IHCantabria

UNIVERSITY OF CANTABRIA

Study of real floating structures under severe weather conditions

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Coastal Hydrodynamics and Infrastructure Group

"The Environmental Hydraulics Institute IHCantabria"

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IHCantabria

- **The Environmental Hydraulics Institute "IHCantabria"** is a research center specialized in basic and applied research and in the development of methodologies and tools to adequately manage aquatic systems.

- **IHCantabria** is located in Santander, north of Spain.

- **IHCantabria** was founded on the 22nd of March 2007, the International Water Day

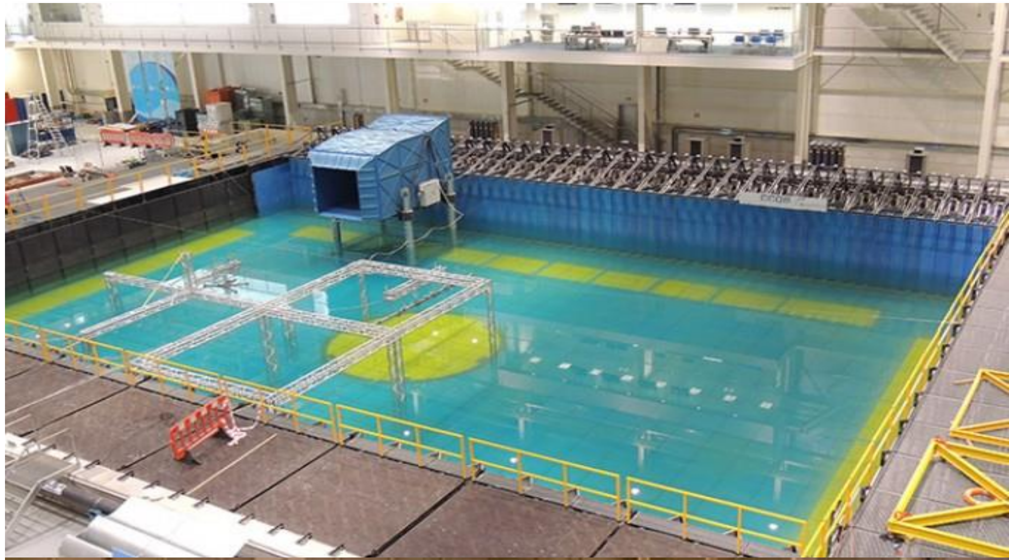
- Over 150 researchers and staff from 13 countries
  - 91,5% of the personnel is financed through the Institute's own projects

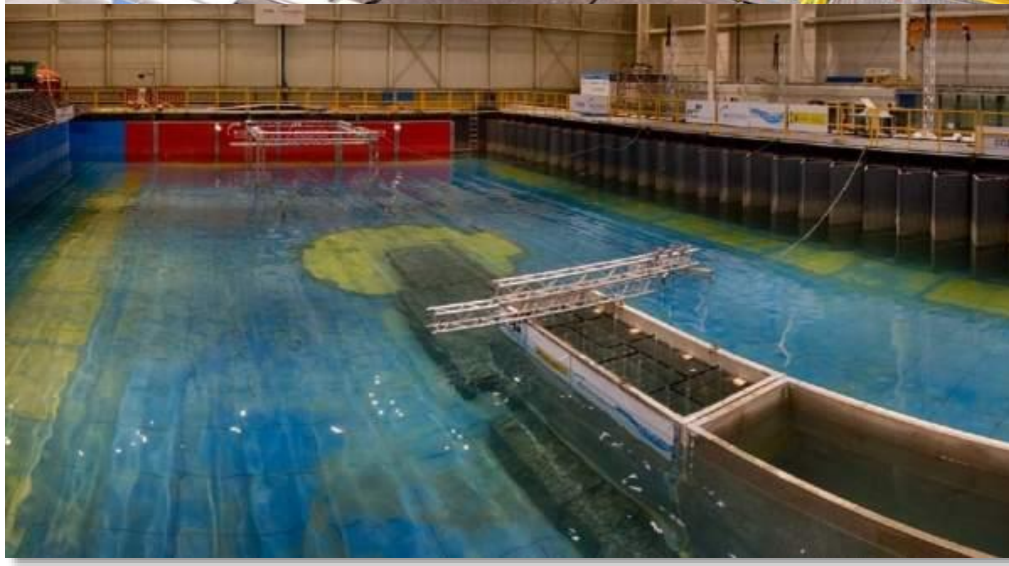
- Ranking "Top Ocean Engineering Institutions":
  - In the last 20 years: 30thin the world
  - 2017 Shanghai Ranking: 6thin the world (PUB – Number of papers autored by an institution)
  - 2018 Shanghai Ranking: 7thin the world (PUB)
  - 2018 Shanghai Ranking: 1st the world (CNIC – Category Normalized Citation Impact)

