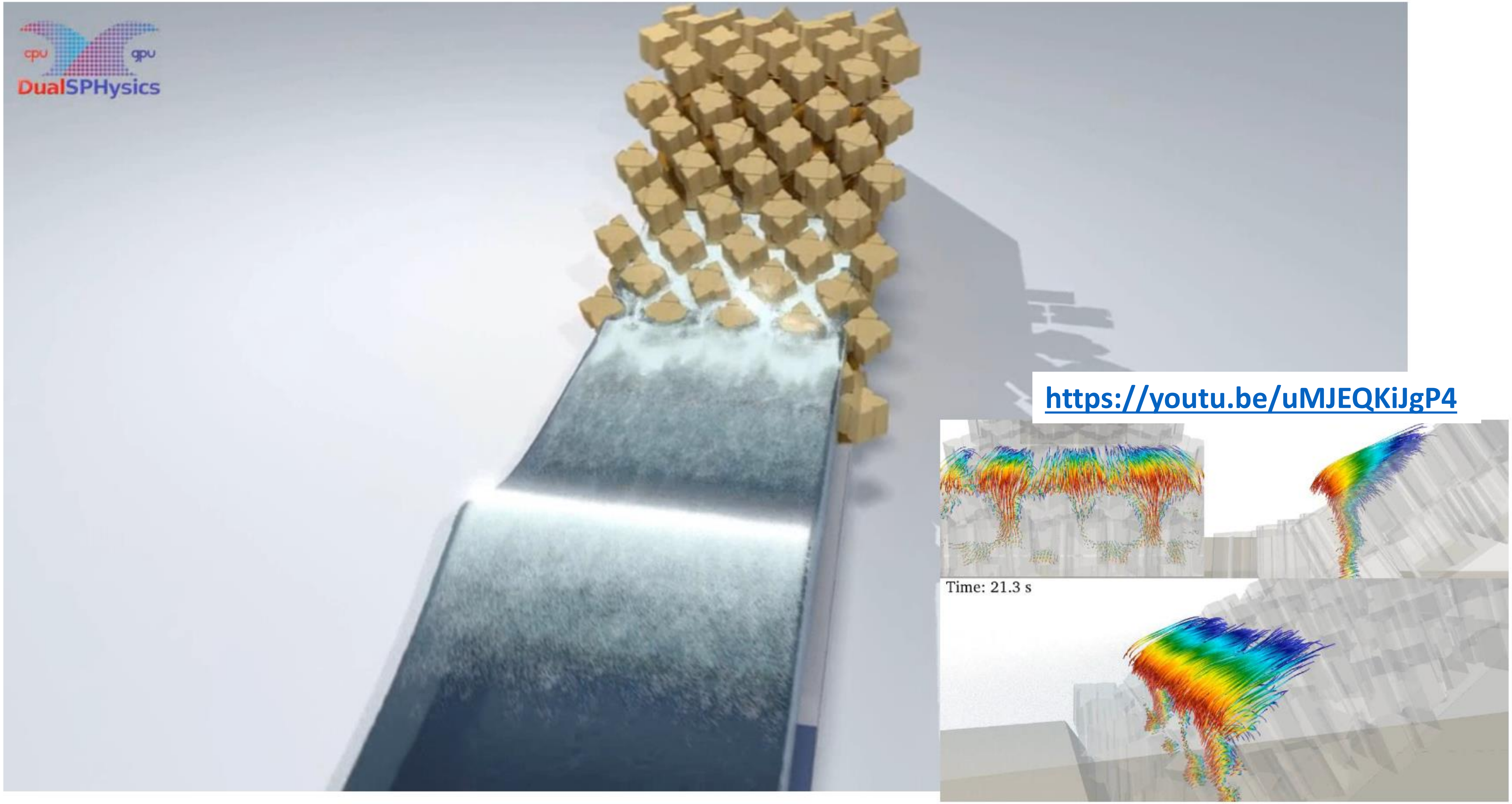
GAP
Fluid-Boundary

1.23·h *0.5·h* *0·h*

DUALSPHYSICS CODE

DYNAMIC BOUNDARY CONDITIONS

Altomare et al., 2014

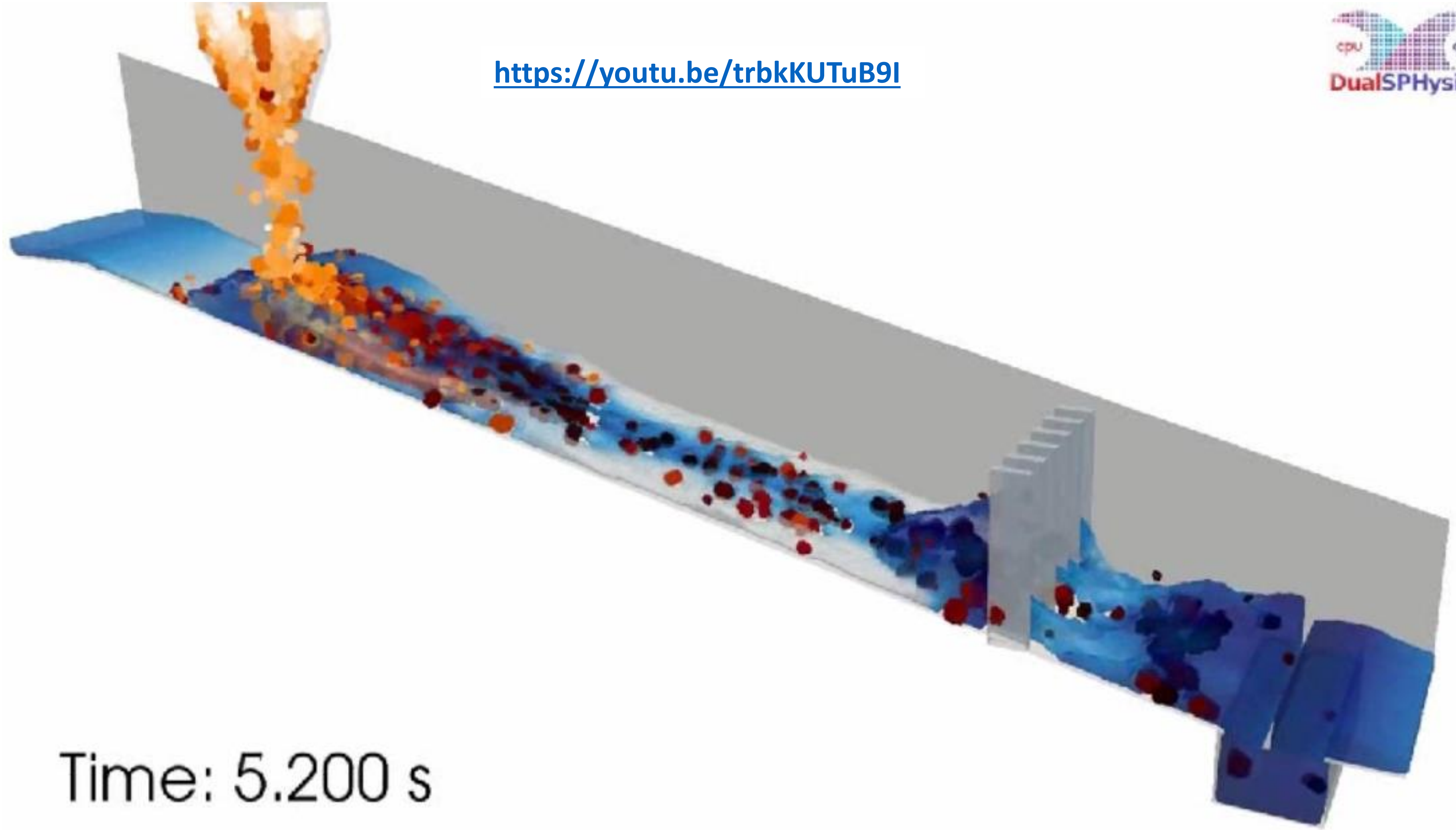


https://youtu.be/uMJEQKiJgP4

DUALSPHYSICS CODE

DYNAMIC BOUNDARY CONDITIONS Canelas et al., 2017

https://youtu.be/trbkKUTuB9I



DUALSPHYSICS CODE

DYNAMIC BOUNDARY CONDITIONS

ADVANTAGES

DBC can be applied to arbitrary 2-D and 3-D geometries
provide good validation in many coastal engineering problems

DISADVANTAGES

unphysical density/pressure values of the boundary particles
high repulsive force resulting in a separation distance (GAP)

Ren et al., 2014 (CENG) applied to DBC a **correction equivalent** to the one provided by Adami et al., 2012 (JCP) for ghost particles of Hu & Adams code

cpu gpu DualSPHysics

Dynamic boundaries (DBC)
Local Uniform STencil (LUST)
Boundary Integral (INTEGRAL)
Ghost particles (GHOST)

DUALSPHYSICS CODE

Numerical simulation of FLOATING MOORED DEVICES 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**

Altomare et al., 2017

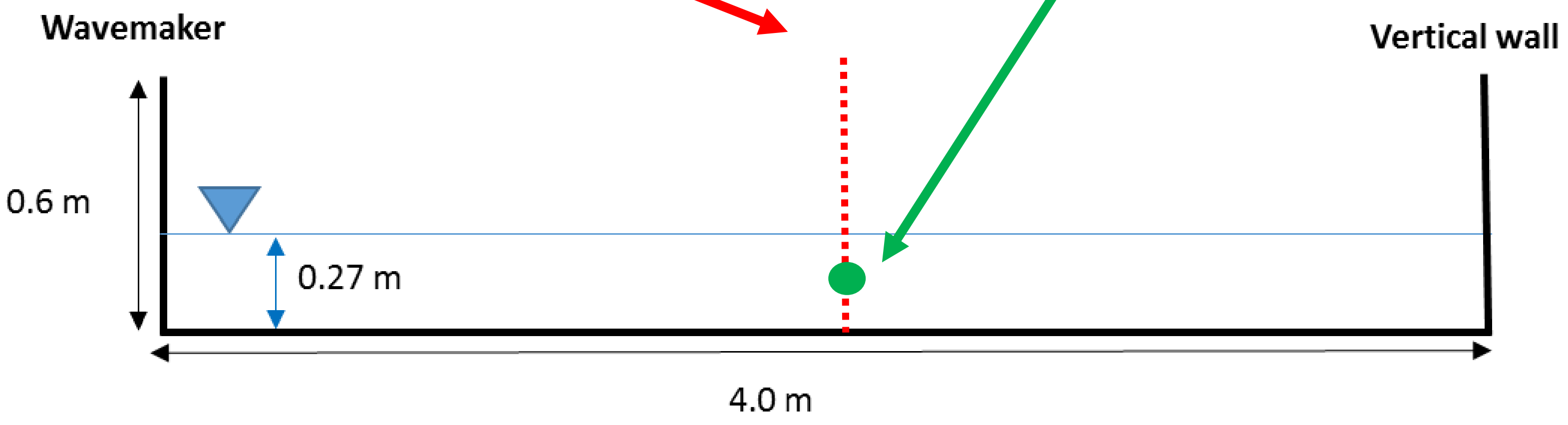
Wave generation, wave propagation and wave absorption

The generated waves are:

- Regular waves: H=0.1m, T=1.3s.
- Irregular waves: H_{m0}=0.1m, T_p=1.3s (JONSWAP spectrum).

