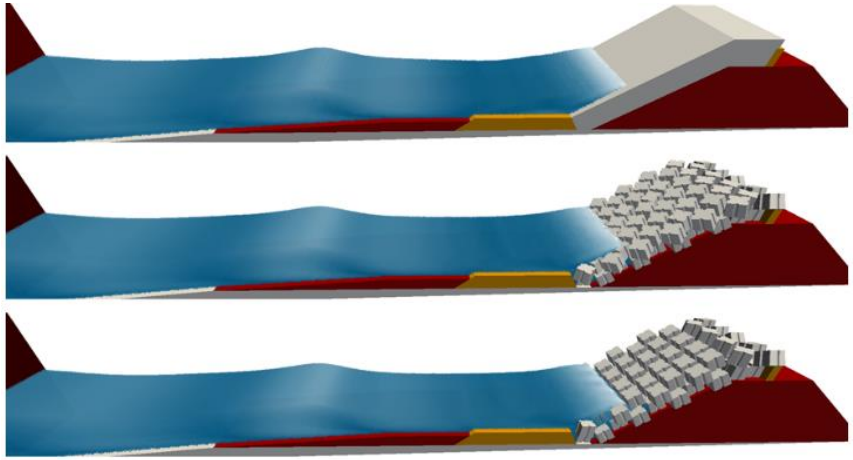
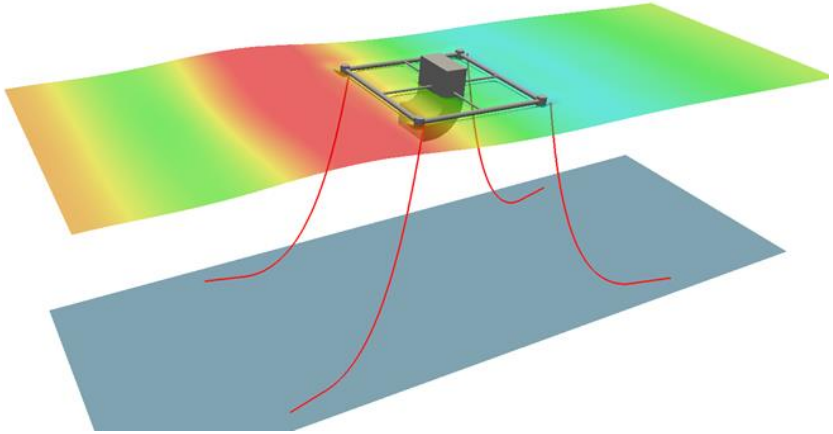
MANCHESTER 1824

The University of Manchester

DualSPHysics in Coastal Engineering





Dr Corrado Altomare

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University of Vigo, SPAIN

Outline of Presentation

- DualSPHysics in coastal protection
  - Wave generation & wave absorption
  - Wave-structure interaction
  - Coupling with wave propagation models
- DualSPHysics in wave energy
  - Wave interaction with floating bodies
  - Catenary moorings
  - Simulation of an Oscillating Water Column

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Motivation

The problems we are interested on:

Wave generation and wave absorption

The wave generation in DualSPHysics mimics the conditions of physical wave facilities.

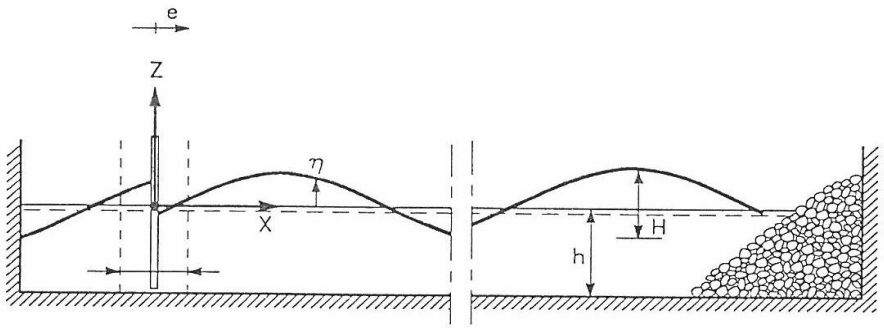
- The wave-maker (**piston**, **flap**, **flap** with **variable draft**) consists of a rigid body formed by boundary particles.

- The motion of the wave generator is prescribed controlling its position (linear or angular) at each instant of time.

- AUTOMATIC WAVE GENERATION:
  - Regular & Irregular
  - 1st and 2nd Order

Wave generation and wave absorption

PISTON-type wavemaker, REGULAR waves, 2nd Order (Frigaard e*t al.*, 1993; Madsen, 1971)



2nd order wave theory

$$\eta(x,t) = \frac{H}{2} \cdot cos(\omega t - kx + \delta) + \left(\frac{kH^2}{16}\right)[3coth(kd)^3 - coth(kd)]cos(2\omega t - 2kx + 2\delta)$$

$$m_1 = \frac{H}{S_0} = \frac{2sinh^2(kd)}{\sinh(kd)\cosh(kd) + kd}$$

Biesel transfer function (1951)

Piston displacement

$$e(t) = \frac{S_0}{2}\sin(\omega t + \delta) + \left[\left(\frac{H^2}{32d}\right)\cdot\left(\frac{3\cosh(kd)}{\sinh^3(kd)}\right) - \frac{2}{m_1}\right]\sin(2\omega t + 2\delta)$$

Wave generation and wave absorption

PISTON-type wavemaker, IRREGULAR waves, 1st Order (Frigaard *et al.*, 1993)

1. Define the wave spectrum (peak frequency, spectrum shape, etc.).
2. Define the frequency band width Δf.
3. Determine frequency $\boldsymbol{\omega_i}$, $\boldsymbol{a_i}$ and $\boldsymbol{\delta_i}$ (random between 0 and 2π) of each linear wave.

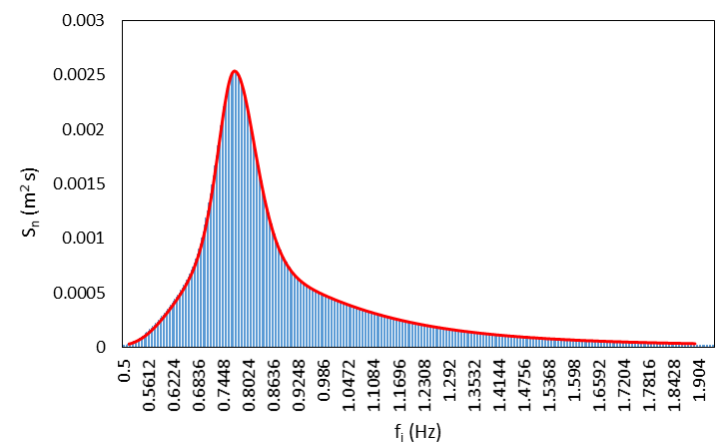
$$\omega_i = 2\pi f_i \qquad\qquad a_i = \sqrt{2S_\eta(f_i)\Delta f} = \frac{H_i}{2}$$

4. Apply Biesel:

$$\frac{H_i}{S_{0,i}} = \frac{2sinh^2(k_i h)}{\sinh(k_i h)\cosh(k_i h) + k_i h}$$

5. Compose all the components into the time series of the piston displacement as:

$$e(t) = \sum_{i=1}^{N} \frac{S_{0,i}}{2} \cos(\omega_i t + \delta_i)$$



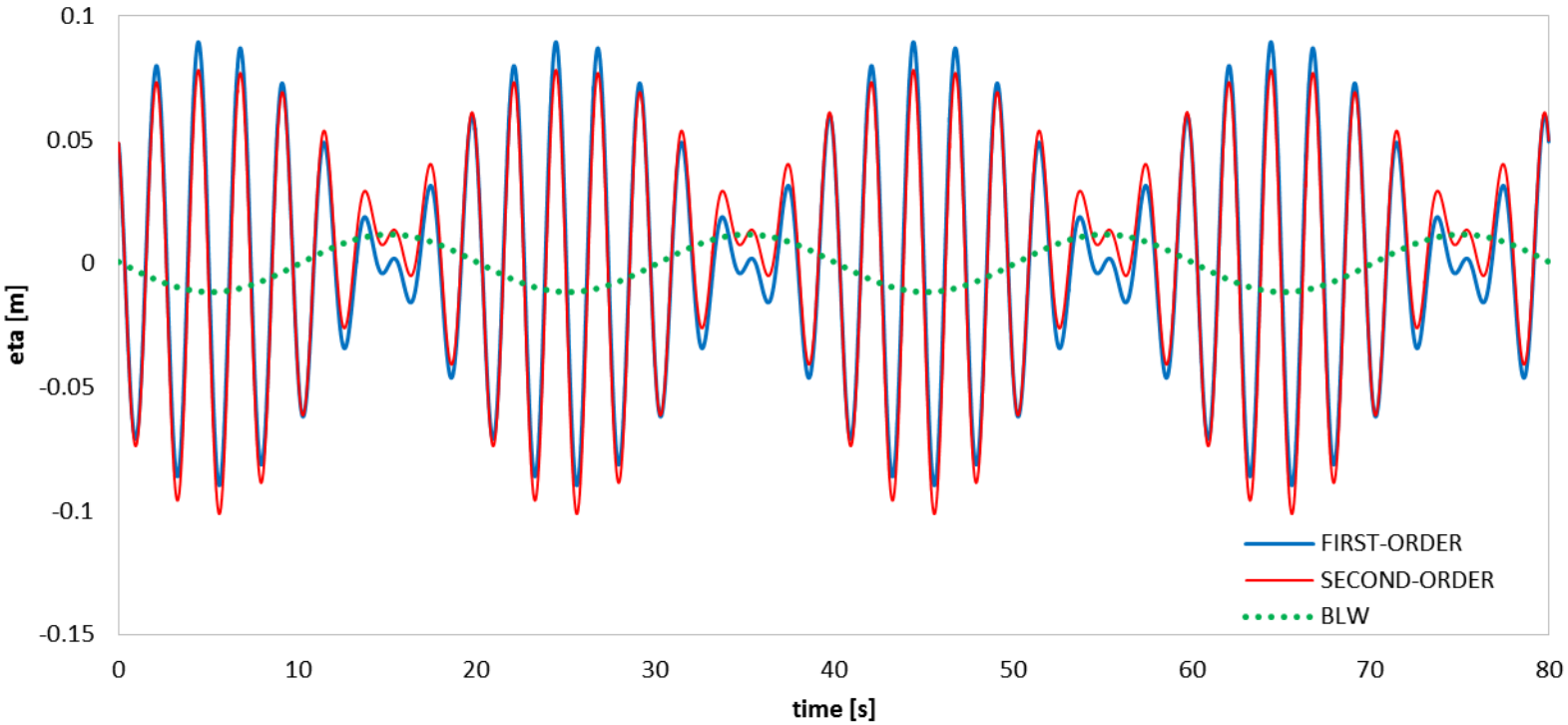
In DualSPHysics:

a) JONSWAP and Pierson-Moskowitz
b) Phase seed

Wave generation and wave absorption

PISTON-type wavemaker, IRREGULAR waves, 2nd Order <u>BOUND LONG</u> waves (Hughes, 1993)

Bound long waves (BLW) refer to the set-down of the water level that is generated by wave groups

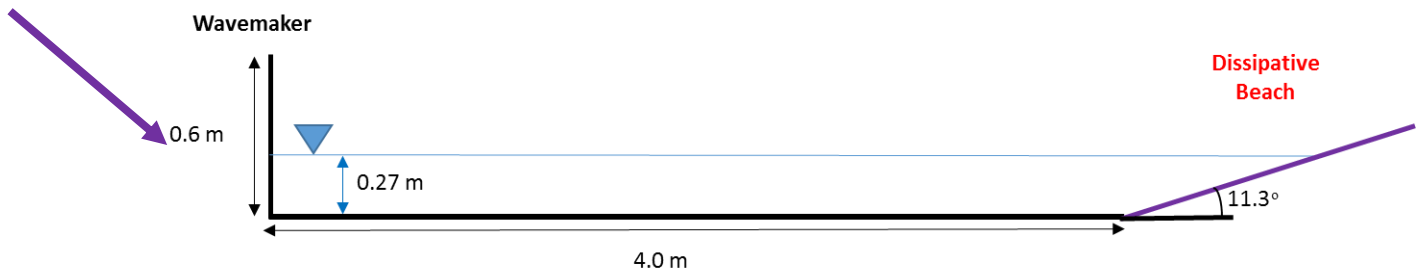


Wave generation and wave absorption

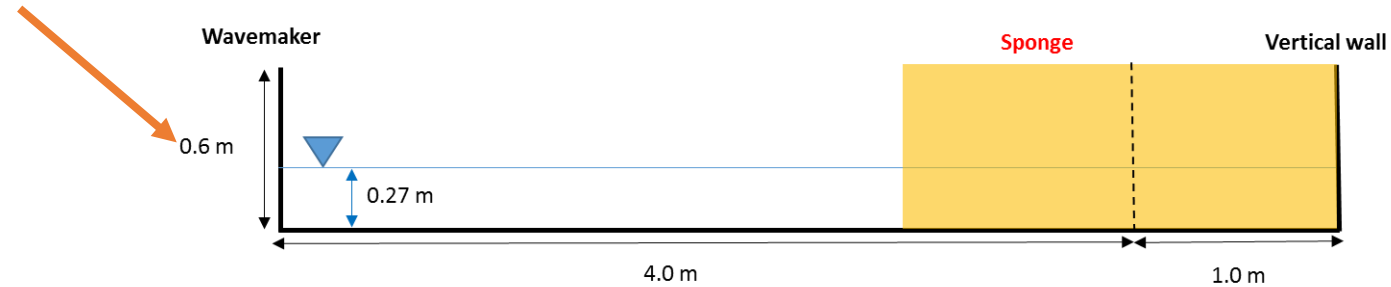
Passive wave absorption

This system can be either:

- dissipative beach



- a “sponge” area



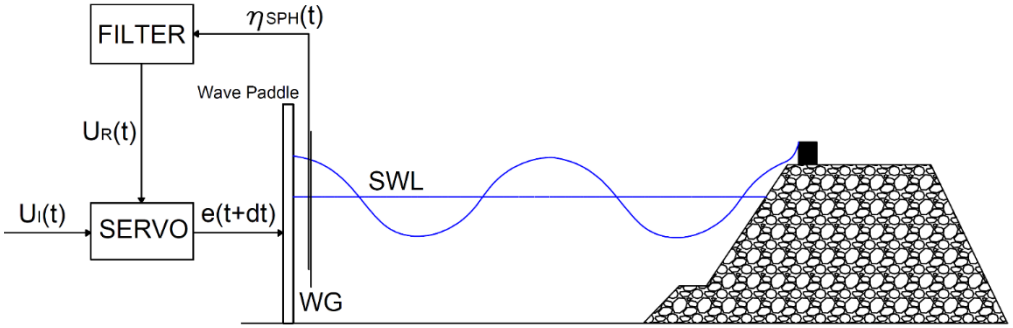
$$\mathbf{v} = \mathbf{v}_0 \cdot f(x, dt)$$

$$f(x, dt) = 1 - dt \cdot \beta \cdot \left(\frac{x - x_0}{x_1 - x_0} \right)^2$$

applied at each time step

Wave generation and wave absorption

Active wave absorption



$$\eta_R(t) = \eta_I(t) - \eta_{SPH}(t)$$

Reflected wave at $\mathbf{4} * \boldsymbol{h}$ from the piston

FILTER

$$U_R(t) = \eta_R(t)\sqrt{g/d}$$

Velocity correction (uniform velocity field)

+

$$U_I(t) = \omega \frac{S_0}{2} \sin(\omega t + \delta)$$

Theoretical wave maker velocity

$$U_C(t + dt) = U_I(t) + U_R(t)$$

Corrected wave maker velocity

SERVO

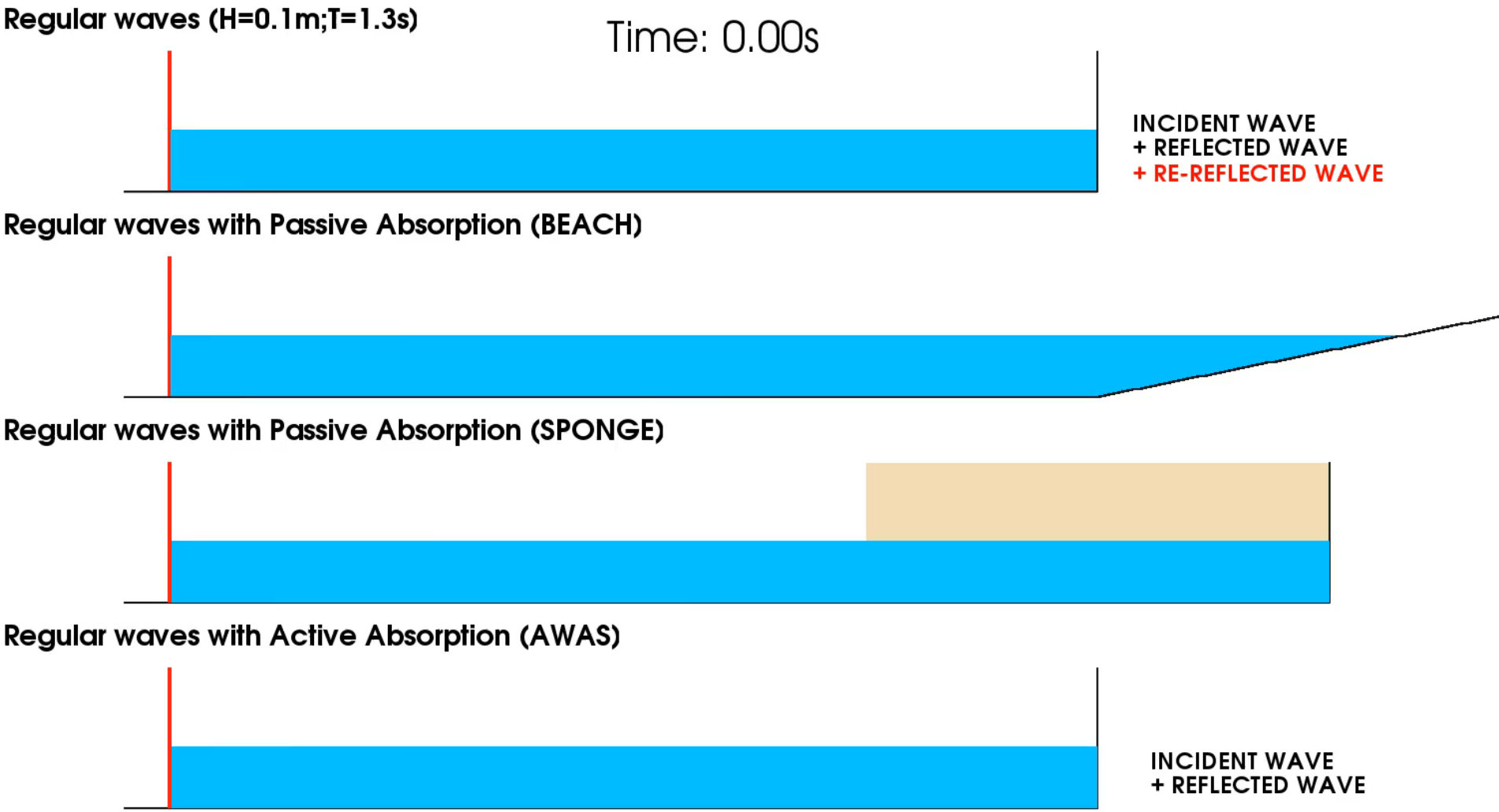
$$e(t + dt) = e(t) + (U_C(t + dt) + U_C(t))\frac{dt}{2}$$

Wave maker position at $\boldsymbol{t + dt}$

(Shaffer and Klopman , 2000)

Wave generation and wave absorption

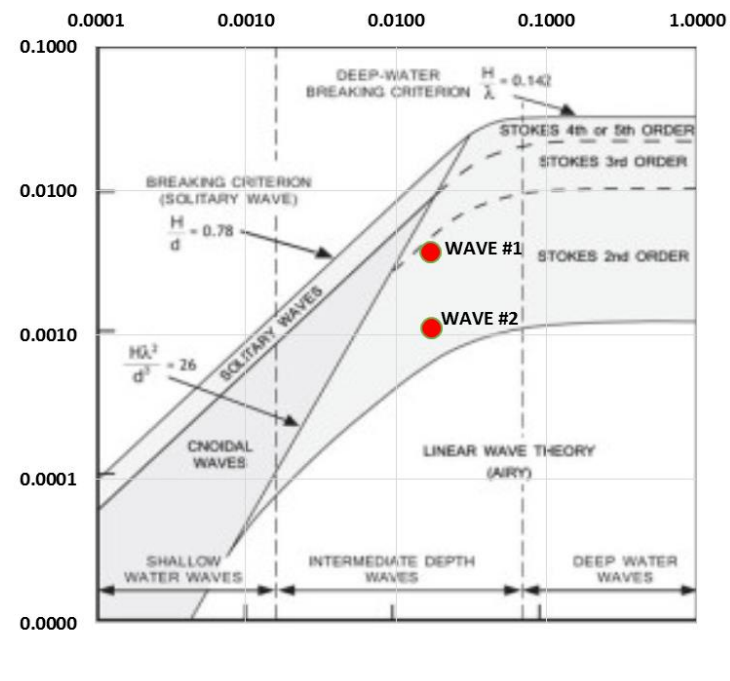
Wave generation and wave absorption (passive and active)
AWAS system in SPH models

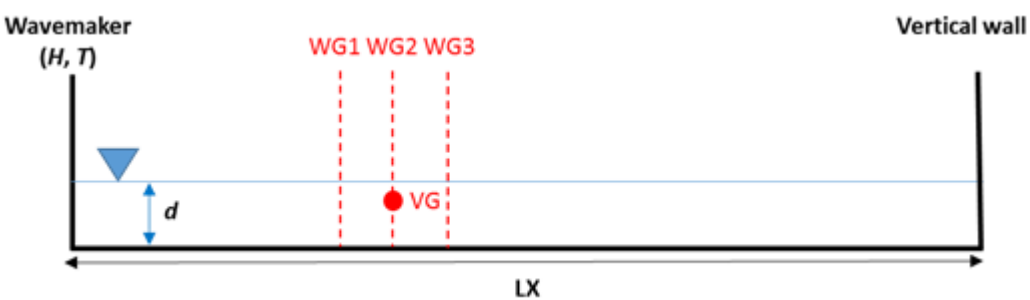


Wave generation and wave absorption

Validation with theoretical results

	Wave #1	Wave #2
Height H or H_{m0}	0.15m	0.10m
Period T or T_p	2.00s	3.00s
Depth d	0.66m	1.50m
Steepness s	0.033	0.010
Wavelength L	4.52m	10.22m

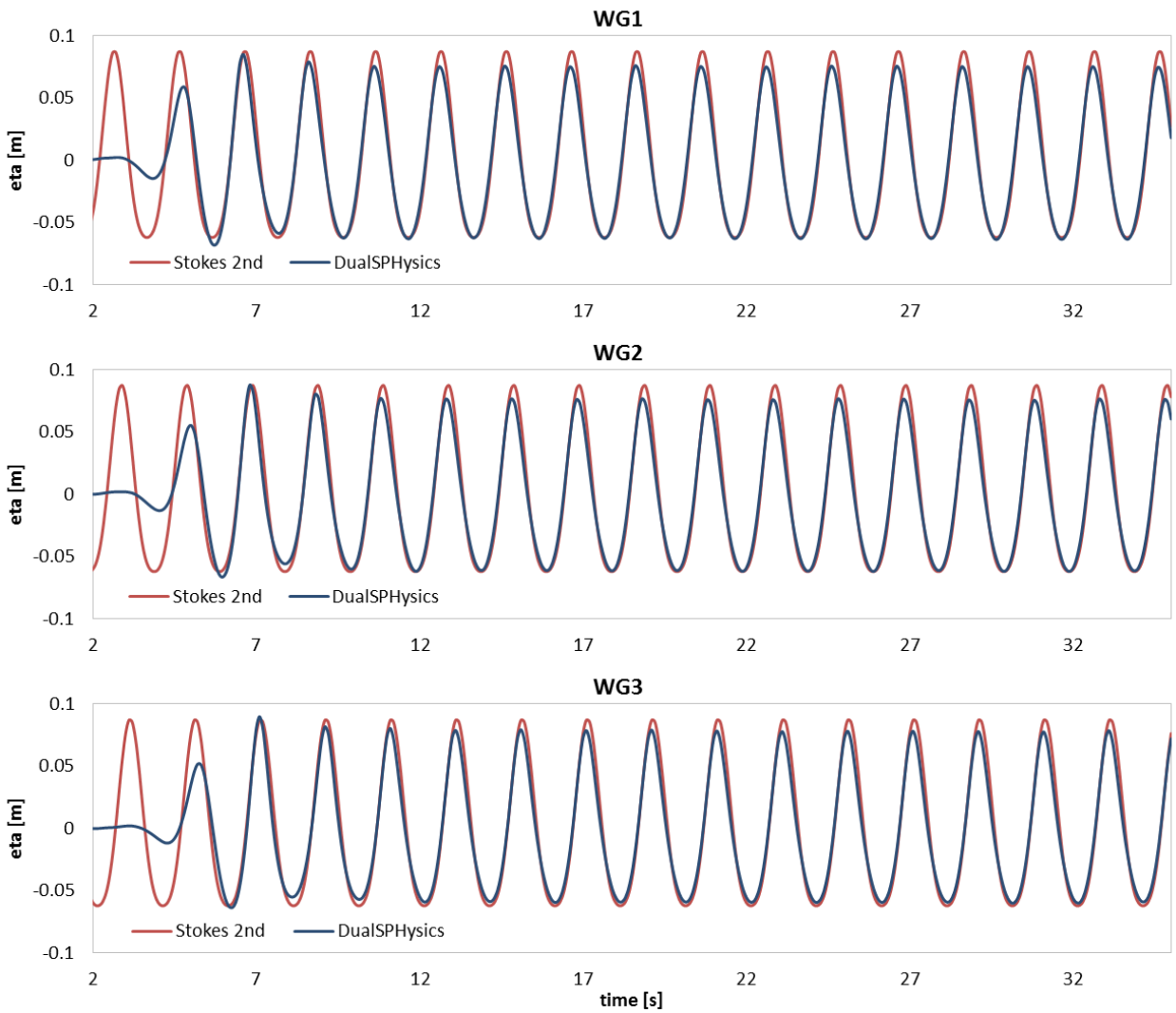




	Wave #1	Wave #2
Wave gauges (WG)	x=6.0, 6.5, 7.1m	x=13.0, 14.0, 15.5m
Velocity gauge (VG)	x=6.5m ; z=0.4m	x=14m ; z=1m
Domain length (LX)	11m	26m
Test duration (t_{max})	35s	50s

Wave generation and wave absorption

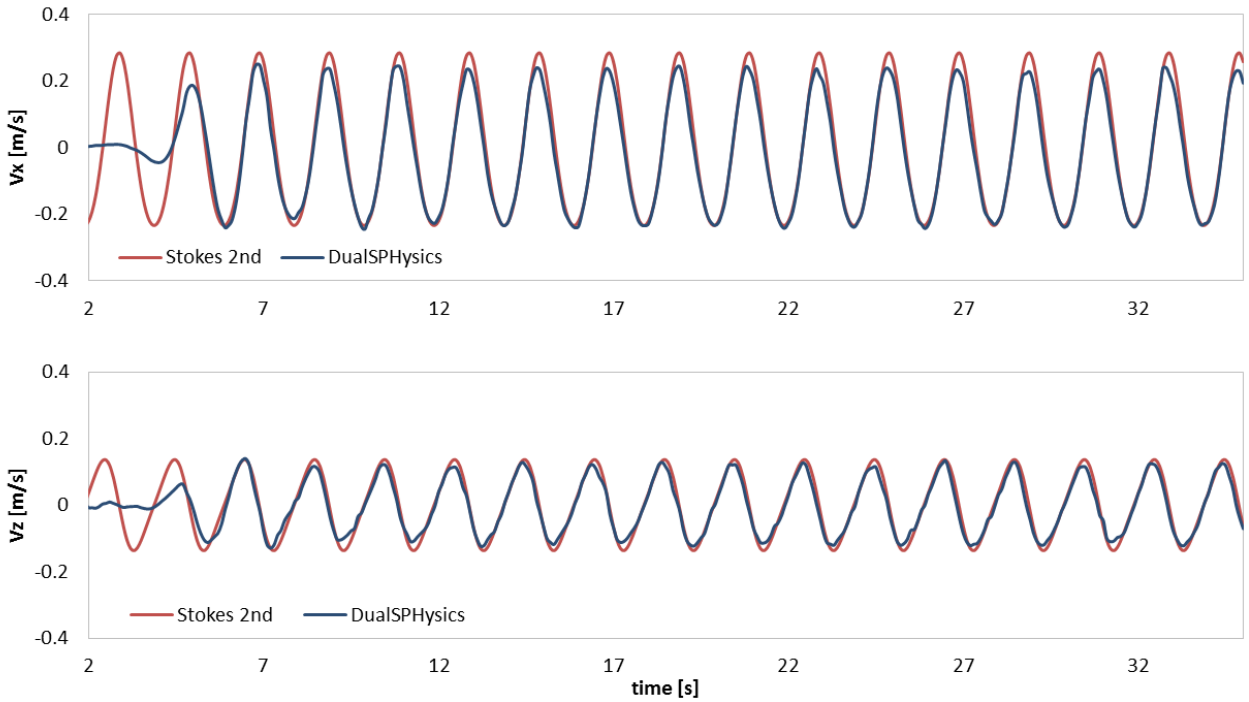
Validation with theoretical results: WAVE GENERATION



