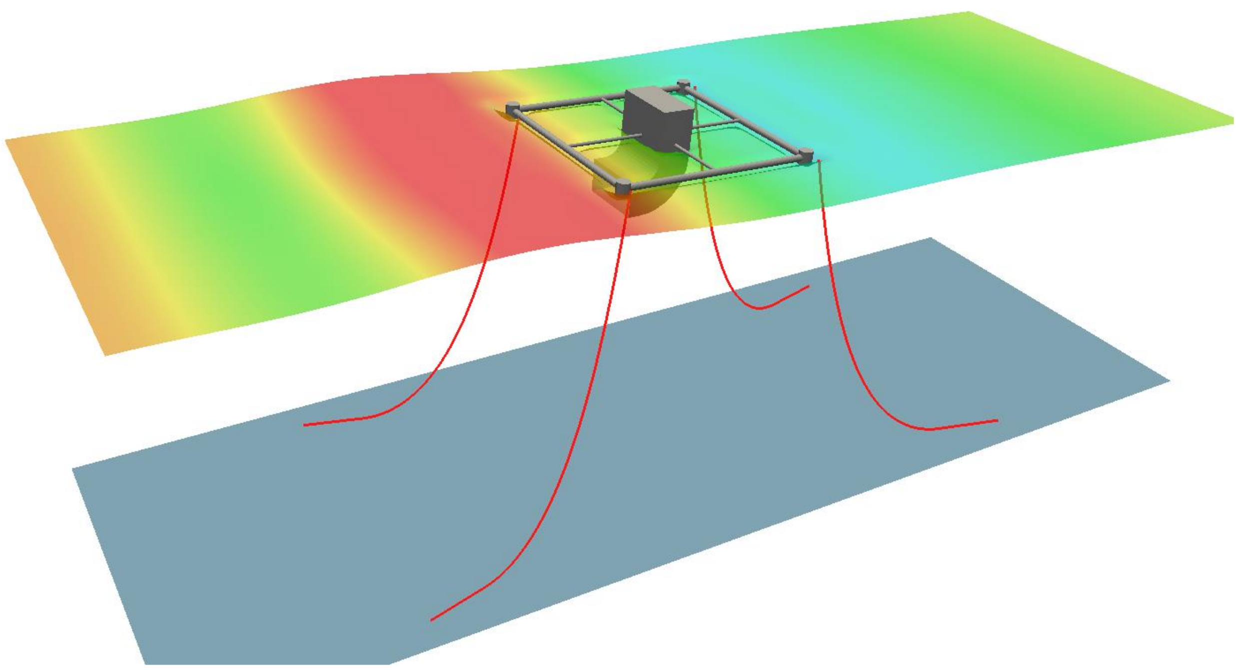
Oscillating Water Column modelling with a SPH model



A.J.C. Crespo, J.M. Domínguez, C. Altomare,
A. Barreiro, M. Gómez-Gesteira

OUTLINE

Oscillating Water Column

- What OWC is?
- Numerical modelling of OWC

SPH functionalities

- Wave generation (1st order & 2nd order)
- Wave active absorption AWAS
- Fluid-driven objects
- Mooring lines

OWC Validation

- Wave decay test
- IH Cantabria experiment

Cases of study

- Onshore OWC in Mutriku (Spain)
- Offshore OWC in the open sea

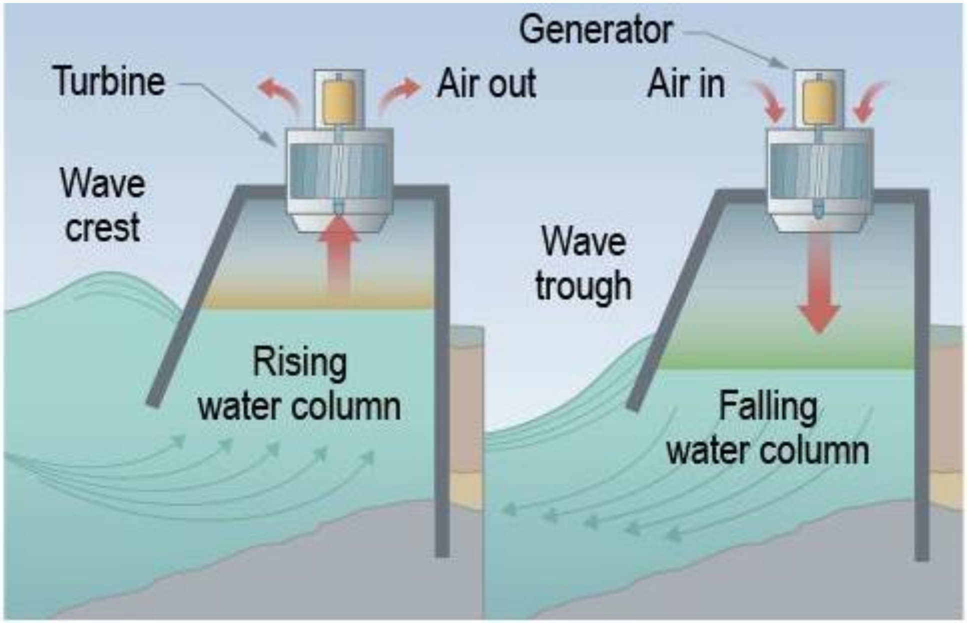
Conclusions and future work

OSCILLATING WATER COLUMN

OWC IN YouTube

- **Animation of how it works:** https://youtu.be/gcStpg3i5V8
- **Funny home-made experiment:** https://youtu.be/mVQ3ZTli_Hs
- **CFD of fixed OWC:** https://youtu.be/B_nZj3uwaRY
- **CFD of floating OWC:** https://youtu.be/aw72cklXx7w
- **SPH of floating OWC:** https://youtu.be/Lyt1GMlDauQ

OSCILLATING WATER COLUMN



http://en.openei.org/

FULL-SCALE PROTOTYPES:

ONSHORE

-**LIMPET** plant near the Scottish island of Islay with a total installed capacity of 500KW

-**PICO** plant in Azores for a power of 400 KW

-**MUTRIKU** plant in País Vasco with 16 x 15.8 kw = 256 KW – 300 KW

(consumption of 1000 population in 1 year)

OFFSHORE

-**OE Buoy** developed by Ocean Energy company (Ireland) is a floating OWC

OSCILLATING WATER COLUMN

NUMERICAL MODELLING

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

TIME CONSUMING
VIOLENT FLOWS

CFD models
Approximate Navier–Stokes

Meshbased methods

VOF

Meshless methods

SPH

OSCILLATING WATER COLUMN

NUMERICAL MODELLING

A) Linear approach (time of frequency domain models)

Simplified hydrodynamic models based on the Cummins equation and linearized hydrodynamic coefficients.
Boundary Element Method (BEM) to compute the added mass, damping coefficients, so that, the movement of the floating body (heave, pitch and roll).

DRAWBACKS:
- Flow is considered inviscid, incompressible, and irrotational.
- Assumption of linear behaviour: we can not model devices in extreme conditions, so wave breaking and overtopping can not be studied.
- Wave height is small compared to the wavelength and water depth (low amplitude).
- Only strictly valid for small oscillations around the mean resting position.

SOFTWARE: *WEC-Sim, Nemoh, WAMIT*

OSCILLATING WATER COLUMN

NUMERICAL MODELLING

B) CFD models that approximate Navier–Stokes equations are widely accepted as being the best way of solving the dynamics involved in WEC analysis.
Present several advantages, not only for solving the velocity field on the whole domain but also for overcoming the limitations of non-linearity so viscous and violent flows can now be simulated.

MESHBASED SOFTWARE:
Volume Of Fluid, OpenFoam / IH-Foam, FLUENT / FLUINCO, REEF3D, STAR-CCM+
These models were used to model OWC (wave interaction and air-jet impinging),
but mainly with fixed detached OWC!

Eulerian methods usually require expensive mesh generation and have severe technical challenges associated with the nonlinearities with rapidly moving geometries

Why SPH

Advantages comparing with other mesh-based CFD codes:

(i) 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

(ii) Handling complex boundary evolution

(iii) Distinguishing between phases due to holding material properties at each individual particle

(iv) Natural incorporation of coefficient discontinuities and singular forces into the numerical scheme

(v) Natural incorporation of derivative instead of the field properties' derivatives into the scheme

(vi) Capable of being coupled with other mesh dependent and meshless techniques

OSCILLATING WATER COLUMN

NUMERICAL MODELLING

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but mainly with fixed detached OWC!

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MESHLESS SOFTWARE:
DualSPHysics to simulate not only fixed detached OWC but **also floating OWC** devices!

OSCILLATING WATER COLUMN

NUMERICAL MODELLING

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

TIME CONSUMING
VIOLENT FLOWS

CFD models
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Meshbased methods

VOF

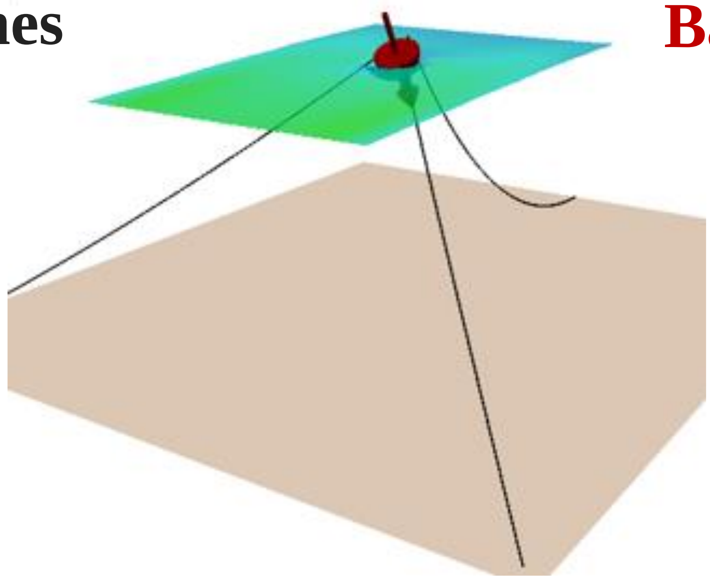
Meshless methods

SPH

SPH TO SIMULATE OWC

NEW SPH FUNCTIONALITIES

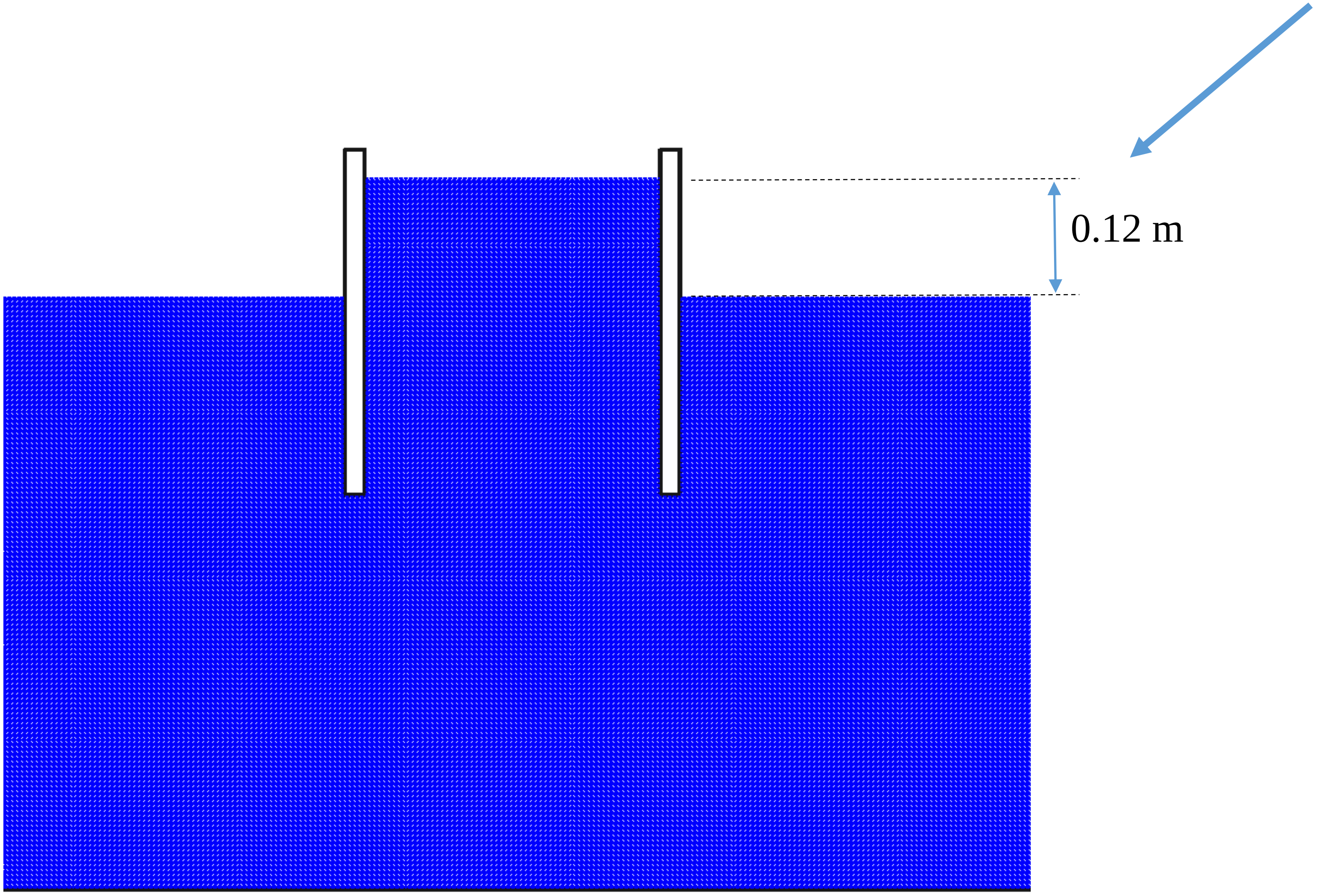
- Wave generation (1st & 2nd order)
- Wave active absorption AWAS — Altomare et al., 2015
- Fluid-driven objects — Canelas et al., 2015
- Mooring lines — Barreiro et al., 2015