Water surface elevation at x=2m

Horizontal and vertical velocity at x=2m z=-0.15m

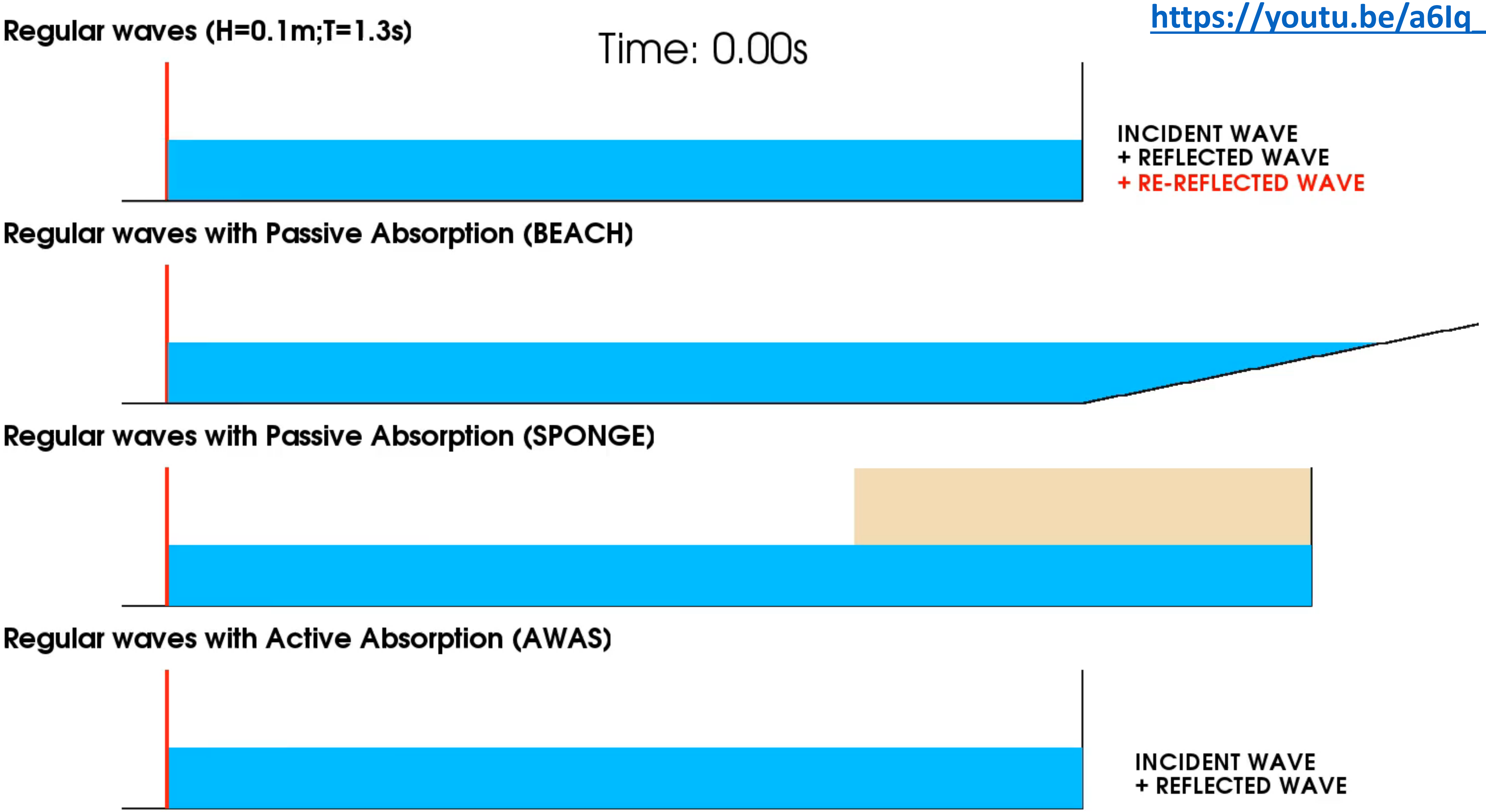


DUALSPHYSICS CODE

Altomare et al., 2017

Wave generation, wave propagation and wave absorption

https://youtu.be/a6Iq_FjU2_I

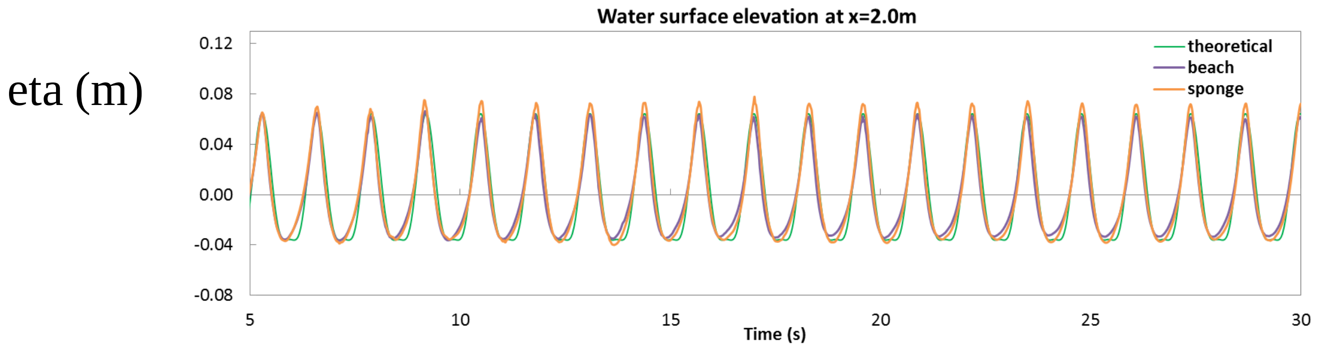


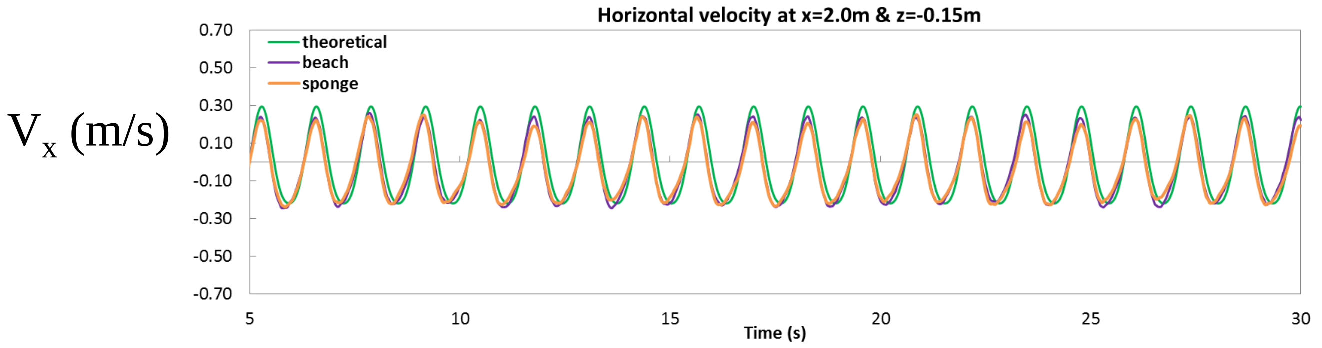
DUALSPHYSICS CODE

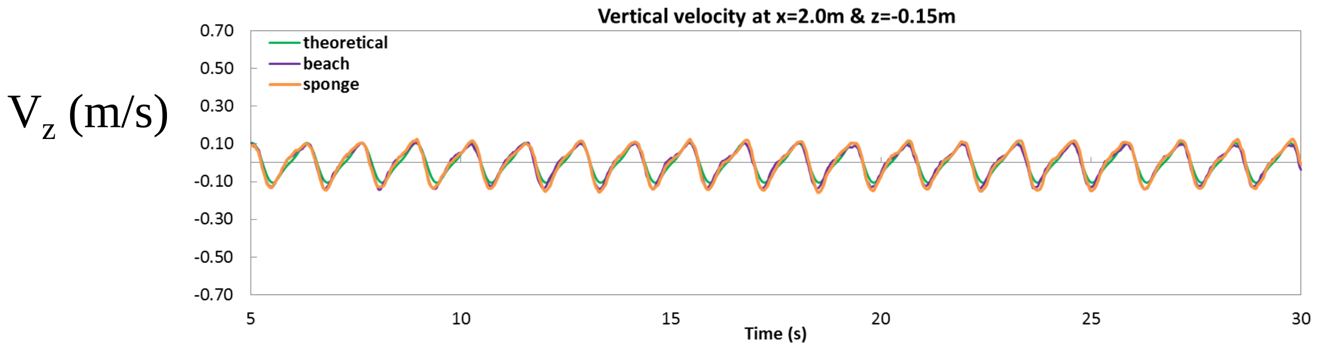
Altomare et al., 2017

Wave generation, wave propagation and wave absorption

Regular waves: H=0.1m, T=1.3s





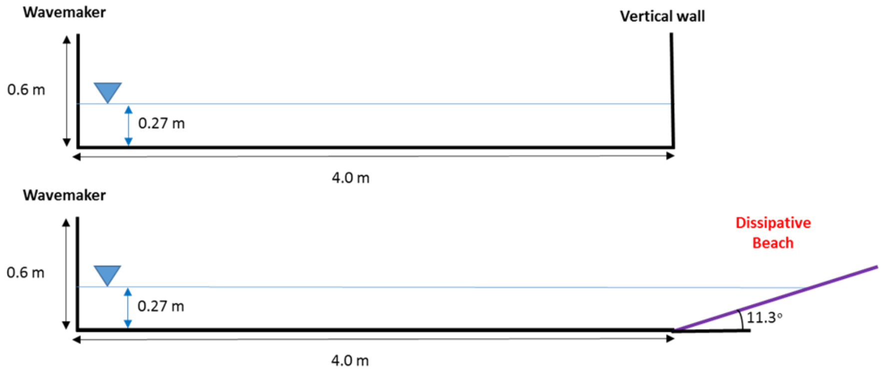


THEORY

2nd Stokes

VS

SPH

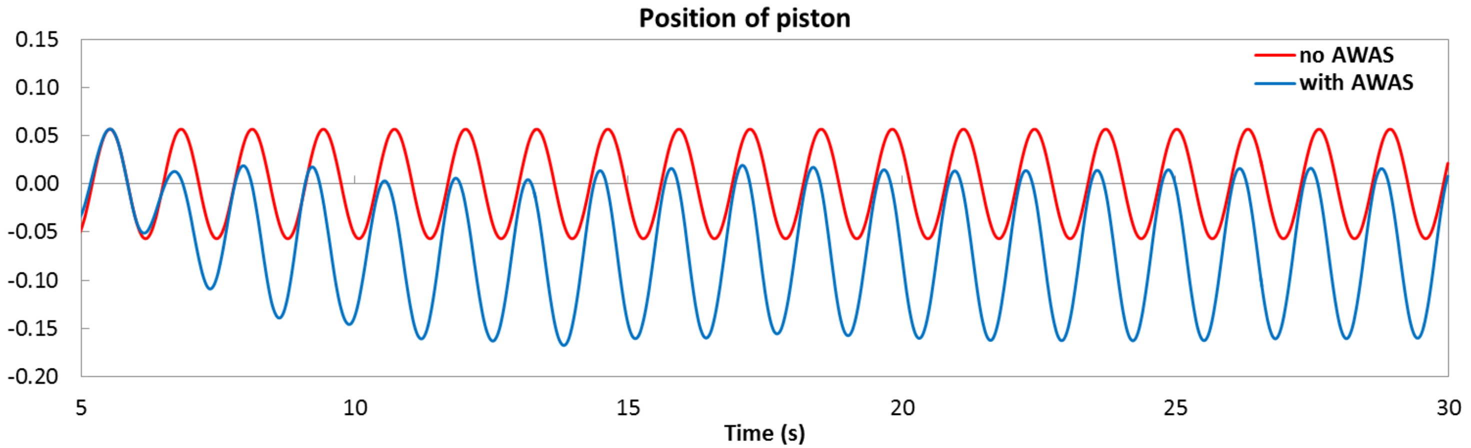


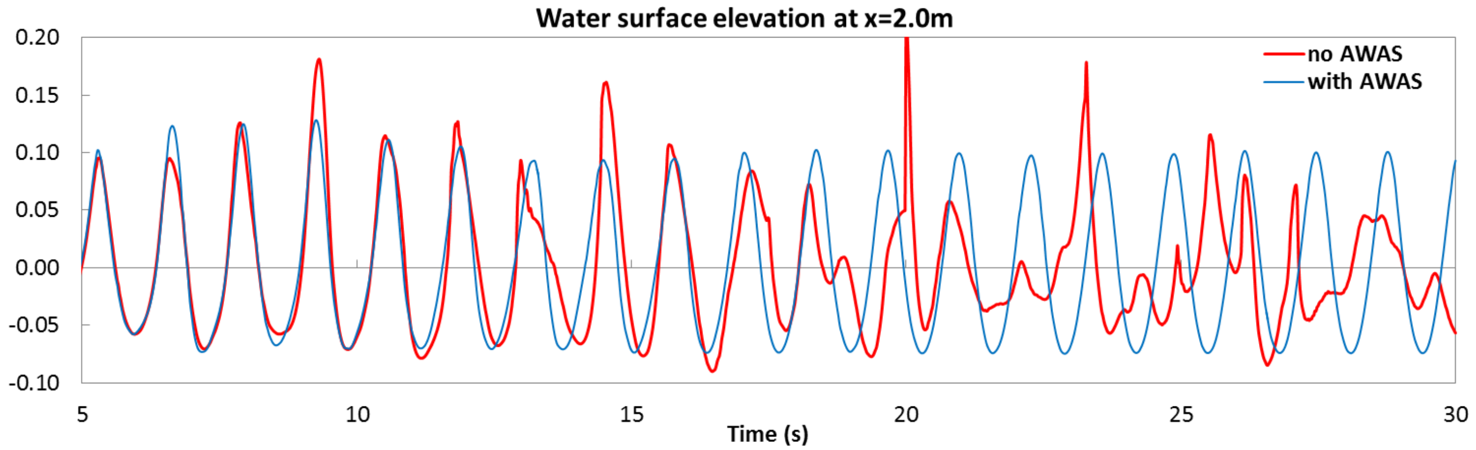
DUALSPHYSICS CODE

Altomare et al., 2017

Wave generation, wave propagation and wave absorption

Regular waves: *H*=0.1m, *T*=1.3s with Active Wave Absorption System (AWAS)





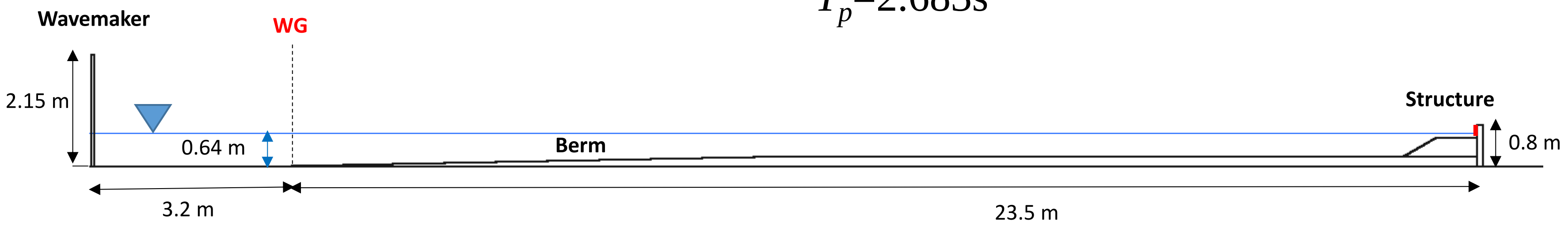
Piston position and water surface elevation for regular waves with and without AWAS