Wave #1

Wave generation and wave absorption

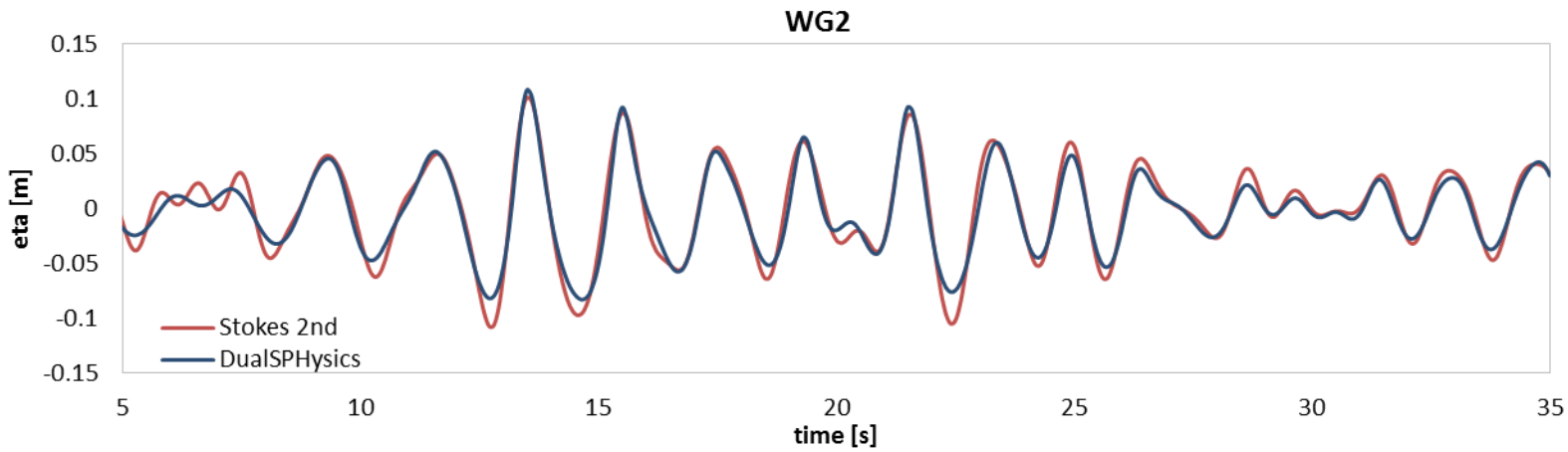
Validation with theoretical results: WAVE GENERATION



Wave #1

Wave generation and wave absorption

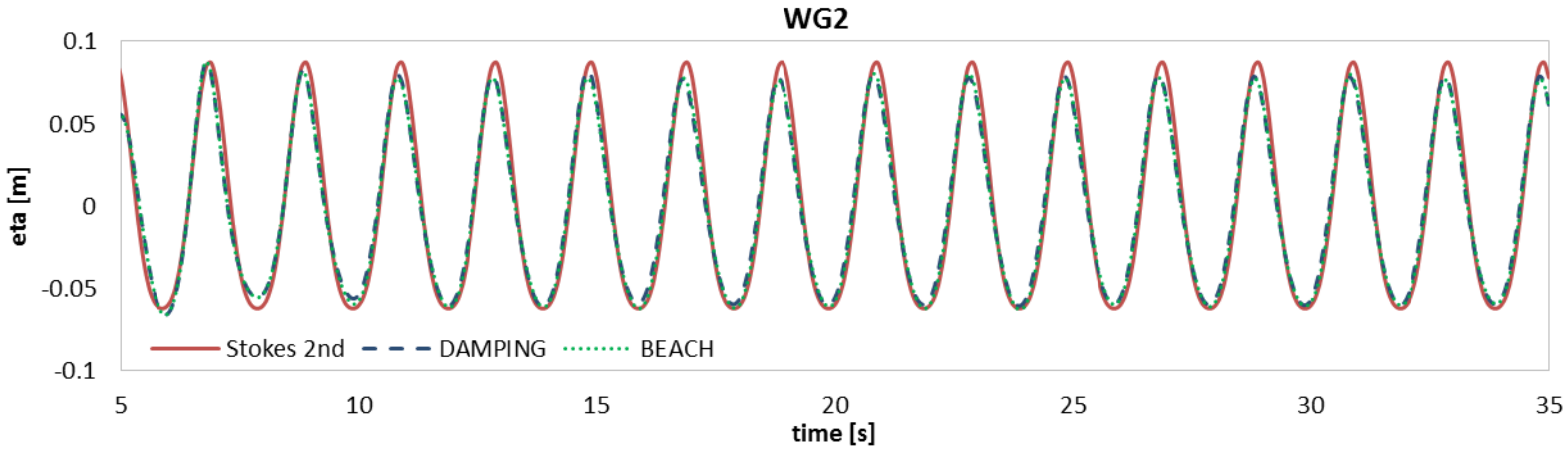
Validation with theoretical results: WAVE GENERATION



Wave #1

Wave generation and wave absorption

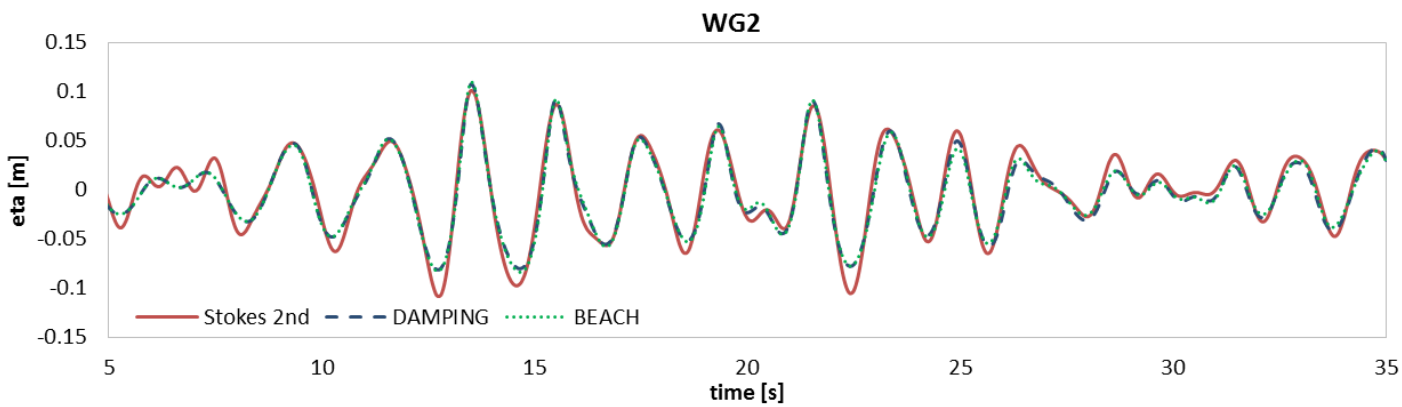
Validation with theoretical results: PASSIVE ABSORPTION

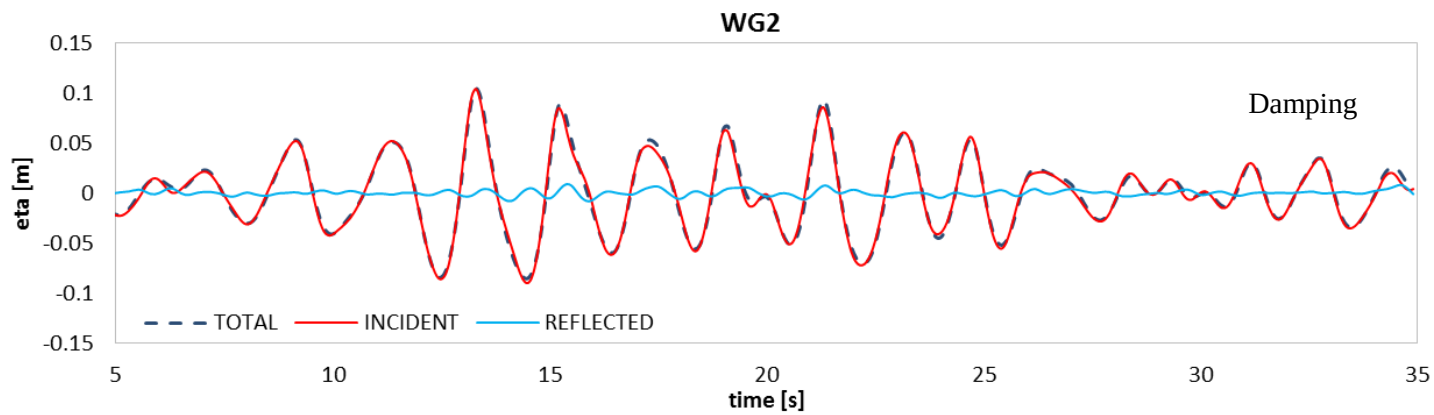


Wave #1

Wave generation and wave absorption

Validation with theoretical results: PASSIVE ABSORPTION



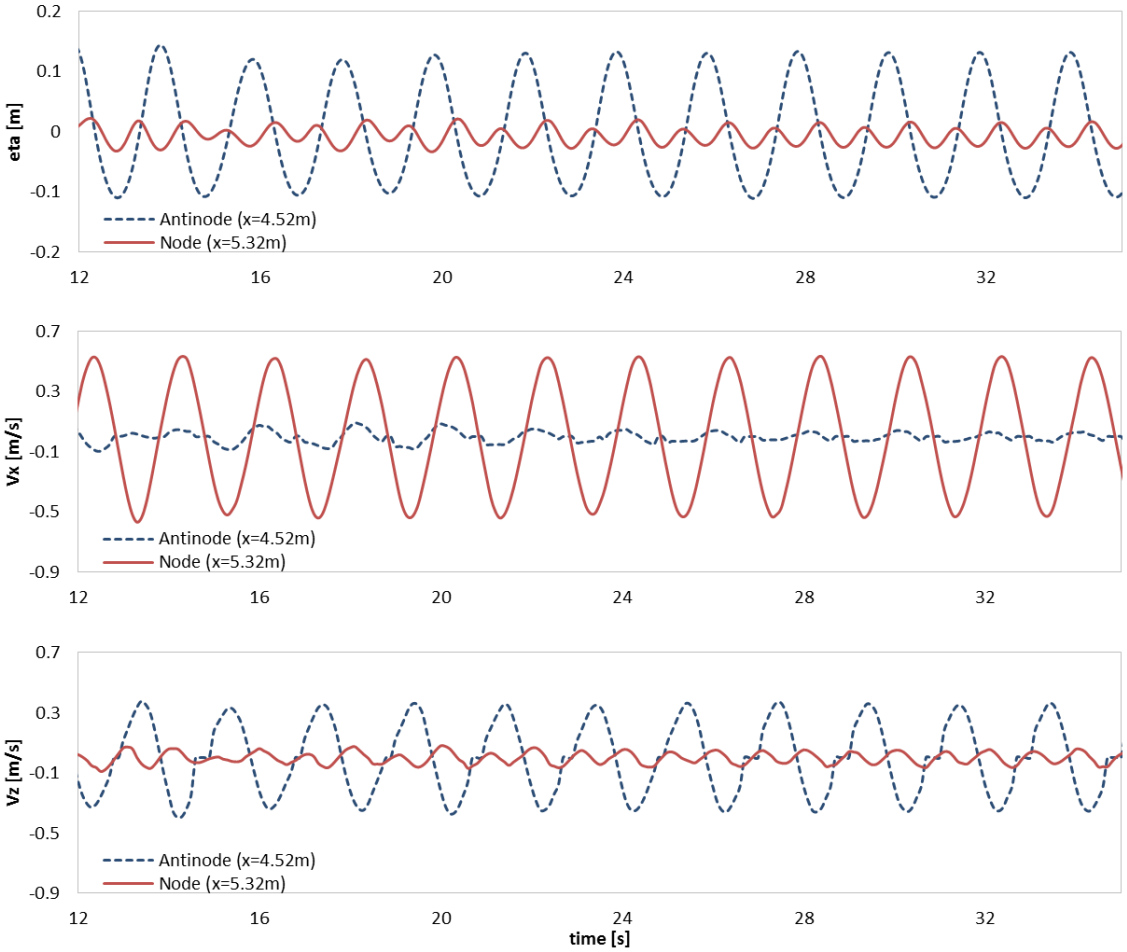


Wave #1

Cr	Wave #1		Wave #2	
	Regular	Irregular	Regular	Irregular
BEACH	11.4%	8.5%	8.4 %	5.7%
DAMPING	12.2%	8.6%	7.9 %	6.5%

Wave generation and wave absorption

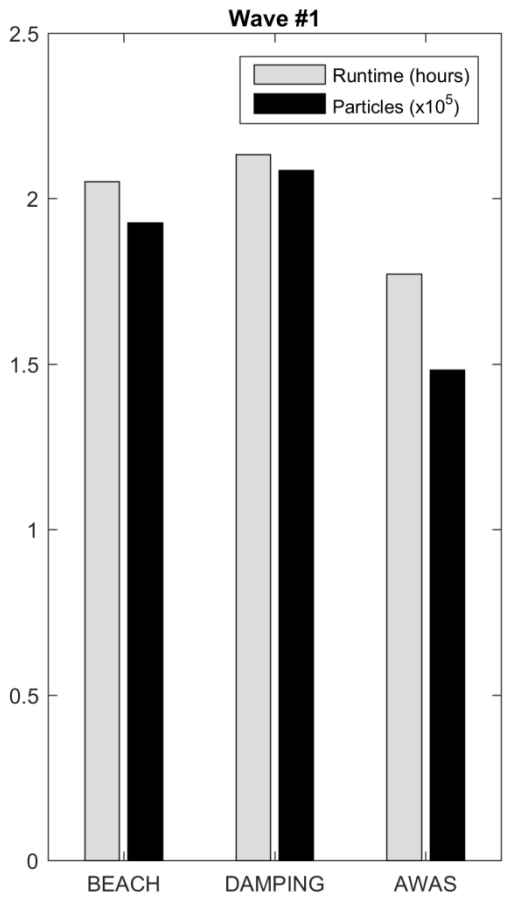
Validation with theoretical results: ACTIVE ABSORPTION

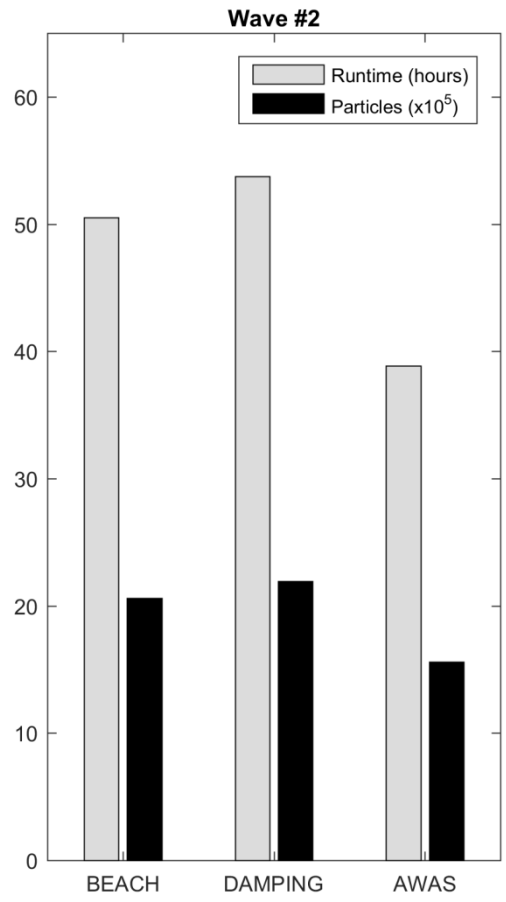


Wave #1

Wave generation and wave absorption

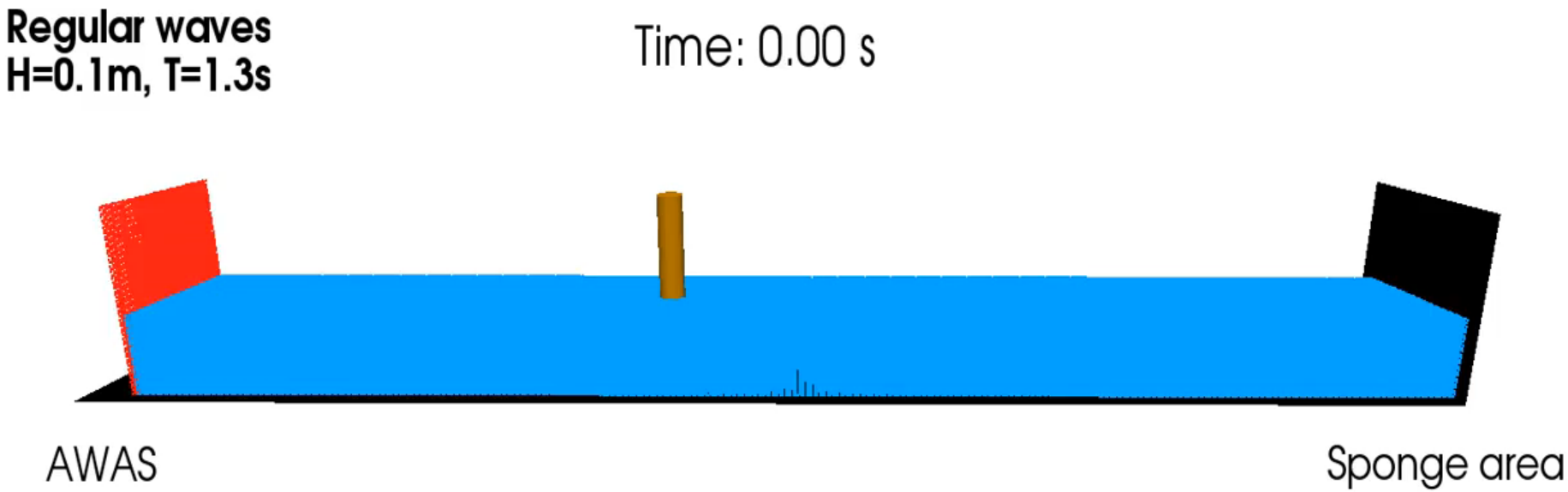
Efficiency





Wave generation and wave absorption

Wave generation and wave absorption (passive and active)
AWAS system in SPH models



WE NEED PASSIVE AND ACTIVE ABSORPTION TO MIMIC THE REAL SEA STATE CONDITIONS

Coastal protection

Study of the run-up in an existing armour block sea breakwater

DETAILED DESCRIPTION OF THE FLOWS !!!

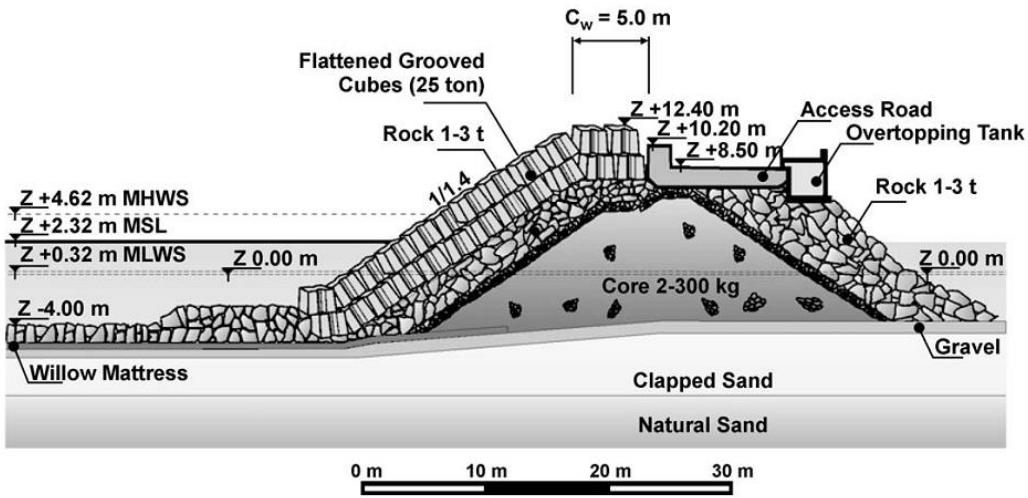
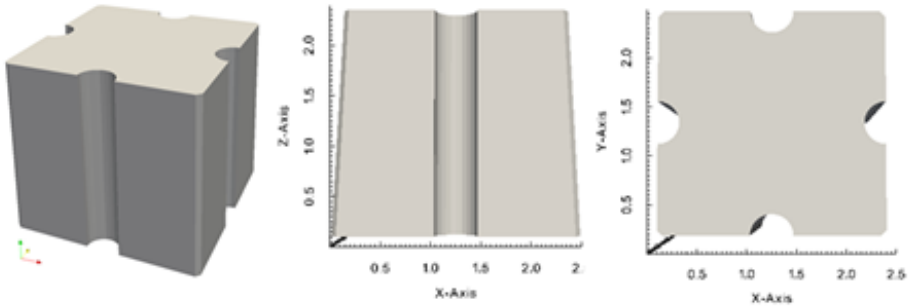


Fig. 2. Cross section of the Zeebrugge rubble mound breakwater at the location of the wave overtopping tank.

Zeebrugge reference geometry (Belgium)



The size of the numerical simulation depends on the initial inter-particle distance

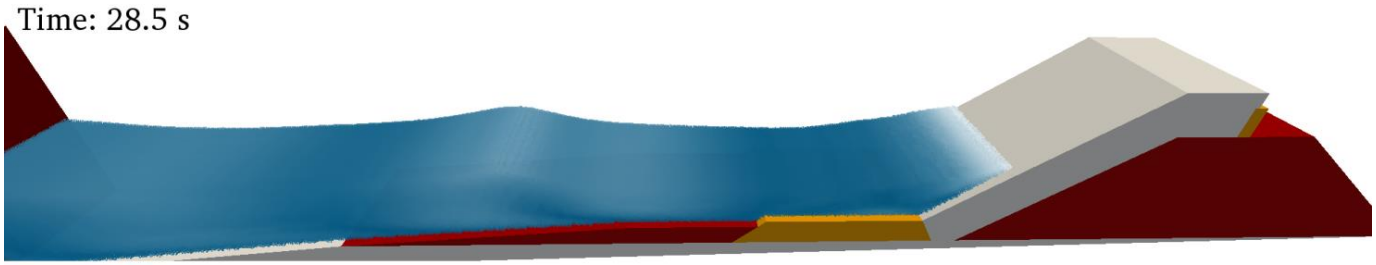
dp = 0.15 m => h = 0.225 m

The SPH domain contains **2,146,095 particles** with 187,353 representing the boundaries