OWC VALIDATION

WAVE DECAY TEST

Initial elevation inside the open chamber=0.12 m



OWC VALIDATION

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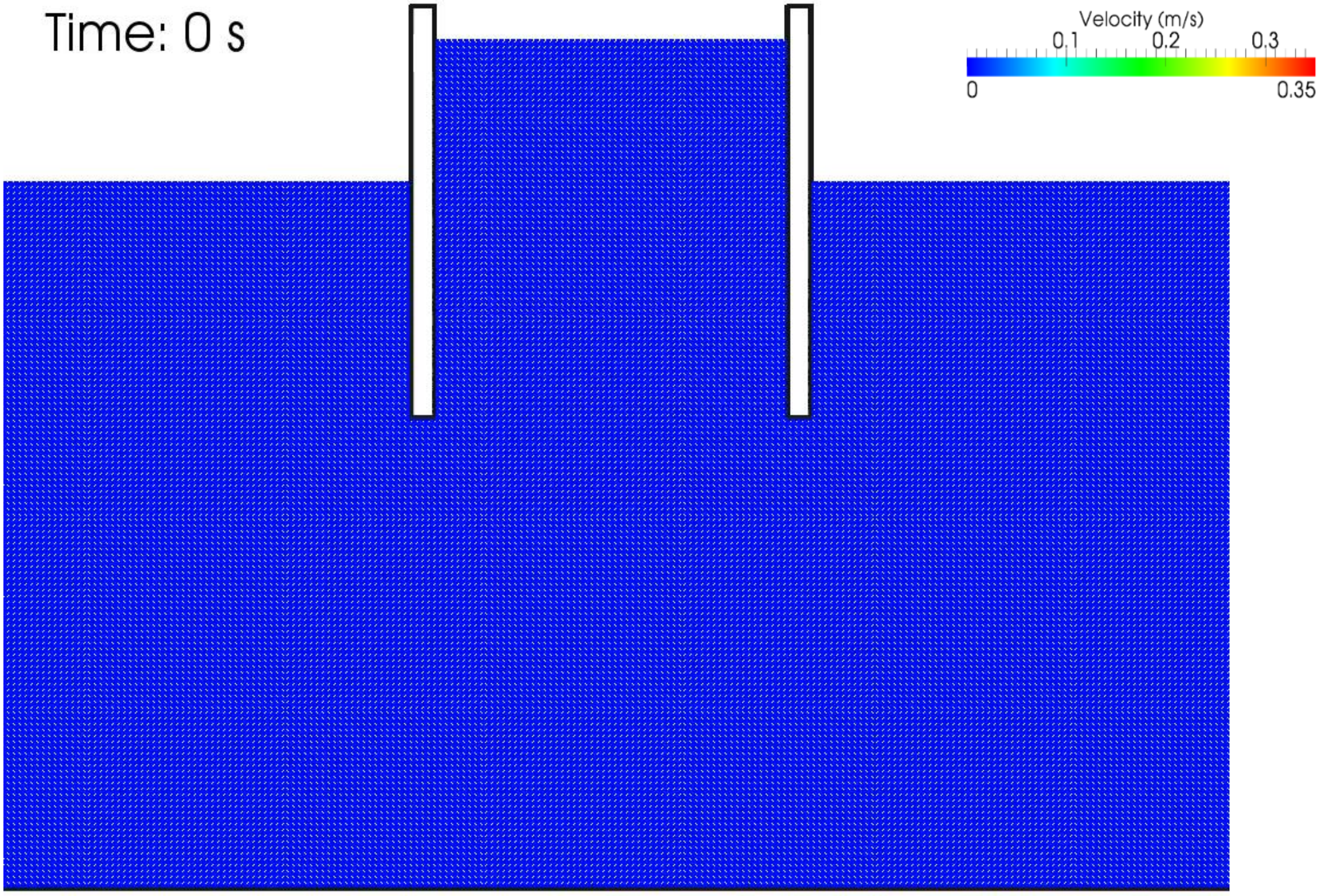

OWC VALIDATION

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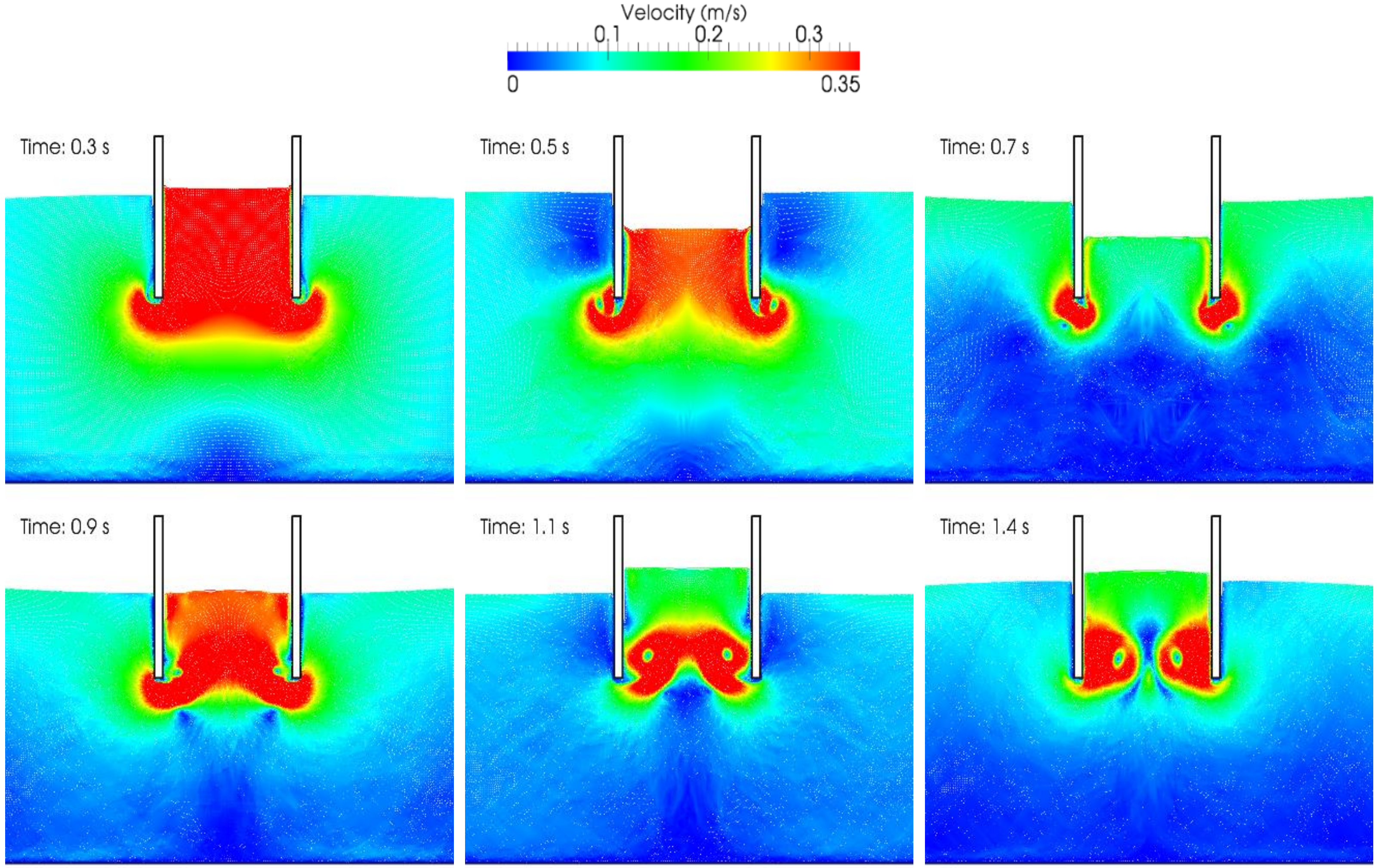
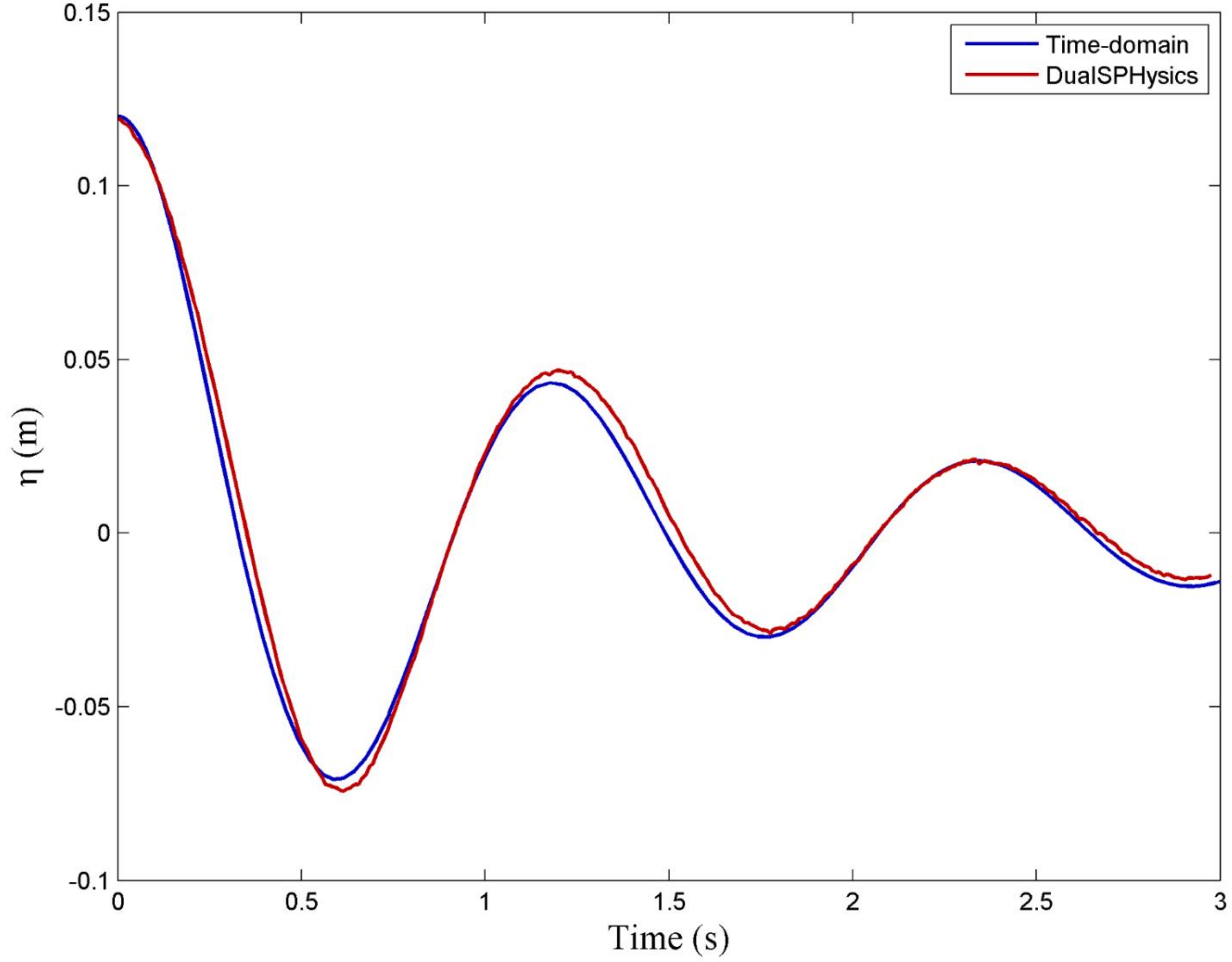