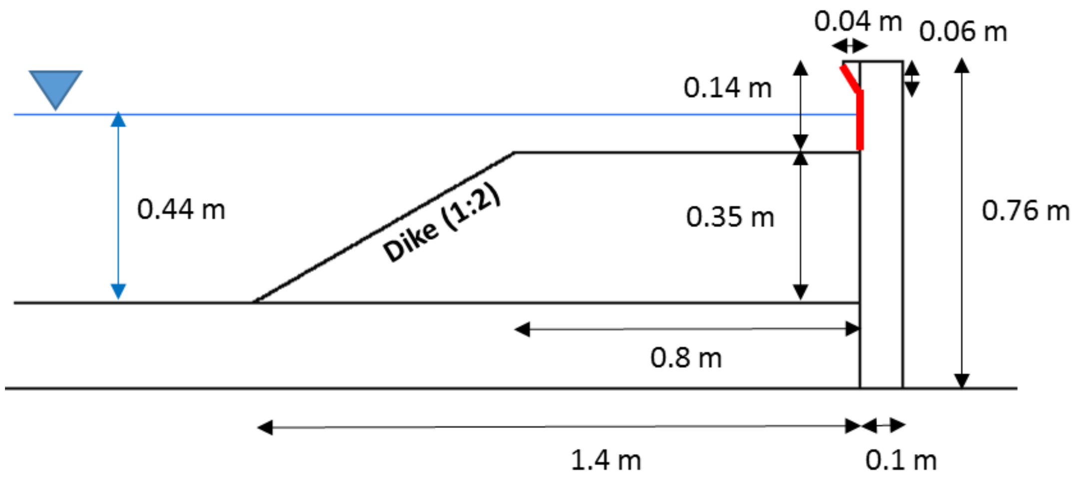
Altomare et al., 2015

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

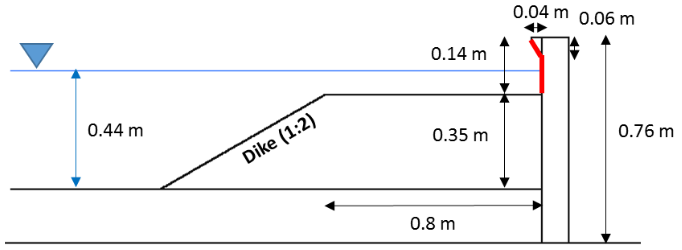


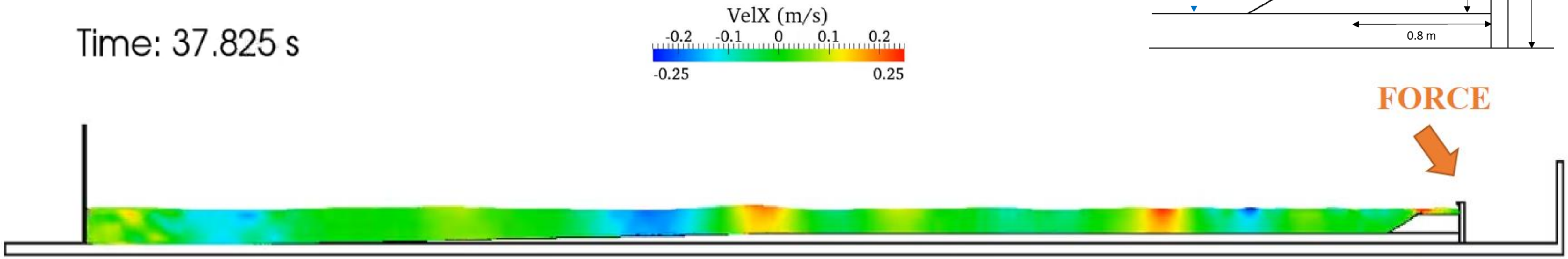


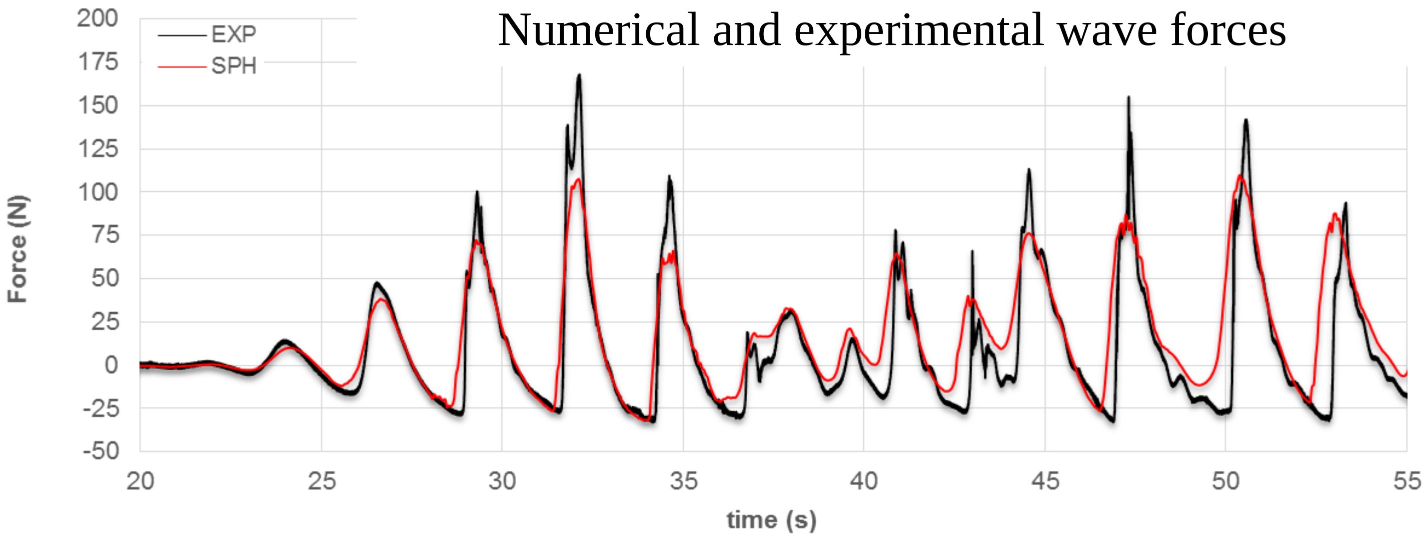
DUALSPHYSICS CODE

Altomare et al., 2015

Interaction between waves and **fixed** structures





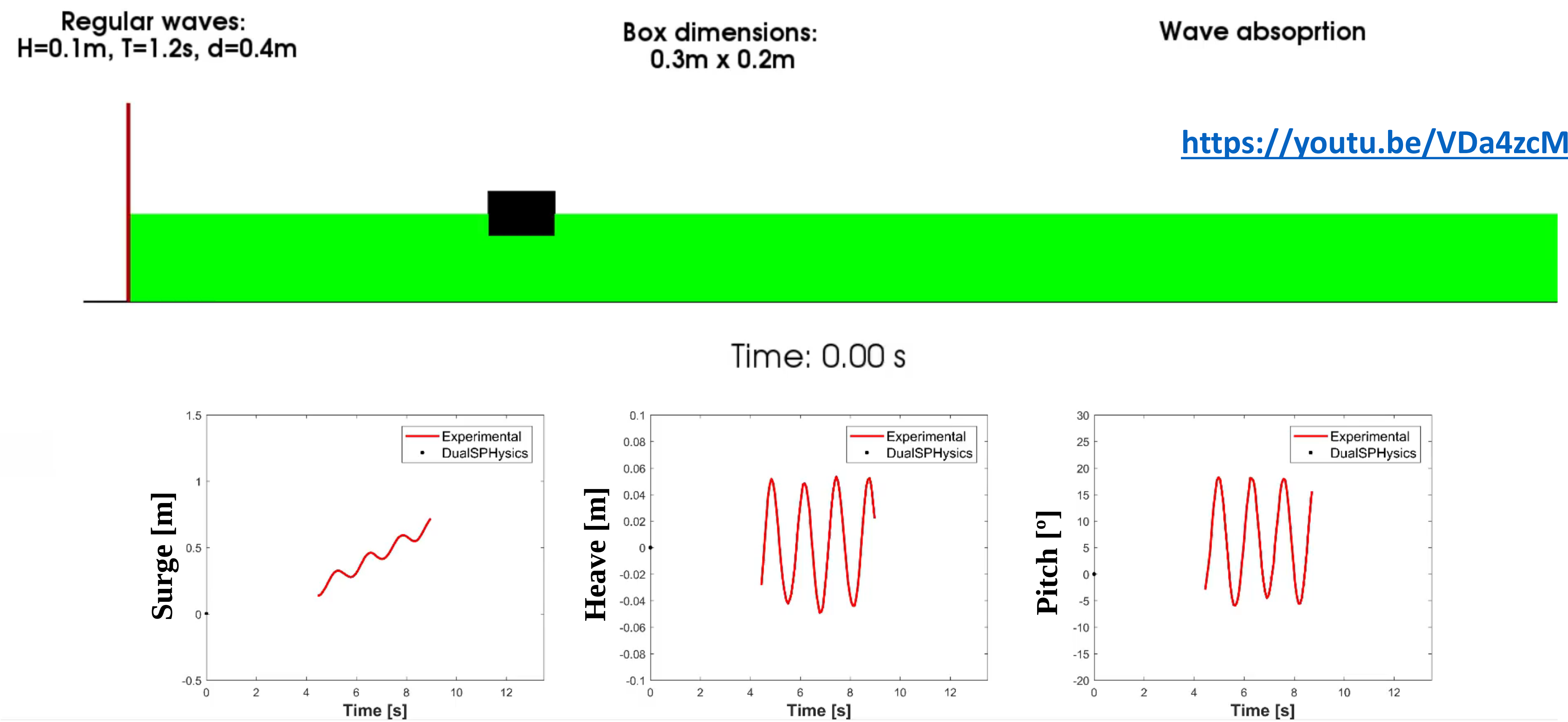


DUALSPHYSICS CODE

Ren et al., 2015

Interaction between waves and floating structures

Floating BOX subjected to REGULAR WAVES



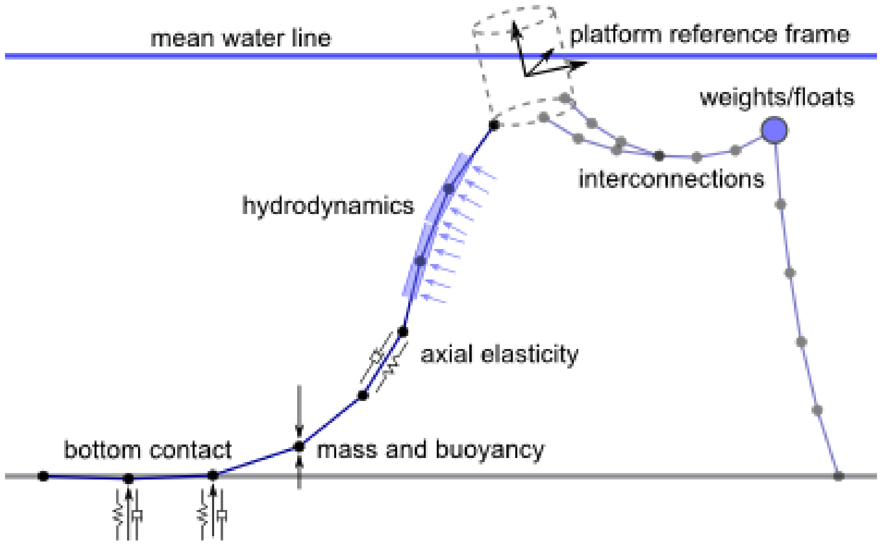
https://youtu.be/VDa4zcMDjJA

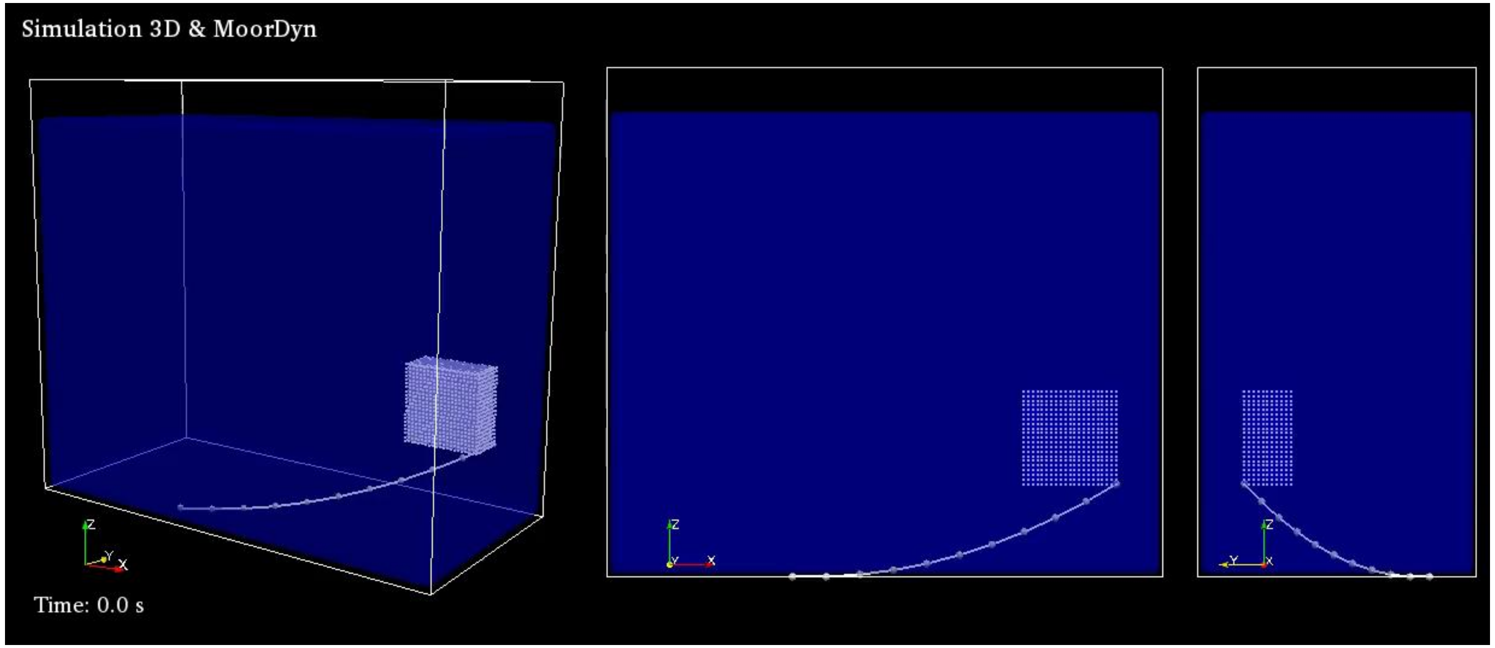
DUALSPHYSICS CODE