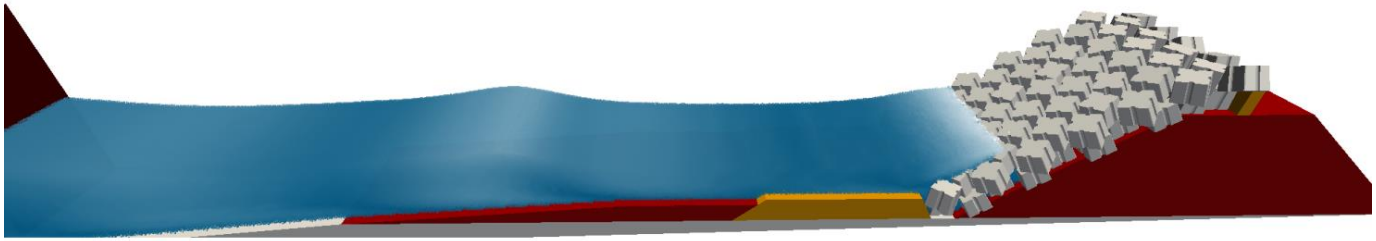
Coastal protection

Study of the run-up in an existing armour block sea breakwater

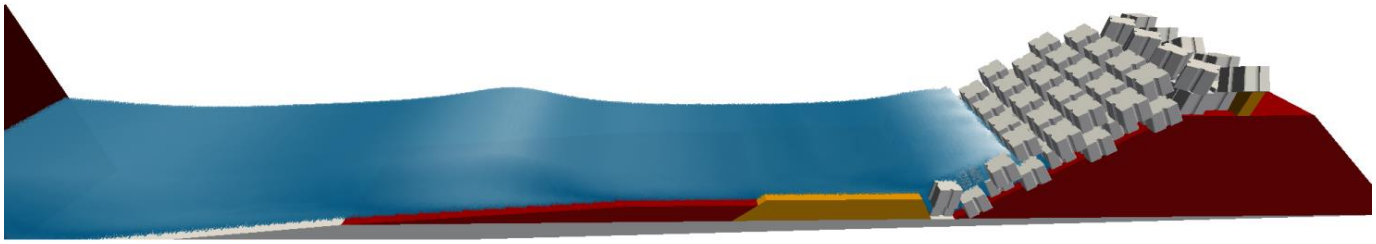
Equivalent Smooth



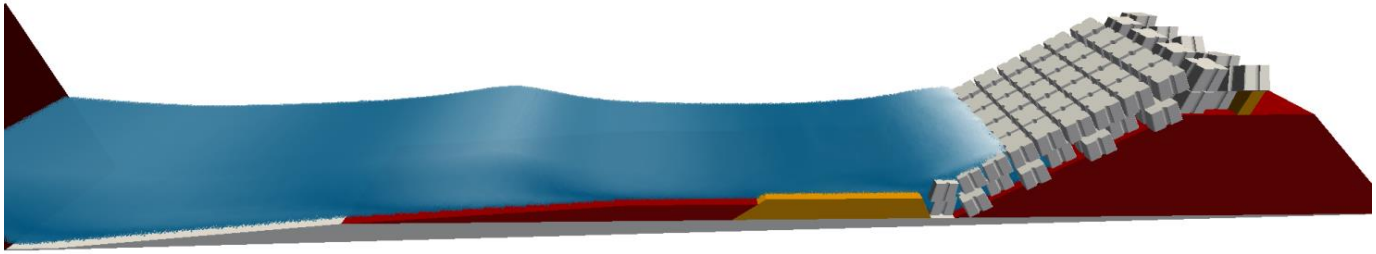
Antifers Irregular Pattern



Antifers Regular 1 Pattern

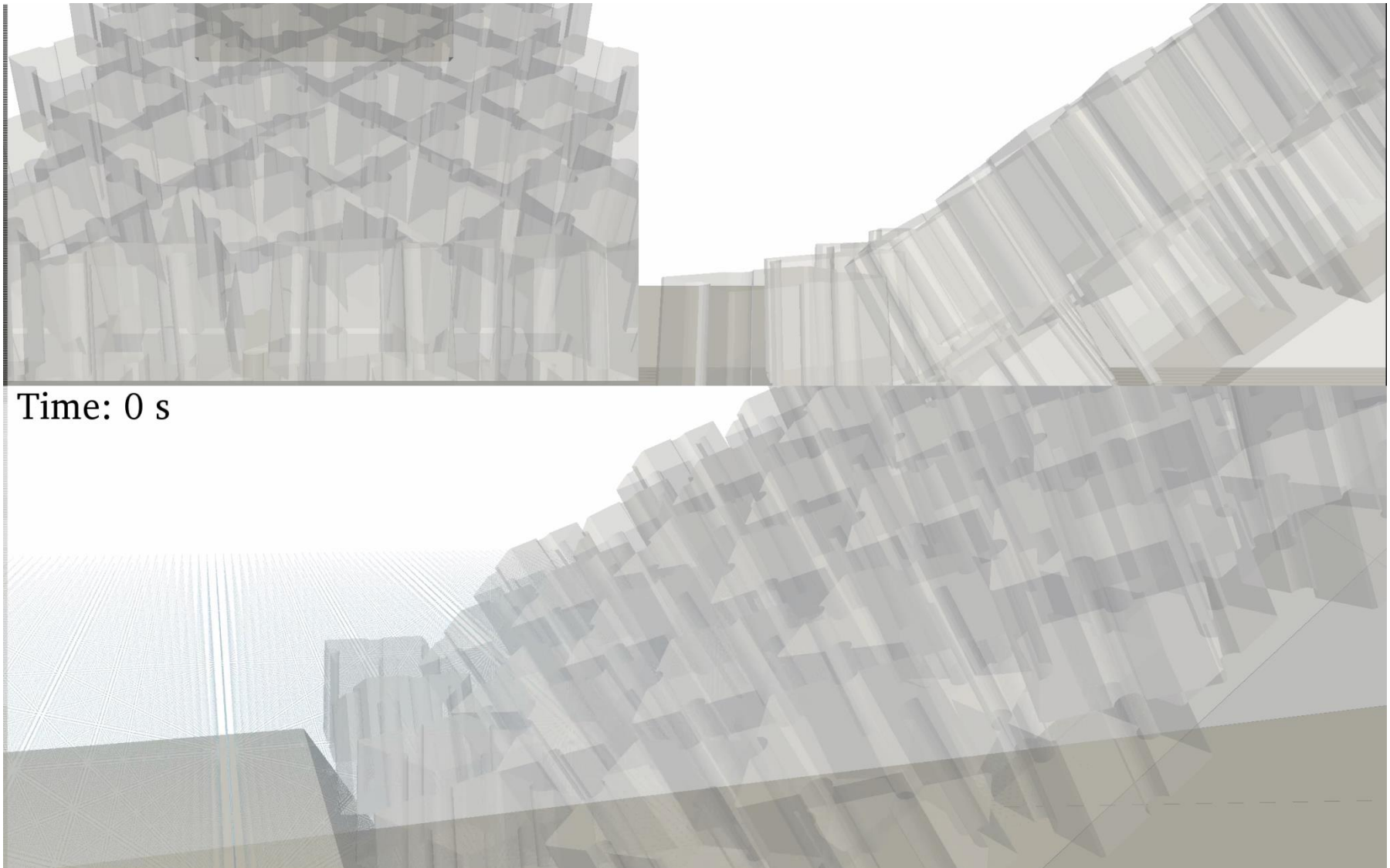


Antifers Regular 2 Pattern



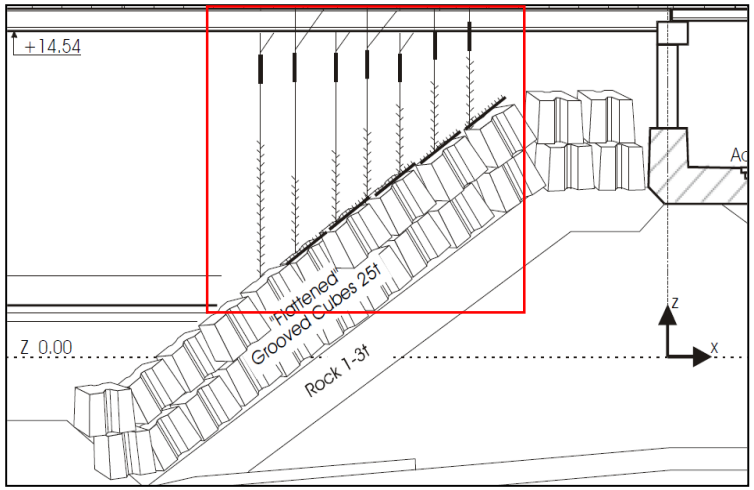
Coastal protection

Study of the run-up in an existing armour block sea breakwater



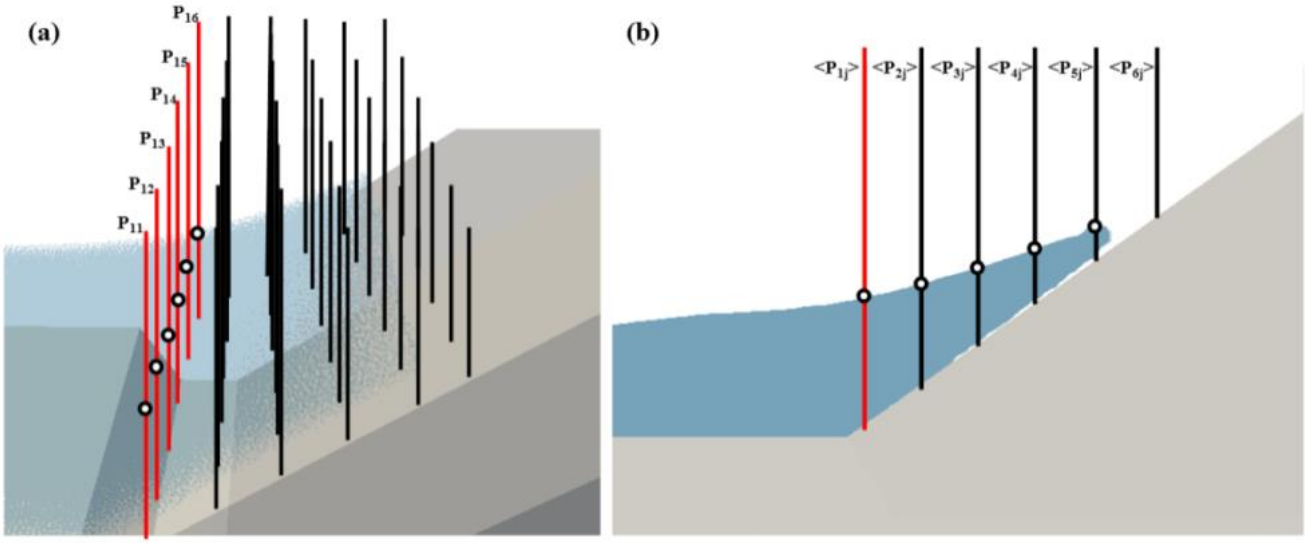
Coastal protection

Study of the run-up in an existing armour block sea breakwater



Measurement system:
IN THE FIELD

NUMERICALLY

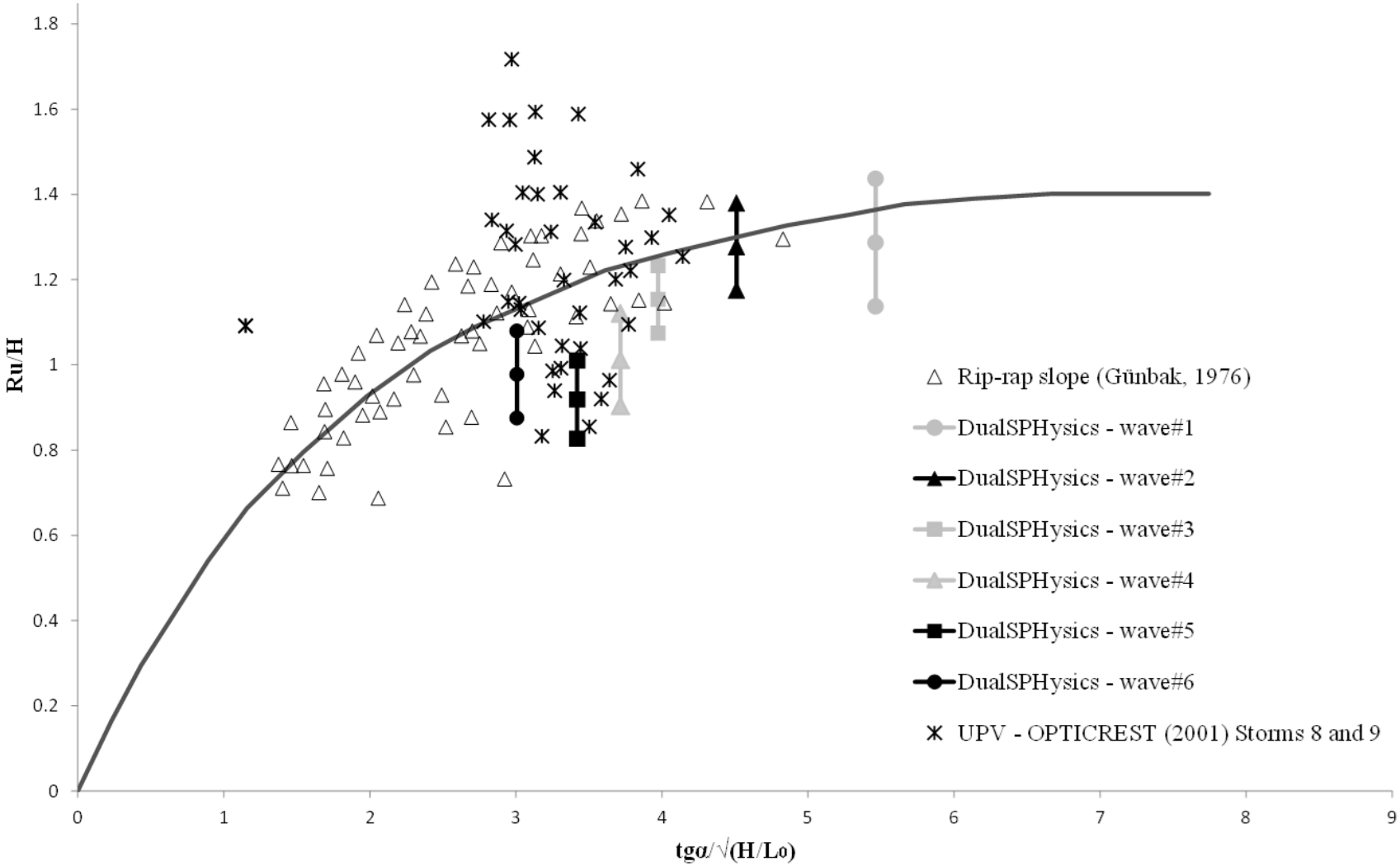


Coastal protection

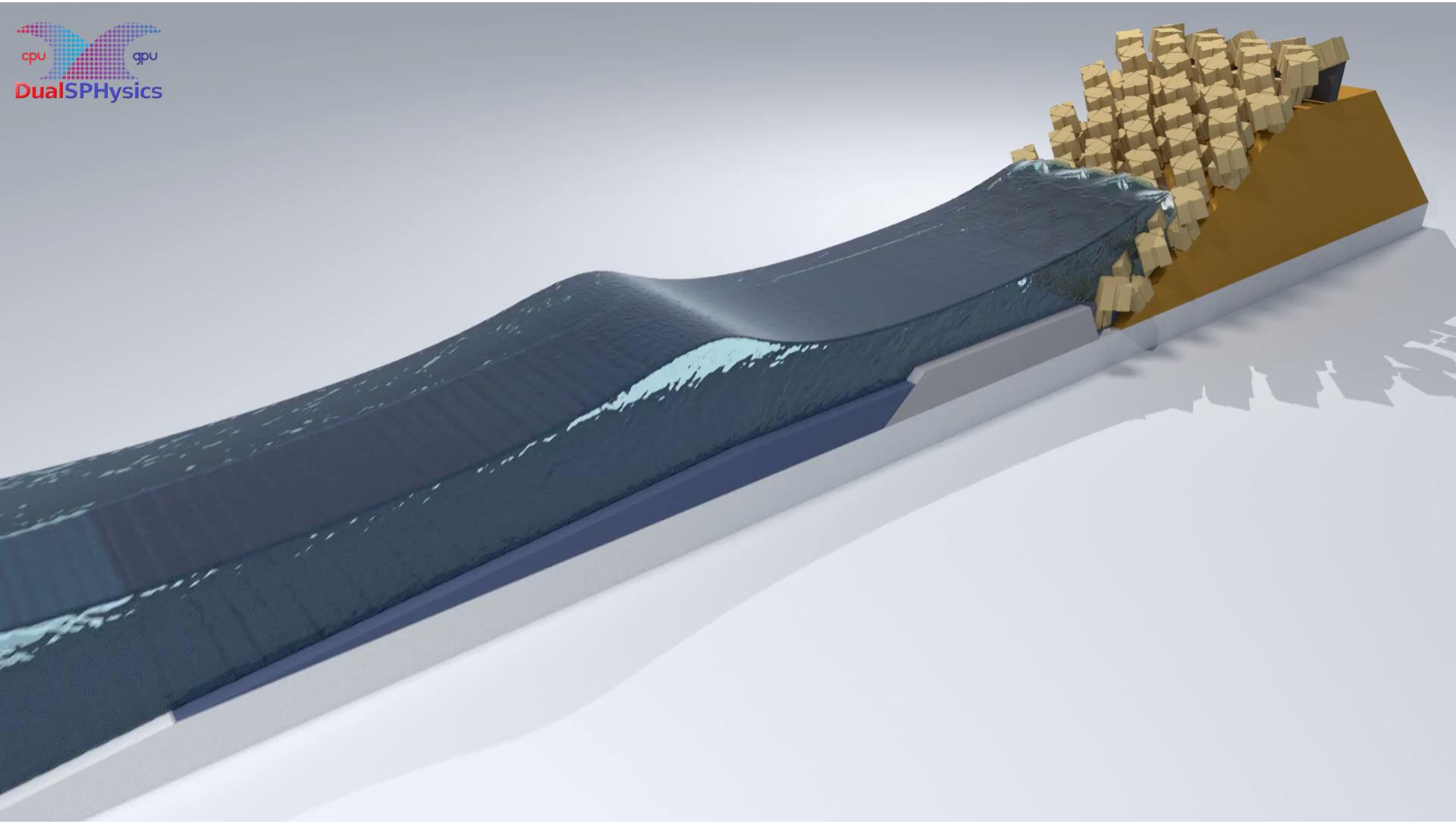
Study of the run-up in an existing armour block sea breakwater

Comparison with experimental results

$$Ru^n = Ru/H$$



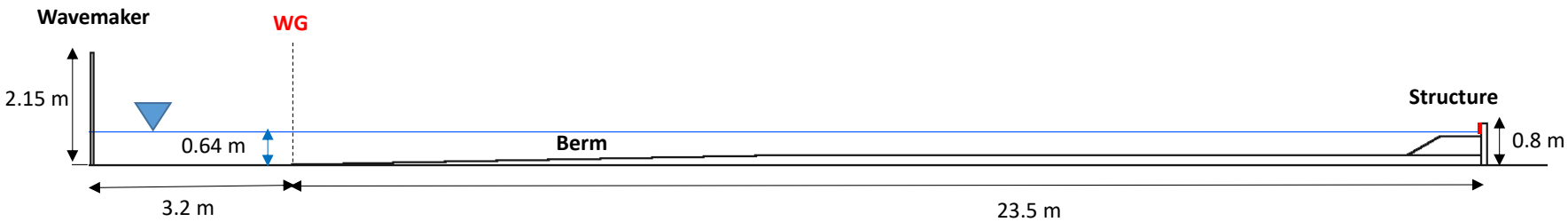
Coastal protection

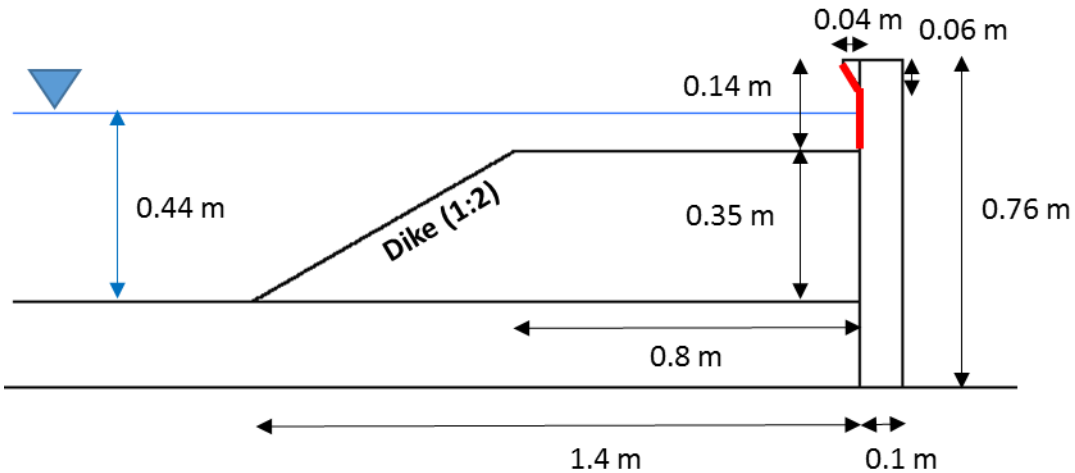


Coastal protection

Estimation of sea wave impact on coastal structures

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

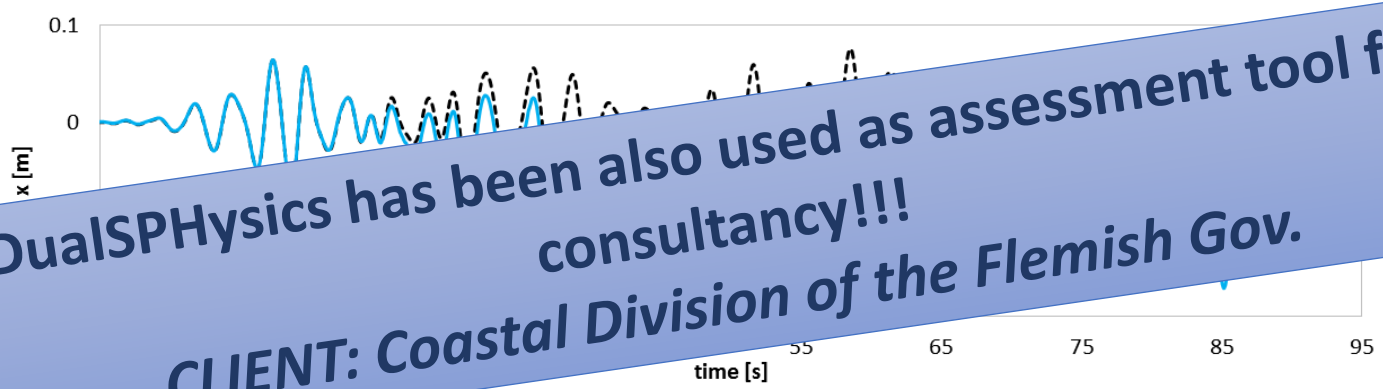




H_{m0}=0.101m
T_p=2.683s

Coastal protection

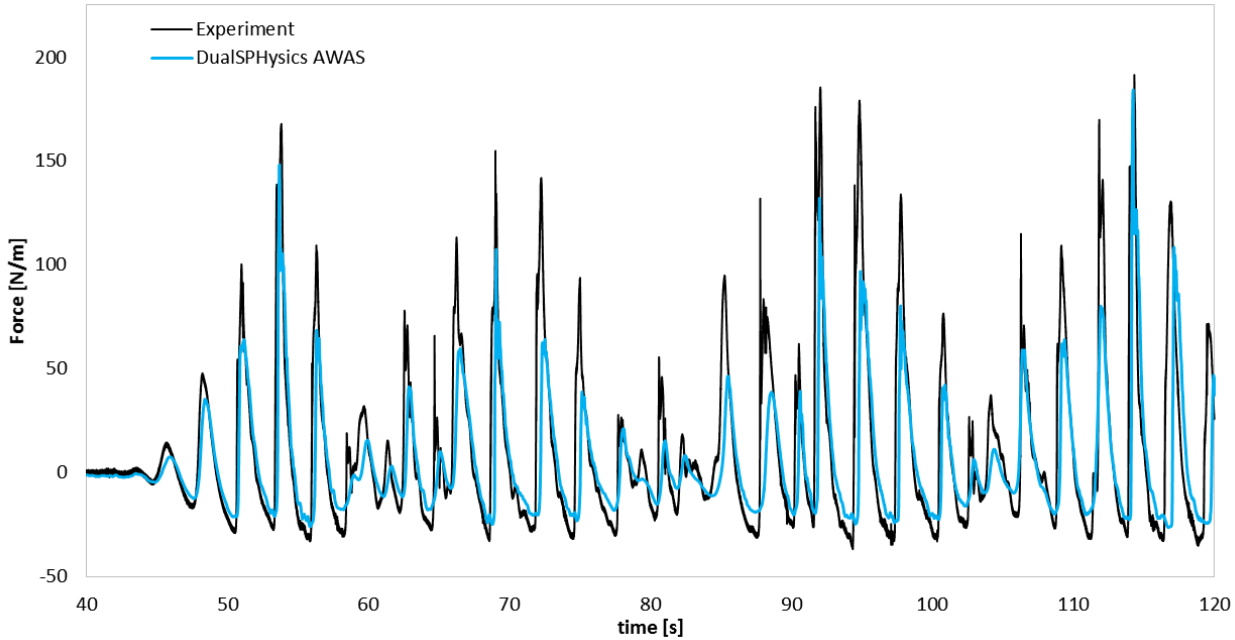
Wavemaker displacement without and with Active Absorption



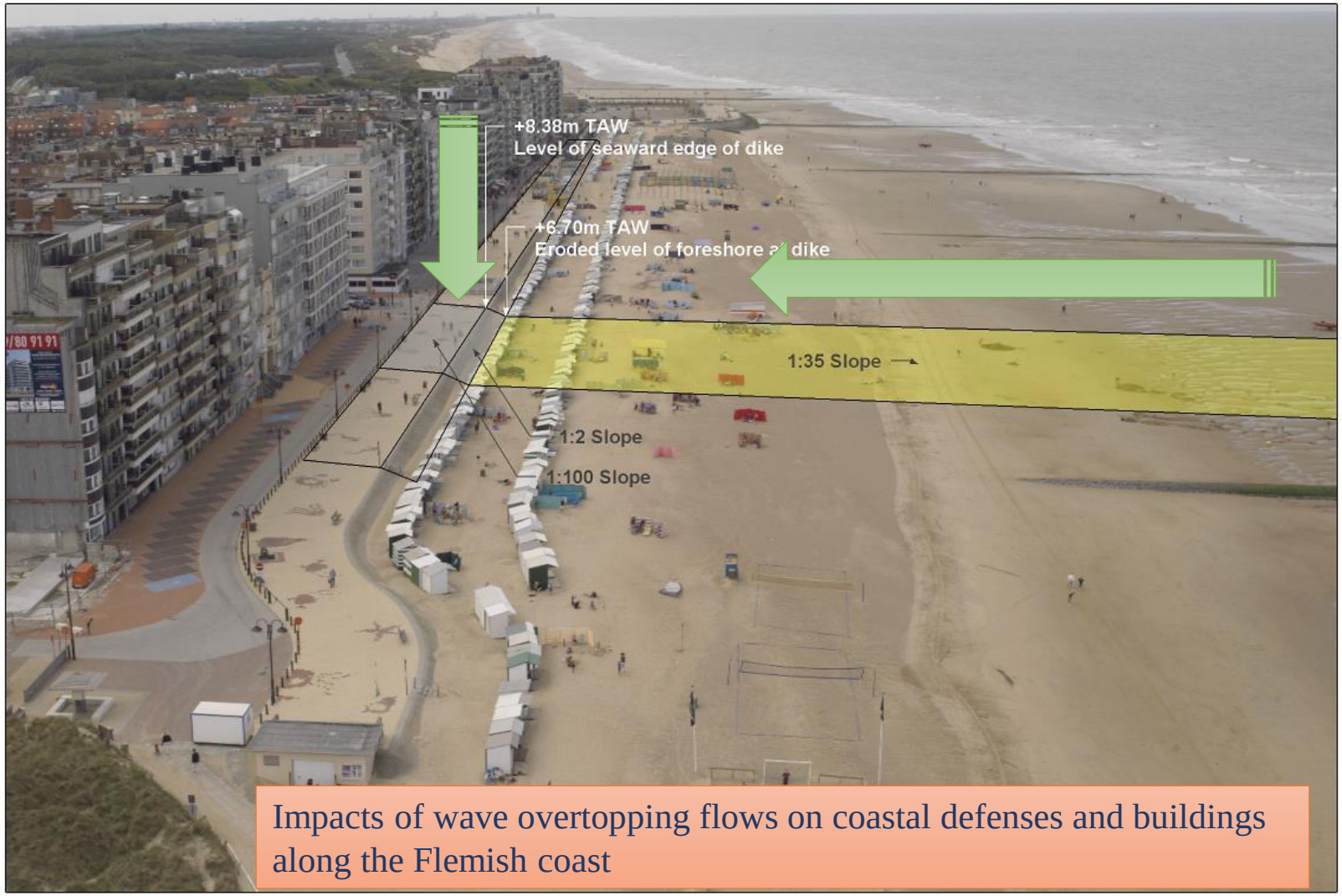
DualSPHysics has been also used as assessment tool for consultancy!!!

CLIENT: Coastal Division of the Flemish Gov.

Comparison between numerical and experimental wave forces

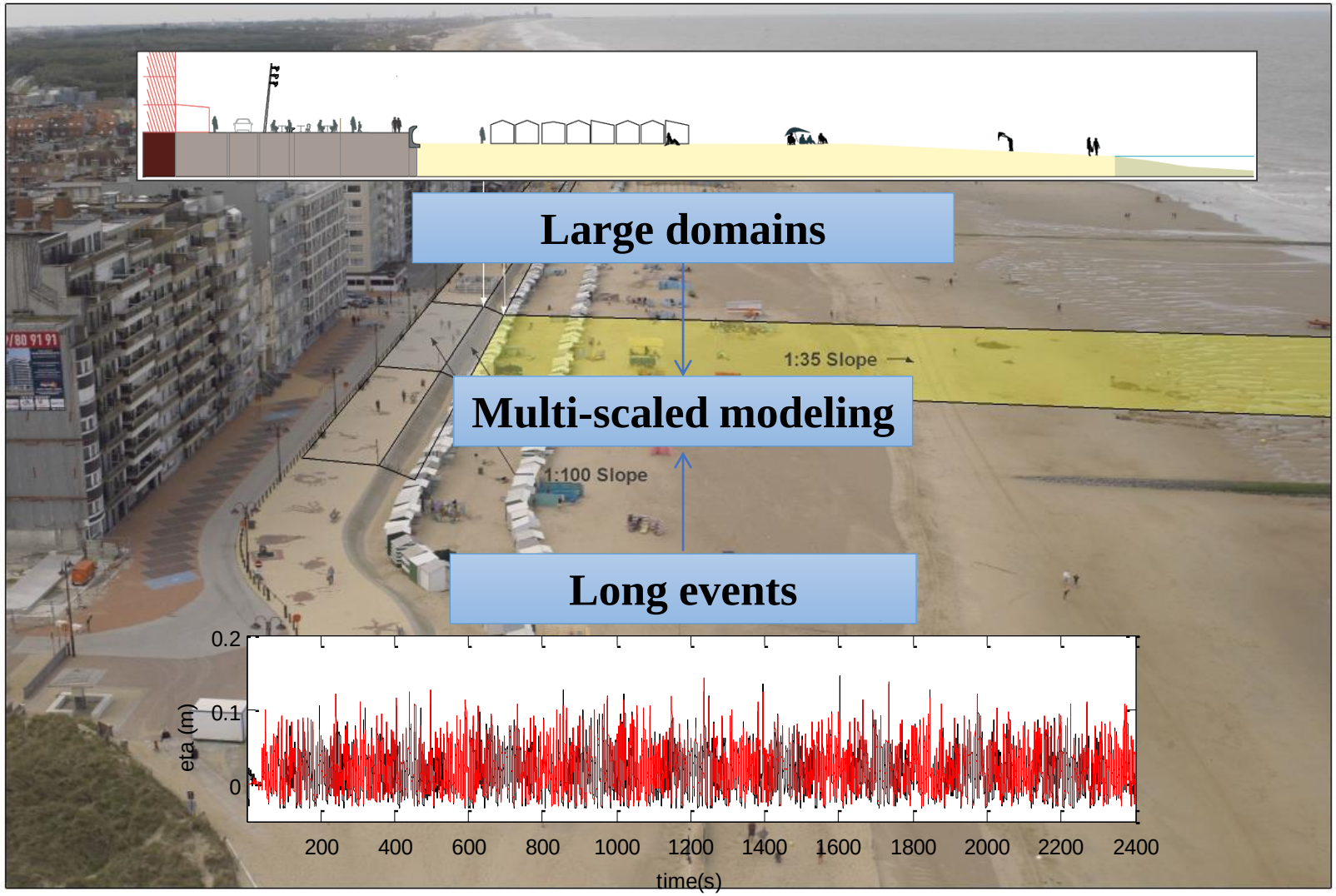


Coupling with SWASH

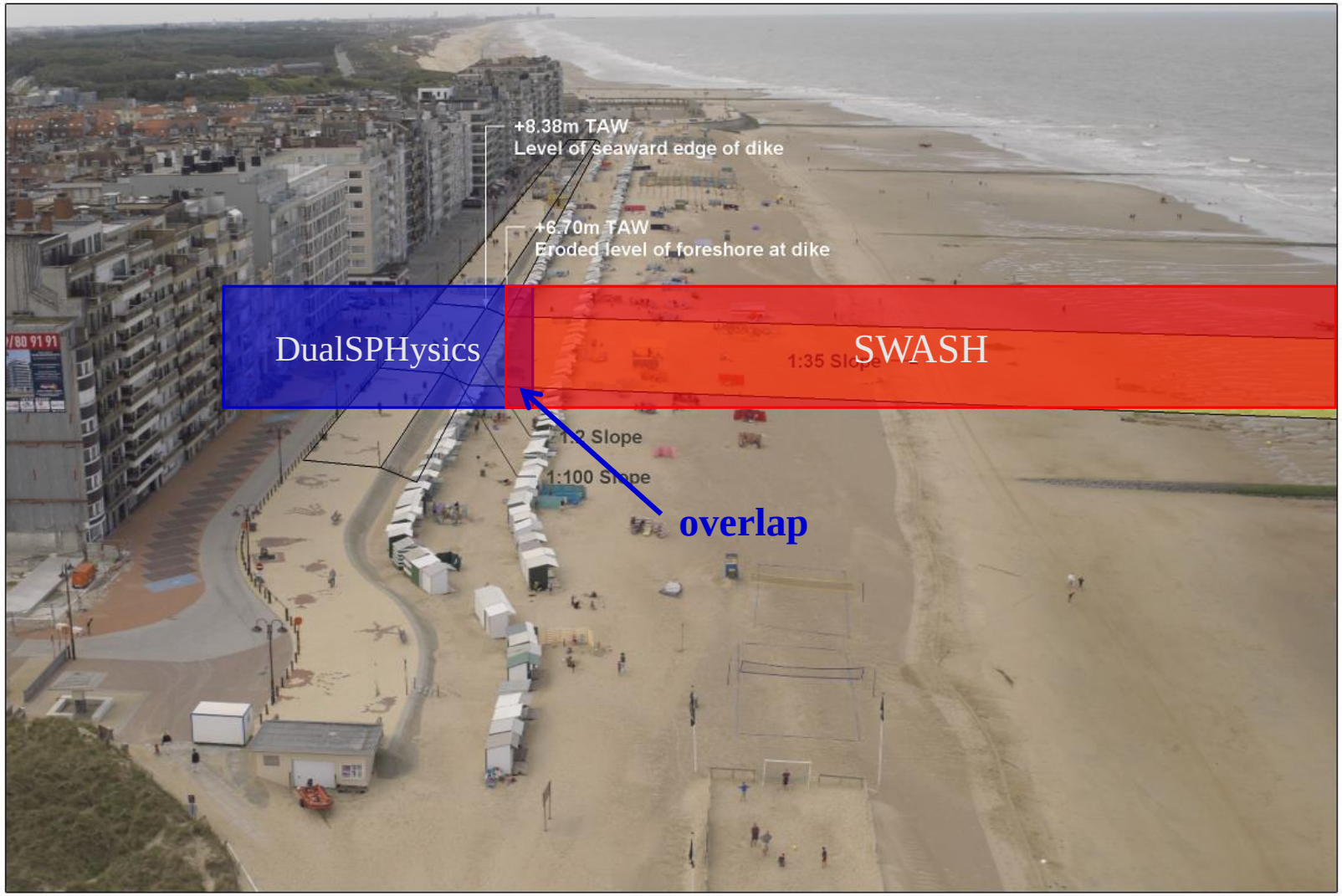


Impacts of wave overtopping flows on coastal defenses and buildings along the Flemish coast

Coupling with SWASH



Coupling with SWASH



Coupling with SWASH

Using the experimental water surface elevation signal

SWASH

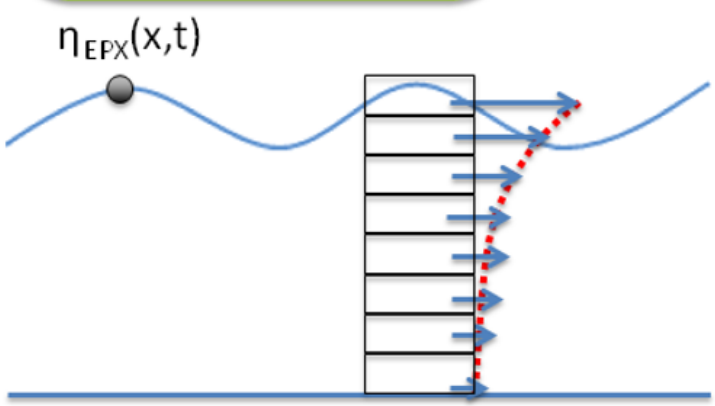
Multi –layered approach to get velocity distribution in time