OWC VALIDATION

WAVE DECAY TEST

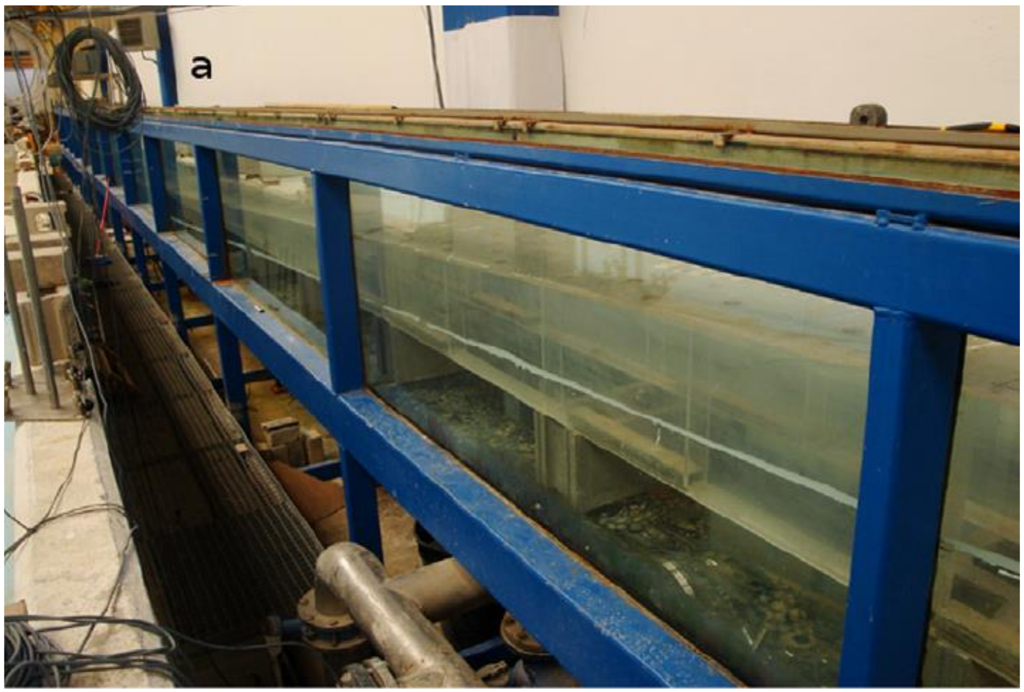


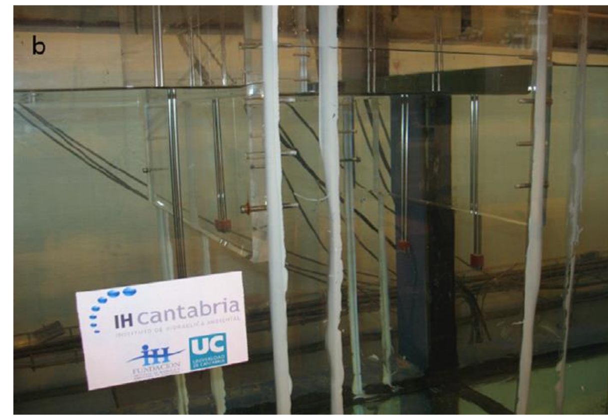
Elevation inside the chamber: Time-domain vs DualSPHysics

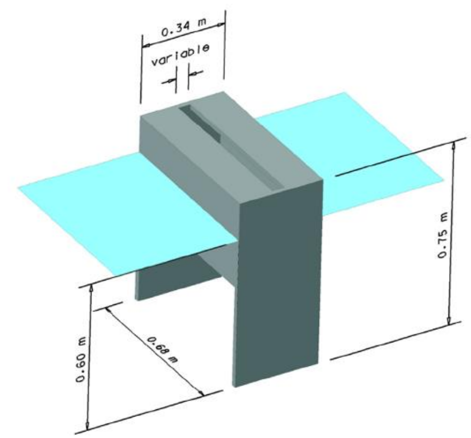
OWC VALIDATION

EXPERIMENT IN IH-CANTABRIA

The experiment (scale of 1/30) was carried out in the IH-Cantabria: Laboratory wave flume (left) and chamber model (right).





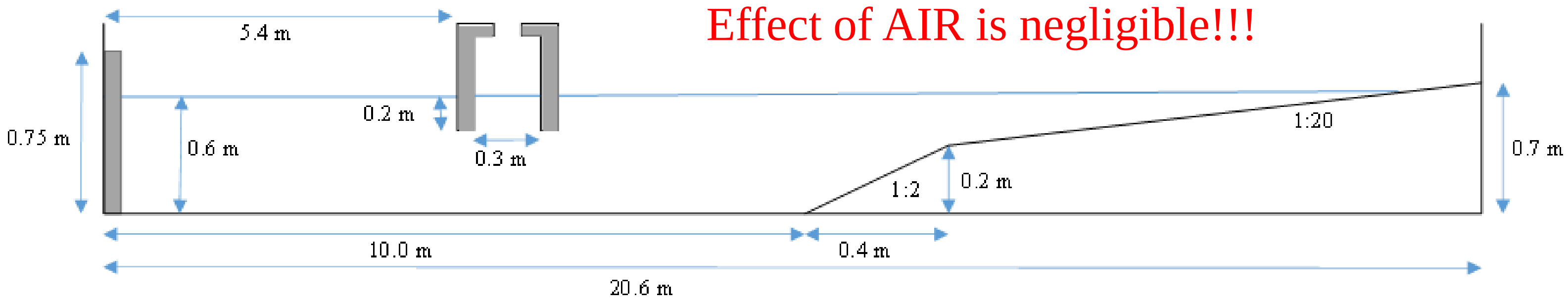


Iturrioz, A., Guanche, R., Armesto, J.A., Alves, M.A., Vidal, C., Losada, I.J. 2014. Time-domain modeling of a fixed detached oscillating water column towards a floating multi-chamber device, Ocean Engineering, 76, 65-74.

OWC VALIDATION

EXPERIMENT IN IH-CANTABRIA

The experiment (scale of 1/30) was carried out in the IH-Cantabria wave flume.
The tank is 20.60 m long and the water depth was of 0.60 m.
A dissipative beach appeared at the end of the flume to avoid reflection.



Effect of AIR is negligible!!!

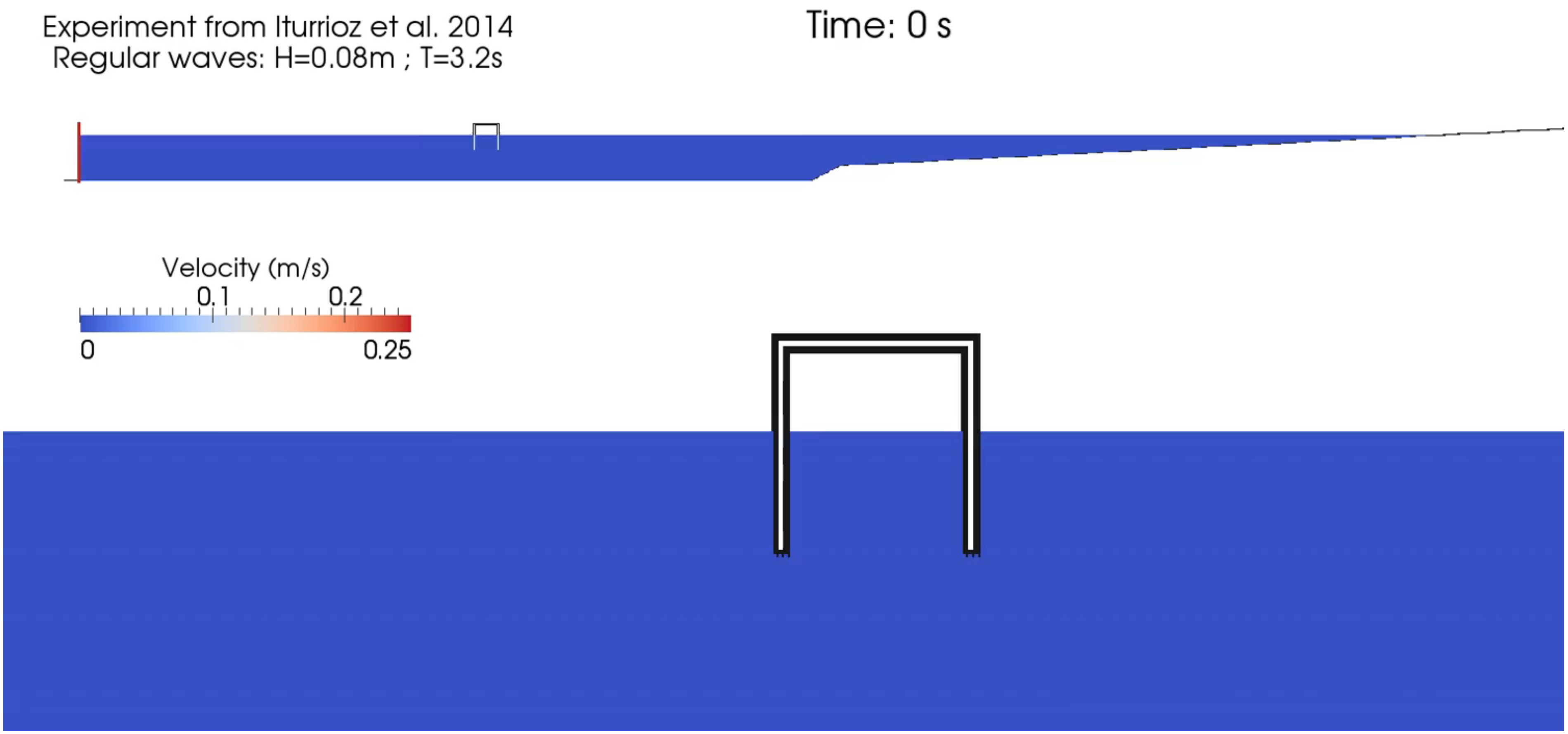
Wave conditions of the 2 experiments in Iturrioz et al. (2014)

	Height (H)	Period (T)	Depth (d)	Wavelength (L)	Relative depth (d/L)	Wave order
Test 31	0.08 m	3.2 s	0.6 m	7.46 m	0.08	Linear wave theory
Test 32	0.08 m	1.1 s	0.6 m	1.83 m	0.33	Stokes 2nd order

Iturrioz, A., Guanche, R., Armesto, J.A., Alves, M.A., Vidal, C., Losada, I.J. 2014. Time-domain modeling of a fixed detached oscillating water column towards a floating multi-chamber device, Ocean Engineering, 76, 65-74.