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.





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

VALIDATION WITH EXPERIMENTS

Decay tests with a floating BOX

- heave free & moored
- pitch free & moored
- surge moored

LABIMA

Regular waves interacting with floating BOX

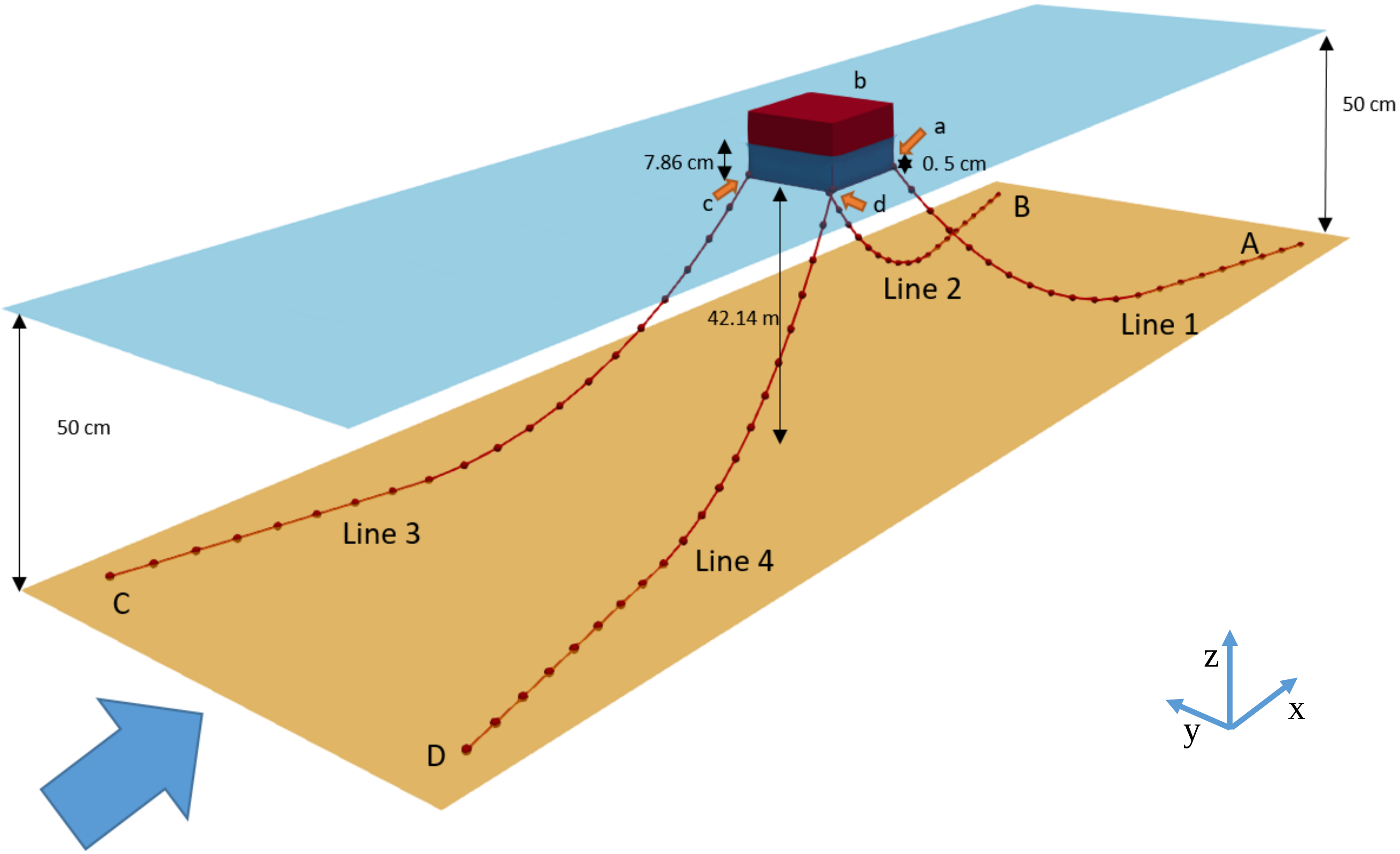
- heave, surge, pitch
- tensions in the moorings

UGENT

VALIDATION WITH EXPERIMENTS

	UGENT	LABIMA
BOX Dimensions	20 cm x 20 cm x 13.2 cm	
BOX Weight	3 kg + 0.6 kg(extra)	
BOX Centre of gravity	(0, 0, -1.26) cm	
BOX Lip draught	7.86 cm	
MOORING Diameter	3.656 mm	
MOORING Weight	0.607 g/cm	
MOORING Length	145.5 cm	167.3 cm
Water depth	50 cm	60 cm