IHCantabria

- Cantabria Coastal and Ocean Basin (**CCOB**) Technical specifications:

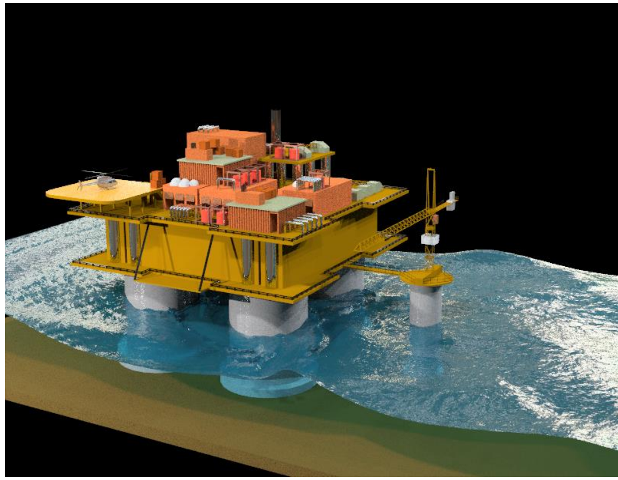
  - Dimension: 30mx44m. Water depth: min: 0.2m; max: 3.2m
  - Central pit: 6 m de diameter y Water depth 8 m
  - **Wave generation**:
    - 64 wave paddle: Piston-hinge
    - Hmax= 1 m (T=3 s) ; Hs,max=0.6m (Tp=3s)
    - multi-directional waves
  - **Current generator**:
    - Design current of 0.2 m/s at 3 m of water depth, maximum water flux 18 m³/s.
  - **Wind generator:**
    - Power controlled set of wind fans. 12 m/s at 1 m far from wind fans. Wind area 10 m width and 2 m height.



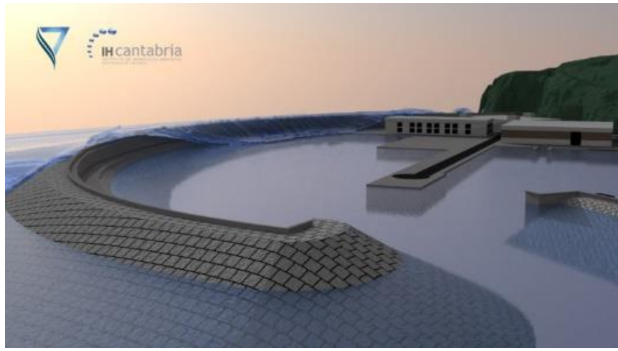


IHCantabria

- Capabilities included by **IHCantabria** and **OpenCFD** in **OpenFOAM**:



❑ OpenFOAM-v1612+:
  - Wave generation
    - Solitary wave using Boussinesq theory
    - Cnoidal wave theory
    - StokesI, StokesII, StokesV wave theory
  - Active wave absorption at the inflow/outflow boundaries based on shallow water theory



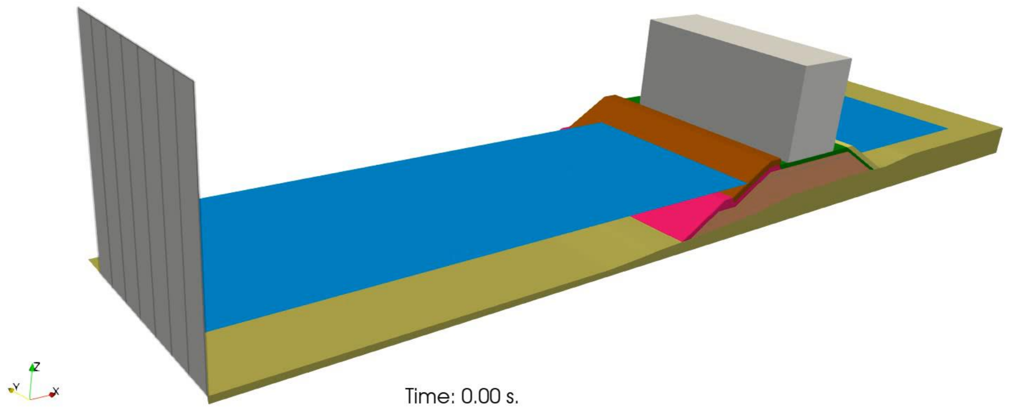
❑ OpenFOAM-v1706:
  - Solitary wave generation models
    - Grimshaw and McCowan wave theory