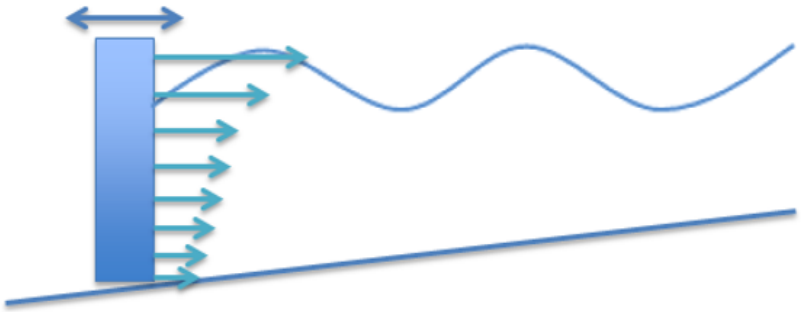
Coupling Point

Velocity data

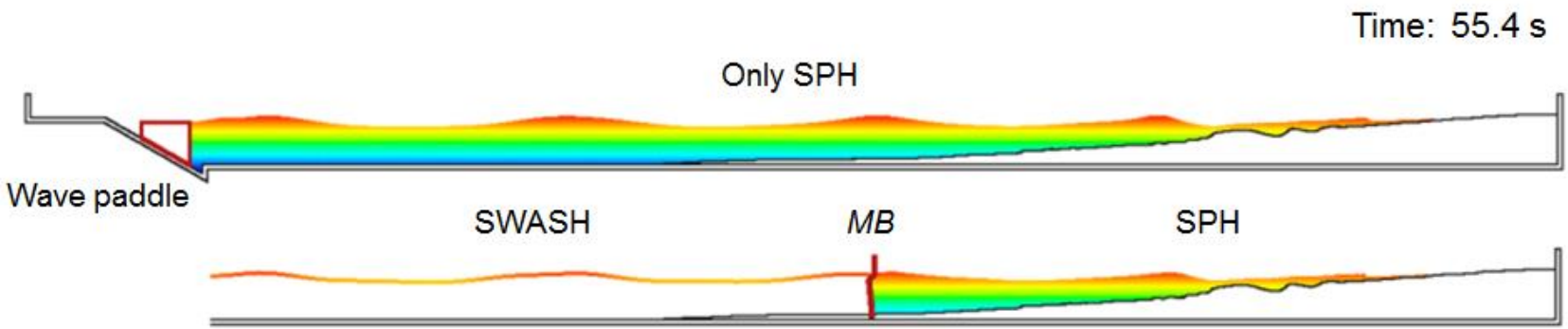
DualSPHysics

SWASH velocity is converted into the displacement of the Moving Boundary

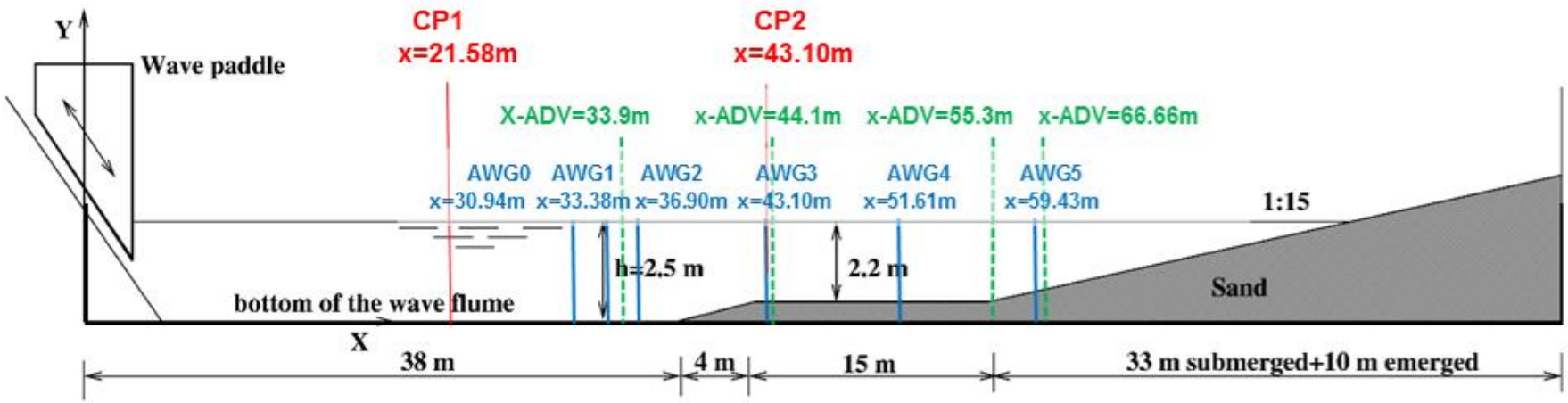




Coupling with SWASH



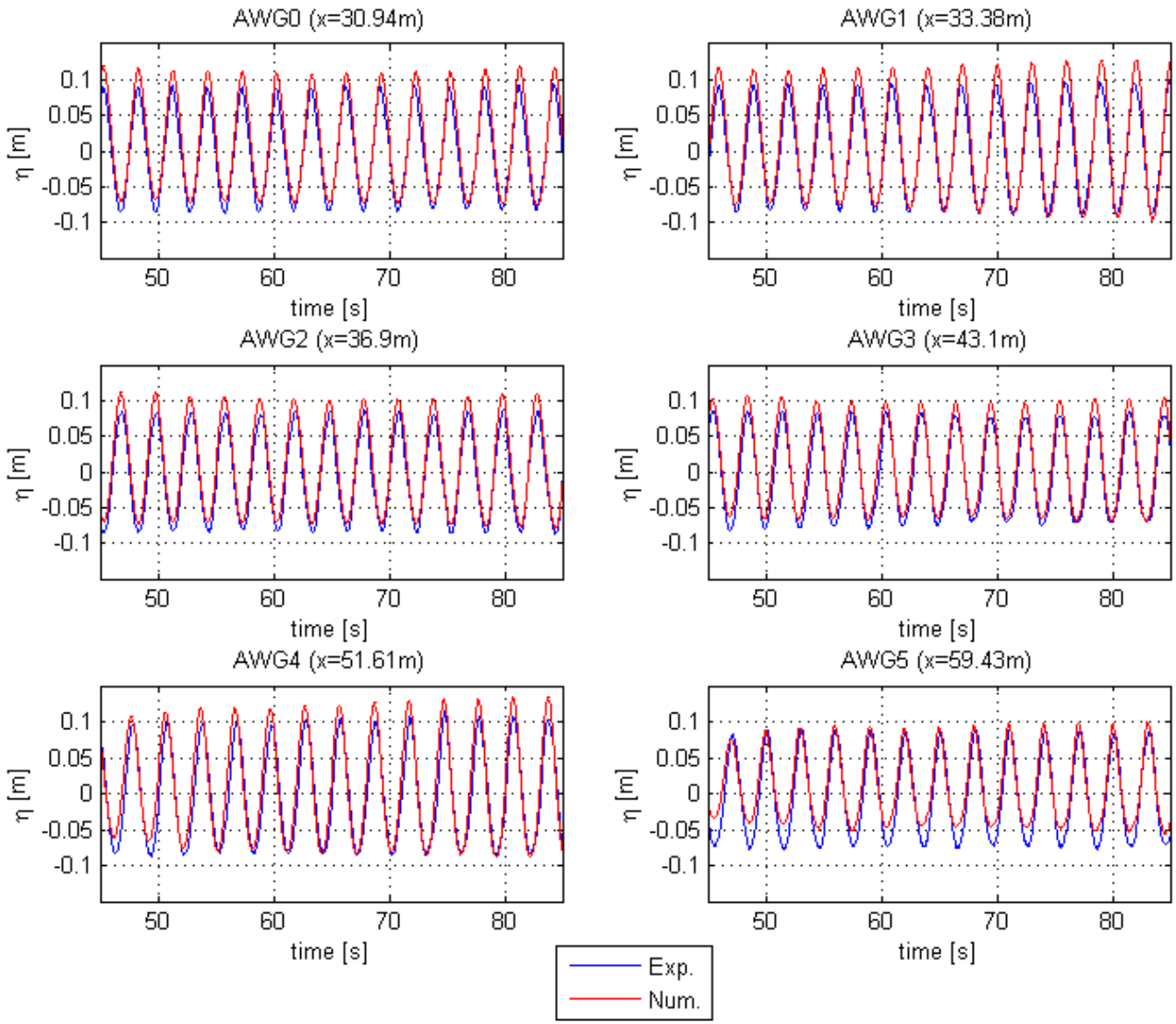
Sketch of the CIEM wave flume and locations of AWGs, ADVs and selected Coupling Points (CP)



Test case	H_{target} [m]	T_{target} [s]
A	0.2	5.5
B	0.2	3.0
C	0.3	5.5
D	0.3	3.0

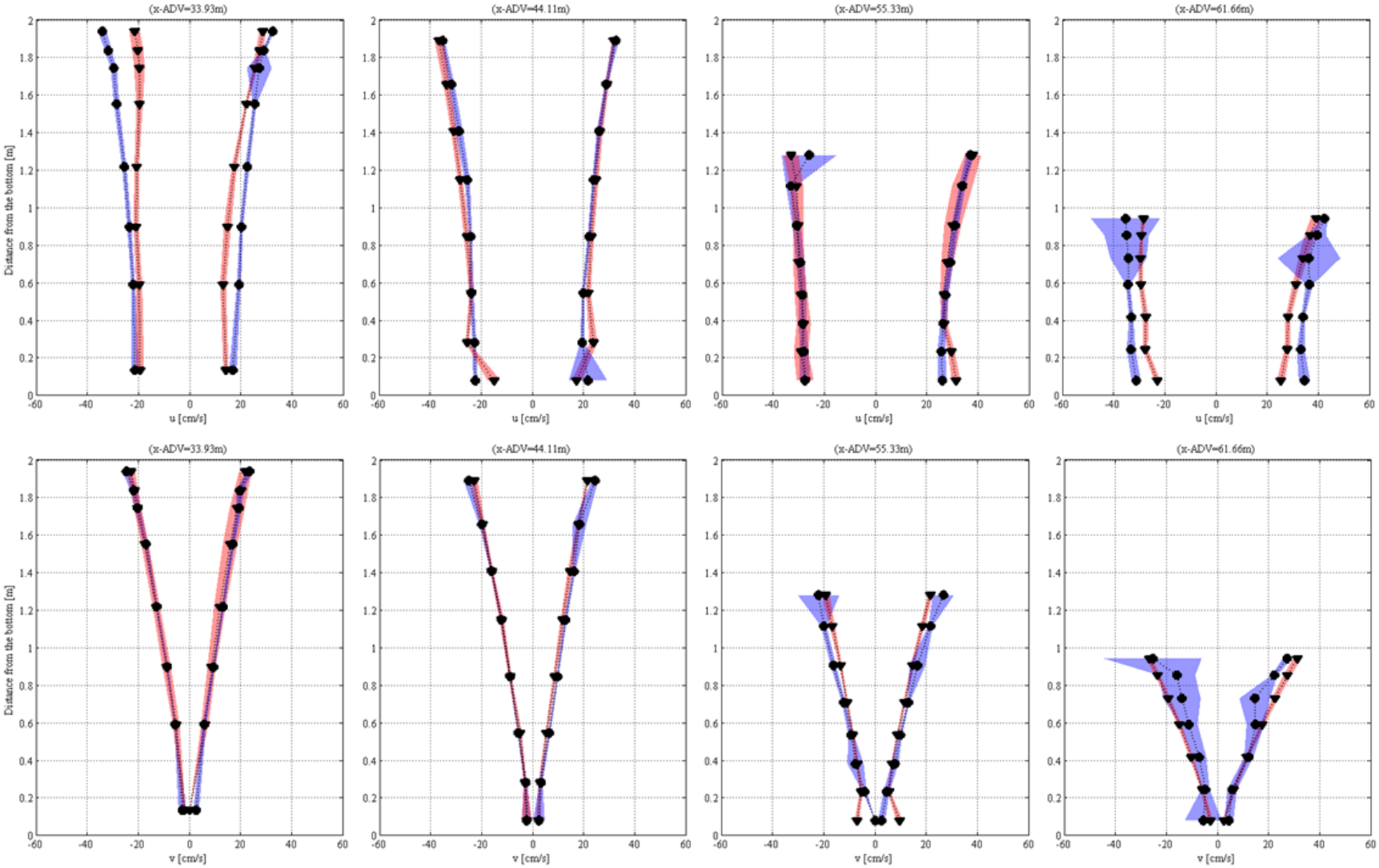
Coupling with SWASH

AWG free surface elevation: comparison between numerical and physical results (CP1, test case B)

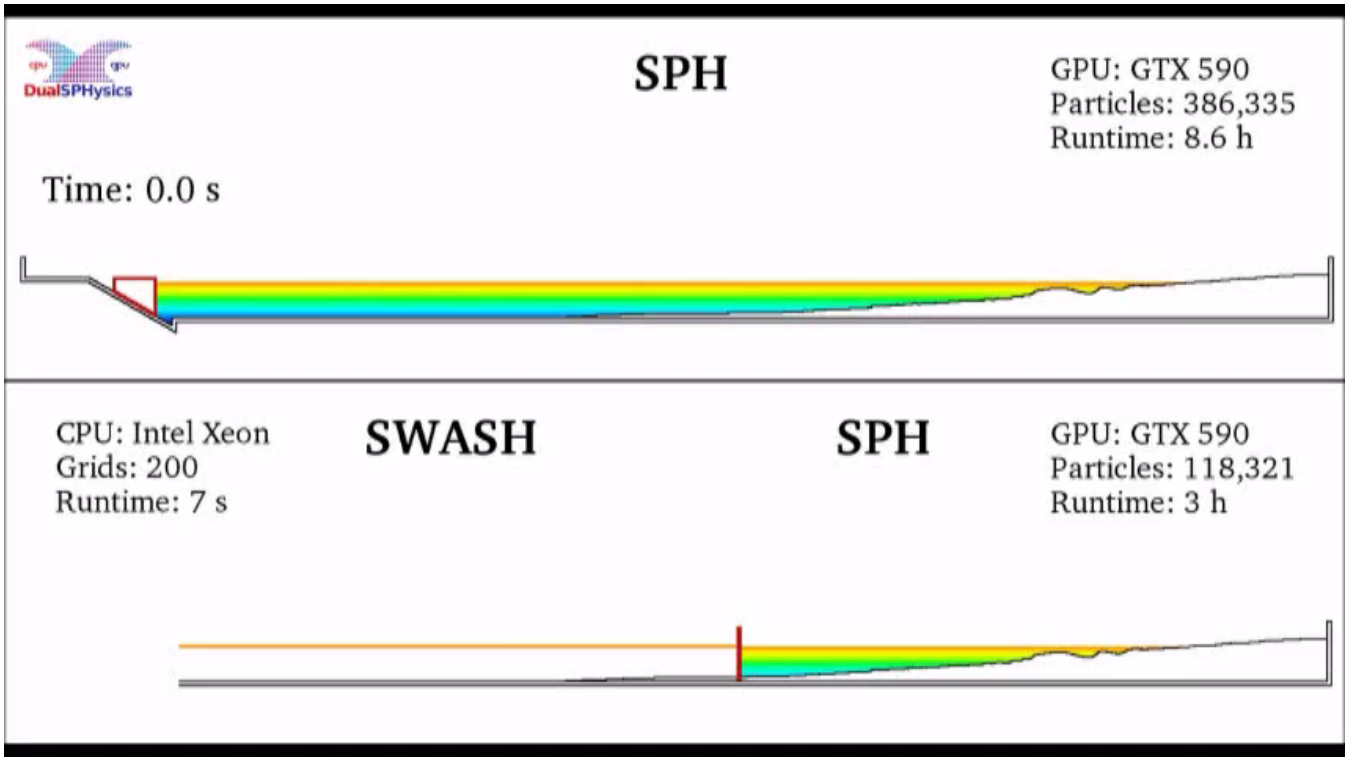


Coupling with SWASH

Horizontal and vertical velocity profiles (experimental in blue, numerical in red): mean values and confidence intervals (CP1, test case D).



Coupling with SWASH

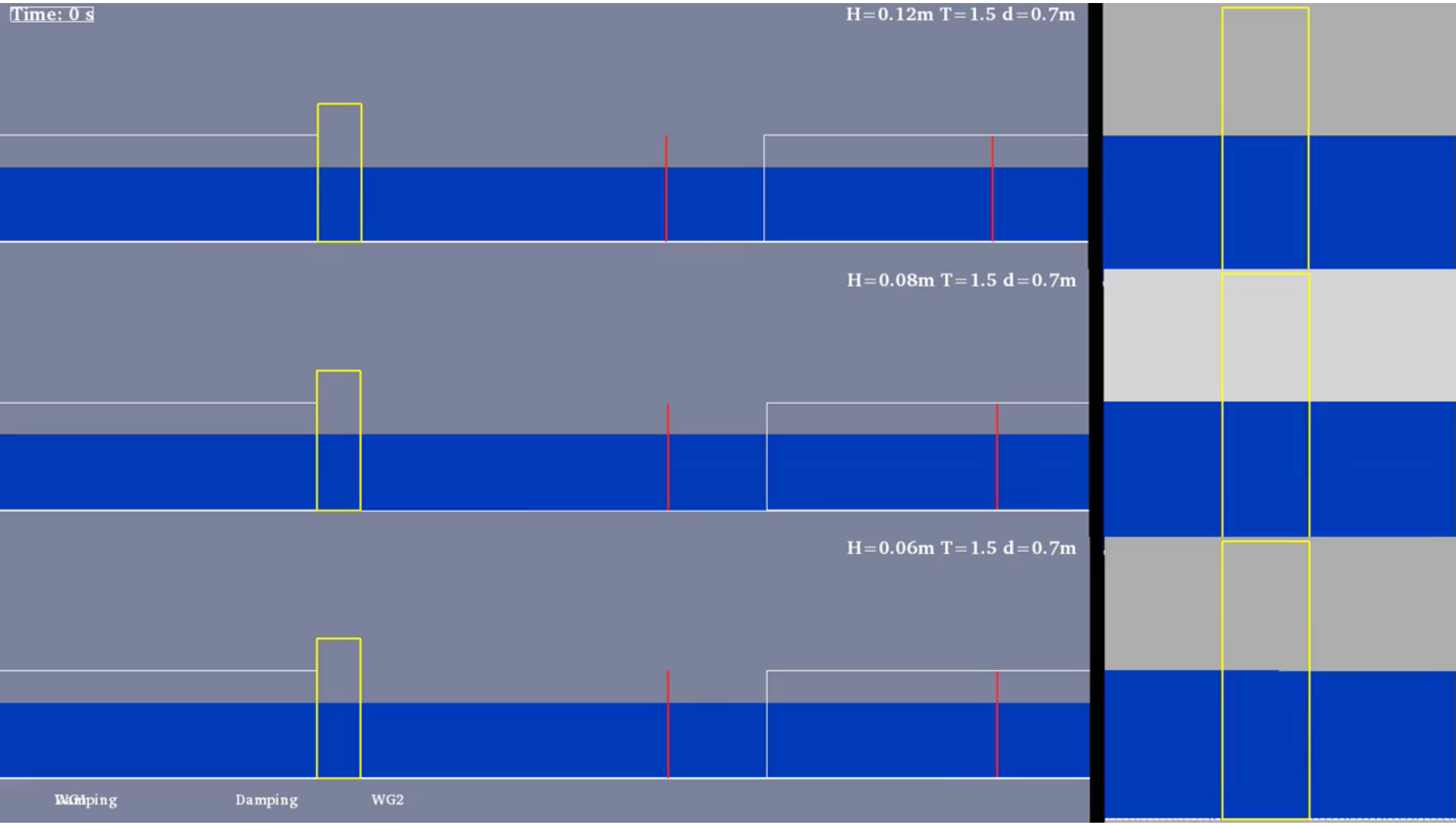


Improvements in time with different hybridisation points (domain sizes and runtimes)

	WP	CP1	CP2
DualSPHysics domain size	100%	78.42%	56.90%
Number of Particles	100%	62.89%	26.89%
Runtime	100%	70.49%	40.98%

Coupling with SWASH

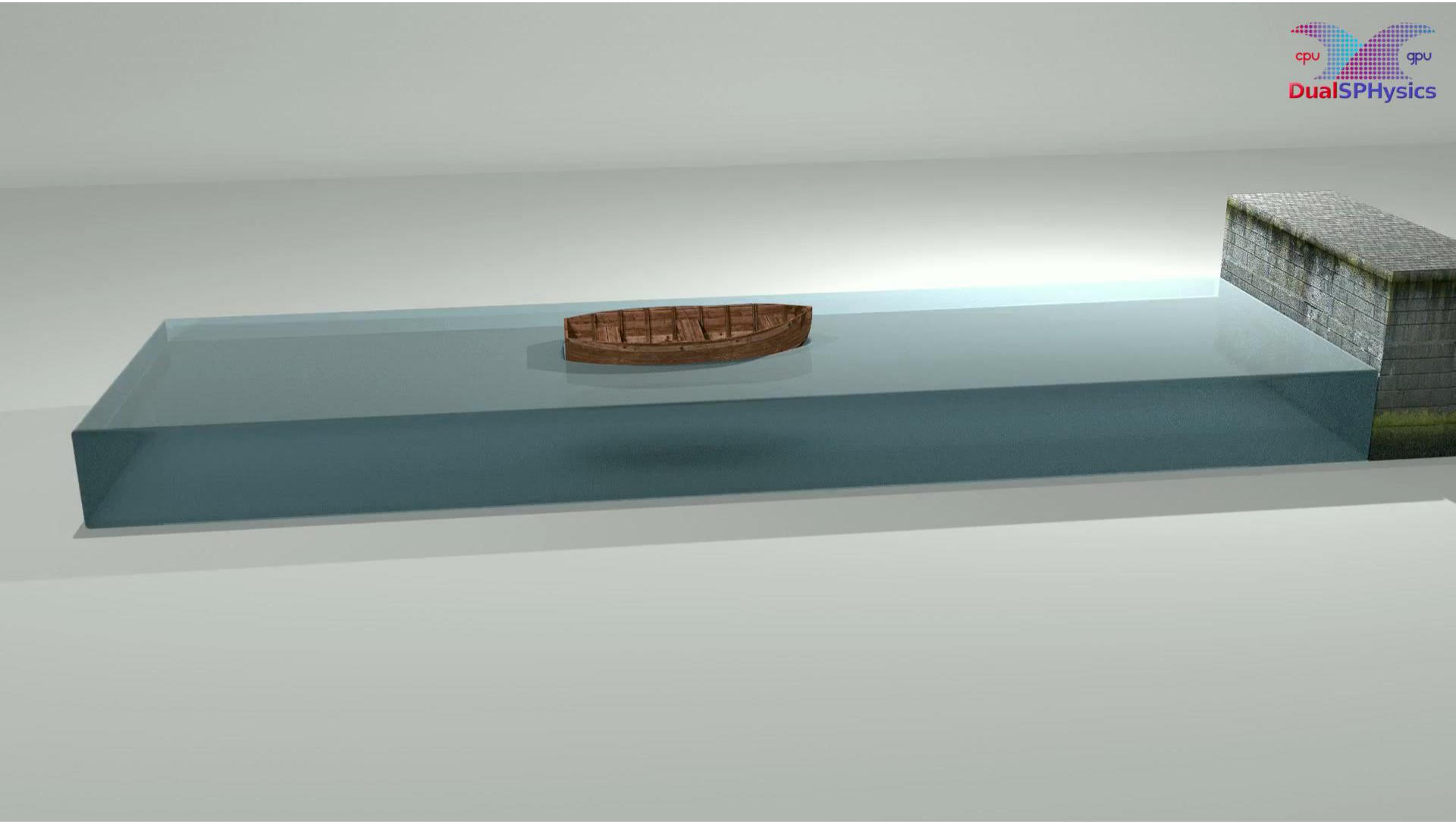
Source Generation (under development)



Outline of Presentation

- DualSPHysics in coastal protection
  - Wave generation & wave absorption
  - Wave-structure interaction
  - Coupling with wave propagation models
- DualSPHysics in wave energy
  - Wave interaction with floating bodies
  - Catenary moorings
  - Simulation of an Oscillating Water Column