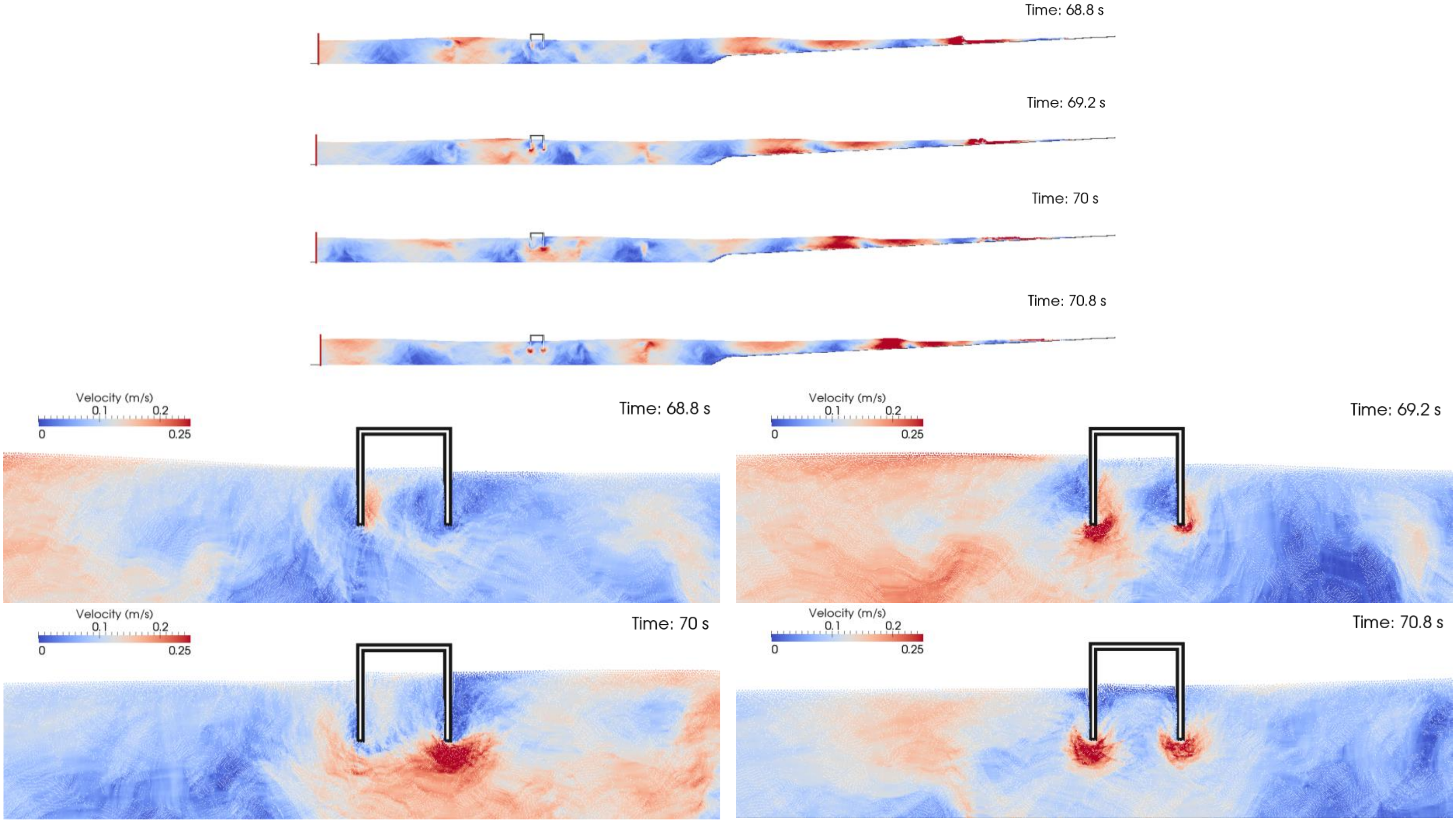
OWC VALIDATION

EXPERIMENT IN IH-CANTABRIA



OWC VALIDATION

EXPERIMENT IN IH-CANTABRIA

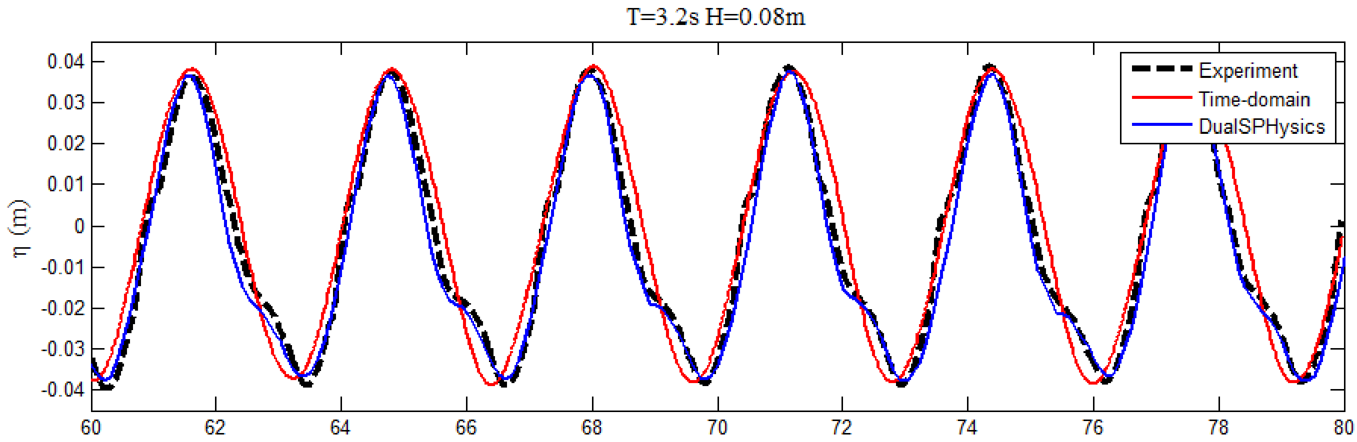


Instants of the simulation of Test31: H=0.08m, T=3.2s.

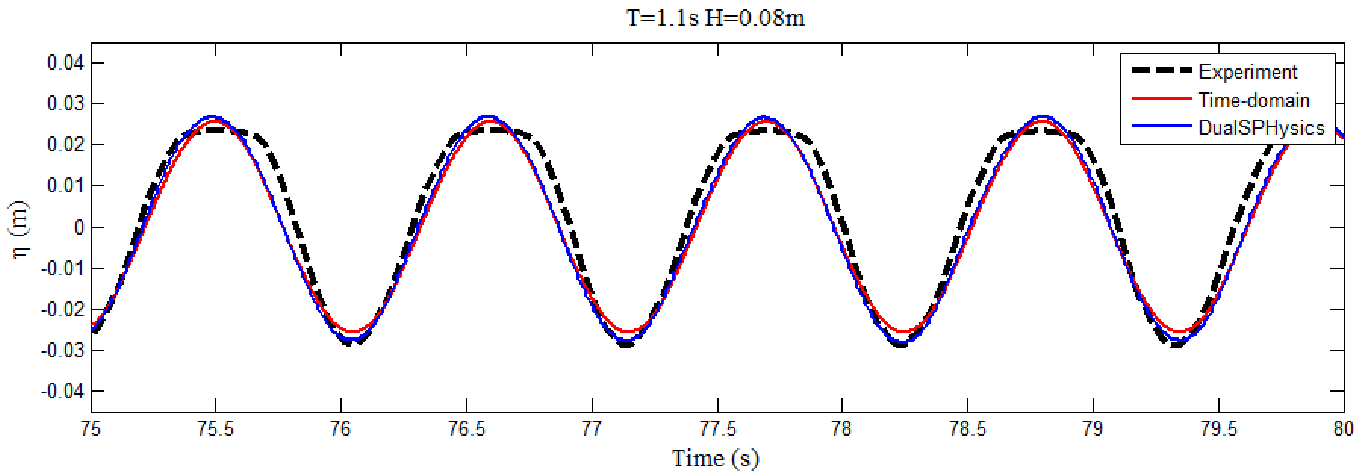
OWC VALIDATION

EXPERIMENT IN IH-CANTABRIA

1st order
T=3.2s
H=0.08m
d=0.6m
L=7.46 m



2nd order
T=1.1s
H=0.08m
d=0.6m
L=1.83 m

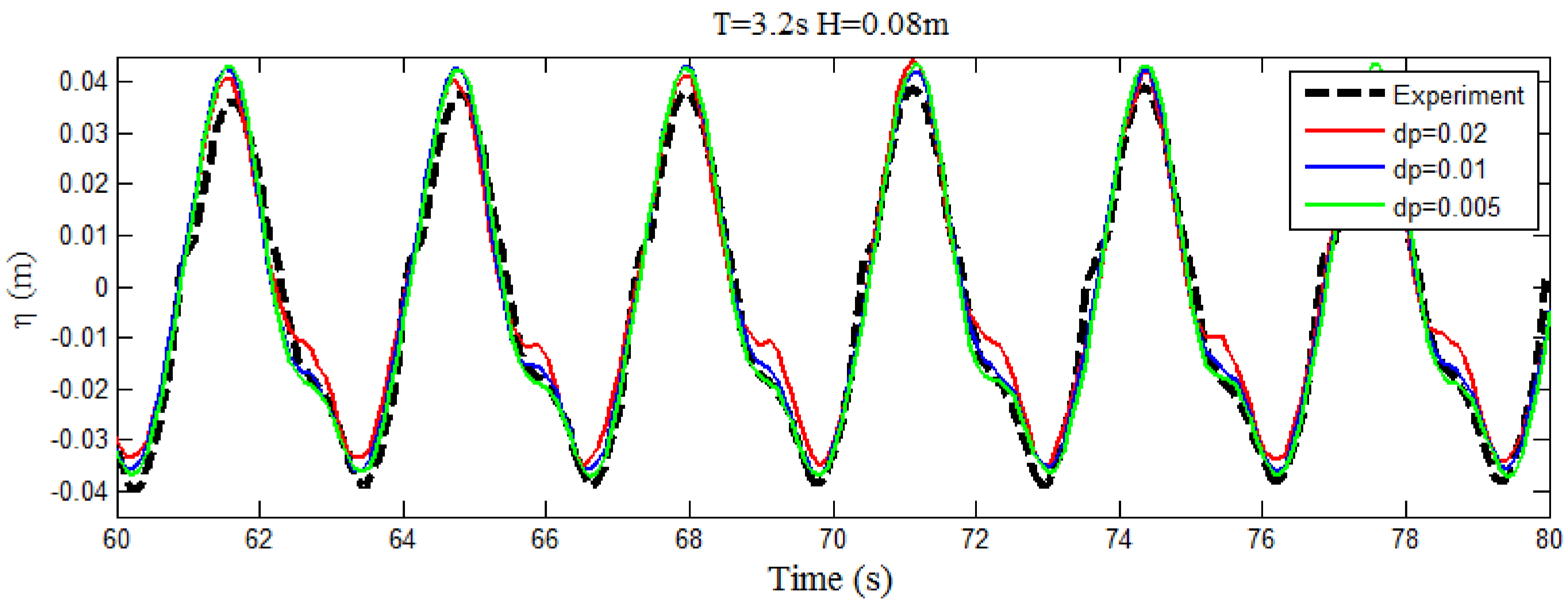


Elevation inside the chamber: **Experiment** vs Time-domain vs DualSPHysics

OWC VALIDATION

EXPERIMENT IN IH-CANTABRIA

Convergence study with different resolutions



Elevation inside the chamber: **Experiment** vs DualSPHysics

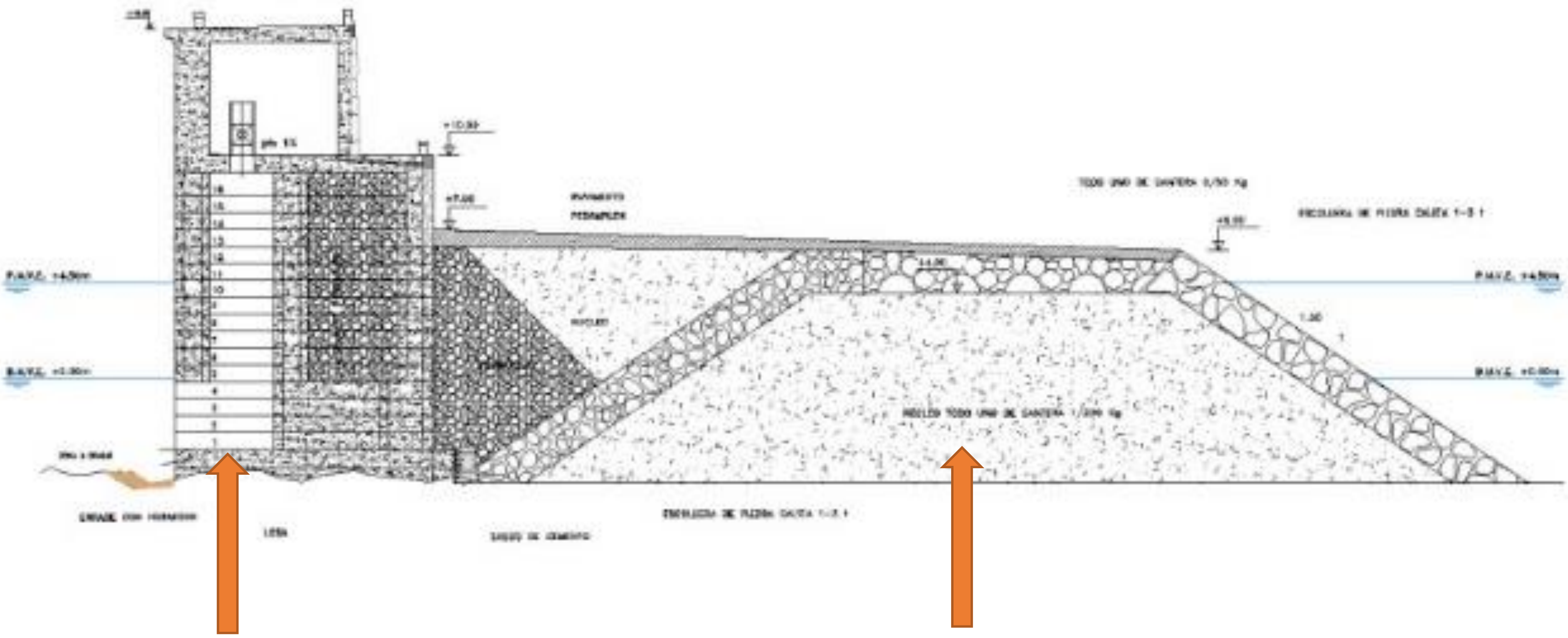
CASES OF STUDY

ONSHORE OWC IN MUTRIKU (SPAIN)