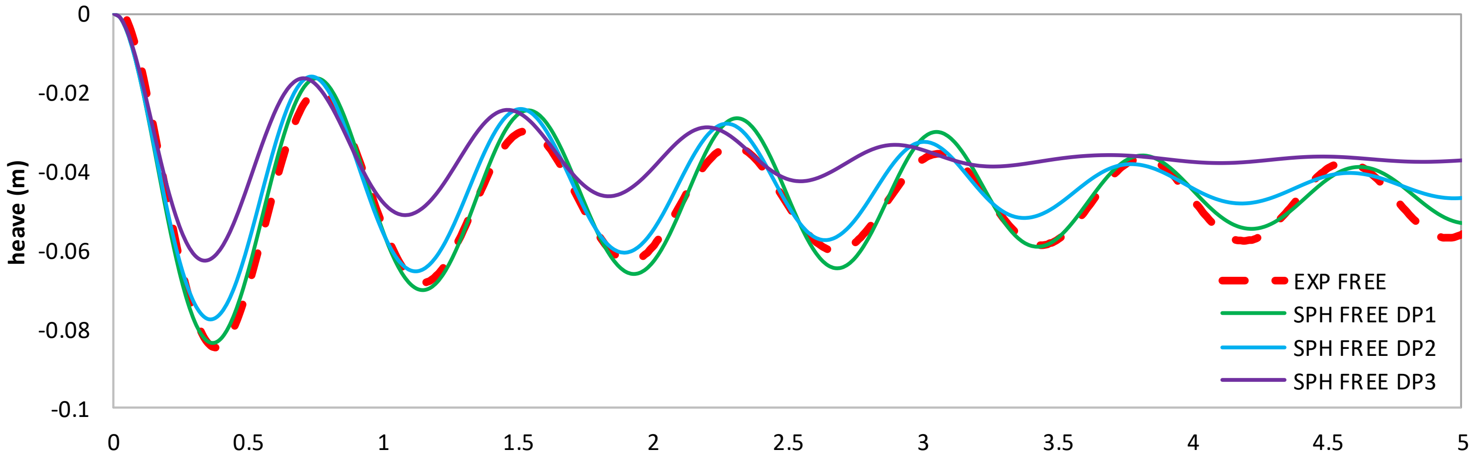
	UGENT x,y,z (cm)	LABIMA x,y,z (cm)
Fairlead a	10, 10, -7.36	10, 9.5, -7.36
Fairlead b	10, -10, -7.36	10, -9.5, -7.36
Fairlead c	-10, -10, -7.36	-10, -9.5, -7.36
Fairlead d	-10, 10, -7.36	-10, 9.5, -7.36
Anchor A	138.5, 42.3, -50	140.6, 34.5, -55.7
Anchor B	138.5, -42.3, -50	140.6, -34.5, -55.7
Anchor C	-138.5, -42.3, -50	-140.6, -34.5, -55.7
Anchor D	-138.5, 42.3, -50	-140.6, 34.5, -55.7

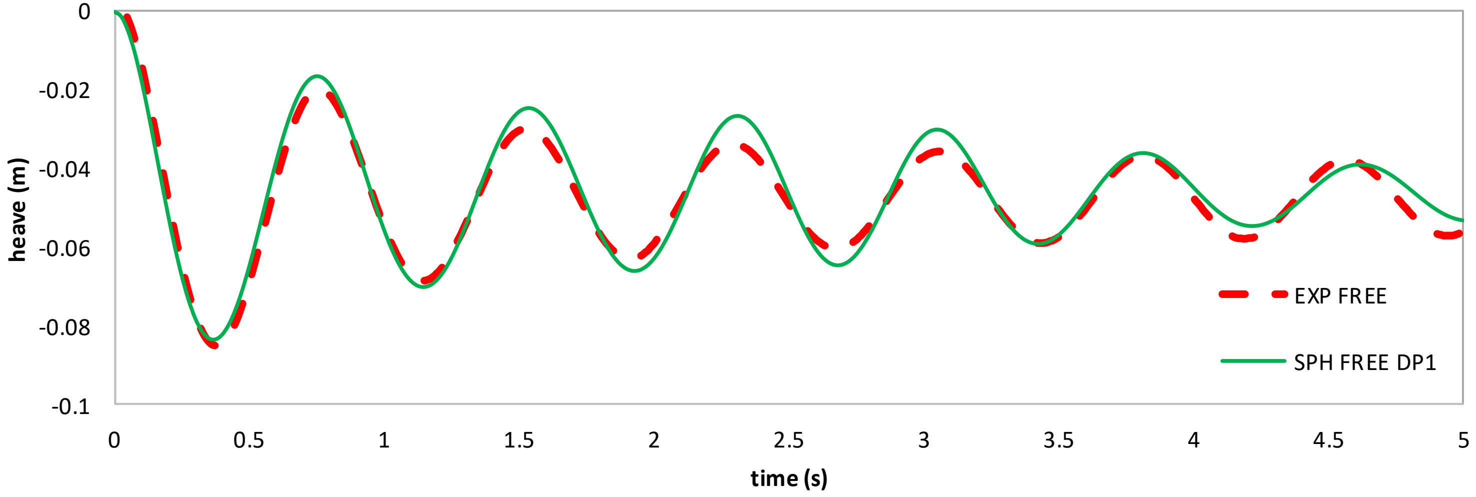


HEAVE DECAY TESTS

FREE (initial shift of +5 cm)

	H_{BOX}=13.2 cm	Shift=5 cm
DP_1=0.25 cm	H_{BOX}/DP_1=52.8	S/DP_1=20
DP_2=0.50 cm	H_{BOX}/DP_2=26.4	S/DP_2=10
DP_3=1.00 cm	H_{BOX}/DP_3=13.2	S/DP_3=5





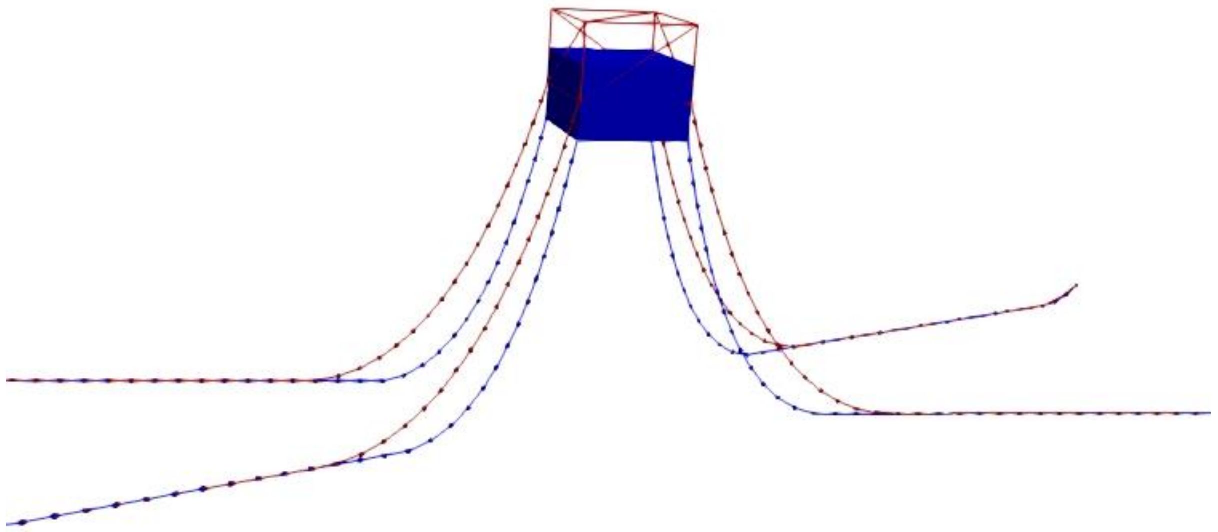
DP_1=0.25 cm

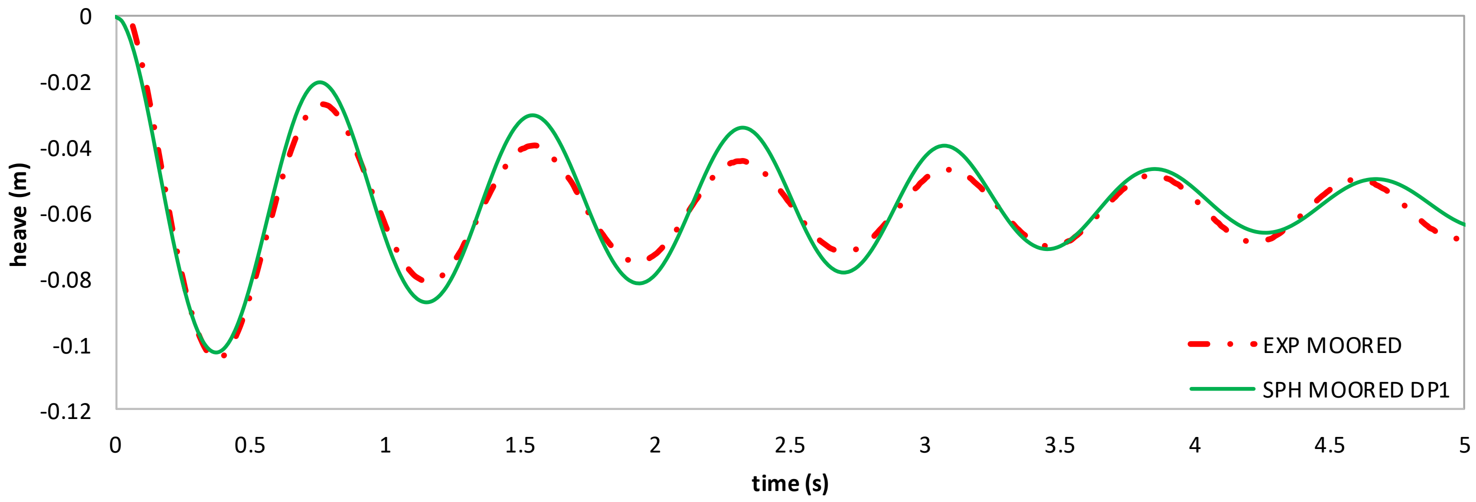
HEAVE DECAY TESTS

MOORED (shift of +6.6 cm)

H_{BOX}=13.2 cm   Shift=6.6 cm

DP_1=0.25 cm H_{BOX}/DP_1=52.8 S/DP_1=26.4





WAVE TESTS

REGULAR	T (s)	H (cm)	d (m)	L (m)
BOX_WAVE1	1.60	12.00	0.5	3.100
BOX_WAVE2	1.80	12.00	0.5	3.615
BOX_WAVE3	2.00	12.00	0.5	4.116