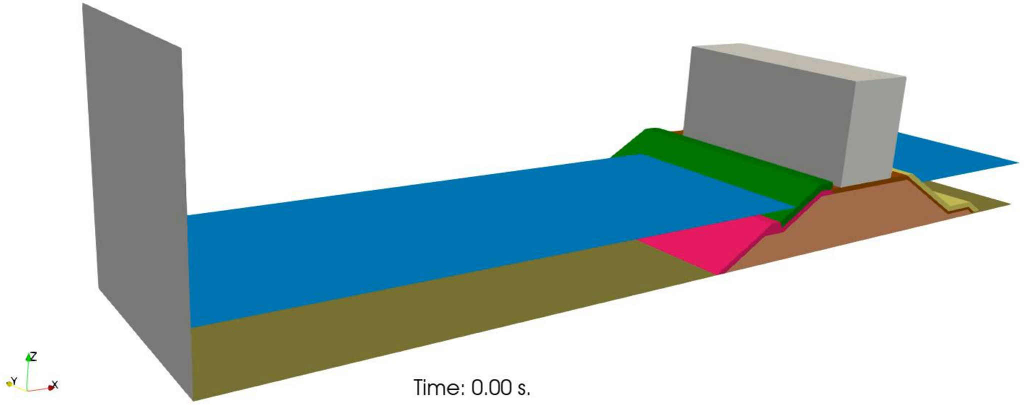
❑ OpenFOAM-v1712:
  - Wave generation
    - StreamFunction wave theory

- Capabilities included by **IHCantabria** and **OpenCFD** in OpenFOAM:

❑ OpenFOAM-v1806:
  - Wave generation
    - Multi-directional irregular waves theory
  - Mangrove-fluid interaction.

❑ OpenFOAM-v1812:
  - Wave generation: dynamic wave paddle
    - Flap type
    - Piston type





OUTLINE

1. Motivation/Goals.

2. Validation of OpenFOAM:
   - Waves and current interaction validation.
   - Waves interaction with a floating object validation.

3. Application:
   - Regular waves and current interaction with floating platform (OC5).

4. Conclusions/Future work.

Motivation/Goal

Motivation:

The ever growing use of floating structures in offshore and coastal engineering (e.g. wind turbines, breakwaters) requires more sophisticated instruments to evaluate the response of such structures to hydrodynamic actions (e.g. waves and current)

Goal:

Applying OpenFOAM-v1812 as a numerical model for studying wave-current interaction with floating objects which allows reproducing large motions with high accuracy.

Copyright:
https://www.energy.gov/eere/wind/articles/offshore-floating-vertical-axis-wind-turbine-project-identifies-promising

Copyright:
http://www.balticfs.eu/en/floating-industrial-structures/floating-breakwater/

Waves-current interaction validation

The Open Source CFD Toolbox

interFoam (OpenFOAM-v1806):

Navier-Stokes equations – VOF equation

$$\nabla \cdot \mathbf{U} = 0$$

$$\frac{\partial \rho \mathbf{U}}{\partial t} + \nabla \cdot (\rho \mathbf{U}\mathbf{U}) - \nabla \cdot (\mu \nabla \mathbf{U}) = \nabla \cdot p^{*} - \mathbf{g} \cdot X \nabla \rho + \nabla \mathbf{U} \cdot \nabla \mu_{eff} + \sigma k \nabla \alpha + F_{mooring}$$

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot \mathbf{U}\alpha + \nabla \cdot \mathbf{U}_c \alpha (1-\alpha) = 0$$

k-ε turbulence model

$$\frac{\partial k}{\partial t} + \mathbf{u} \cdot \nabla k - \nabla \cdot (D_k \nabla k) + \beta_k k = F_k$$

$$\frac{\partial \epsilon}{\partial t} + \mathbf{u} \cdot \nabla \epsilon - \nabla \cdot (D_\epsilon \nabla \epsilon) + \beta_\epsilon \epsilon = F_\epsilon$$

+ Wave–current interaction

Waves-current interaction validation

WAVE-CURRENT VALIDATION (Kemp 1982)

IHFOAM

- Wave+current validation (I)

Waves propagating with the current
Kemp et al. (1982)

Waves with current; $T = 1{\cdot}006$ s

	Smooth boundary			
	WCA1	WCA3	WCA4	WCA5
H (mm)	20·7	30·3	39·4	44·4
L (mm)	1426	1425	1430	1433
α_r (%)	10·4	9·9	8·6	8·6
d (mm)	200			
Mean centre-line velocity (current alone) u_B (mm/s)	183			