CASES OF STUDY

ONSHORE OWC IN MUTRIKU (SPAIN)

Cross section of Mutriku breakwater

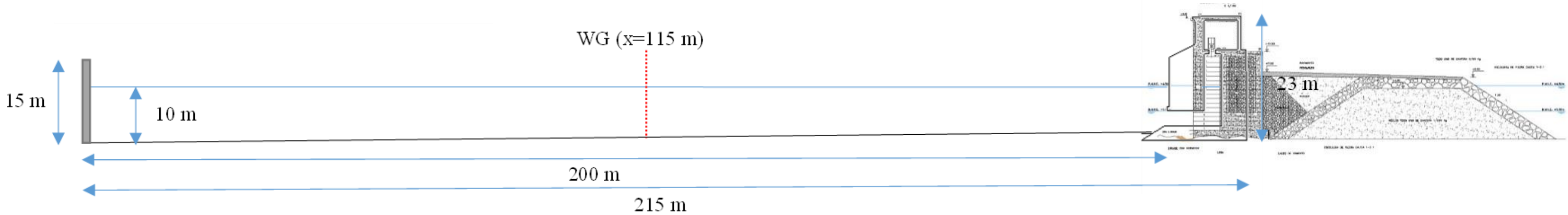


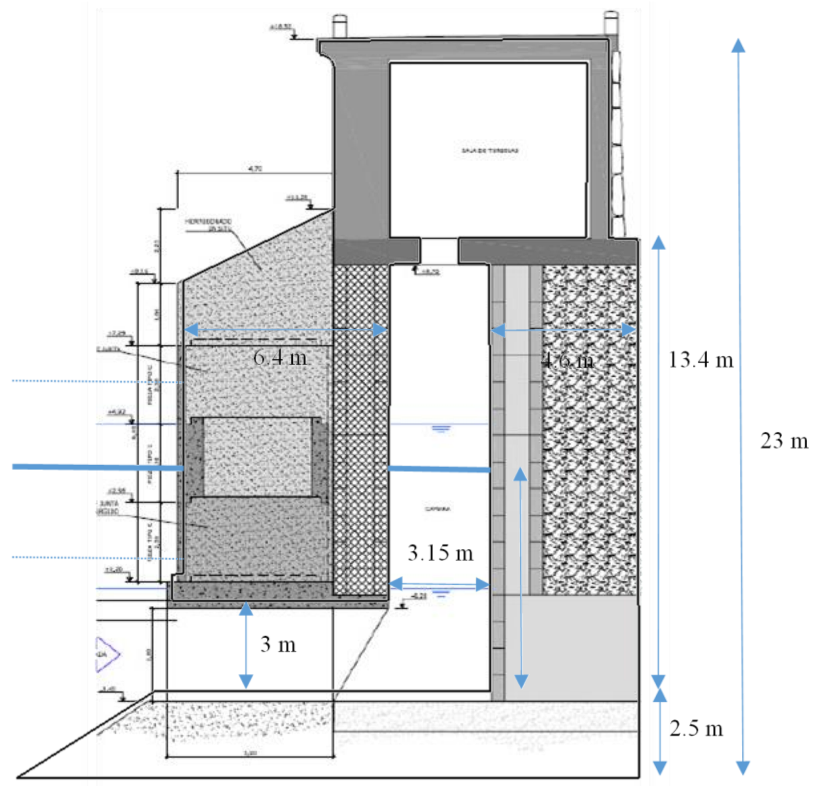
OWC CHAMBER **BREAKWATER**

CASES OF STUDY

ONSHORE OWC IN MUTRIKU (SPAIN)

Cross section of Mutriku breakwater

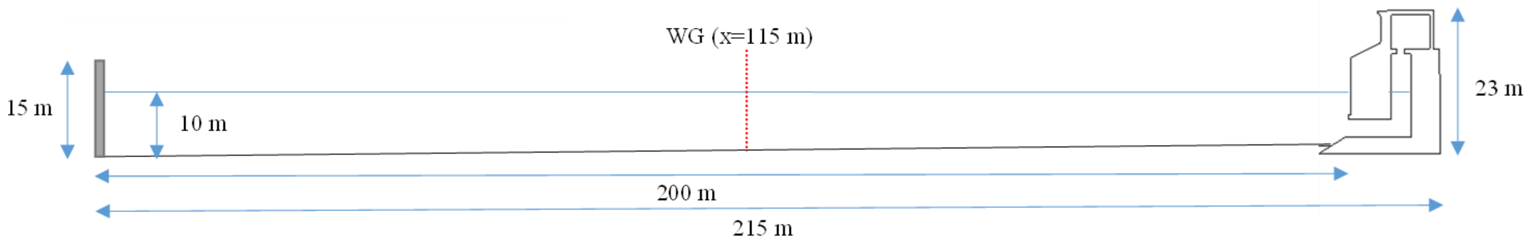


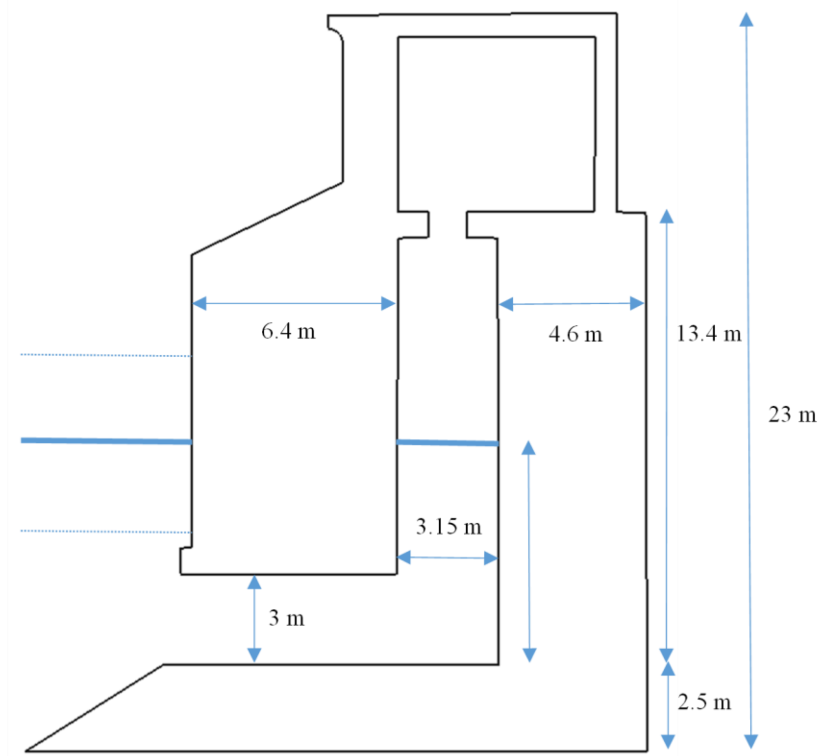


CASES OF STUDY

ONSHORE OWC IN MUTRIKU (SPAIN)

Real dimensions for DualSPHysics simulation





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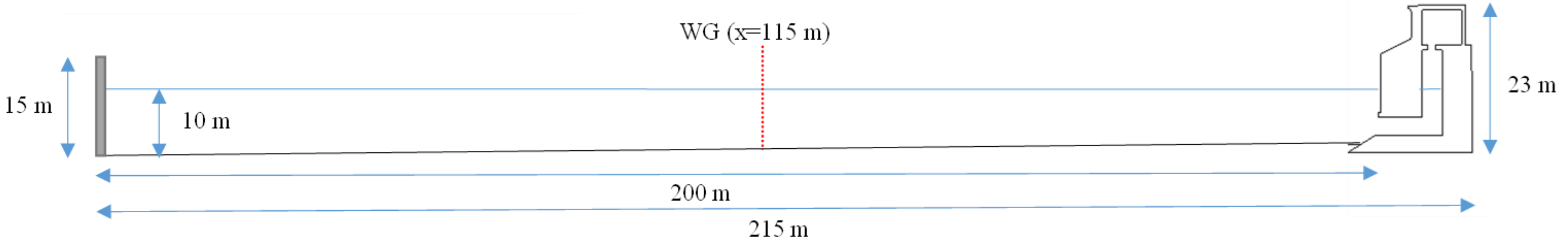


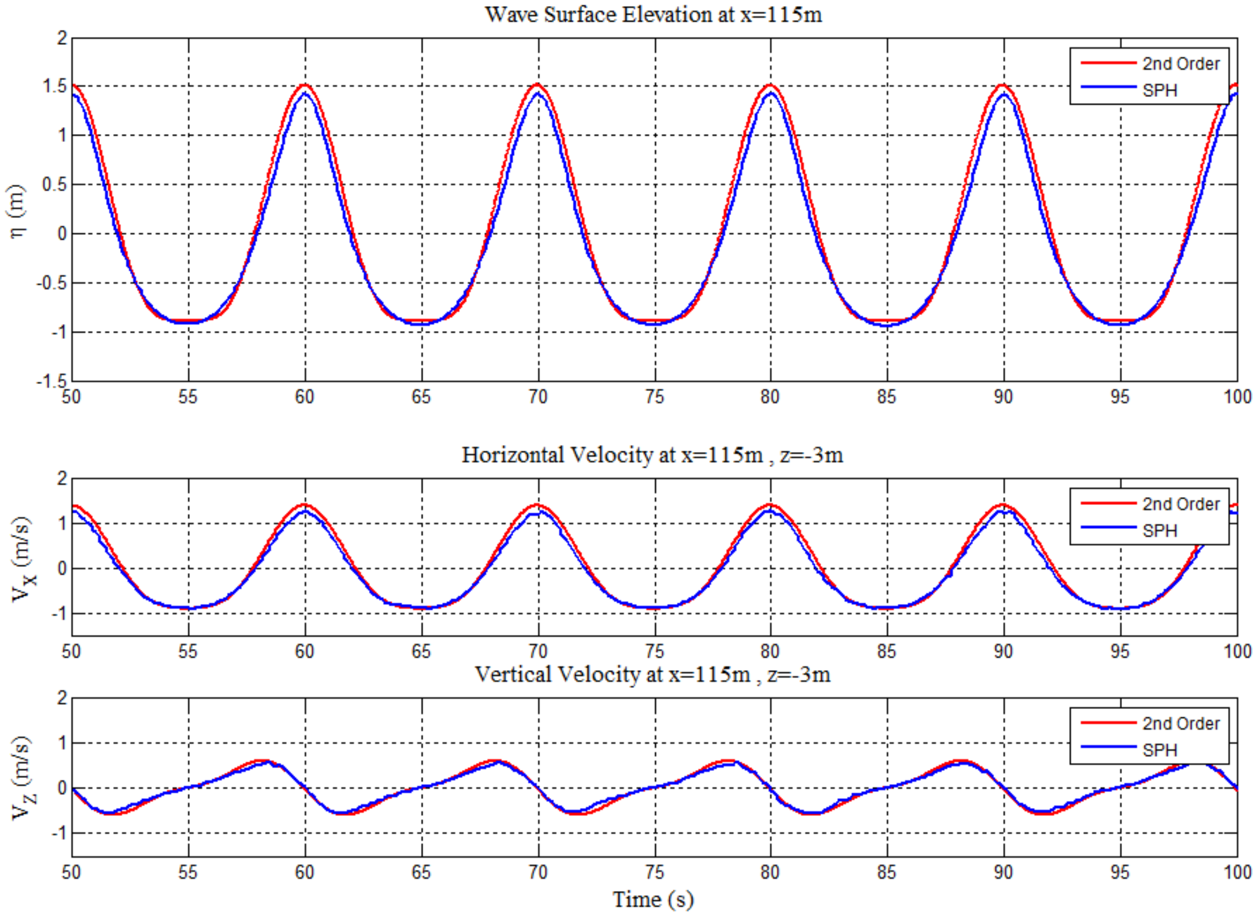
Realistic wave conditions in the Cantábrico coast