DP_3=1.00 cm

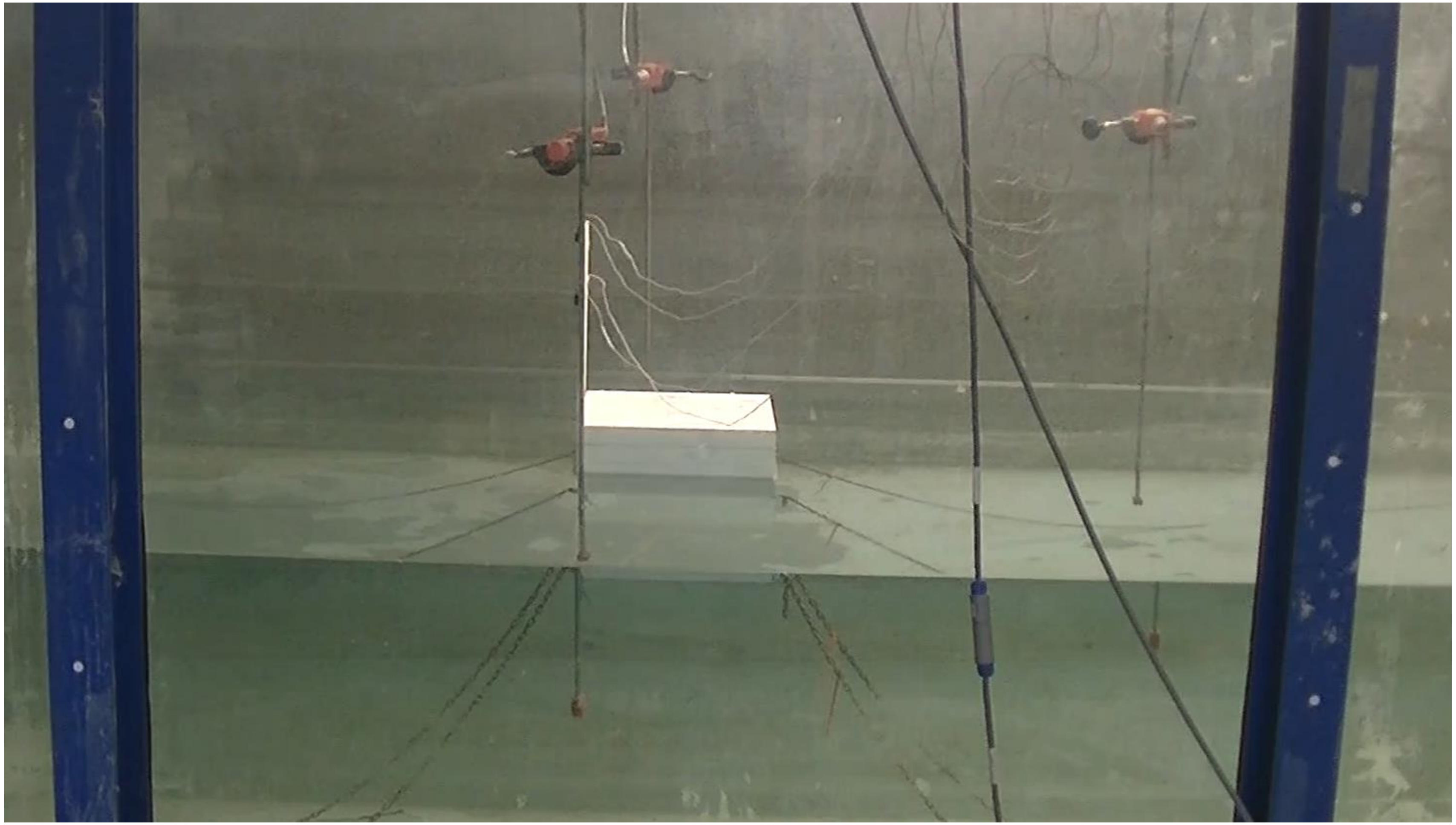
Altomare et al., 2017

H_{BOX}=13.2 cm

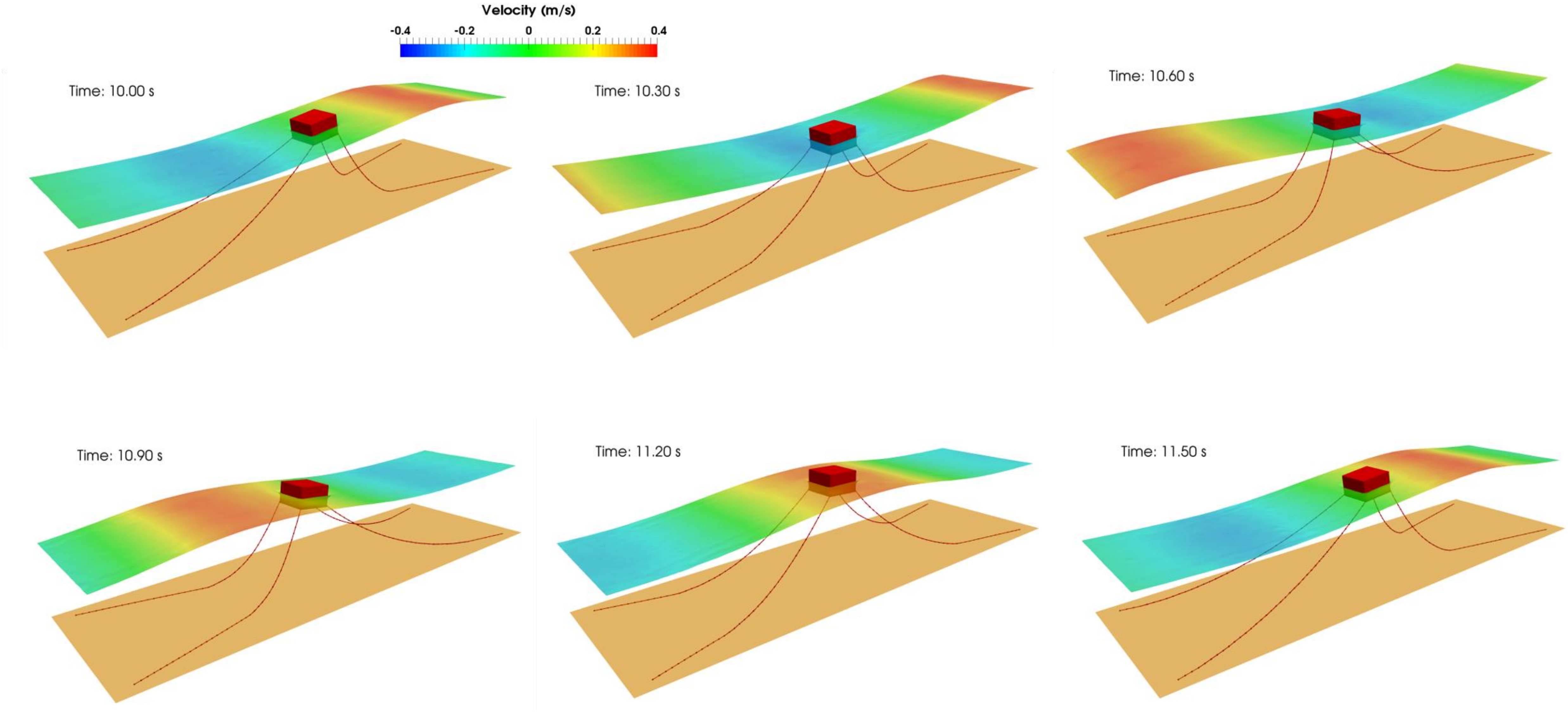
H_{BOX}/DP_3=13.2

H_{WAVE}=12 cm

H_{WAVE}/DP_3=12



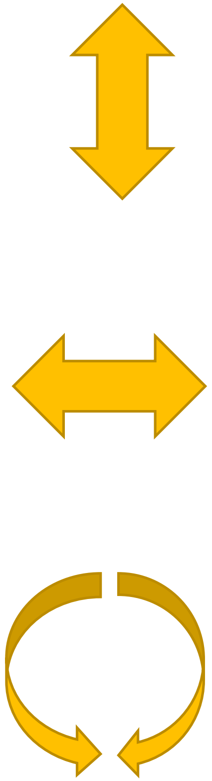
WAVE TESTS *BOX_WAVE1*



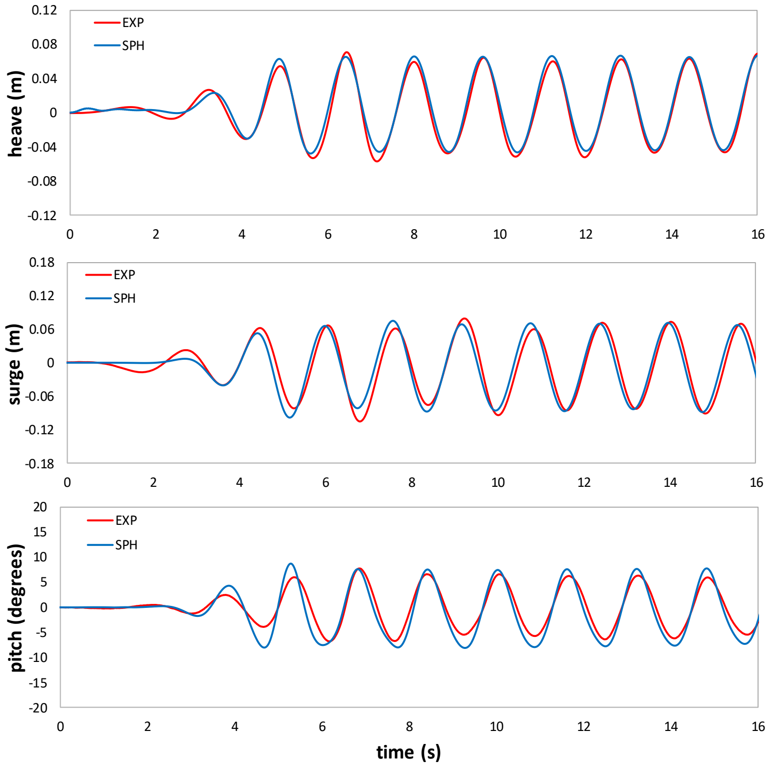
https://youtu.be/YUSxGXPkYvE

WAVE TESTS

BOX MOTIONS

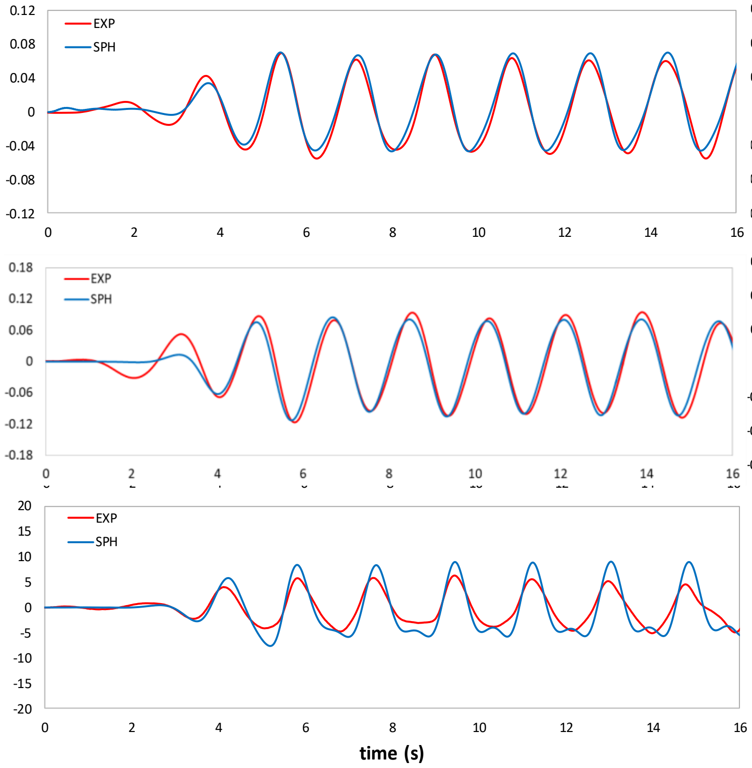


BOX_WAVE1



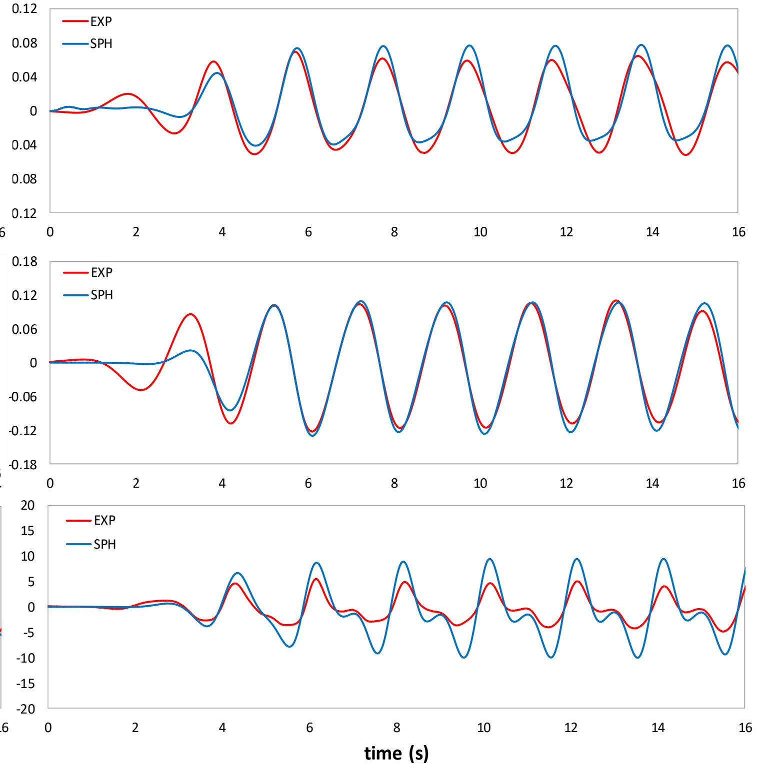
T=1.6s	H=12cm

BOX_WAVE2



T=1.8s	H=12cm

BOX_WAVE3

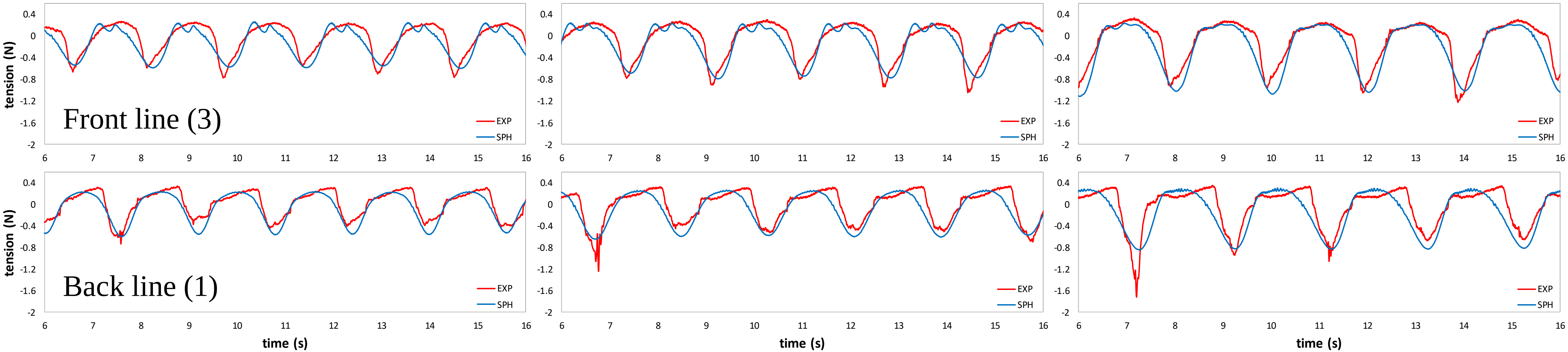


T=2.0s	H=12cm

WAVE TESTS

MOORING TENSIONS

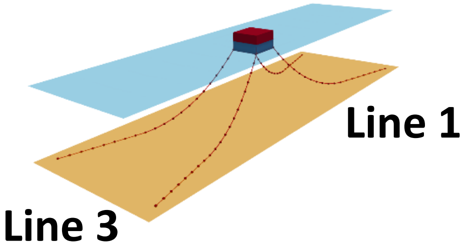
BOX_WAVE1 — *BOX_WAVE2* — *BOX_WAVE3*



T=1.6s	H=12cm

T=1.8s	H=12cm

T=2.0s	H=12cm



HEAVE DECAY TESTS

	H_{BOX}=13.2 cm	Shift=5 cm
DP_1=0.25 cm	H_{BOX}/DP_1=52.8	S/DP_1=20
DP_2=0.50 cm	H_{BOX}/DP_2=26.4	S/DP_2=10
DP_3=1.00 cm	H_{BOX}/DP_3=13.2	S/DP_3=5

?

WAVE TESTS

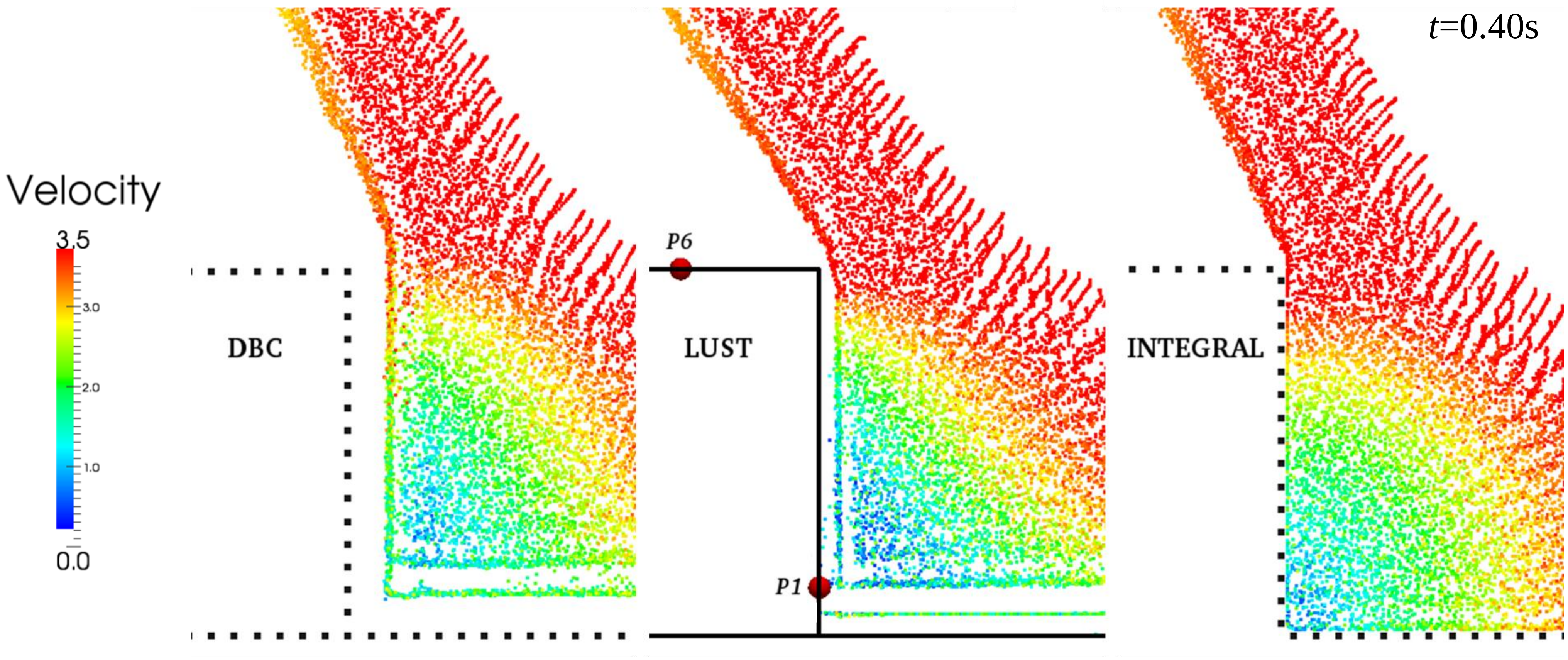
DP_3=1.00 cm	
H_{BOX}=13.2 cm	H_{WAVE}=12 cm
H_{BOX}/DP_3=13.2	H_{WAVE}/DP_3=12

DBC leads to a GAP Fluid-Boundary = 1.2*h-1.3*h

DUALSPHYSICS CODE

Domínguez et al. SPHERIC 2015
SPHERIC Benchmark Test Case #2

DYNAMIC BOUNDARY CONDITIONS



GAP *1.23·h* *0.5·h* *0·h*

Fluid-Boundary

HEAVE DECAY TESTS

	H_{BOX}=13.2 cm	Shift=5 cm