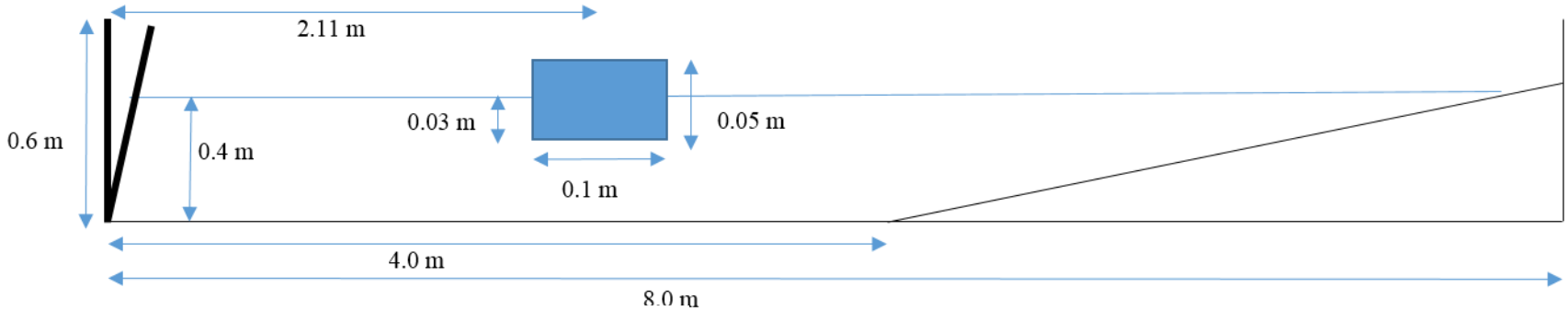
Wave interaction with floating bodies

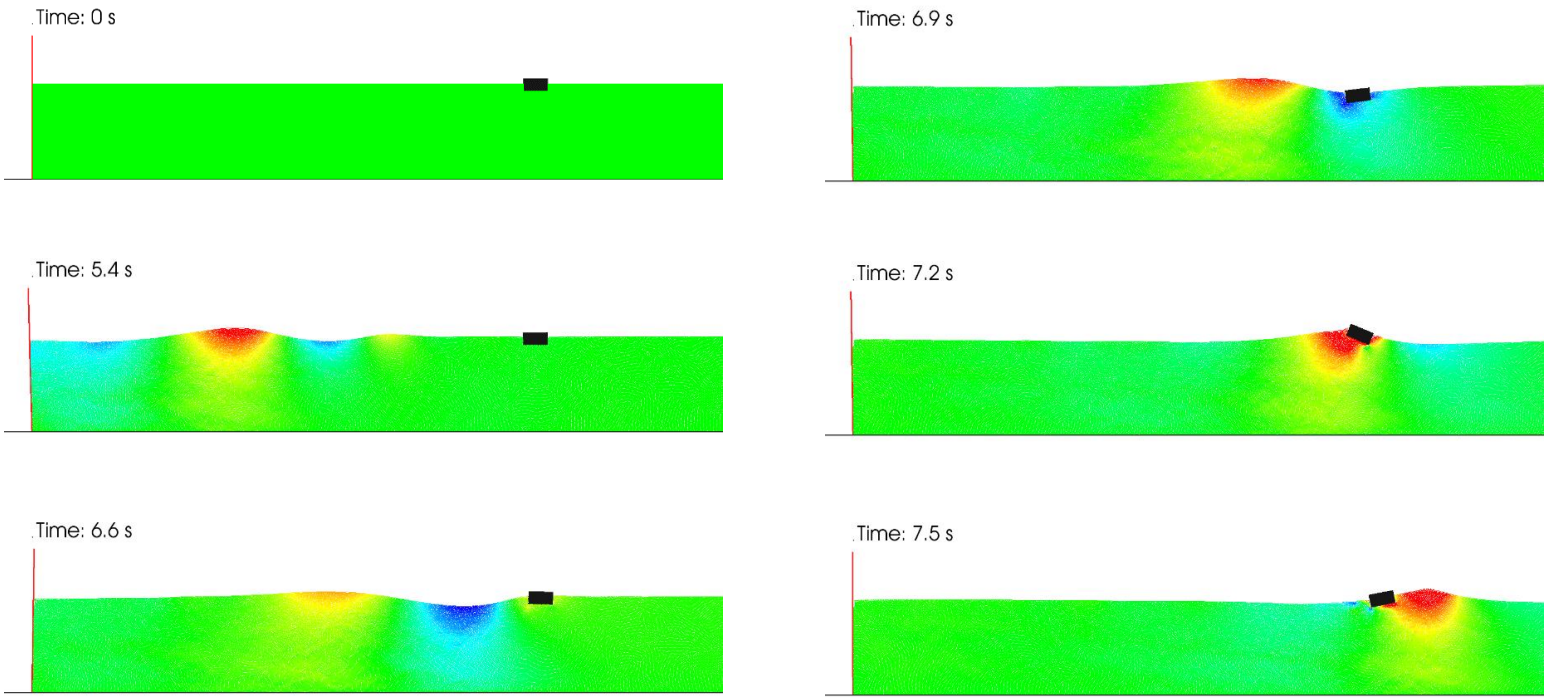


Wave interaction with floating bodies

Floating body subjected to a wave packet is validated with experimental data

Hădzić et al., 2015





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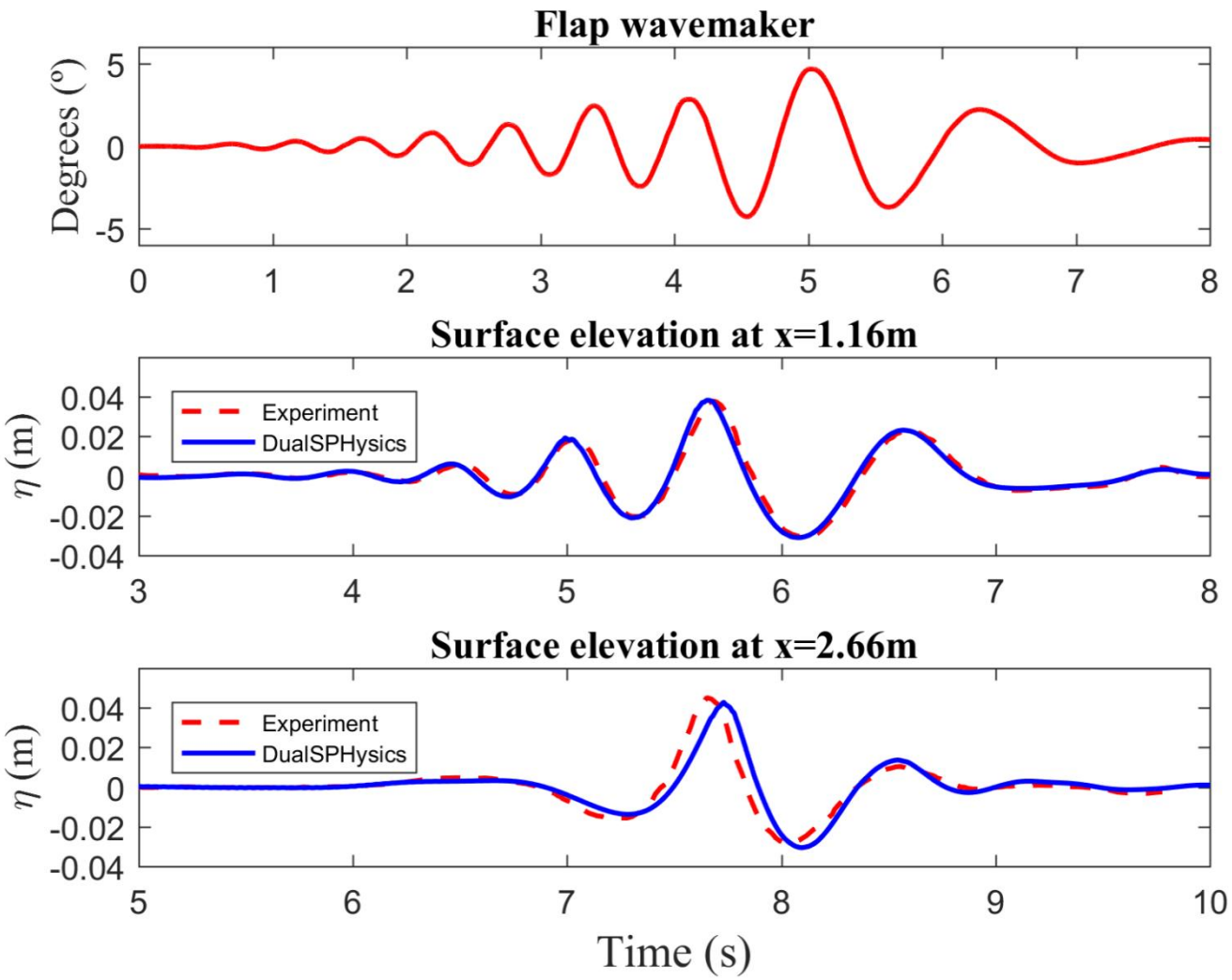
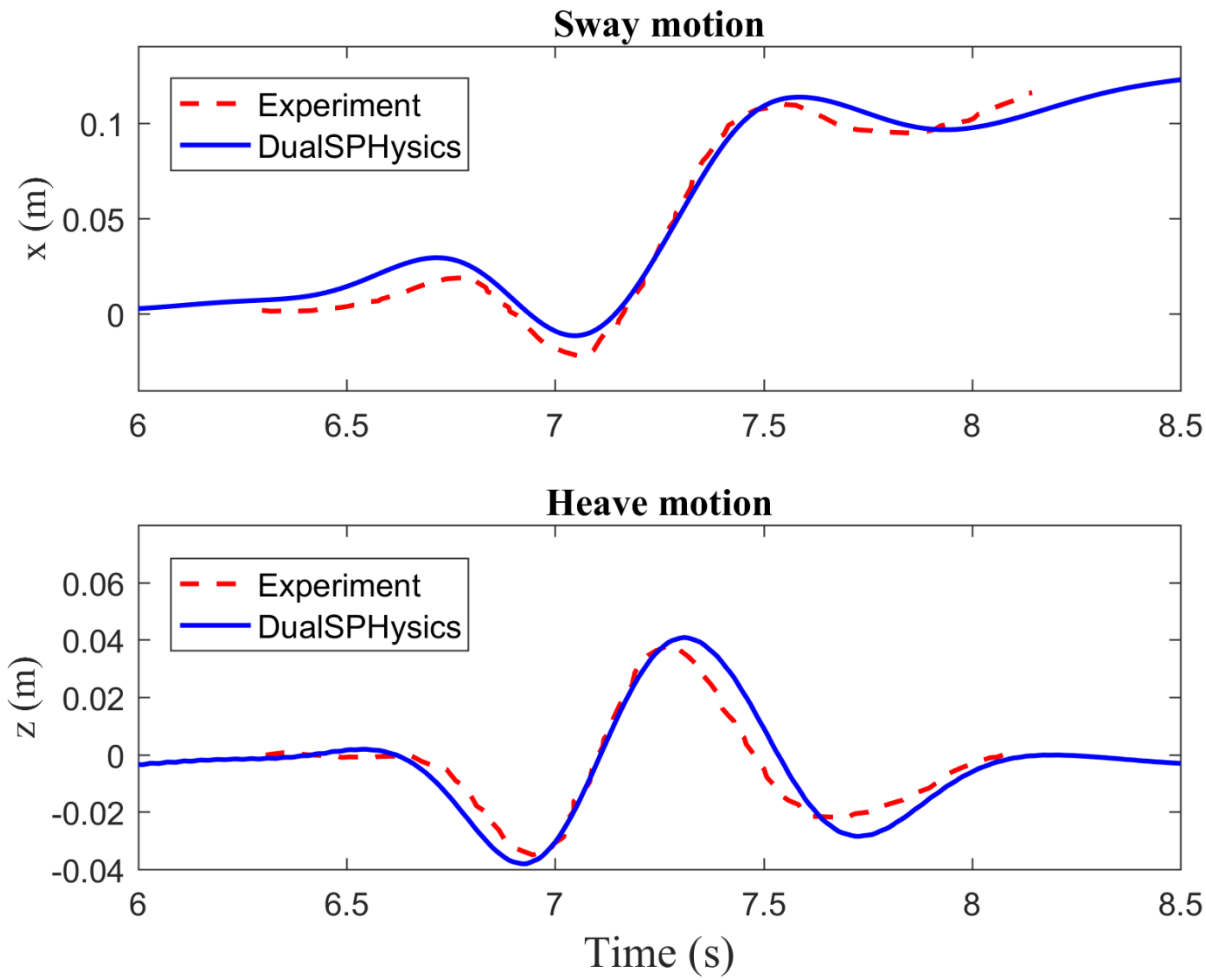
Wave interaction with floating bodies



Wave interaction with floating bodies



Floating moored objects

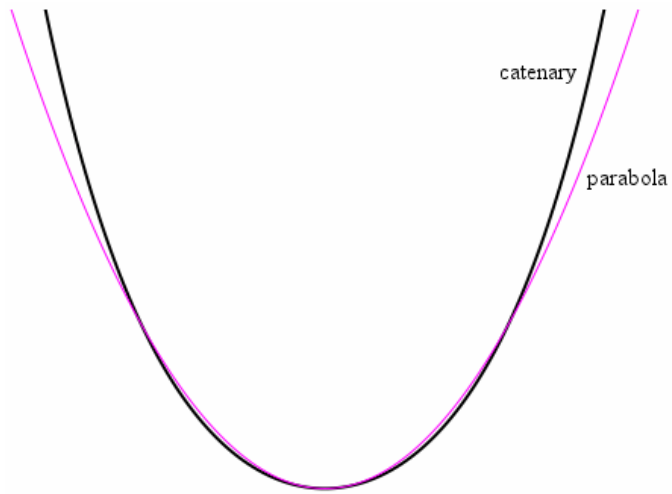
These objects are floating in the water and moored,
thus a proper formulation is needed and must be validated

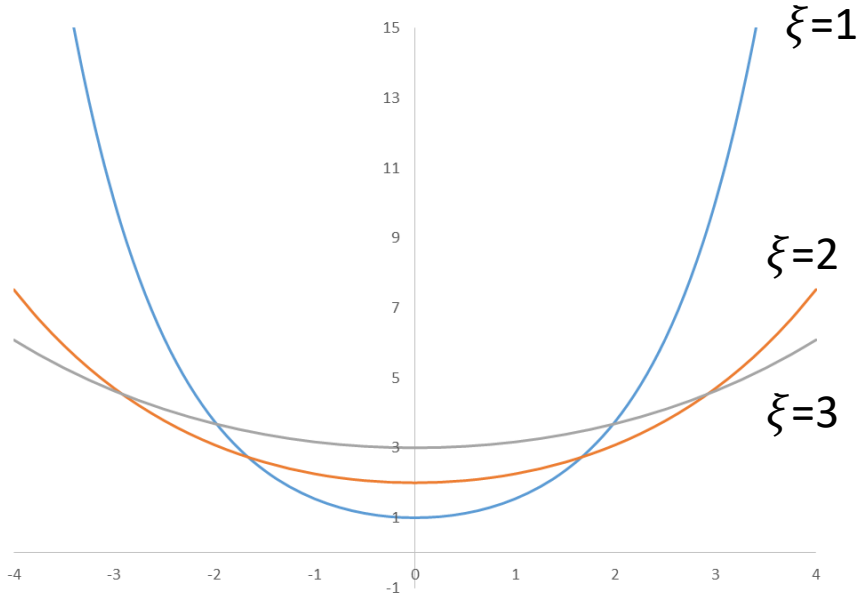
Floating moored objects

The **catenary function** refers to the mathematical description of a line with mass hanging between two points.

$$y = \xi \cosh\left(\frac{x}{\xi}\right)$$

ξ is the form parameter

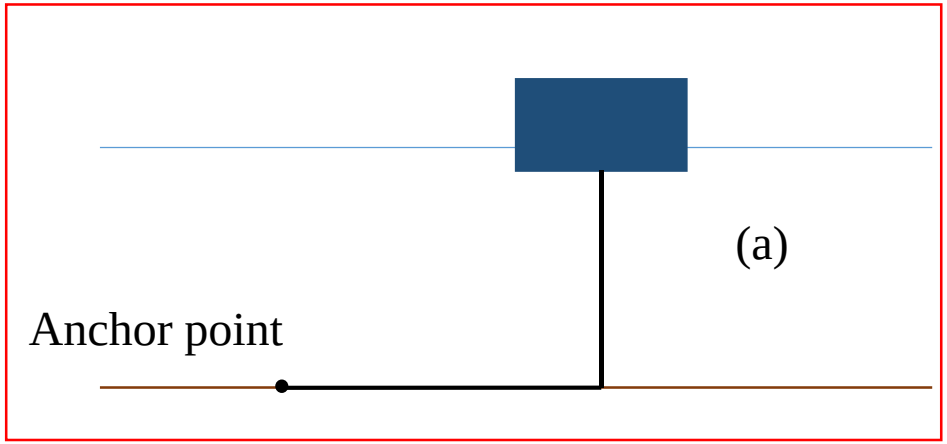


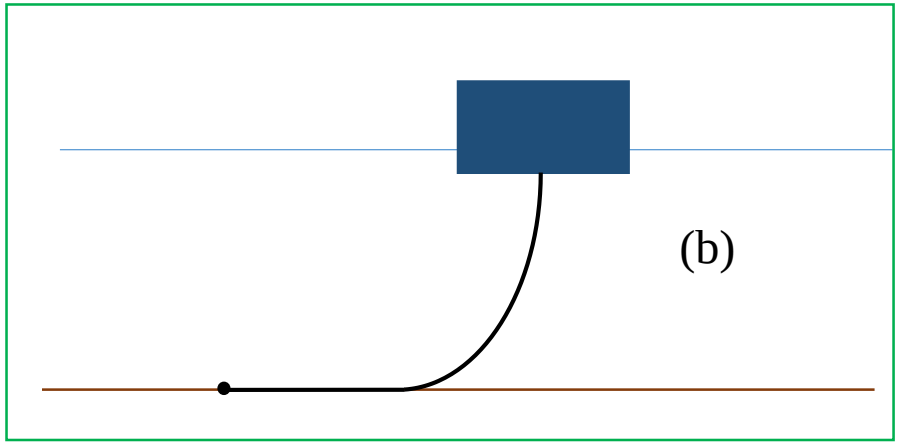


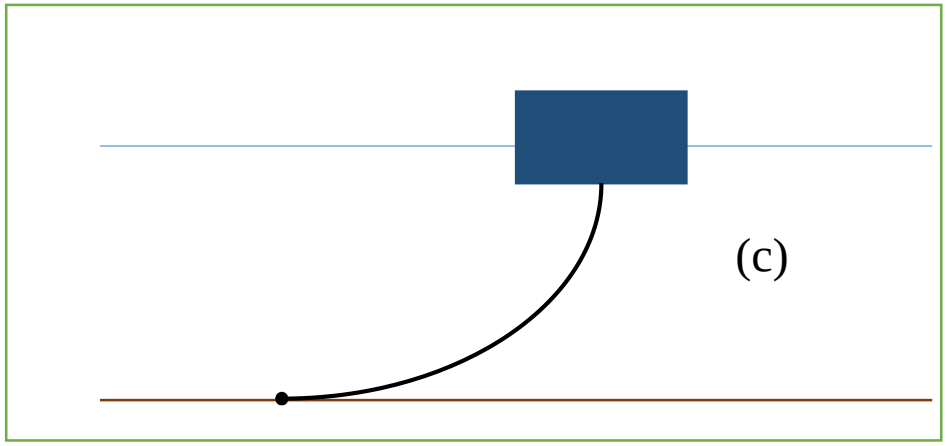
The maths from the work of **Faltinsen (1993)** is behind this implementation

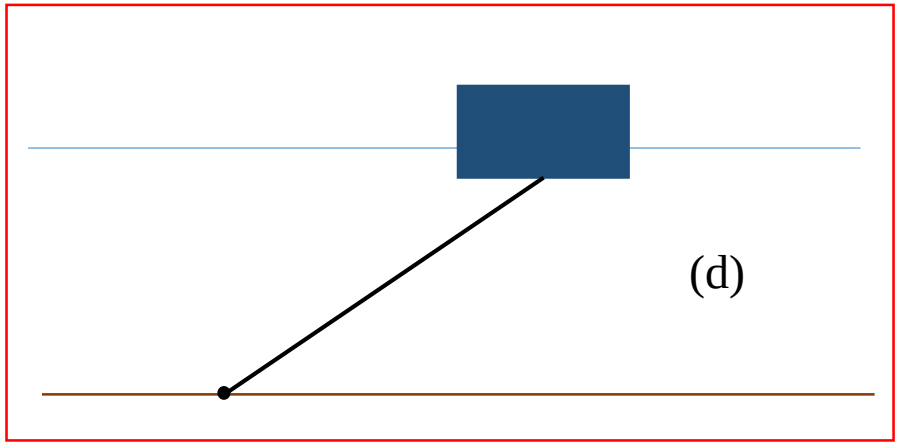
Floating moored objects

FOUR different conditions for moorings are considered:
the resting chain, partially resting chain, partially extended chain and the fully extended chain





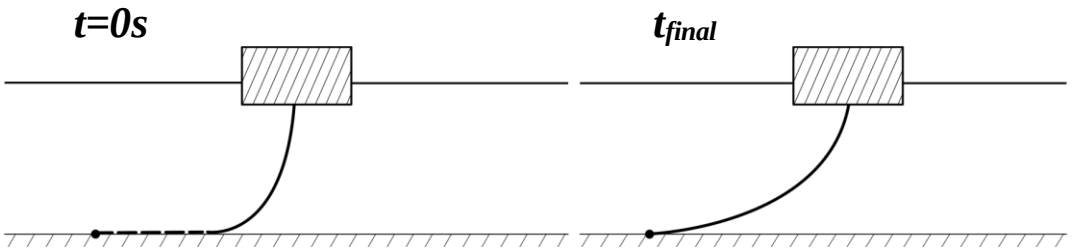


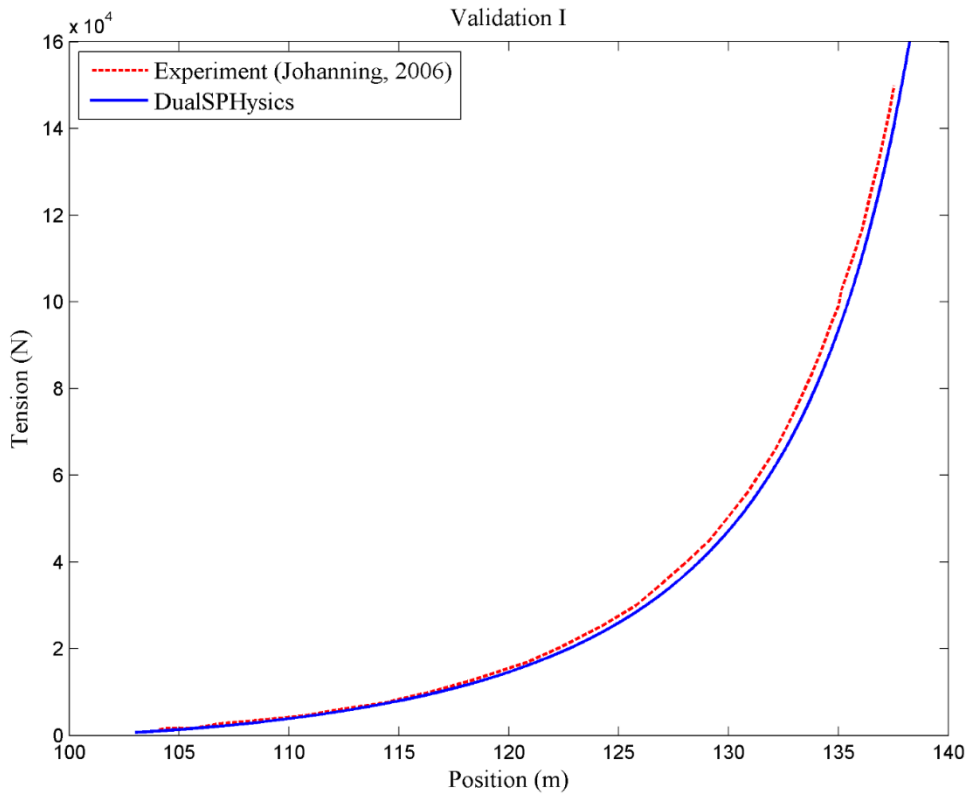


Floating moored objects

Validation with experimental data from **Johanning et al (2006; 2007)**

(a)
one line

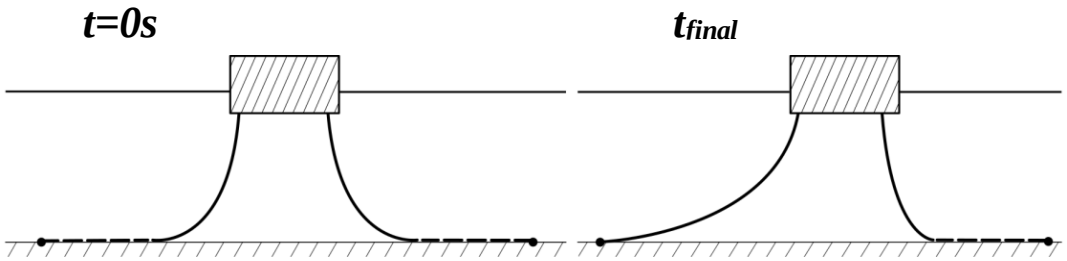


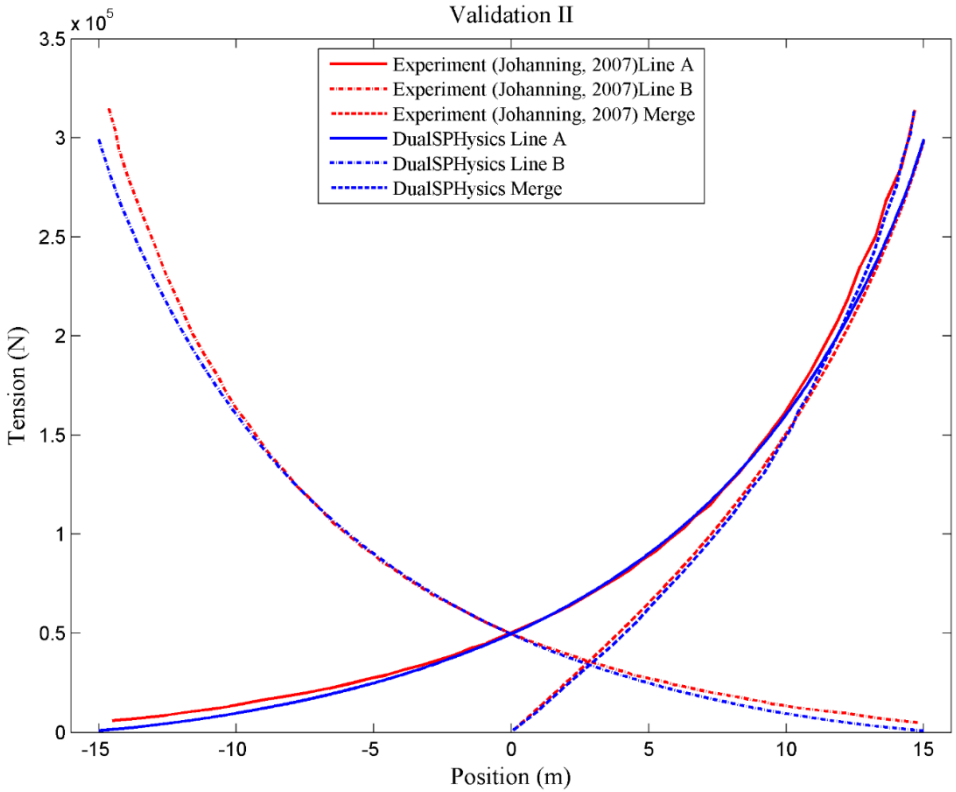


Floating moored objects

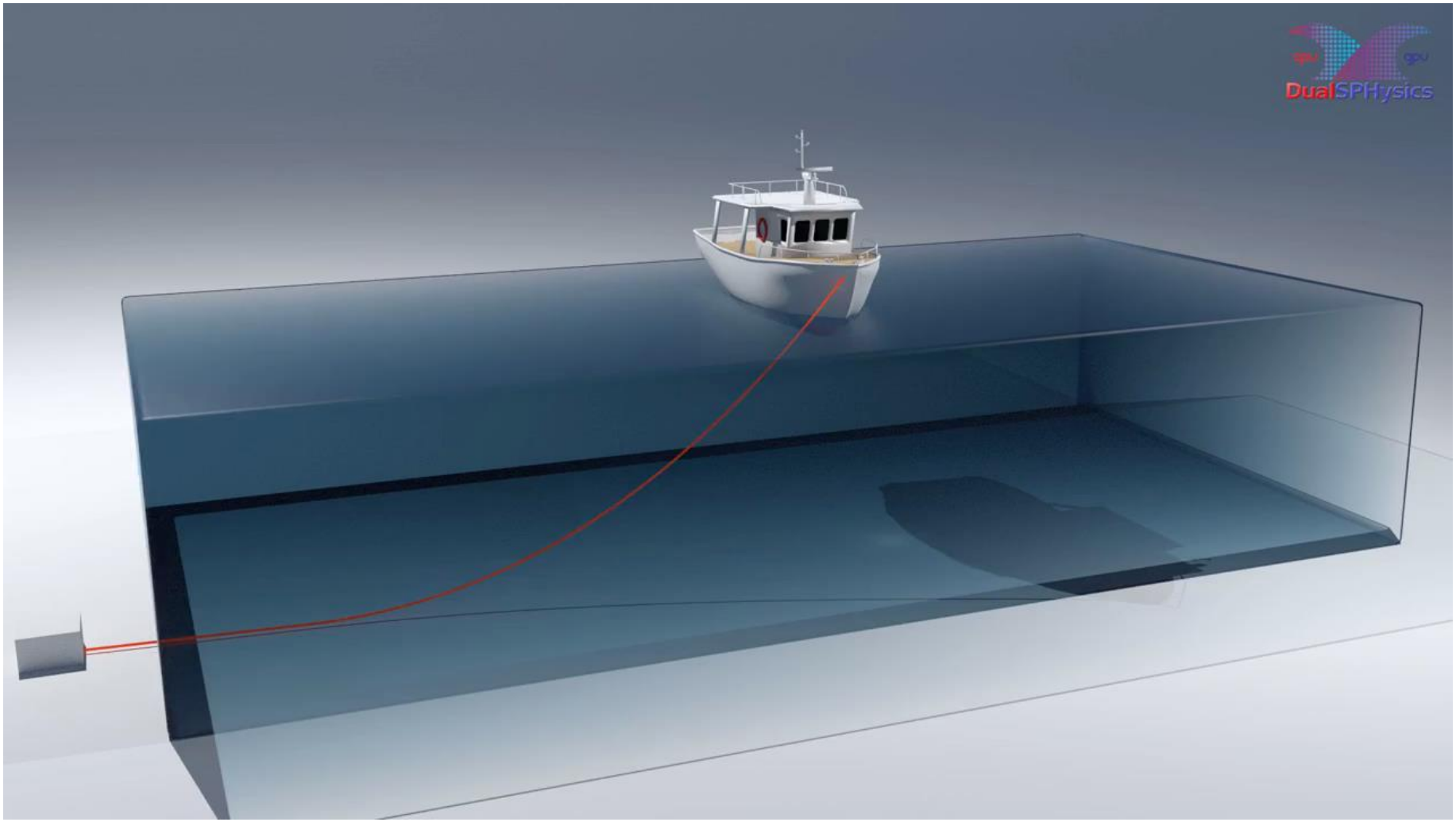
Validation with experimental data from **Johanning et al (2006; 2007)**