	Height (H)	Period (T)	Depth (d)	Wavelength (L)	Relative depth (d/L)	Wave order
Test 41	0.8 m	8 s	10 m	70.90 m	0.14	Linear wave theory
Test 42	0.8 m	9 s	10 m	81.73 m	0.12	Linear wave theory
Test 43	0.8 m	10 s	10 m	92.37 m	0.11	Linear wave theory
Test 44	1.6 m	10 s	10 m	92.37 m	0.11	Linear wave theory
Test 45	2.4 m	10 s	10 m	92.37 m	0.11	Stokes 2nd order
Test 46	0.8 m	10 s	7.75 m	82.64 m	0.09	Linear wave theory
Test 47	0.8 m	10 s	12.25 m	100.58 m	0.12	Linear wave theory

CASES OF STUDY

ONSHORE OWC IN MUTRIKU (SPAIN)

WAVE PROPAGATION?? Test 45: H=2.4m T=10s in a long tank without OWC

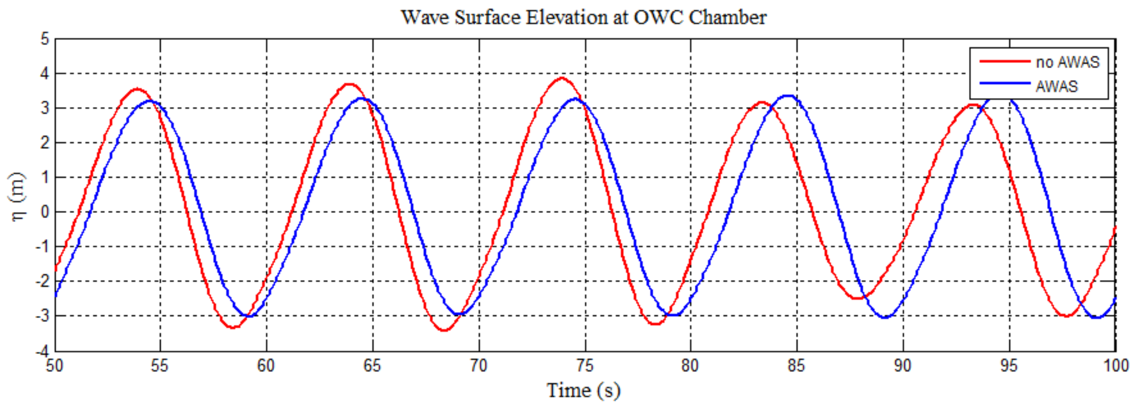


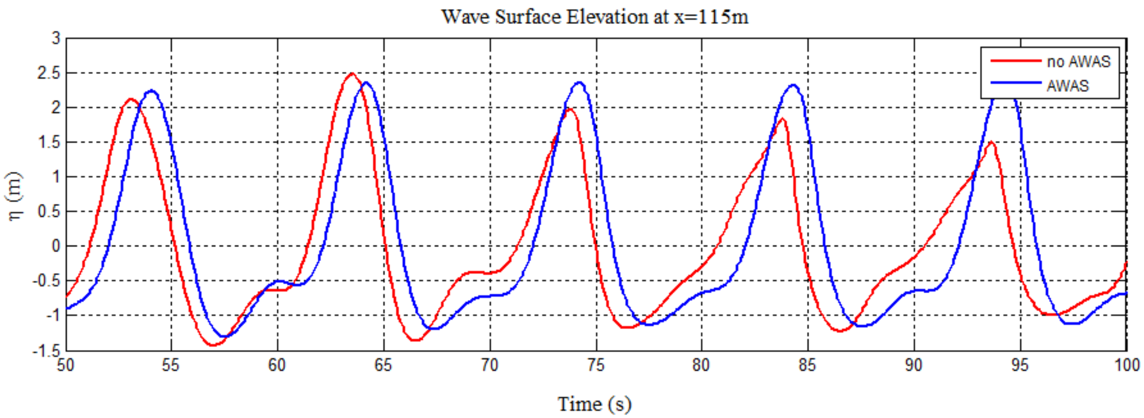
Elevation and orbital velocity: Theoretical vs DualSPHysics

CASES OF STUDY

ONSHORE OWC IN MUTRIKU (SPAIN)

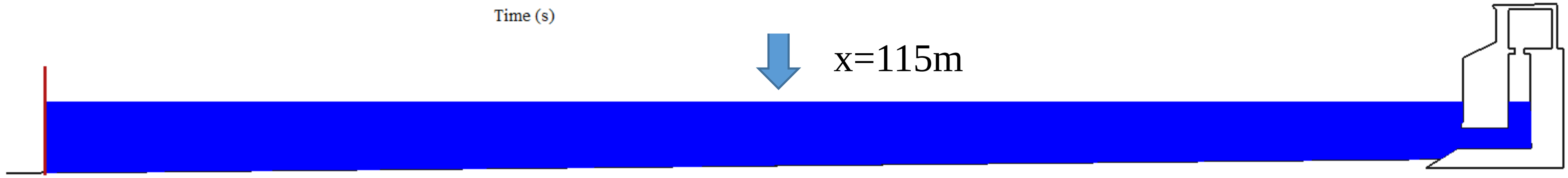
ACTIVE ABSORPTION?? Test 45: H=2.4m T=10s





OWC chamber

x=115m



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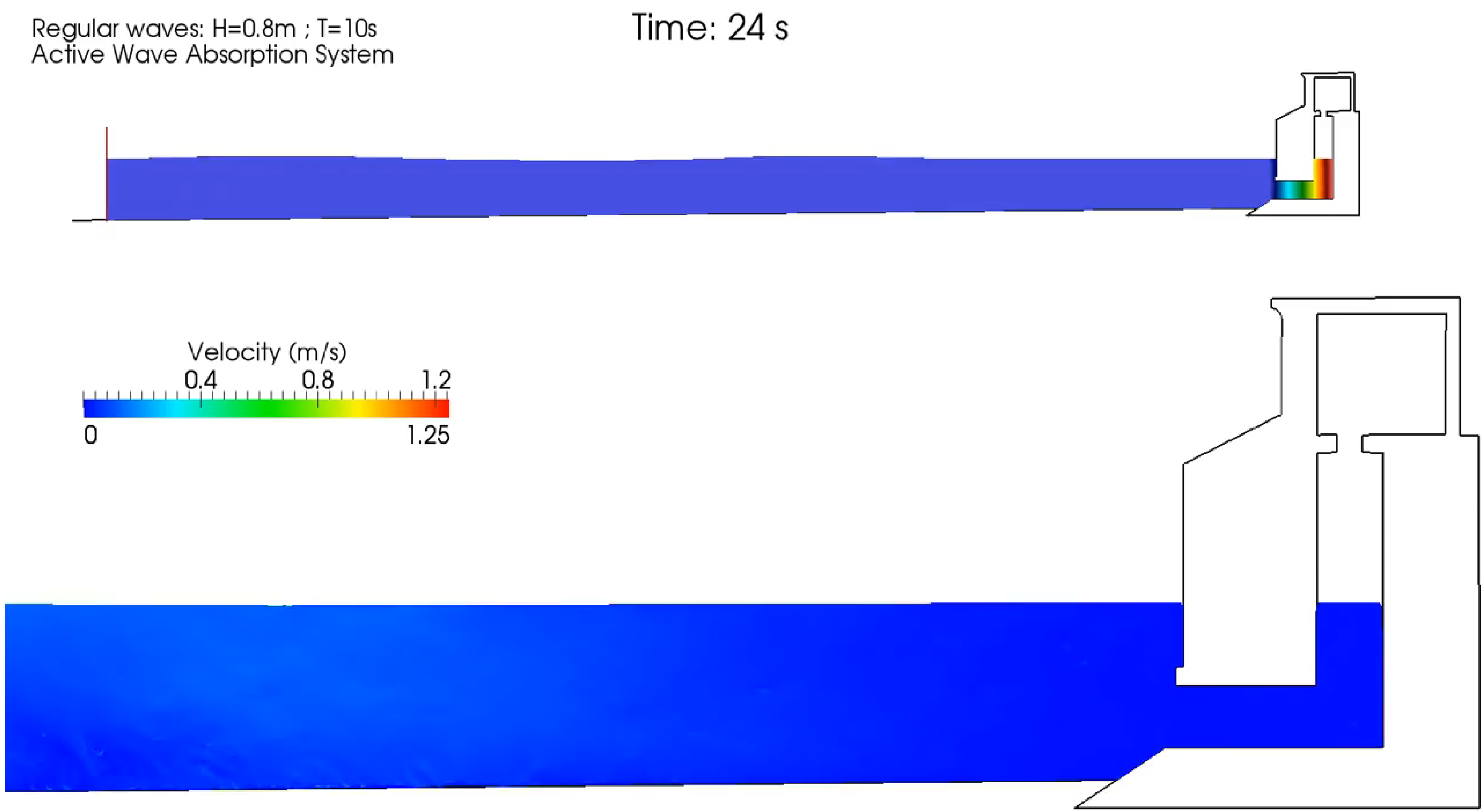

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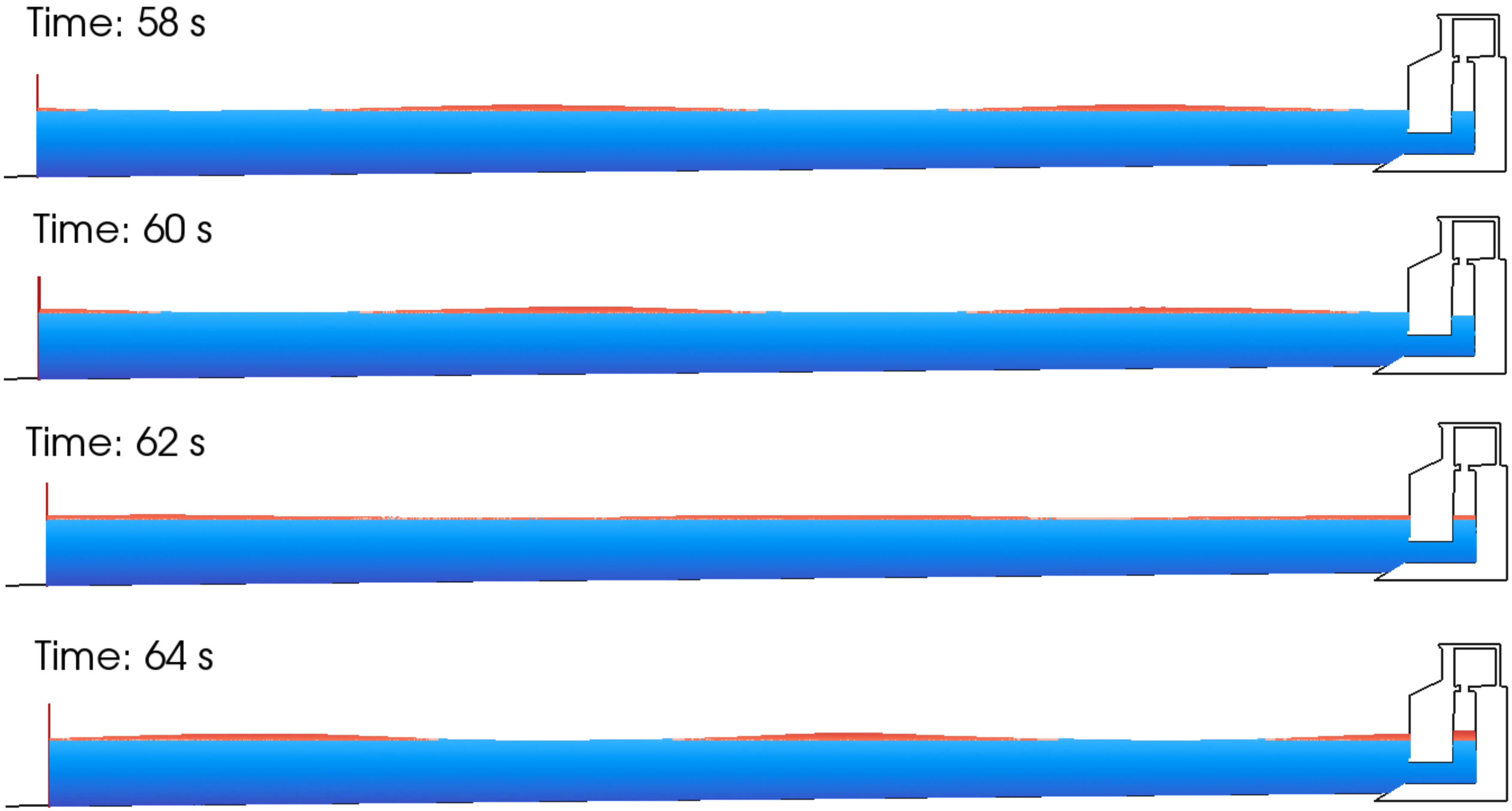
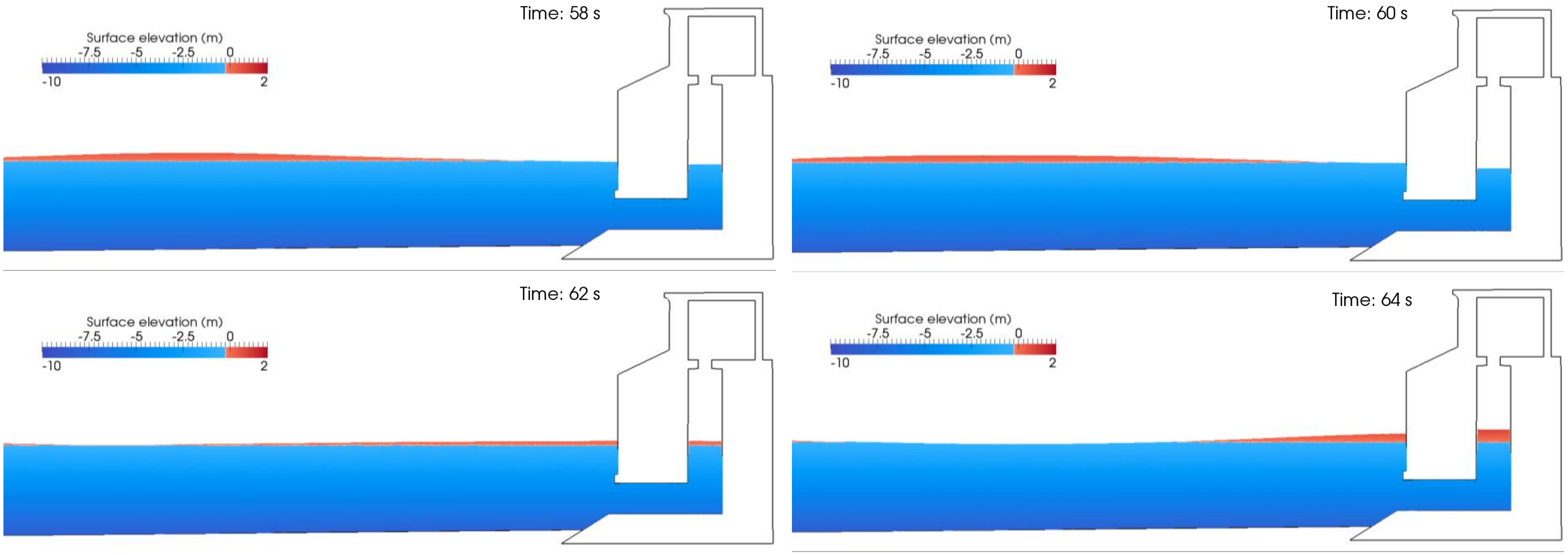
ONSHORE OWC IN MUTRIKU (SPAIN)