DP_1=0.25 cm	H_{BOX}/DP_1=52.8	S/DP_1=20
DP_2=0.50 cm	H_{BOX}/DP_2=26.4	S/DP_2=10
DP_3=1.00 cm	H_{BOX}/DP_3=13.2	S/DP_3=5

?

WAVE TESTS

DP_3=1.00 cm

H_{BOX}=13.2 cm	H_{WAVE}=12 cm
H_{BOX}/DP_3=13.2	H_{WAVE}/DP_3=12

DBC leads to a GAP Fluid-Boundary = 1.2*h-1.3*h

GAP has an important effect when solving

CONTINUITY EQUATION $\frac{d\rho}{dt}$ with low resolution

It is necessary to increase the spatial resolution when solving **density driven phenomena** with DBC

HEAVE DECAY TESTS

	H_{BOX}=13.2 cm	Shift=5 cm
DP_1=0.25 cm	H_{BOX}/DP_1=52.8	S/DP_1=20
DP_2=0.50 cm	H_{BOX}/DP_2=26.4	S/DP_2=10
DP_3=1.00 cm	H_{BOX}/DP_3=13.2	S/DP_3=5

?

WAVE TESTS

DP_3=1.00 cm

H_{BOX}=13.2 cm	H_{WAVE}=12 cm
H_{BOX}/DP_3=13.2	H_{WAVE}/DP_3=12

Higher resolution implies higher accuracy because:

i) the smoothing length is reduced, thus the gap (1.3*h) is reduced,

ii) the number of particles of the floating interacting with surrounding fluid particles increases

DUALSPHYSICS CODE

Numerical simulation of FLOATING MOORED DEVICES needs:

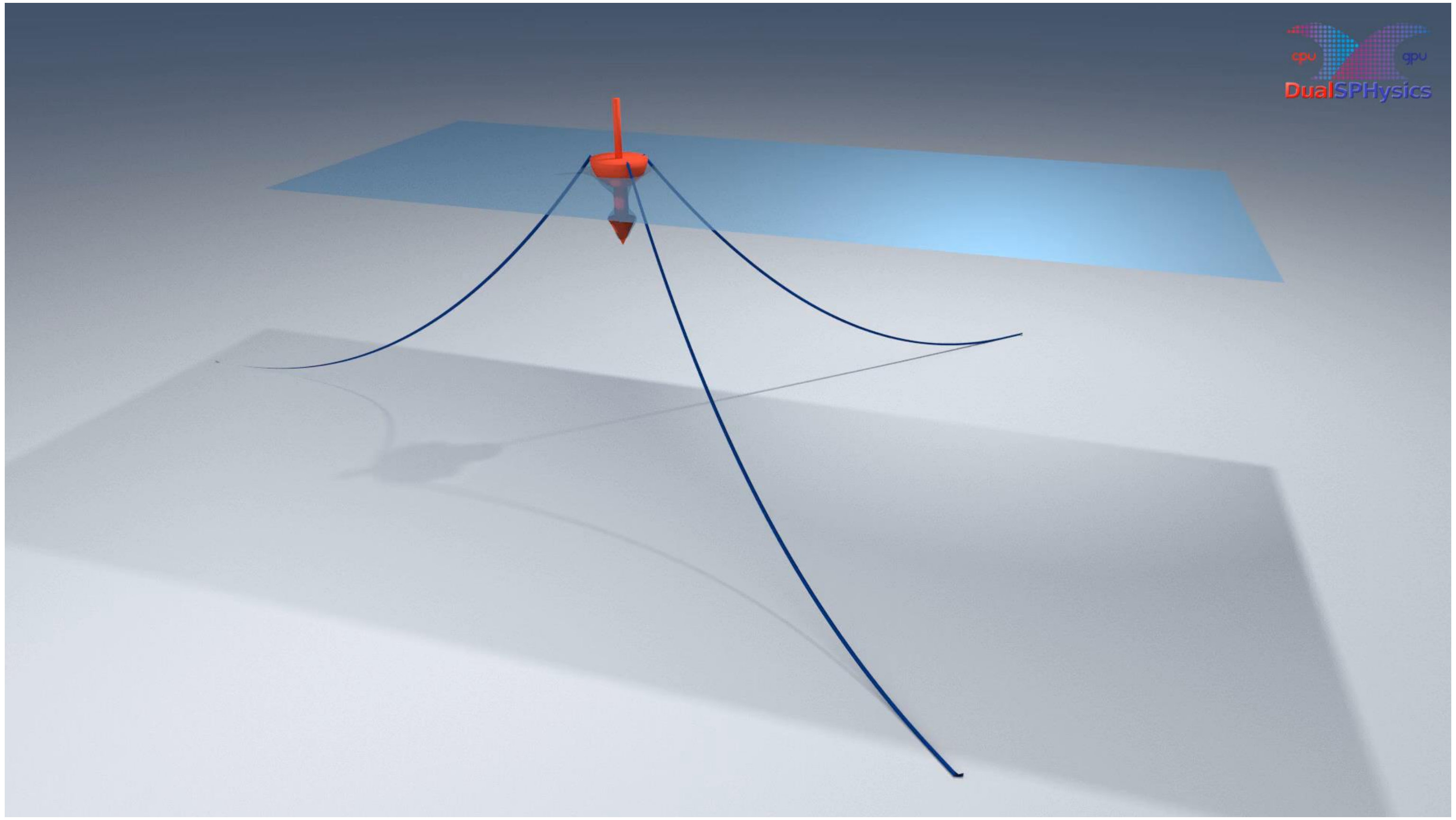
- **Wave generation, wave propagation and wave absorption** ✓
- **Interaction between waves and fixed structures** ✓
- **Interaction between waves and floating structures** ✓
- **Interaction between waves and floating moored structures** ✓