(b)
two lines

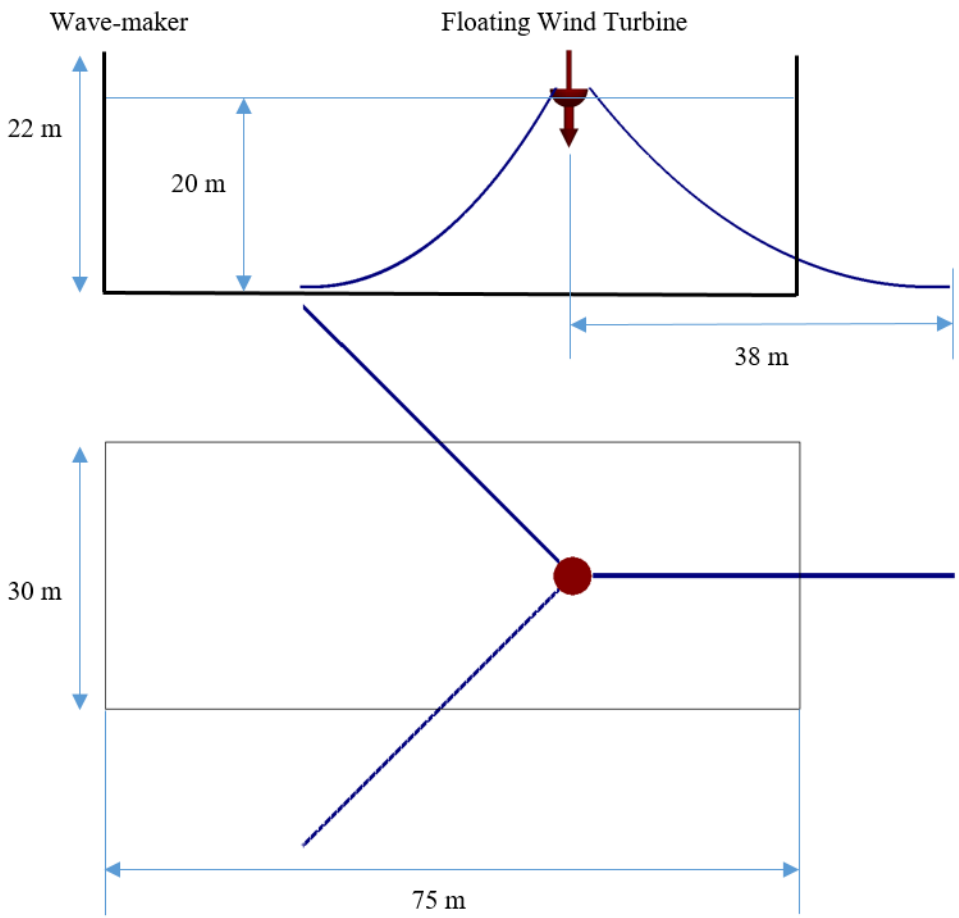


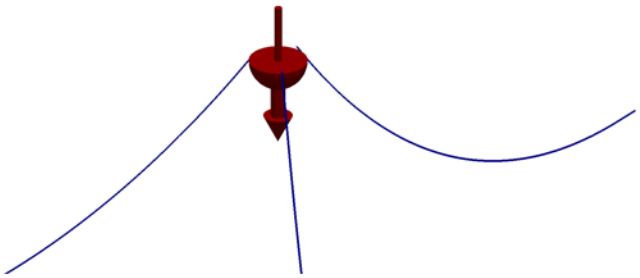


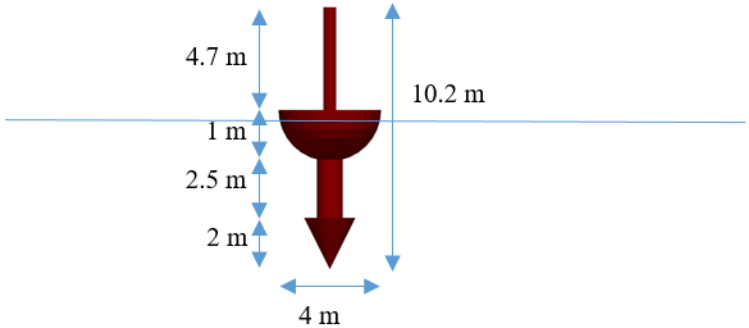
Floating moored objects

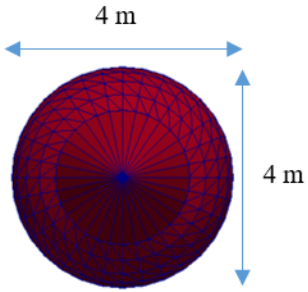


Floating moored objects

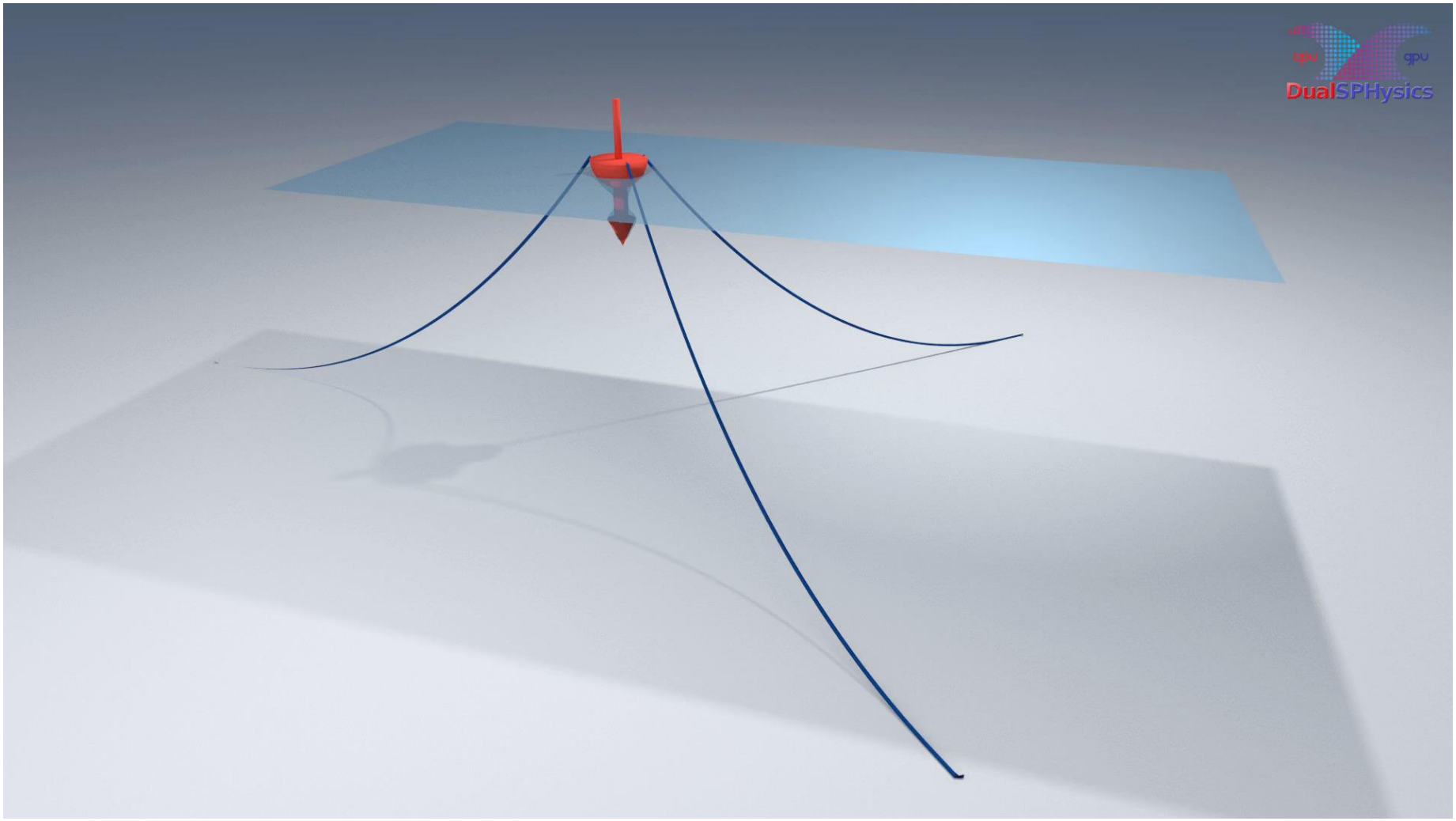




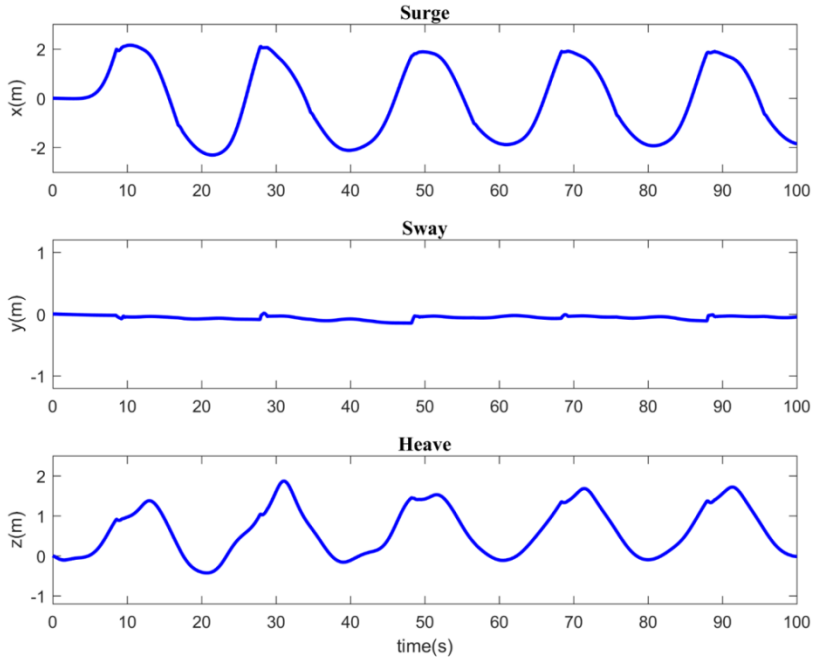


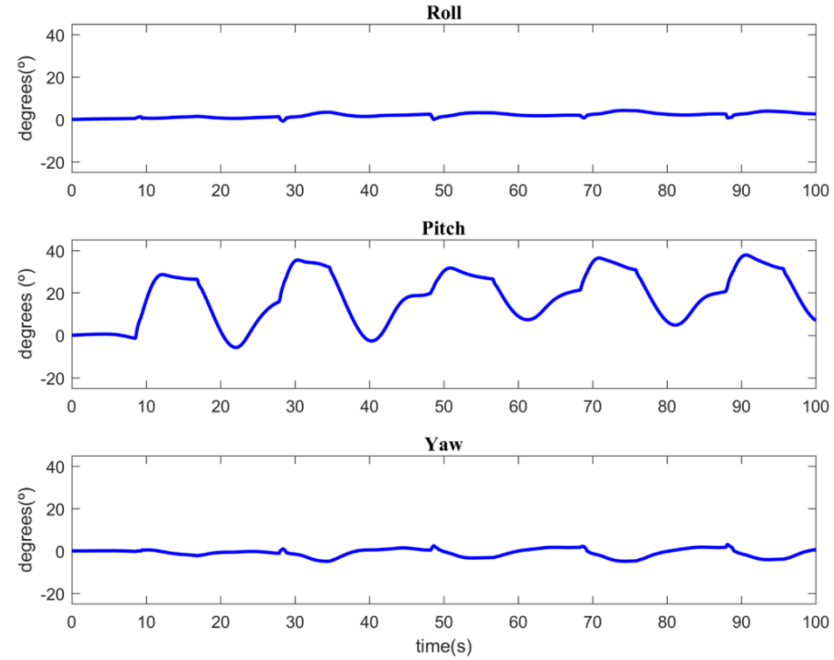


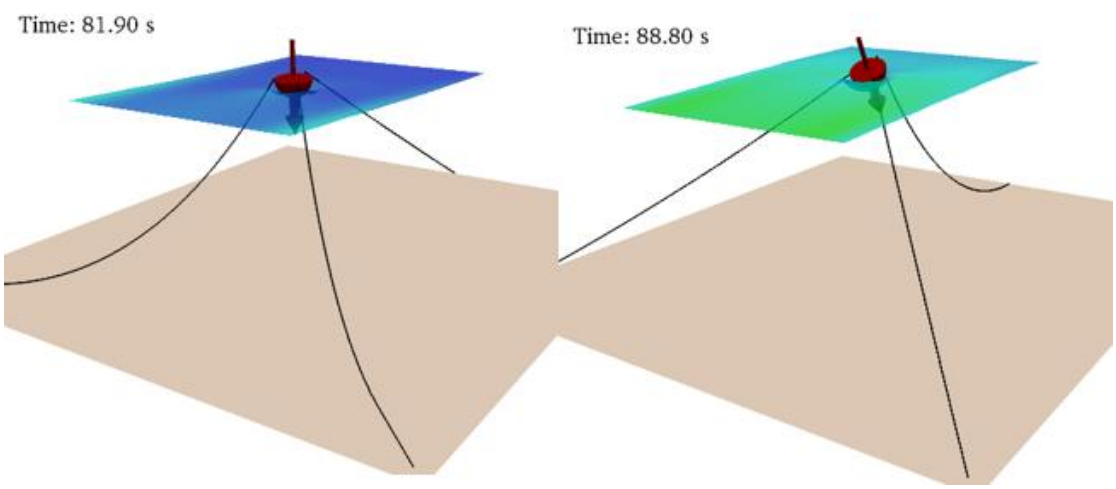
Floating moored objects



Floating moored objects

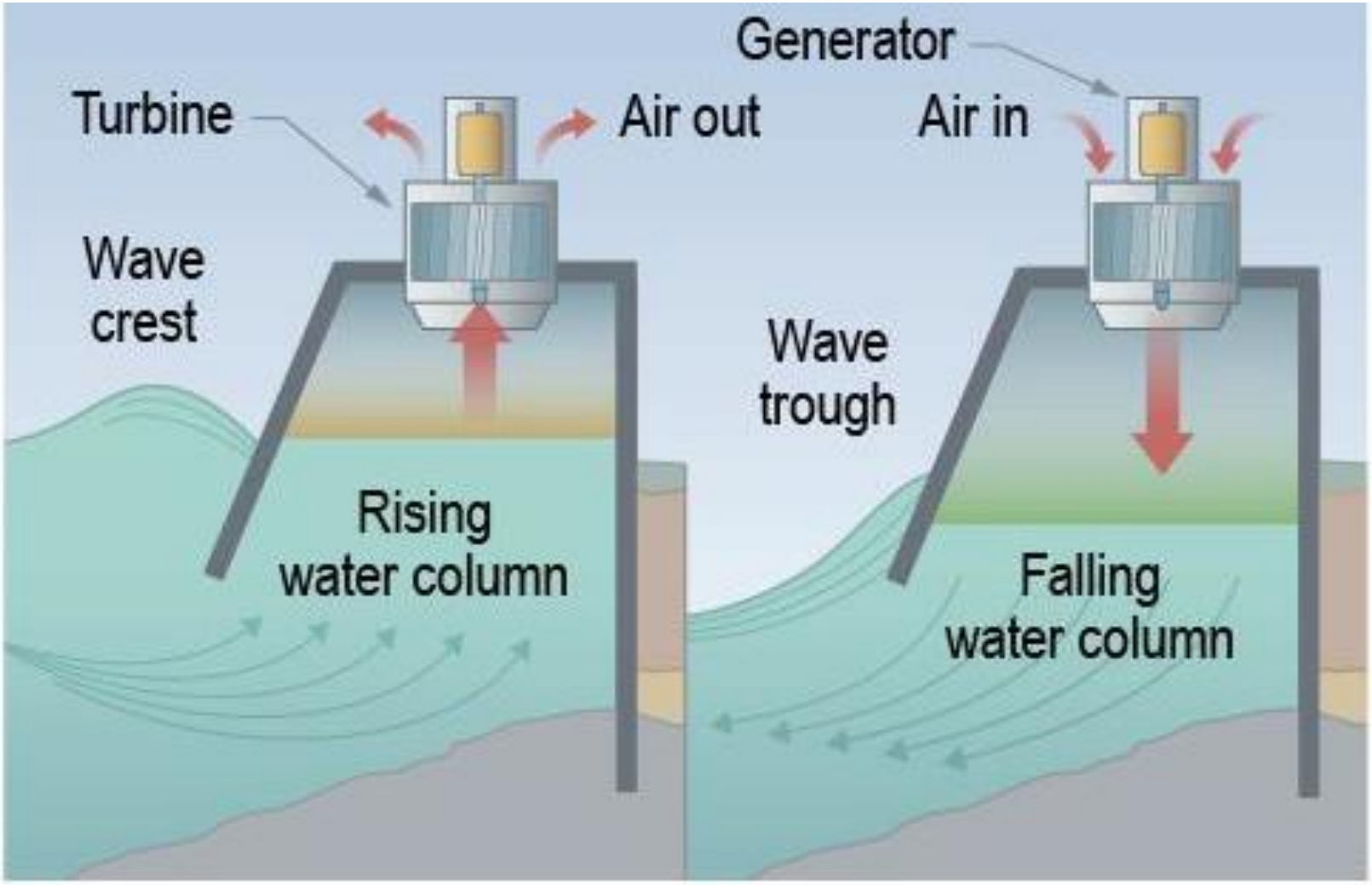






WE ARE NOW VALIDATION MOORINGS WITH MORE EXPERIMENTS

Design of Oscillating Water Column



http://en.openei.org/

Design of OWC

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

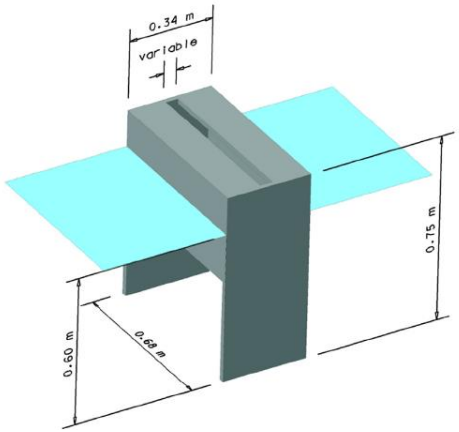
OpenFoam

Meshless methods

SPH

EXPERIMENT IN IH-CANTABRIA

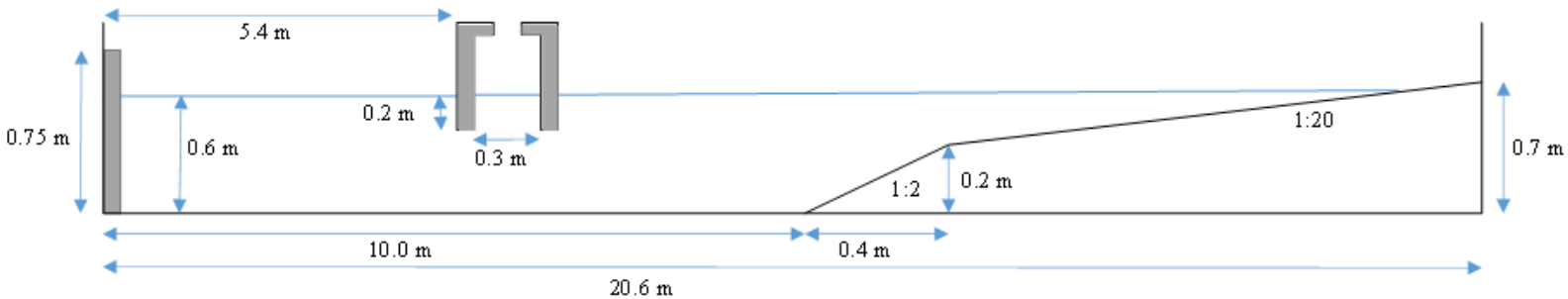
The experiment (scale of 1/30) was carried out in the IH-Cantabria: Laboratory wave flume (left) and chamber model (right).



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.

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.



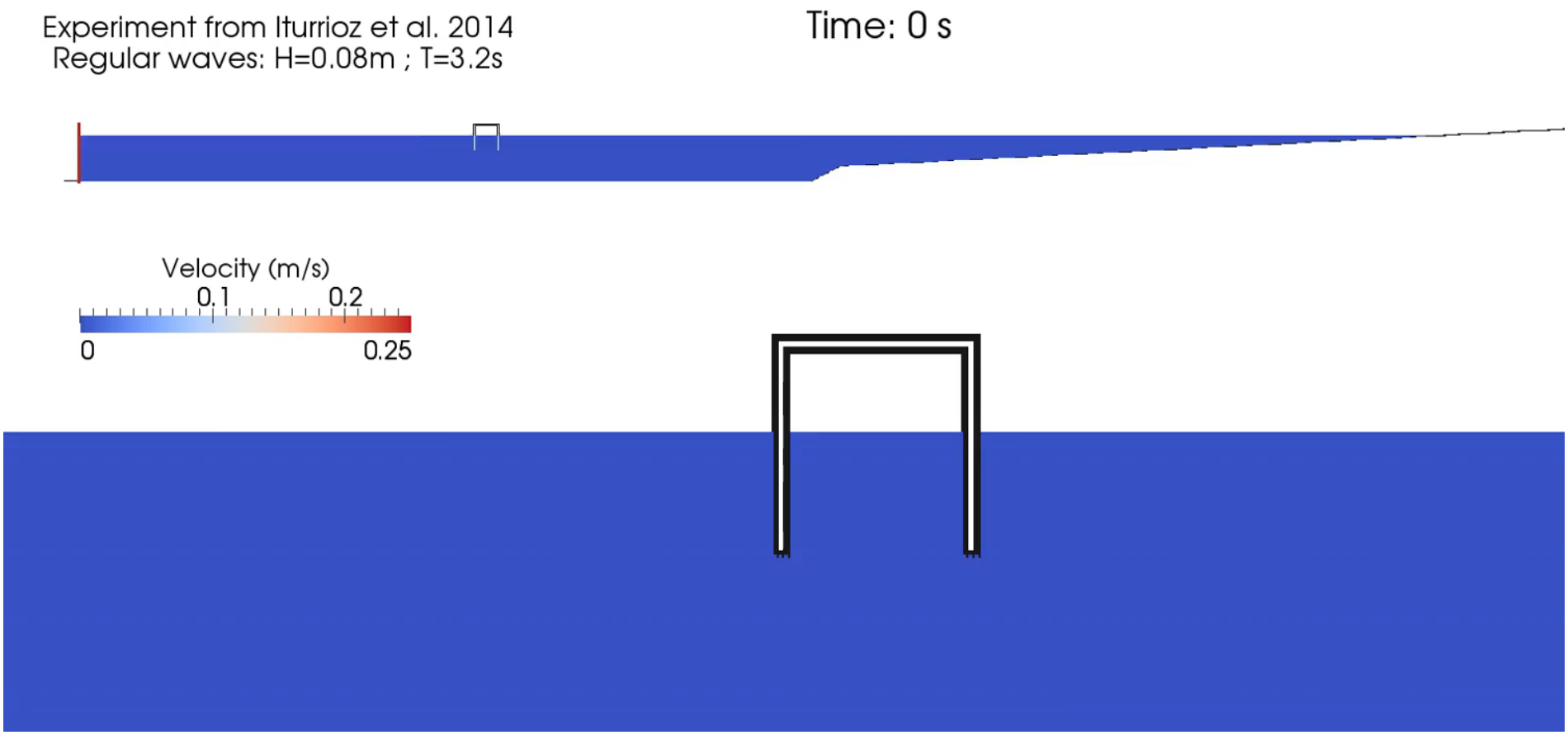
Wave conditions of the experiments in Iturrioz et al. (2014)

Height (H)	Period (T)	Depth (d)	Wavelength (L)	Relative depth (d/L)	Wave order
0.08 m	3.2 s	0.6 m	7.46 m	0.08	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.

Design of OWC

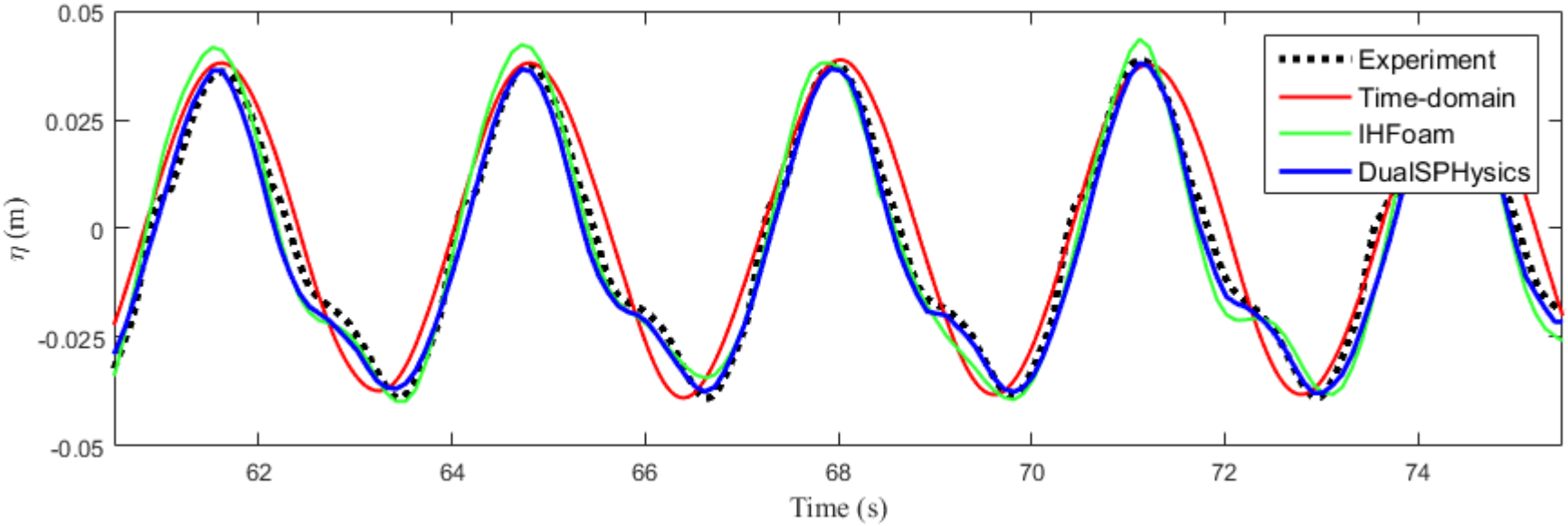
EXPERIMENT IN IH-CANTABRIA



Design of OWC

EXPERIMENT IN IH-CANTABRIA

2nd order: T=3.2s, H=0.08m, d=0.6m, L=7.46 m



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

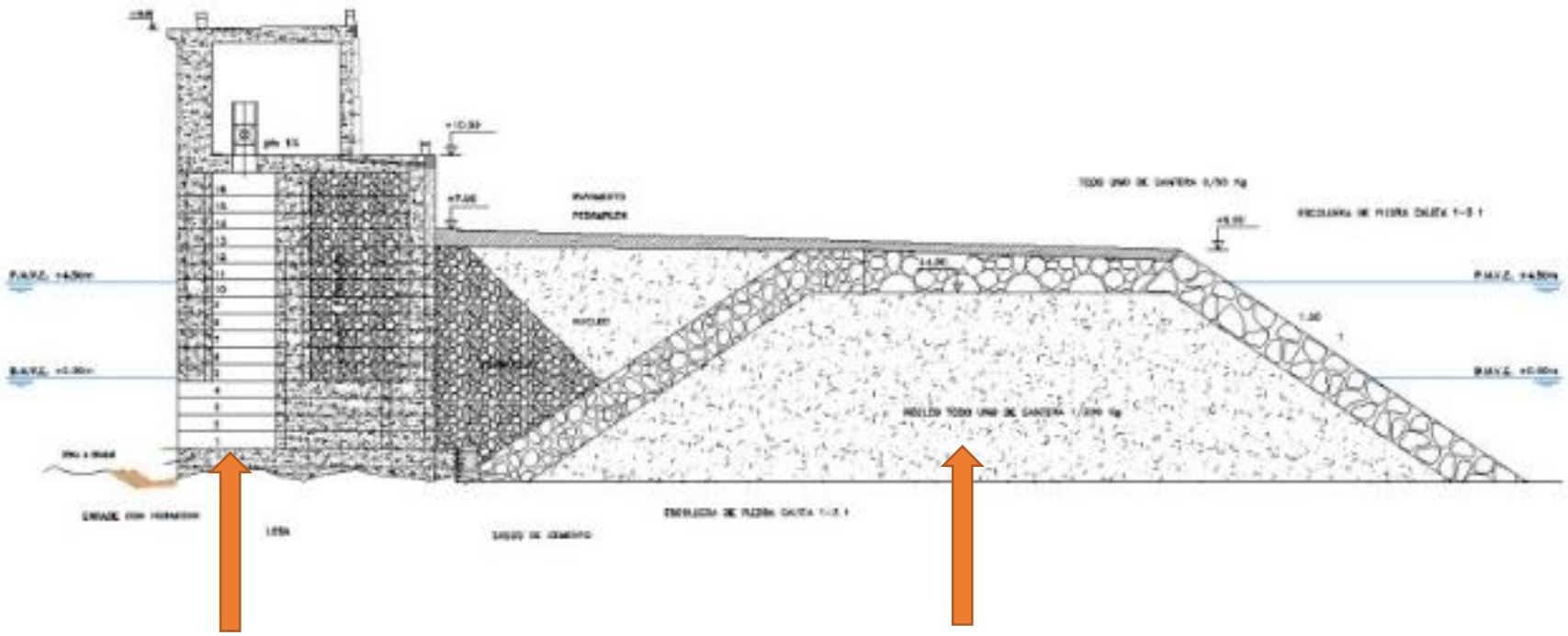
Design of OWC

ONSHORE OWC IN MUTRIKU (SPAIN)

Design of OWC

ONSHORE OWC IN MUTRIKU (SPAIN)

Cross section of Mutriku breakwater

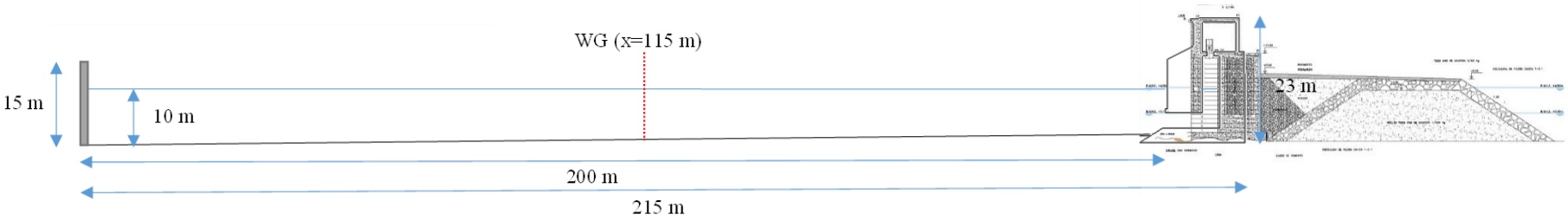


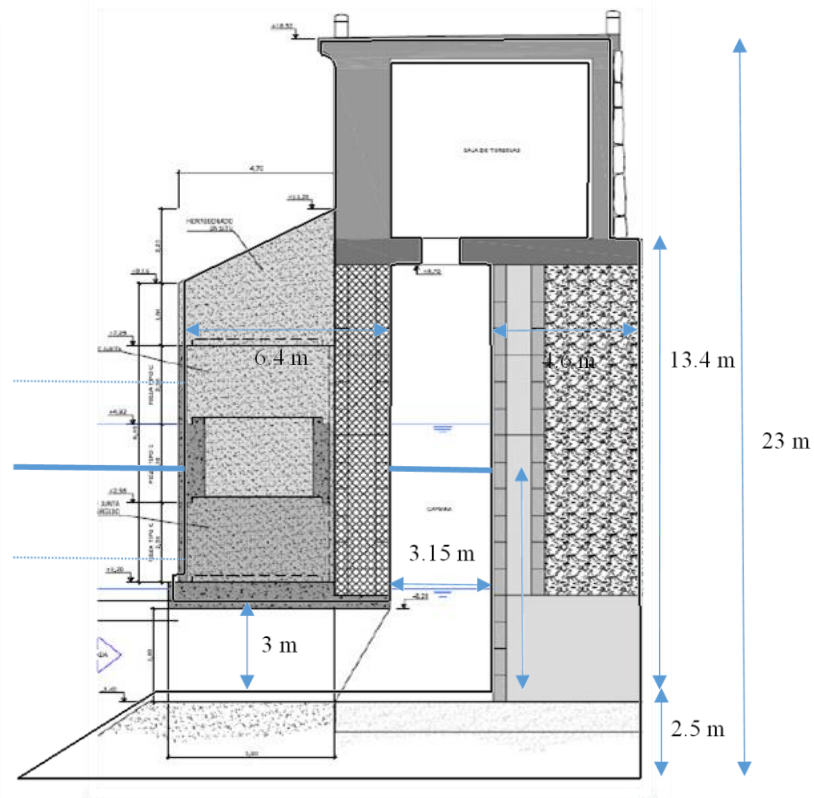
OWC CHAMBER **BREAKWATER**

Design of OWC

ONSHORE OWC IN MUTRIKU (SPAIN)