Instants of the simulation of Test43: H=0.8m, T=10s with AWAS

CASES OF STUDY

ONSHORE OWC IN MUTRIKU (SPAIN)



Instants of the simulation of Test43: H=0.8m, T=10s with AWAS

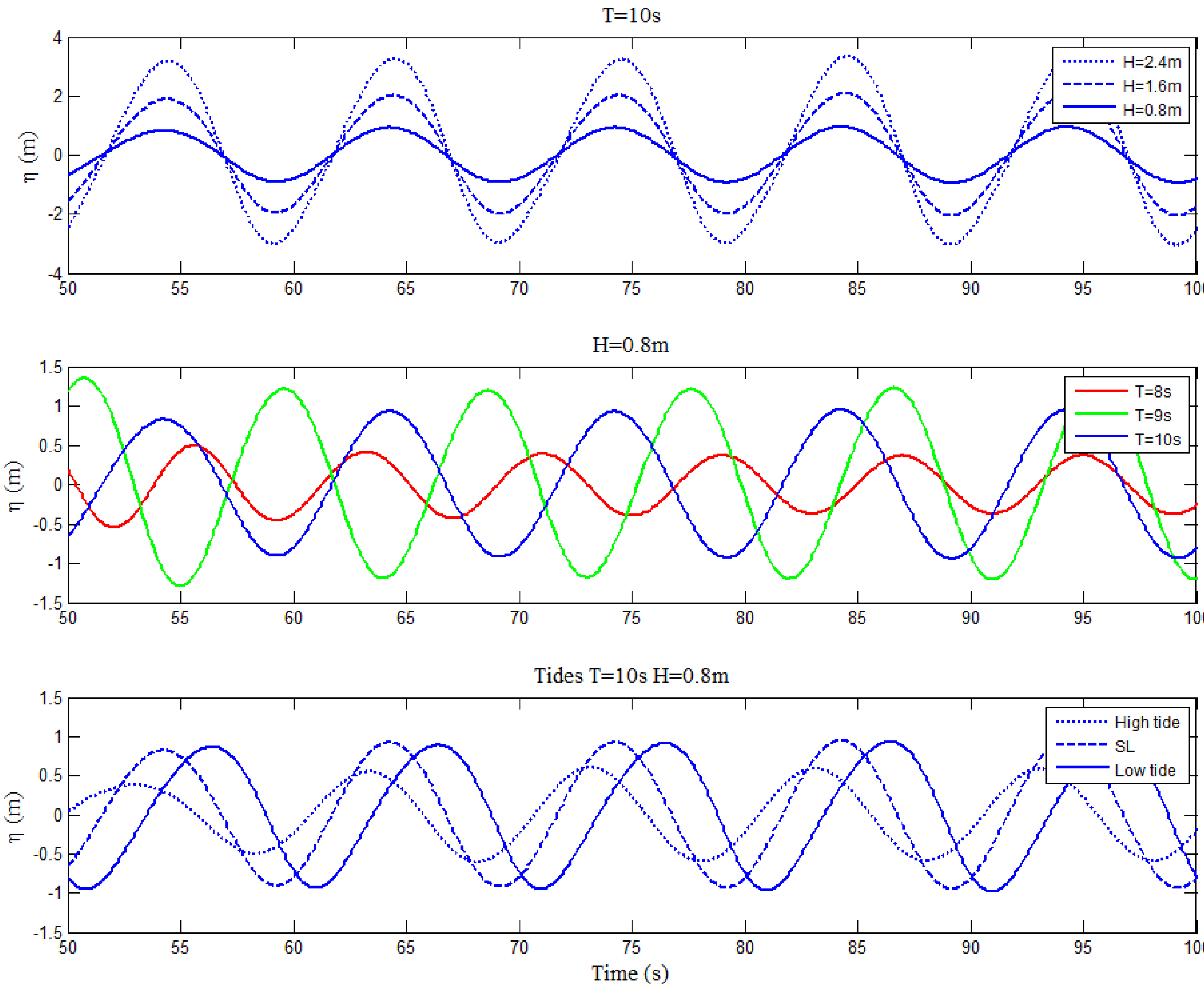
CASES OF STUDY

ONSHORE OWC IN MUTRIKU (SPAIN)

T with different H
H=0.8m T=10s
H=1.6m T=10s
H=2.4m T=10s

H with different T
H=0.8m T=8s
H=0.8m T=10s
H=0.8m T=12s

Different tides
H=0.8m T=10s
H=0.8m T=10s low
H=0.8m T=10s high

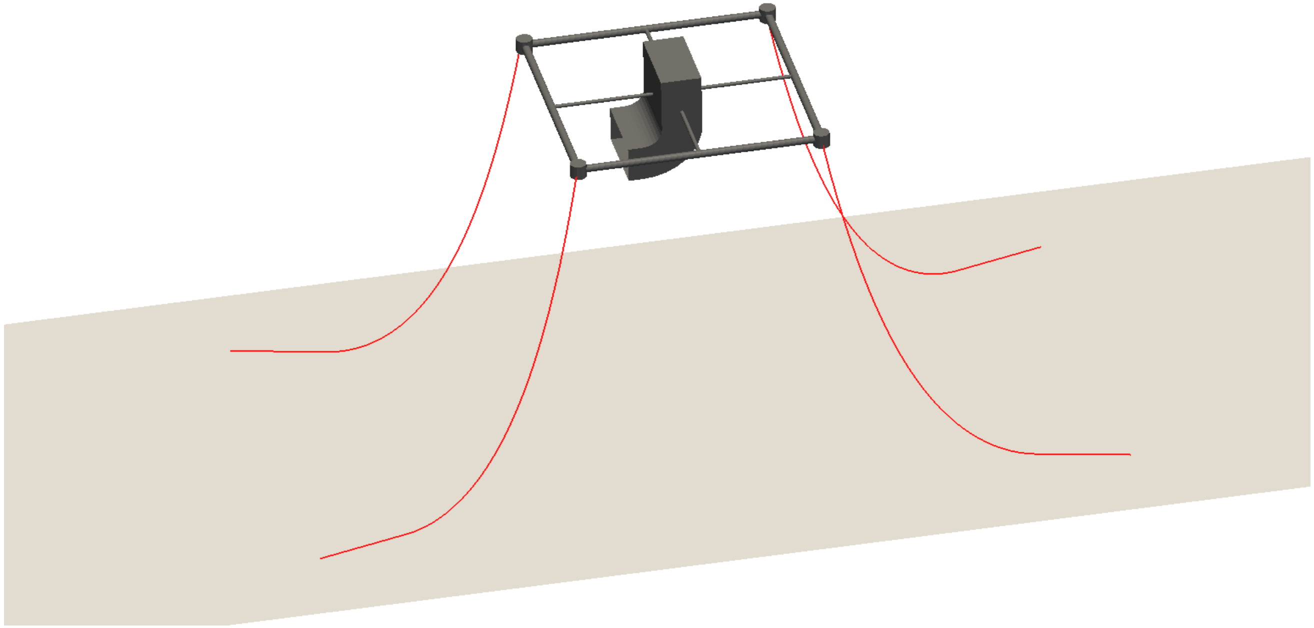


Elevation inside the Mutriku chamber

CASES OF STUDY

OFFSHORE FLOATING OWC IN THE OPEN SEA

The simulation of a floating OWC in open sea with SPH includes:
- Wave generation of regular waves with T=9s & H=1.8m.
- Passive wave absorption at the end of the tank with dissipative beach.
- AWAS system to generate a regular train that interacts with floating OWC
- Forces of catenary moorings are added to the total force of the floating structure



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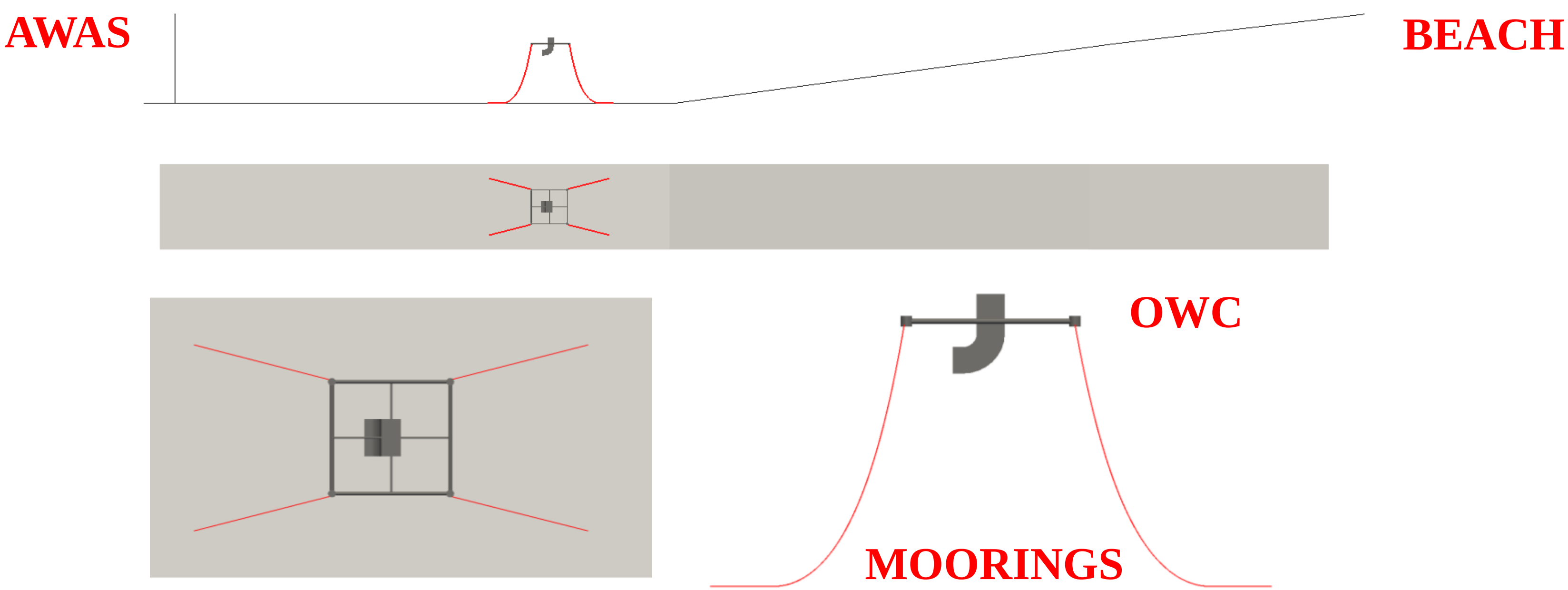