CONCLUSIONS

DualSPHysics code can be then employed to simulate more complex floating devices such as:

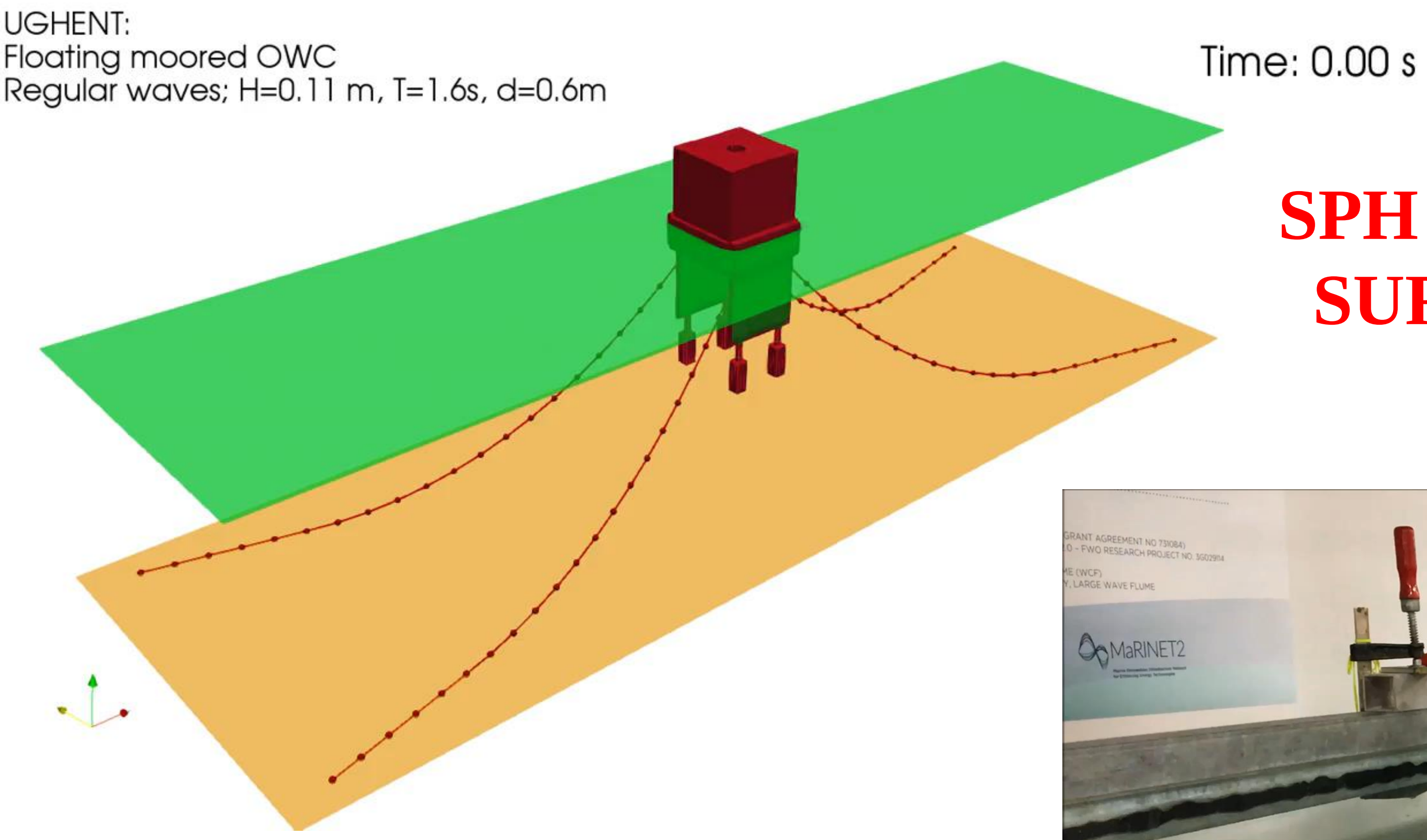
- marine wind turbines
- buoys and measurement devices
- floating WECs
- offshore platforms …

SPH is ideal to study SURVIVABILITY

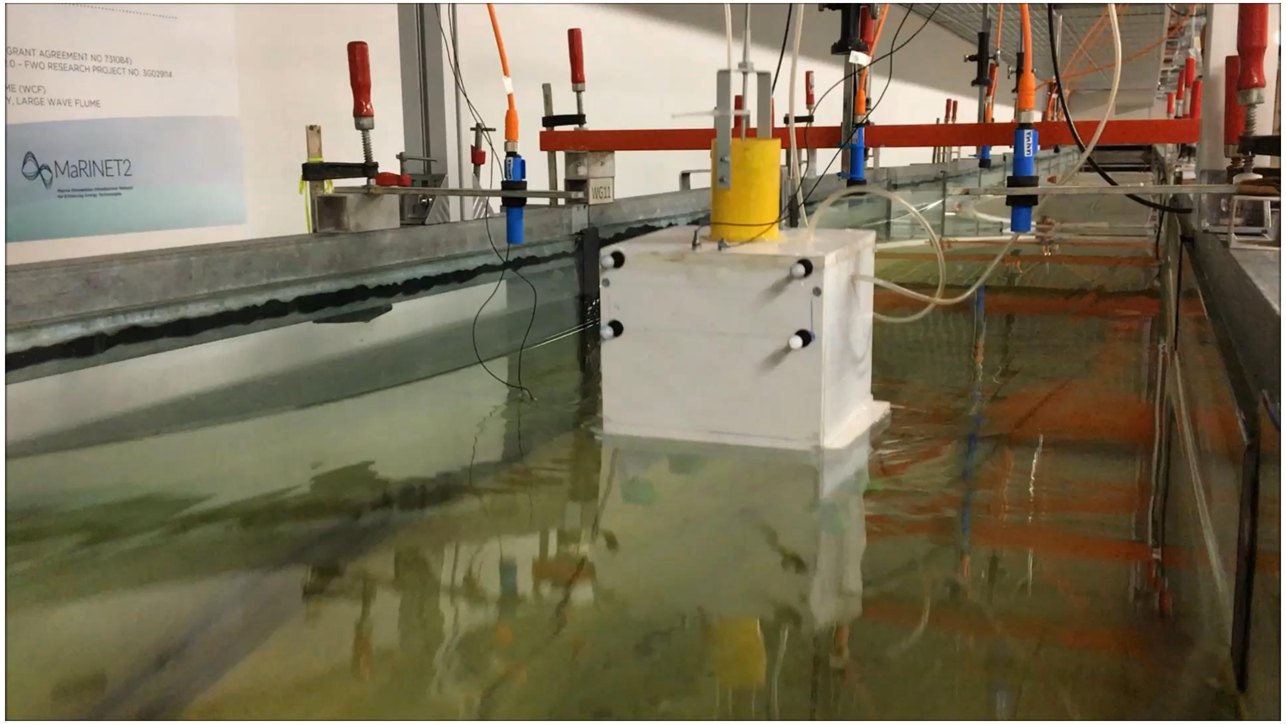


CONCLUSIONS

Floating Oscillating Water Column Wave Energy Converter

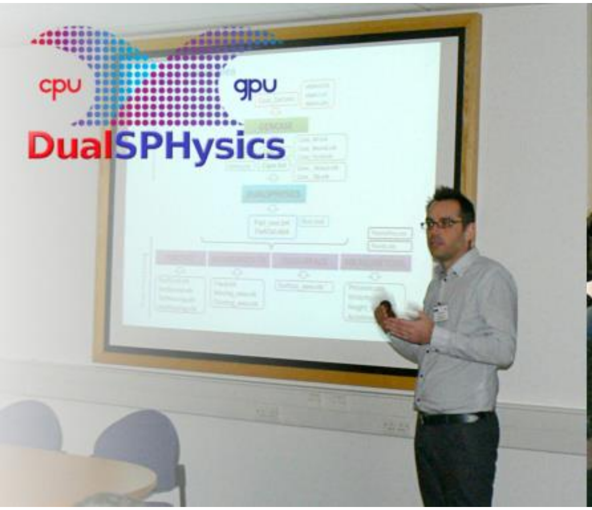


SPH is ideal to study SURVIVABILITY



MaRINET2

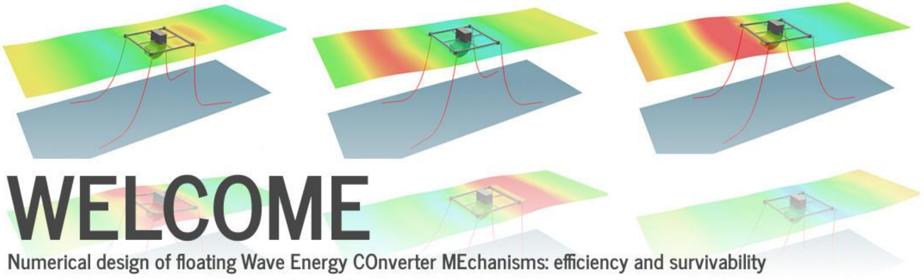
DualSPHysics Users Workshop

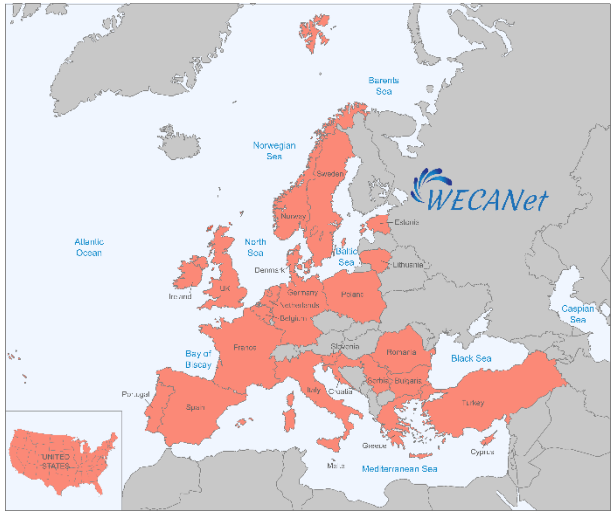


1st DualSPHysics Users Workshop, University of Manchester, U.K., 8-9 September 2015
2nd DualSPHysics Users Workshop, University of Manchester, U.K., 6-7 December 2016
3rd DualSPHysics Users Workshop, University of Parma, Italy, 13-15 November 2017
4th DualSPHysics Users Workshop, IST, University of Lisbon, Portugal 22-24 October 2018

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