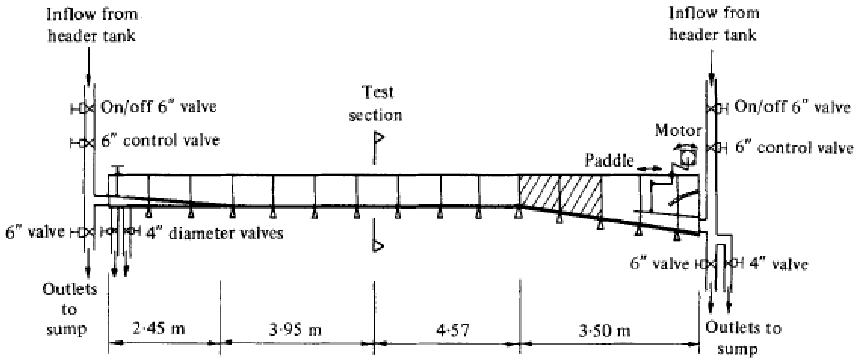
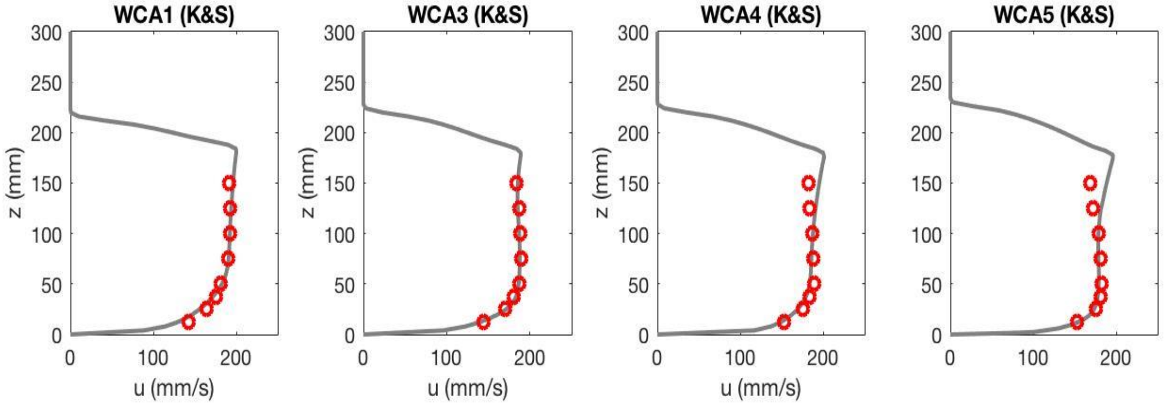


FIGURE 1. Diagram of channel layout and recirculating system.



Ks = 0.005 m
Cs = 0.3

Waves-current interaction validation

WAVE-CURRENT VALIDATION (Umeyama 2005)