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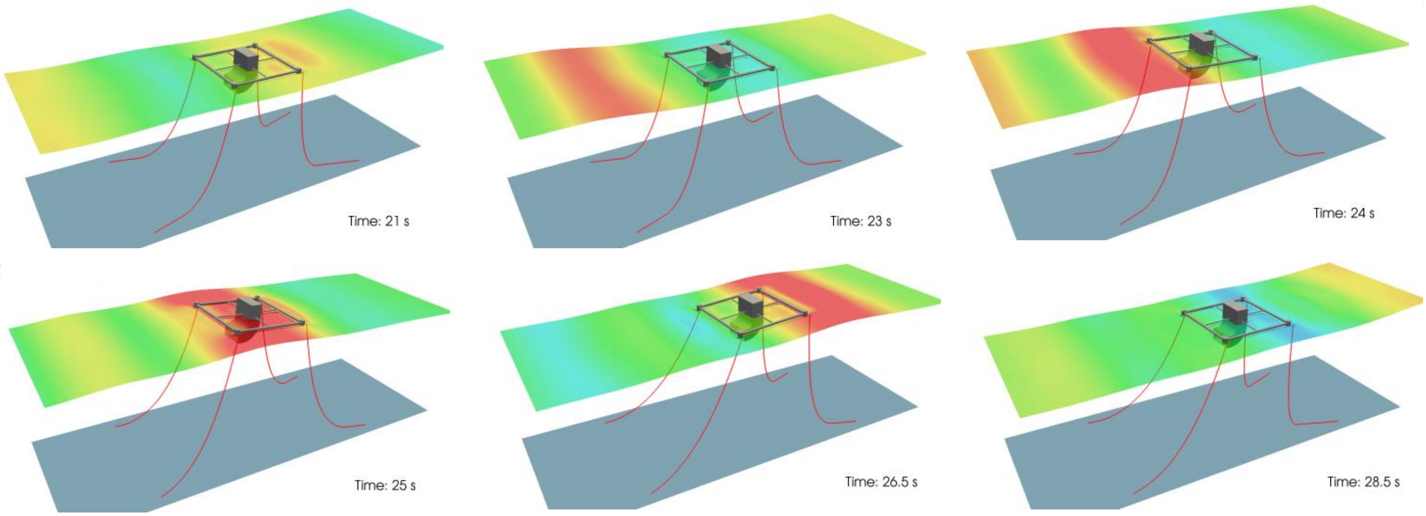
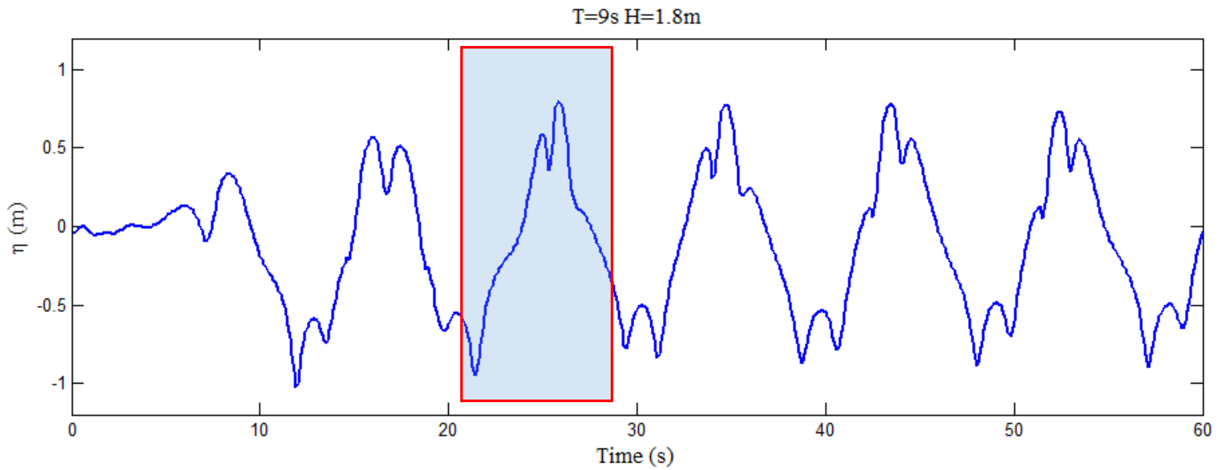
OFFSHORE FLOATING OWC IN THE OPEN SEA

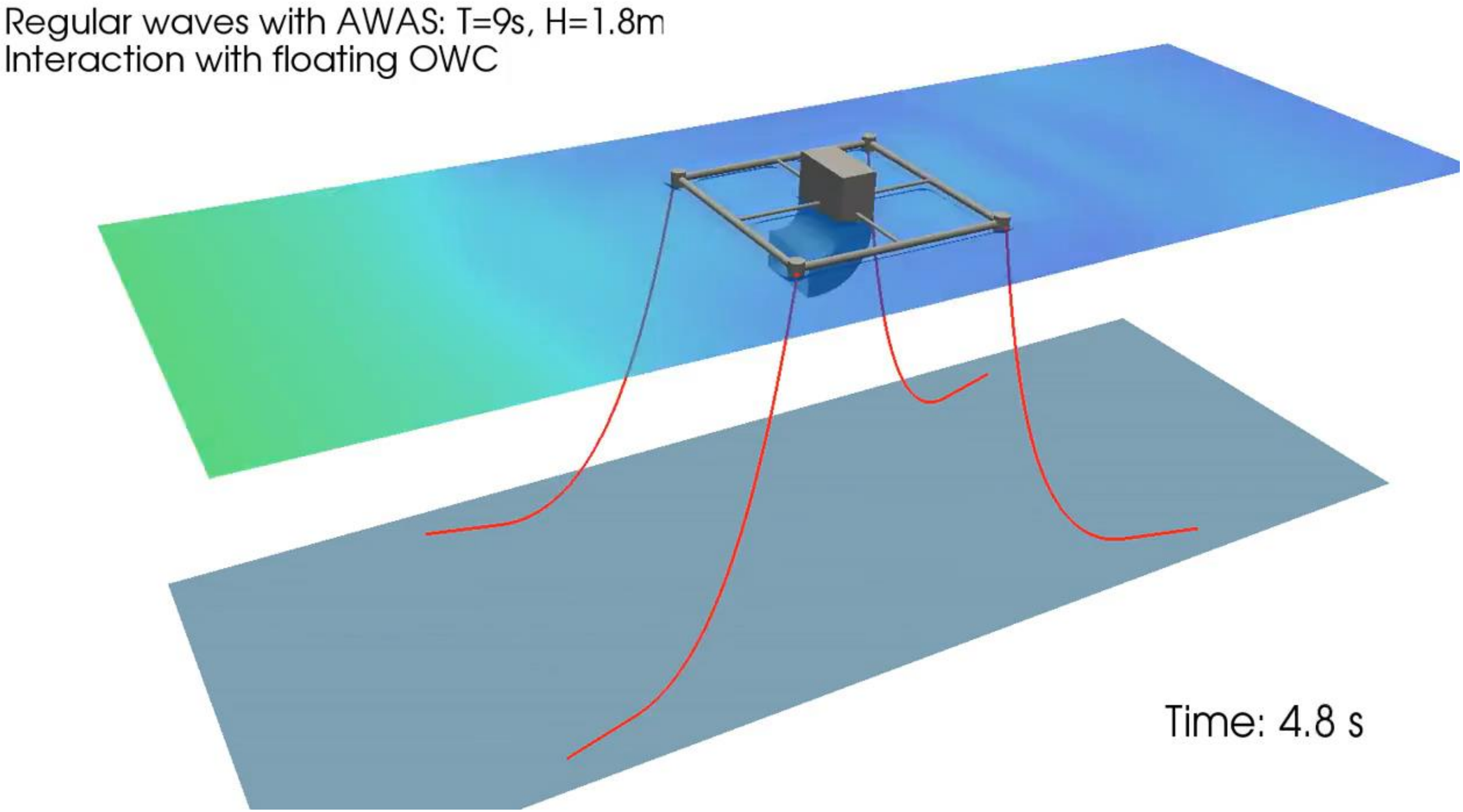




Elevation inside the **floating** OWC chamber

CASES OF STUDY

OFFSHORE FLOATING OWC IN THE OPEN SEA



CONCLUSIONS & FUTURE WORK

CONCLUSIONS:

- SPH is validated with fixed OWC experiments
  for that scale, the effect of air is negligible!!!
- SPH can measure wave surface elevation in realistic OWC chambers
  changes of pressure air are not considered!!!
- SPH can be used for the design of OWC chamber (geo, entrance, cavity ...)
- SPH is able to simulate floating OWC and to measure elevation inside

NEXT:

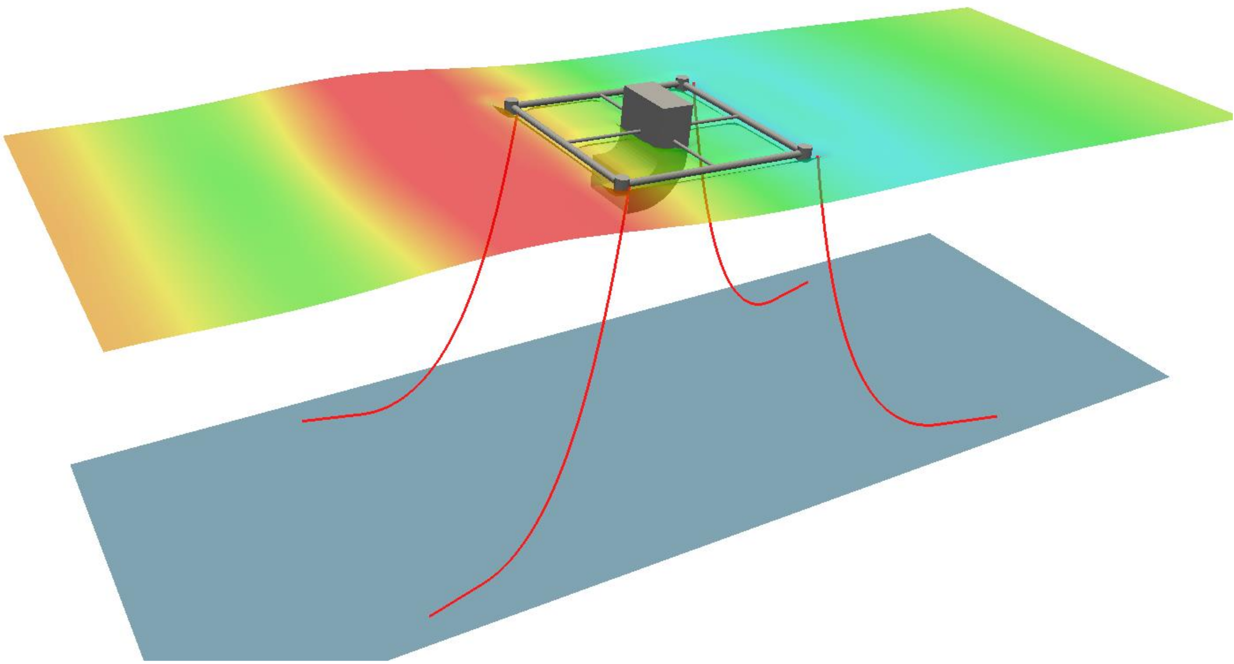
i) Air pressure in OWC chamber + PTO system
ii) Array of chambers: onshore and offshore
iii) Different wave directions, short crested waves
iv) Shielding effects and reflections in a wave farm

THANKS FOR YOUR ATTENTION

Universidade Vigo

flanders HYDRAULICS RESEARCH

Oscillating Water Column modelling with a SPH model



DualSPHysics cpu gpu

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