Cross section of Mutriku breakwater

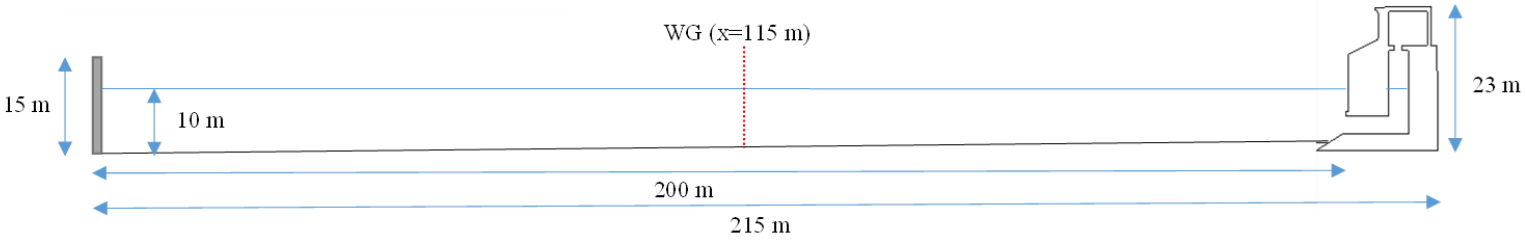


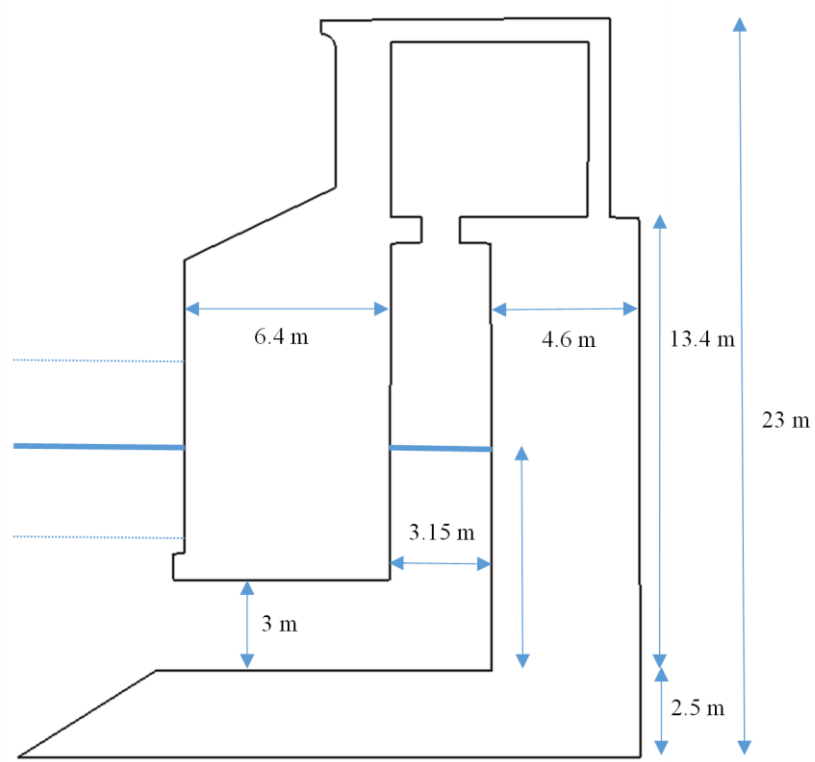


Design of OWC

ONSHORE OWC IN MUTRIKU (SPAIN)

Real dimensions for DualSPHysics simulation

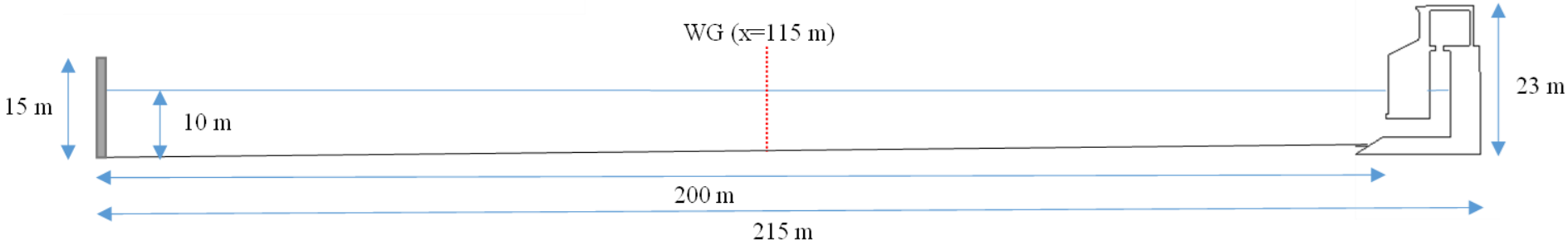




Design of OWC

ONSHORE OWC IN MUTRIKU (SPAIN)

Real dimensions for DualSPHysics simulation



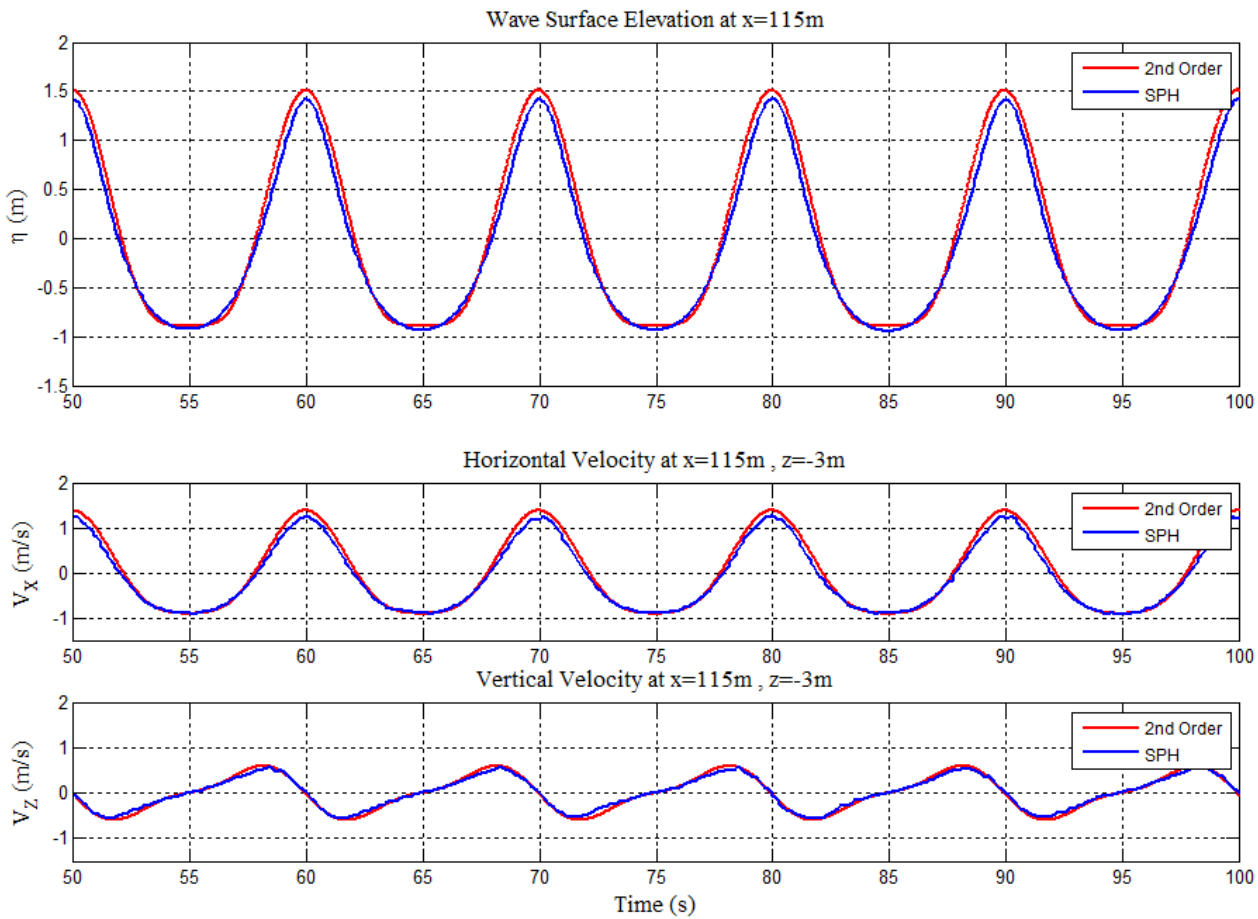
Realistic wave conditions in the Cantábrico coast

	Height (H)	Period (T)	Depth (d)	Wavelength (L)	Relative d (d/L)	Wave theory
Test M1	**0.8 m**	**10 s**	**10 m**	**92.4 m**	**0.108**	**Stokes, 2nd order**
Test M2	1.2 m	10 s	10 m	92.4 m	0.108	Stokes, 2nd order
Test M3	1.6 m	10 s	10 m	92.4 m	0.108	Stokes, 2nd order
Test M4	2.0 m	10 s	10 m	92.4 m	0.108	Stokes, 2nd order
Test M5	2.4 m	10 s	10 m	92.4 m	0.108	Stokes, 2nd order
Test M6	0.8 m	8 s	10 m	70.9 m	0.141	Stokes, 2nd order
Test M7	0.8 m	8.5 s	10 m	76.4 m	0.131	Stokes, 2nd order
Test M8	0.8 m	9 s	10 m	81.7 m	0.122	Stokes, 2nd order
Test M9	0.8 m	9.5 s	10 m	87.1 m	0.115	Stokes, 2nd order
Test M1	**0.8 m**	**10 s**	**10 m**	**92.4 m**	**0.108**	**Stokes, 2nd order**
Test M10	0.8 m	10 s	7.75 m	82.7 m	0.094	Stokes, 2nd order
Test M11	0.8 m	10 s	8.88 m	87.8 m	0.101	Stokes, 2nd order
Test M1	**0.8 m**	**10 s**	**10 m**	**92.4 m**	**0.108**	**Stokes, 2nd order**
Test M12	0.8 m	10 s	11.12 m	96.6 m	0.115	Stokes, 2nd order
Test M13	0.8 m	10 s	12.25 m	100.6 m	0.122	Stokes, 2nd order

Design of OWC

ONSHORE OWC IN MUTRIKU (SPAIN)

WAVE PROPAGATION?? Test M5: H=2.4m T=10s in a *long tank of constant depth*

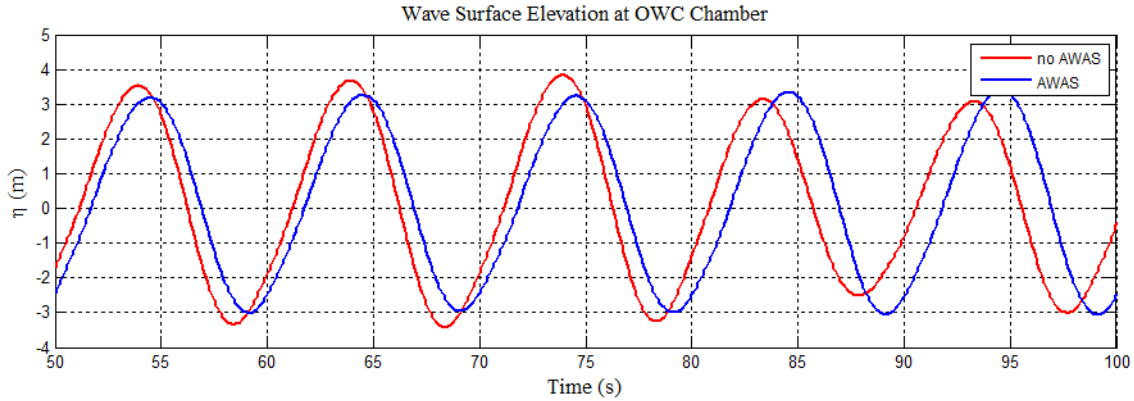


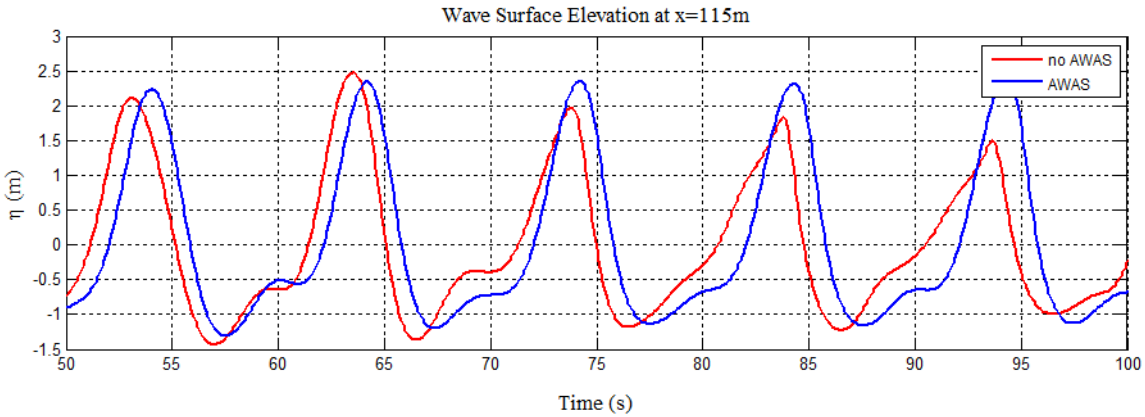
Elevation and orbital velocity: Theoretical vs DualSPHysics

Design of OWC

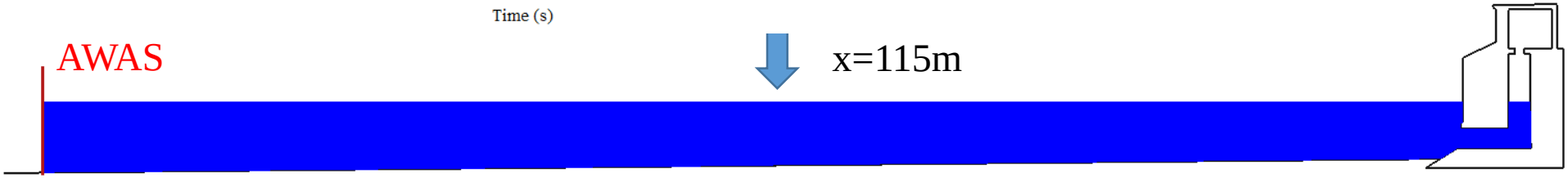
ONSHORE OWC IN MUTRIKU (SPAIN)

ACTIVE ABSORPTION?? Test M5: H=2.4m T=10s



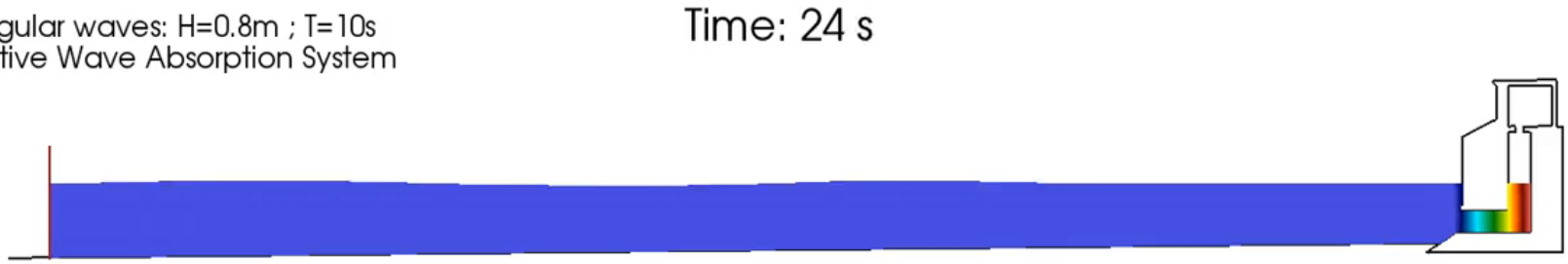


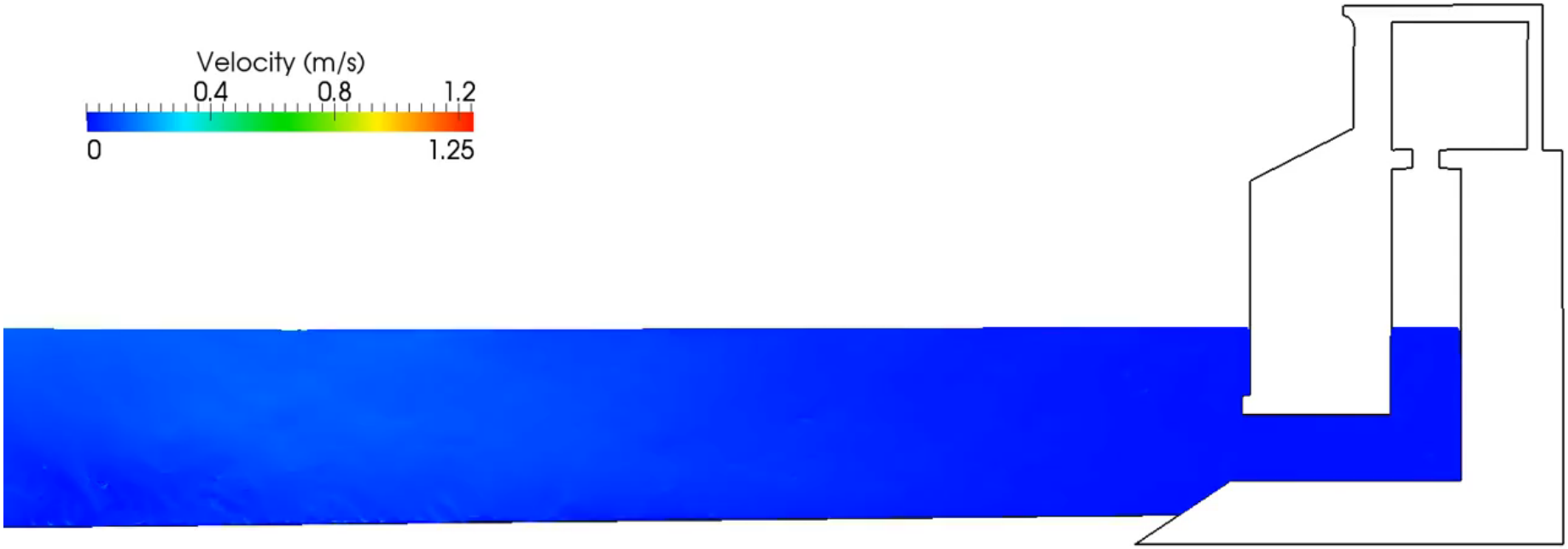
OWC chamber



Design of OWC

ONSHORE OWC IN MUTRIKU (SPAIN)



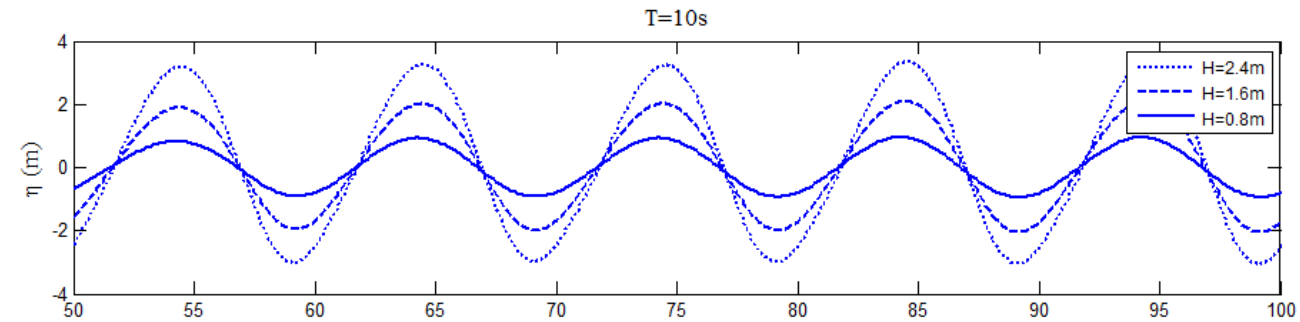


Design of OWC

ONSHORE OWC IN MUTRIKU (SPAIN)

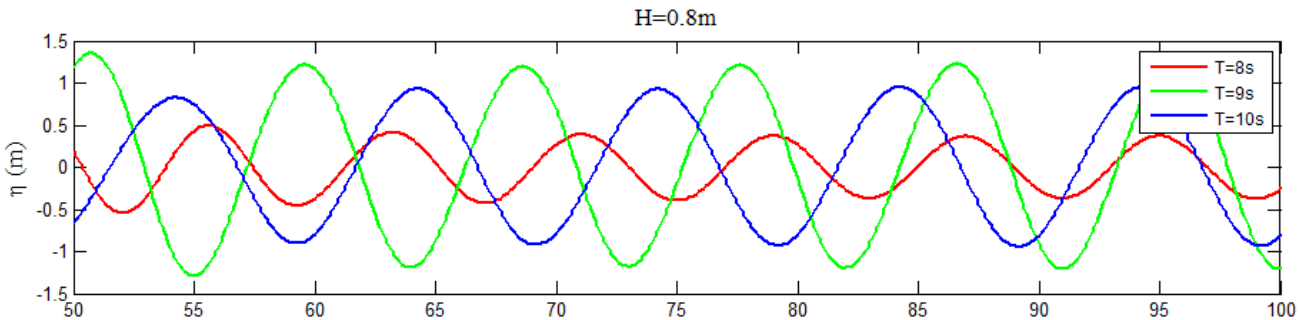
T with different H

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



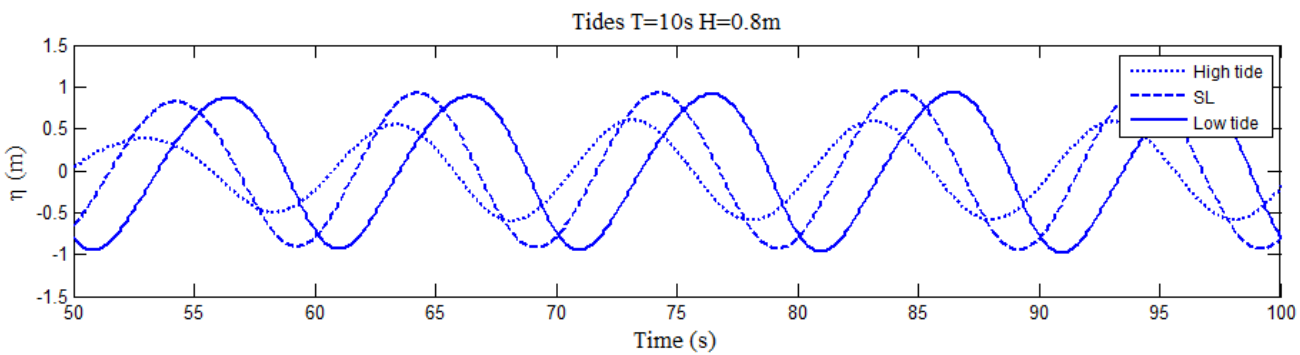
H with different T

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



Different tides

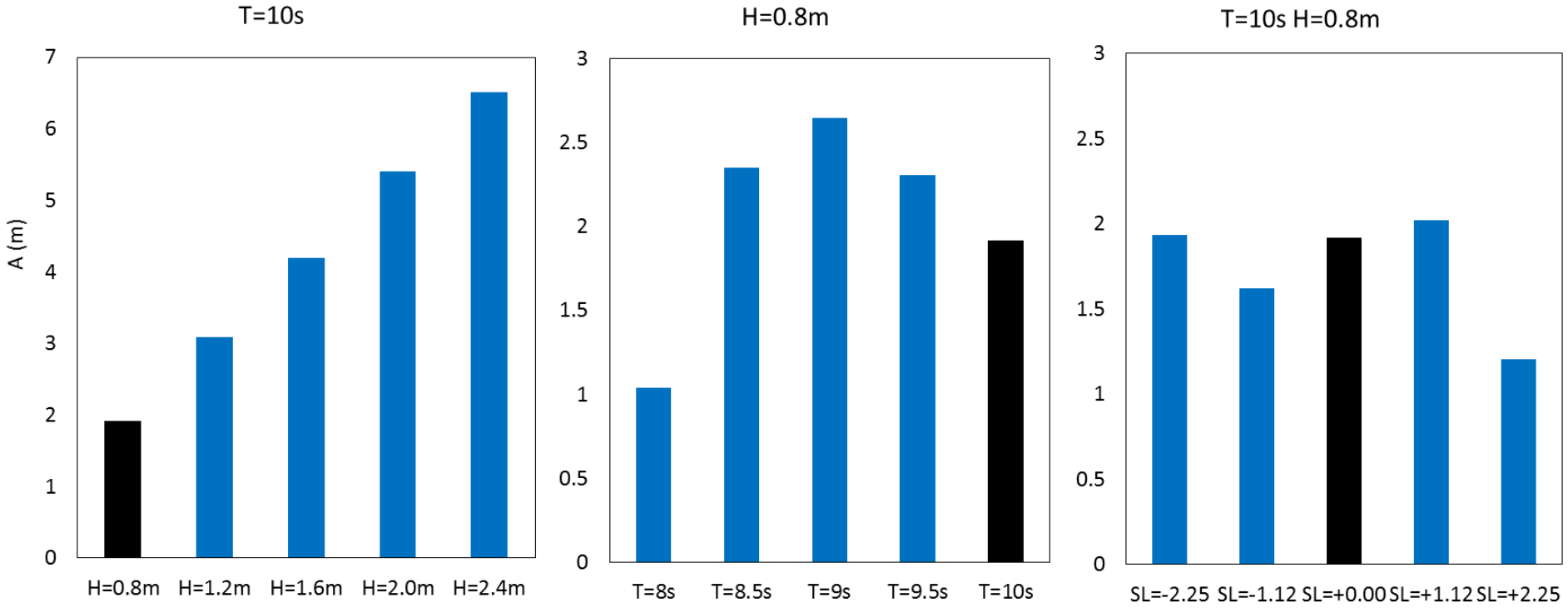
H=0.8m T=10s
H=0.8m T=10s low
H=0.8m T=10s high



Elevation inside the Mutriku chamber

Design of OWC

ONSHORE OWC IN MUTRIKU (SPAIN)



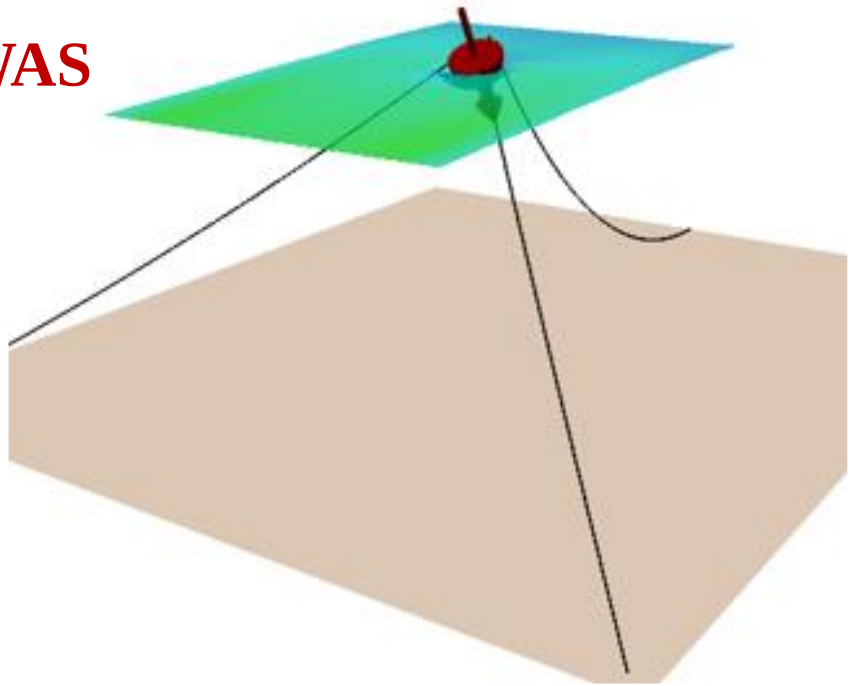
Maximum amplitudes of the free-surface elevations
inside the OWC chamber of Mutriku for different wave conditions.