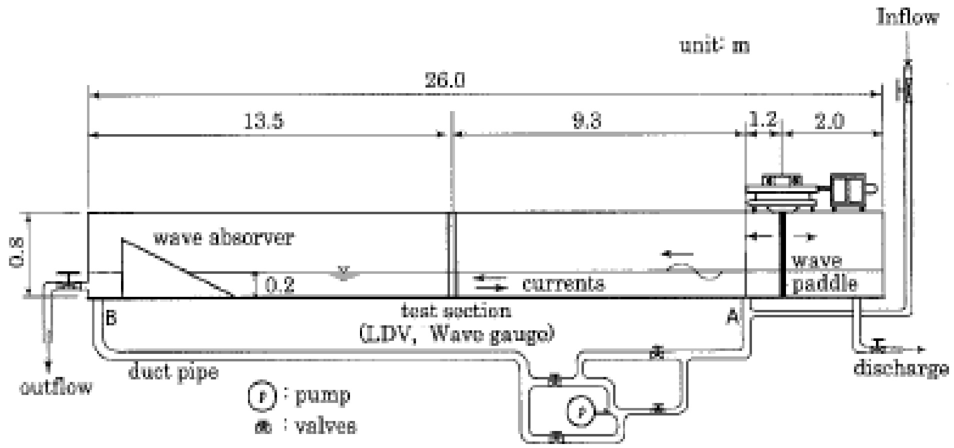
IHFOAM

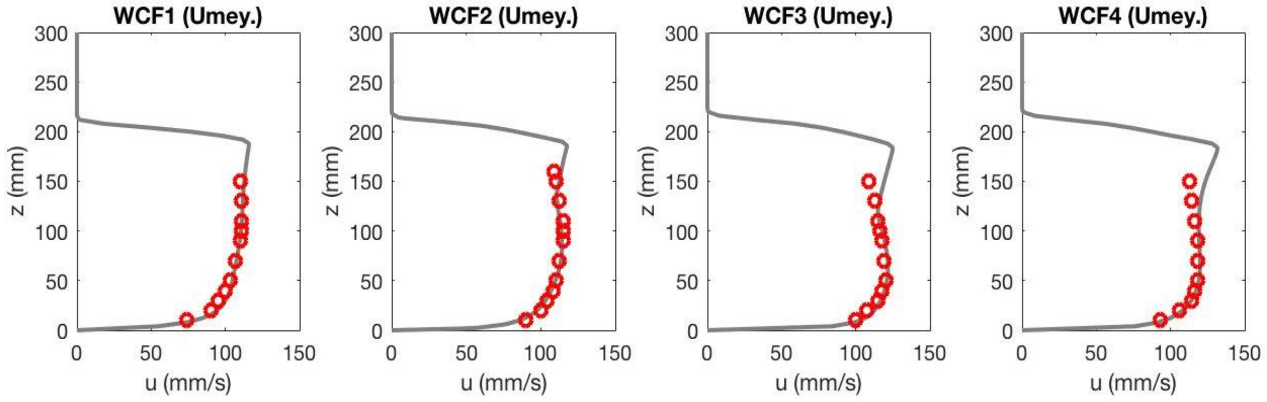
- Wave+current validation (II)

Waves propagating with the current
Umeyama (2005)

Run	WCF1	WCF2	WCF3	WCF4
Paddle stroke	25	30	40	50
Wave height (cm)	1.75	2.31	2.47	2.50
Period (s)	0.9	1.0	1.2	1.4
u/U^{a}	0.706	0.845	0.858	0.875

[a] u = particle velocity for small amplitude waves; U = 12.0 cm/s.





Ks = 0.001 m
Cs = 0.3

Waves-current interaction validation

WAVE-CURRENT VALIDATION (Umeyama 2005)

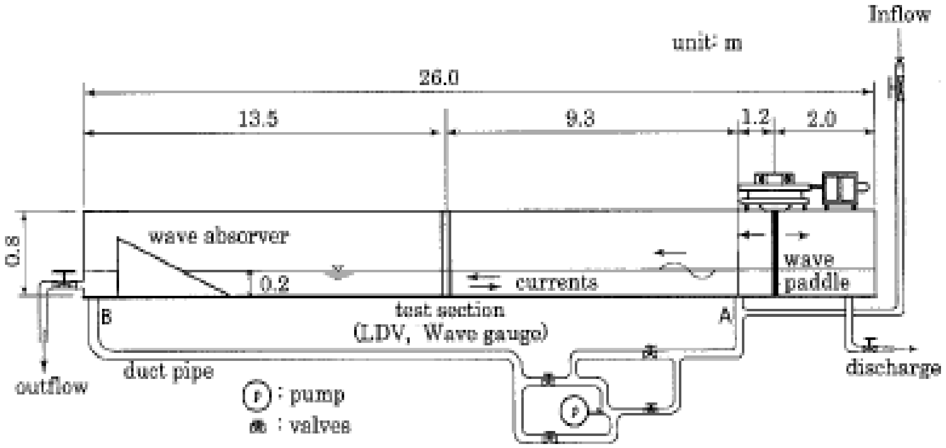
IHFOAM

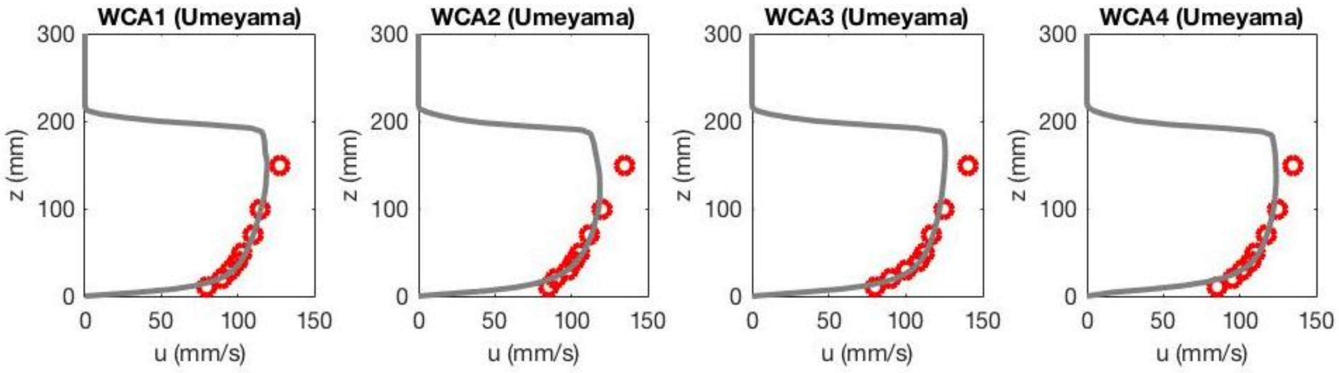
- Wave+current validation (III)

Waves propageting against current
Umeyama (2005)

Run	WCA1	WCA2	WCA3	WCA4
Paddle stroke	25	30	40	50
Wave height (cm)	1.80	2.15	2.22	2.70
Period (s)	0.9	1.0	1.2	1.4
u/U^{a}	0.706	0.845	0.858	0.875

[a] u = particle velocity for small amplitude waves; U = 12.0 cm/s.





Ks = 0.001 m
Cs = 0.3

Waves-floating object interaction validation

OpenFOAM

The Open Source CFD Toolbox

overInterDyMFoam (OpenFOAM-v1806):

Navier-Stokes equations – VOF equation

$$\nabla \cdot \mathbf{U} = 0$$

$$\frac{\partial \rho \mathbf{U}}{\partial t} + \nabla \cdot (\rho \mathbf{U}\mathbf{U}) - \nabla \cdot (\mu \nabla \mathbf{U}) = \nabla \cdot p^* - \mathbf{g} \cdot X \nabla \rho + \nabla \mathbf{U} \cdot \nabla \mu_{eff} + \sigma k \nabla \alpha + F_{mooring}$$

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot \mathbf{U}\alpha + \nabla \cdot \mathbf{U}_c \alpha (1 - \alpha) = 0$$

k-ε turbulence model

$$\frac{\partial k}{\partial t} + \mathbf{u} \cdot \nabla k - \nabla \cdot (D_k \nabla k) + \beta_k k = F_k$$

$$\frac{\partial \epsilon}{\partial t} + \mathbf{u} \cdot \nabla \epsilon - \nabla \cdot (D_\epsilon \nabla \epsilon) + \beta_\epsilon \epsilon = F_\epsilon$$

Waves-floating object interaction validation

Mooring modelling:

Linear spring and damping

$$F_{mooring} = -k(|\vec{r}| - l_r) - c(\vec{r} \, x \, \vec{v})$$

6DoF Rigid Body Motion (OpenFOAM® library)

$$F = \sum F_{ext} + F_{flow}$$

$$M = \sum M_{ext} + M_{flow}$$

$$\rightarrow$$

$$\sum F = ma$$

$$\sum M = \alpha I$$

$$\rightarrow$$

$$\omega_{new} = \int_{t_{old}}^{t} \alpha dt = \omega_{old} + \alpha \Delta t$$

$$v_{new} = \int_{t_{old}}^{t} a dt = v old + a \Delta t$$

Waves-floating object interaction validation

Dynamic mesh handling: OVERSET MESH (v1712 OF)

1) Grid generation (overlapping grids: background and floating body mesh)

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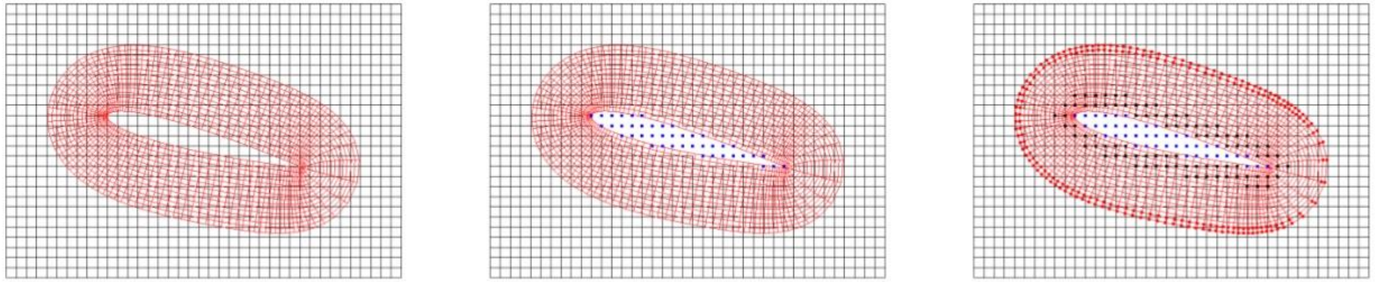
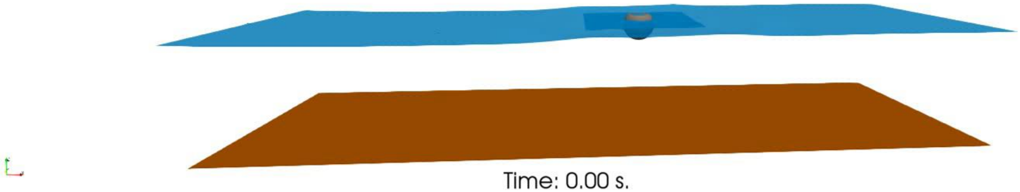
http://celeritassimtech.com/?page_id=113