Design of OWC

OFFSHORE FLOATING OWC IN THE OPEN SEA

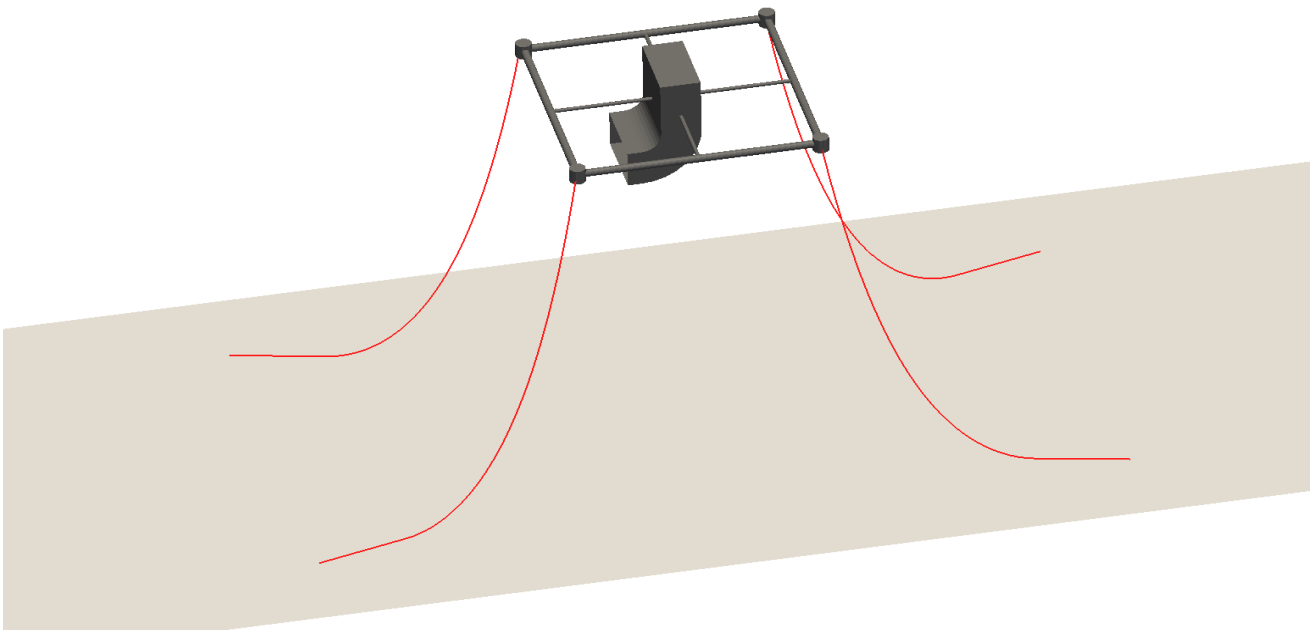
NEW SPH FUNCTIONALITIES

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



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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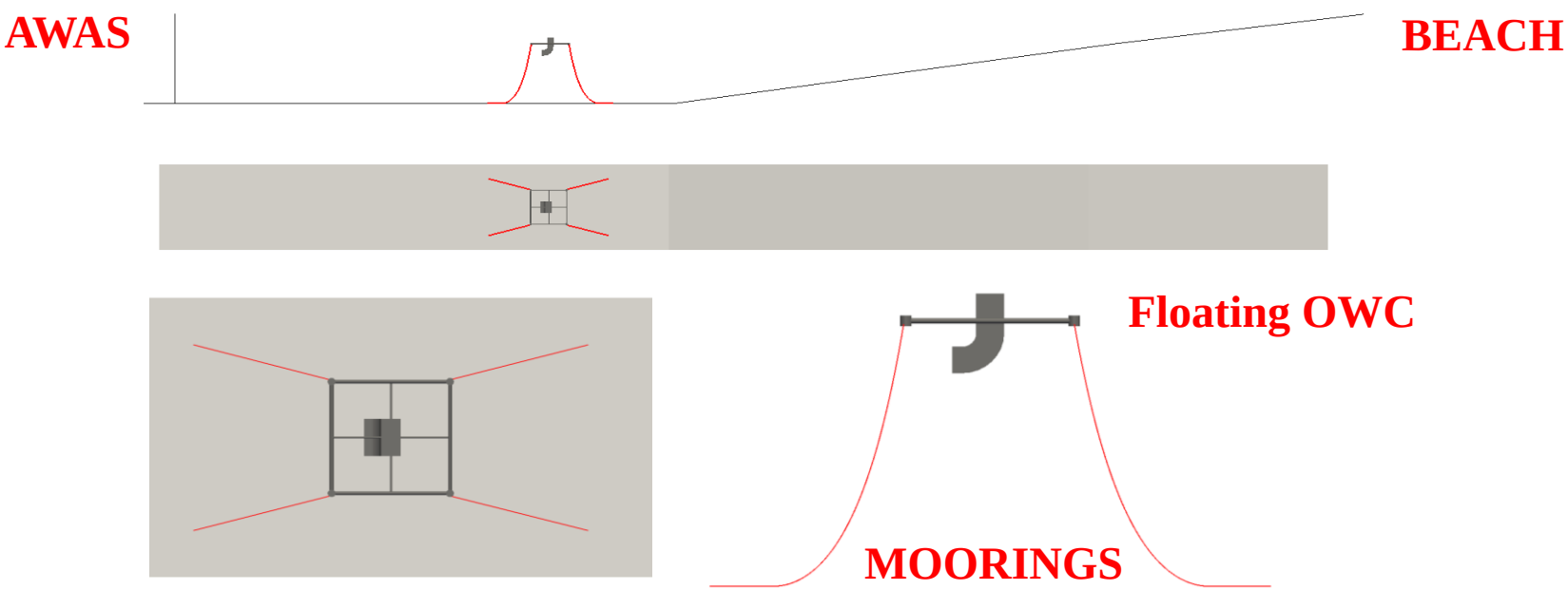
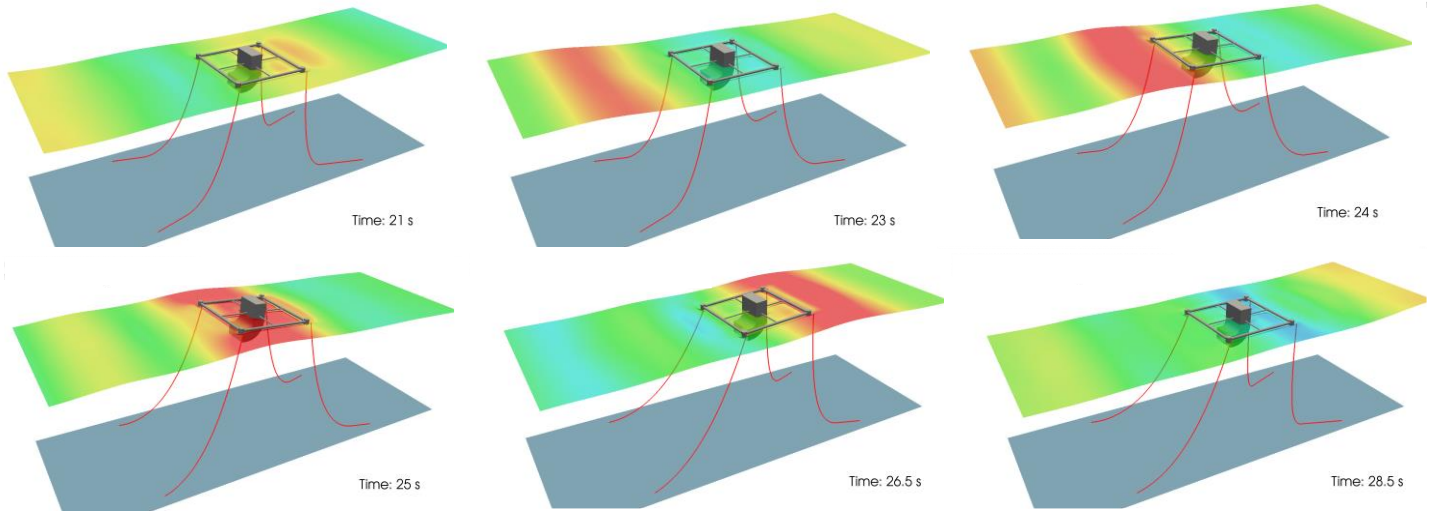
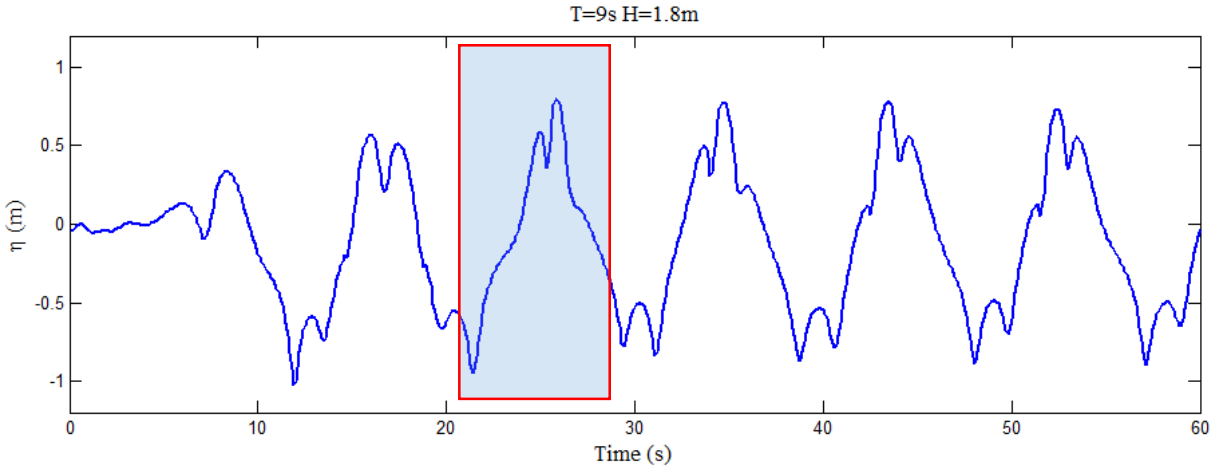


Design of OWC

OFFSHORE FLOATING OWC IN THE OPEN SEA

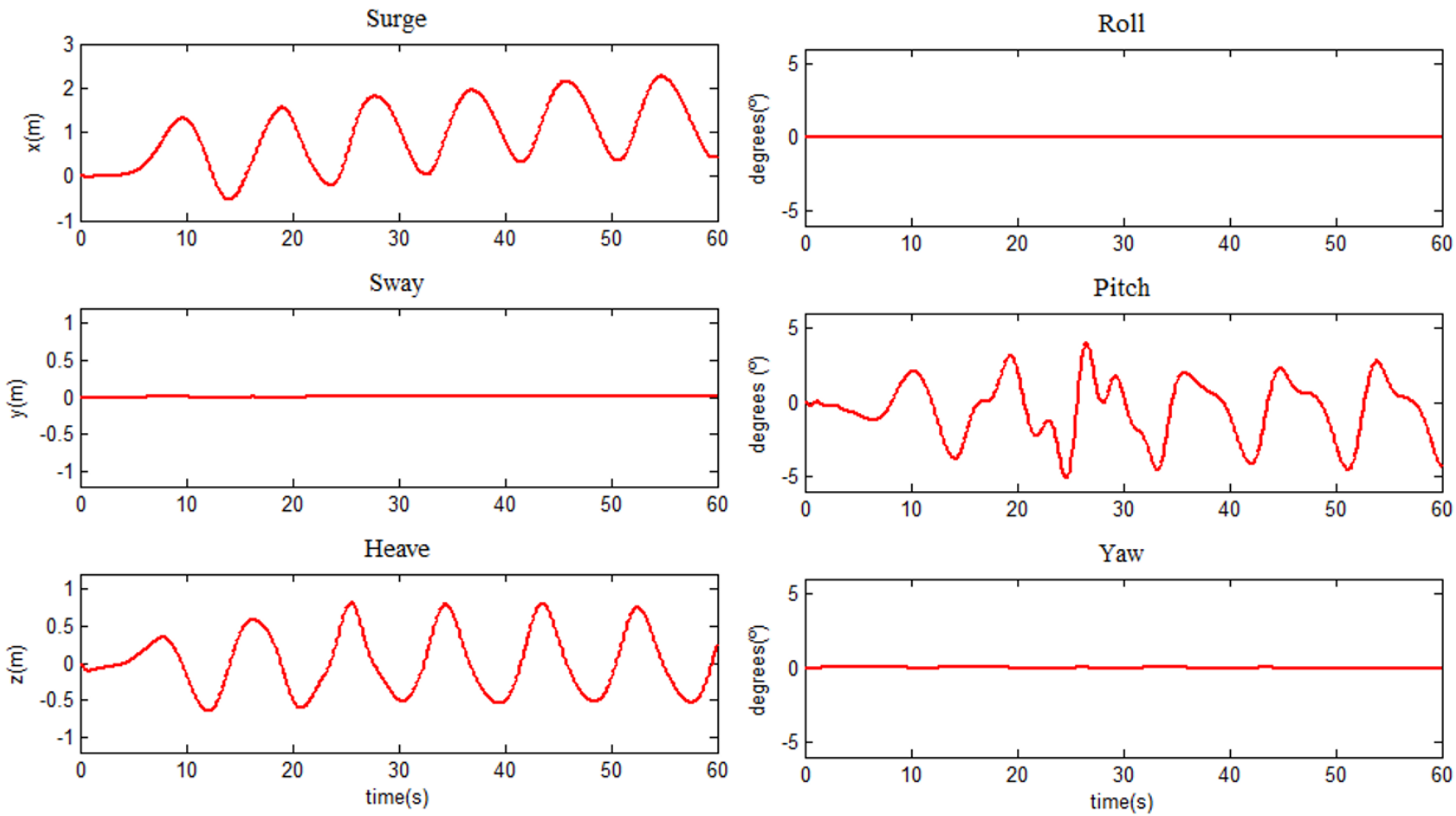




Elevation inside the **floating** OWC chamber

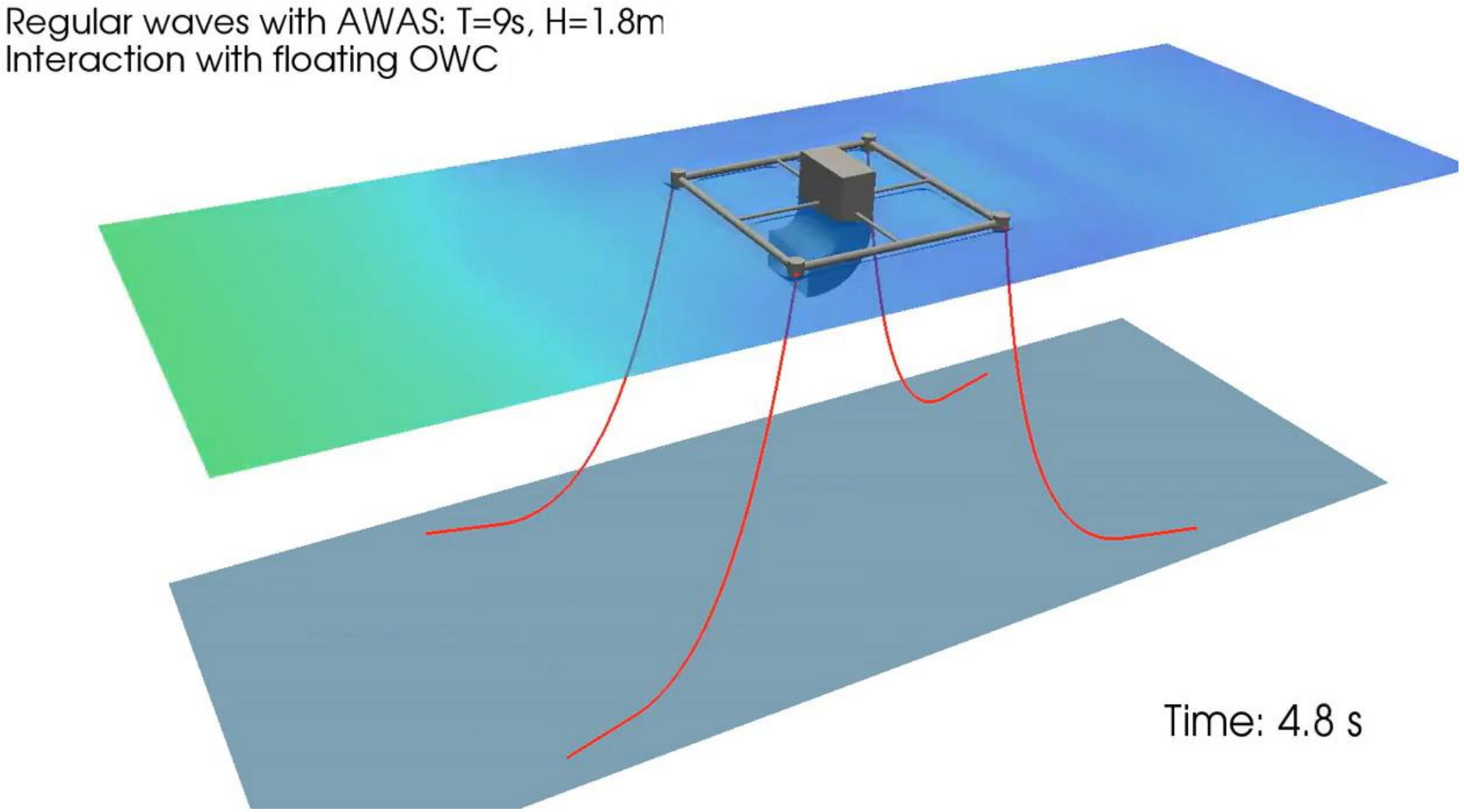
OFFSHORE FLOATING OWC IN THE OPEN SEA

Time histories of the motions of the floating OWC
(surge, sway and heave motion, and roll, pitch and yaw rotation).



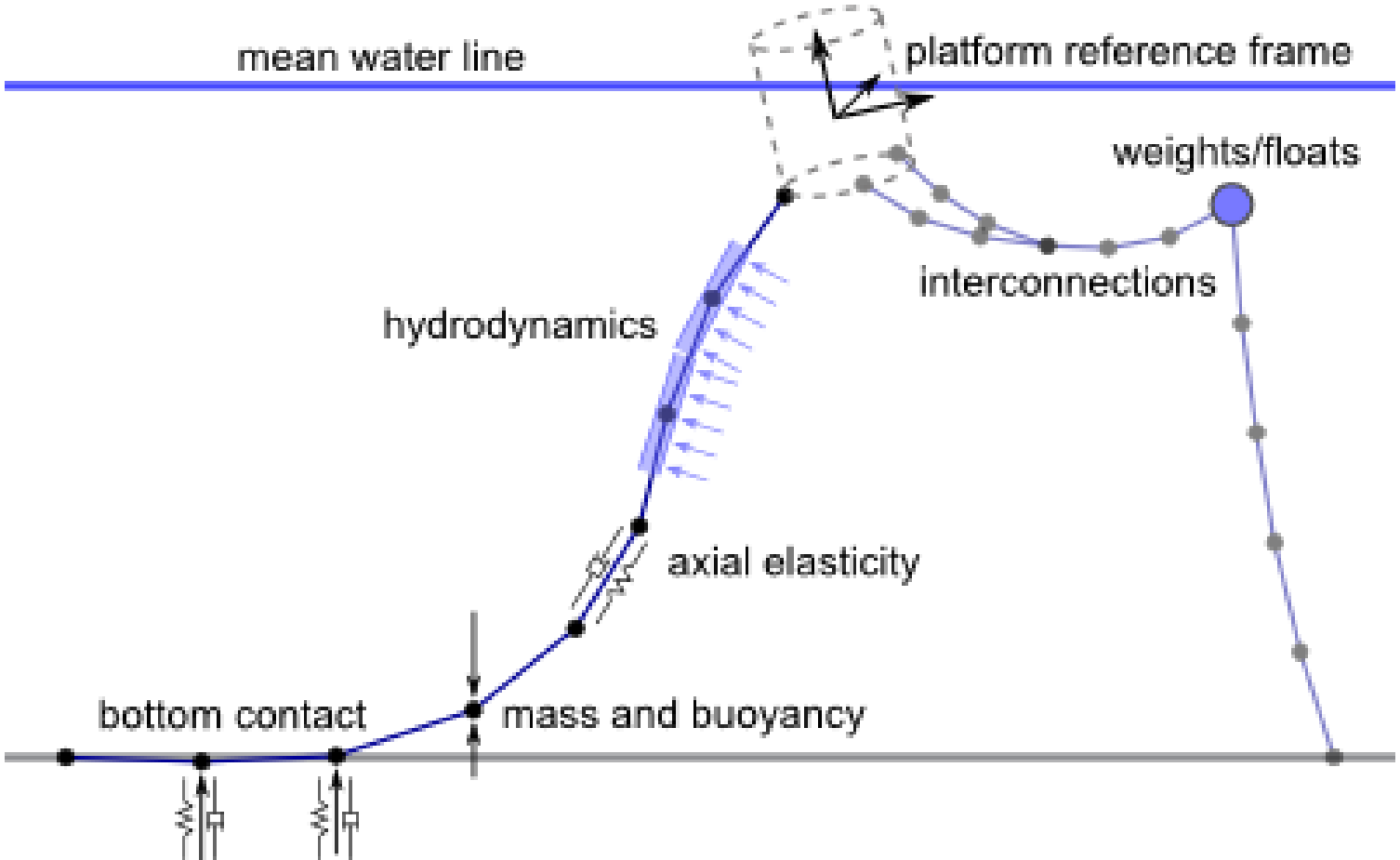
Design of OWC

OFFSHORE FLOATING OWC IN THE OPEN SEA



Future developments

- **Source Generation in combination with SWASH**
- **Multiphase: air+water**
- **Coupling with MoorDyn** http://www.matt-hall.ca/moordyn/



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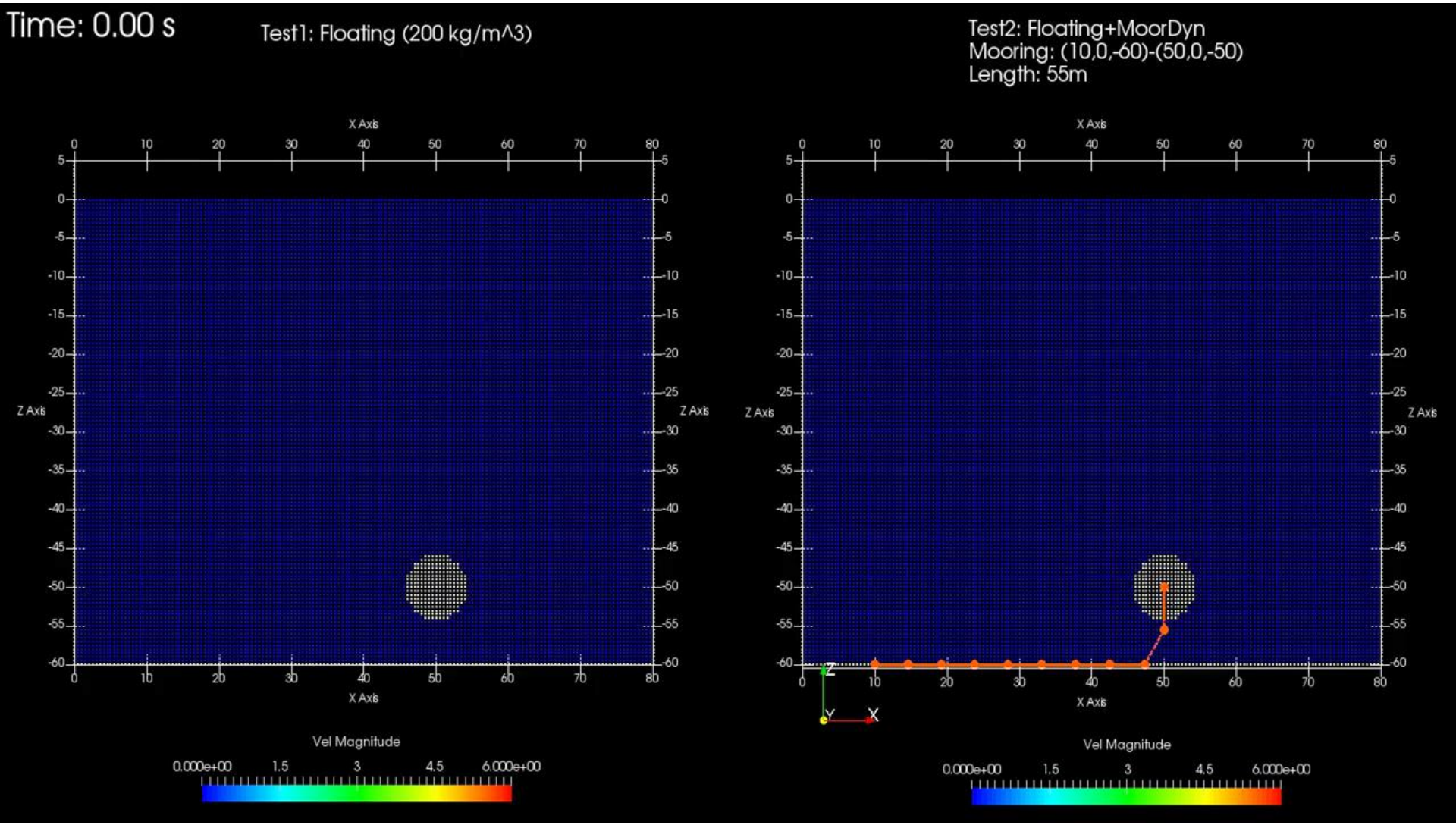

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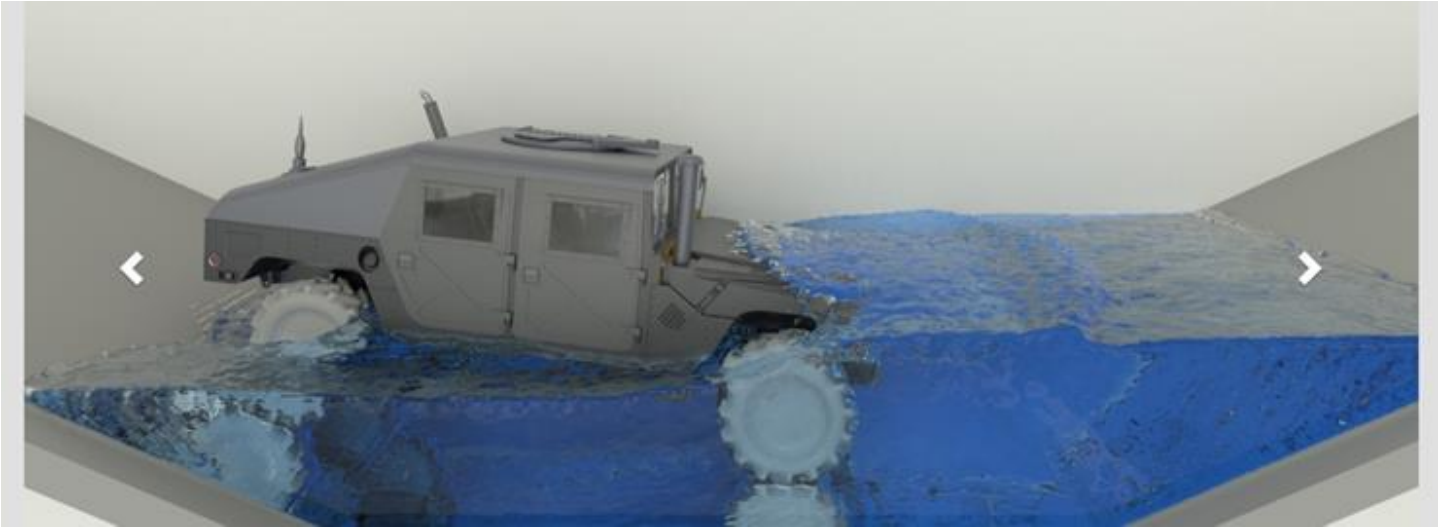
PROJECTCHRONO

An Open Source Multi-physics Simulation Engine



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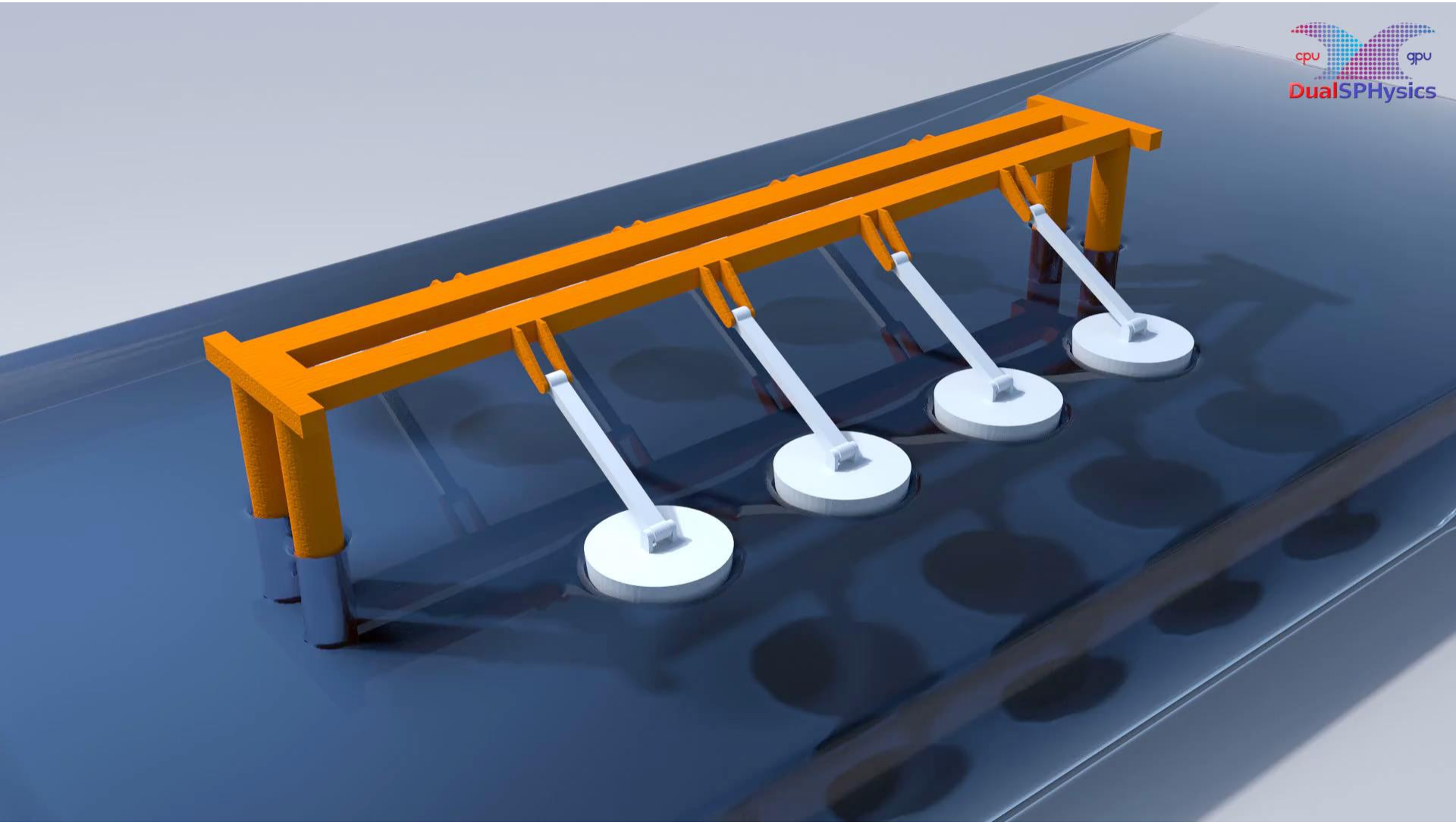

MANCHESTER 1824

The University of Manchester

Thank you

Acknowledgements

- DualSPHysics team: all developers and contributors
- Special thanks to Ghent University and FHR

Website

Free open-source **DualSPHysics** code:

http://www.dual.sphysics.org

cpu gpu

DualSPHysics