2) Hole cutting

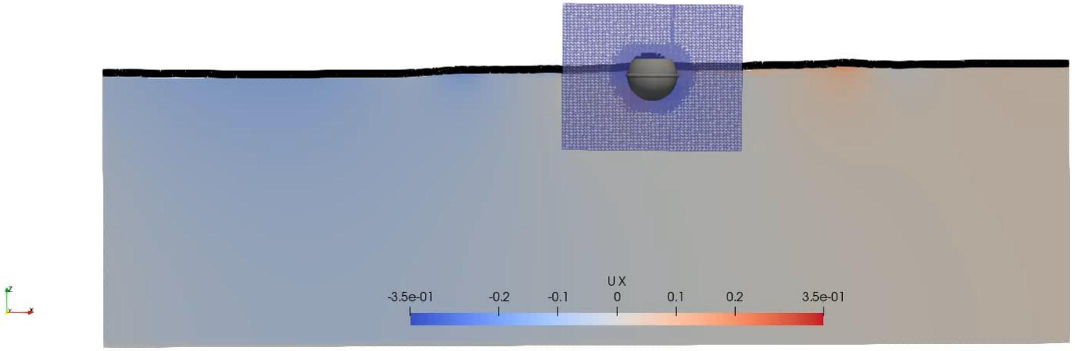
3) Interpolation
- Fringe
- Donor



Background (black) floating (red) — Cutted point (blue) — Fringe (black) donor (red)



Example :



Waves-floating object interaction validation

ONLY WAVES (Rahman et al., 2006).

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Numerical modeling of dynamic responses and mooring forces of submerged floating breakwater

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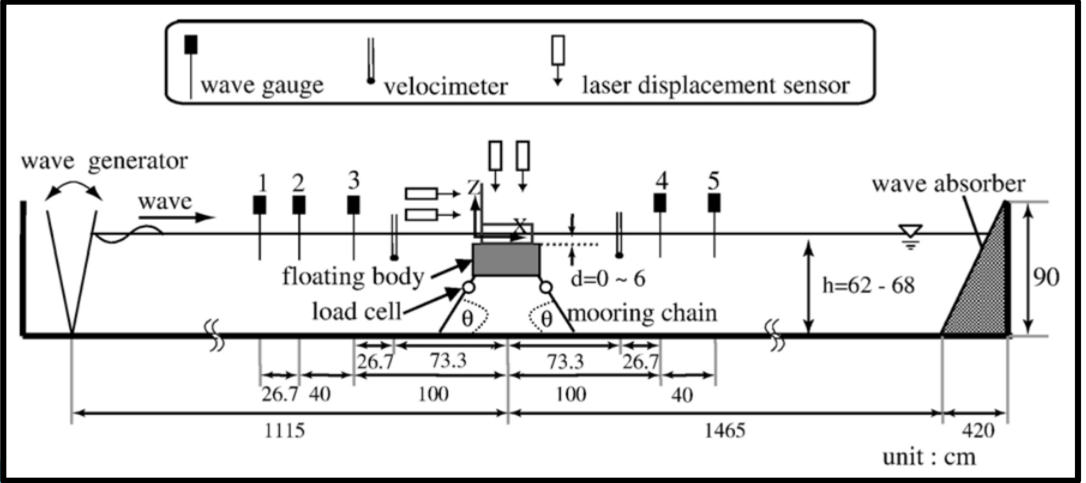
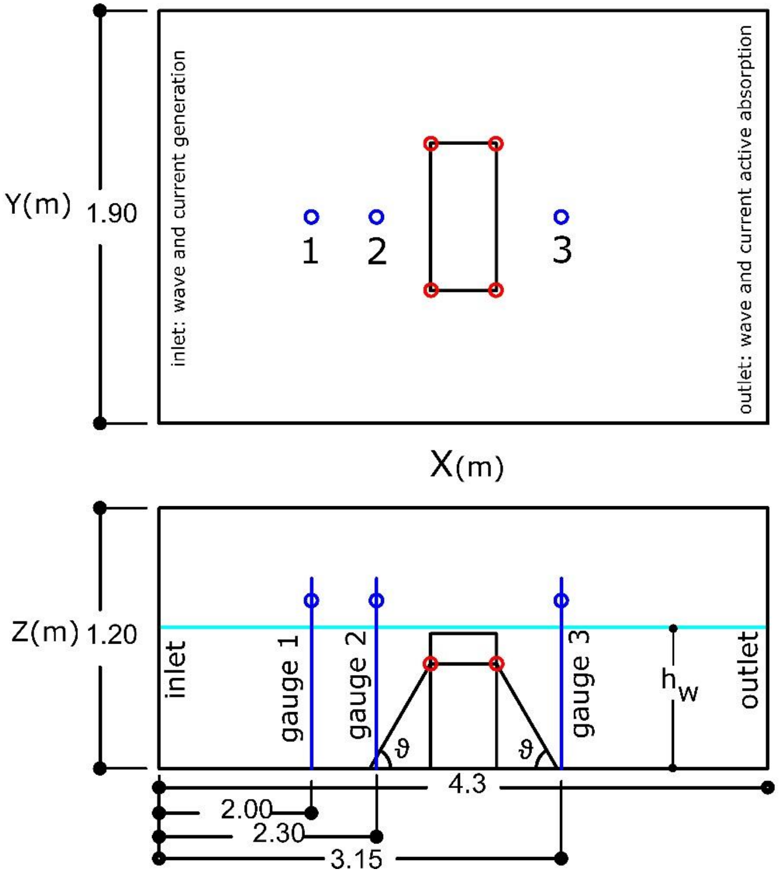
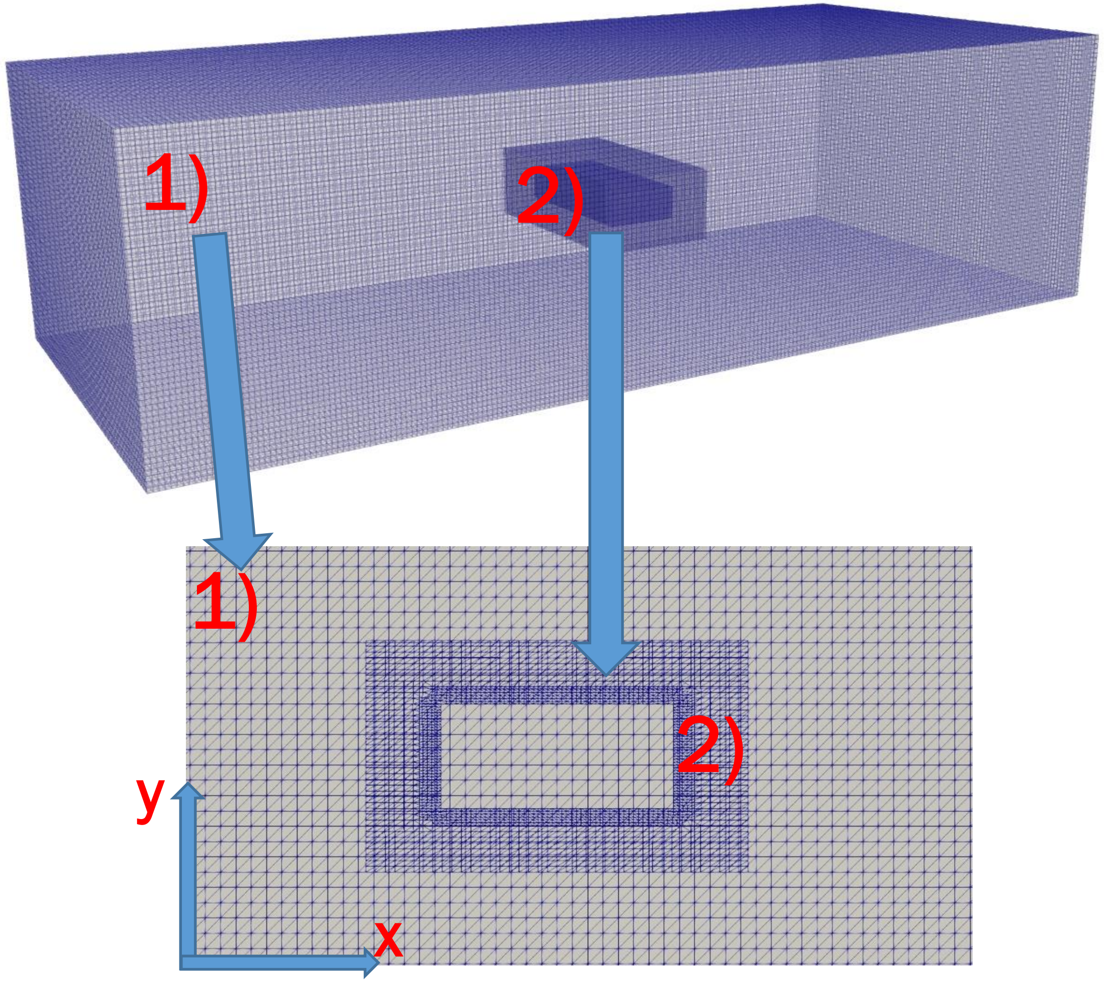


Waves-floating object interaction validation

ONLY WAVES (Rahman et al., 2006).





CASE A: 4 vertical mooring chains ($\theta = 90°$)

CASE B: 4 inclined mooring chains ($\theta = 60°$)

Waves-floating object interaction validation

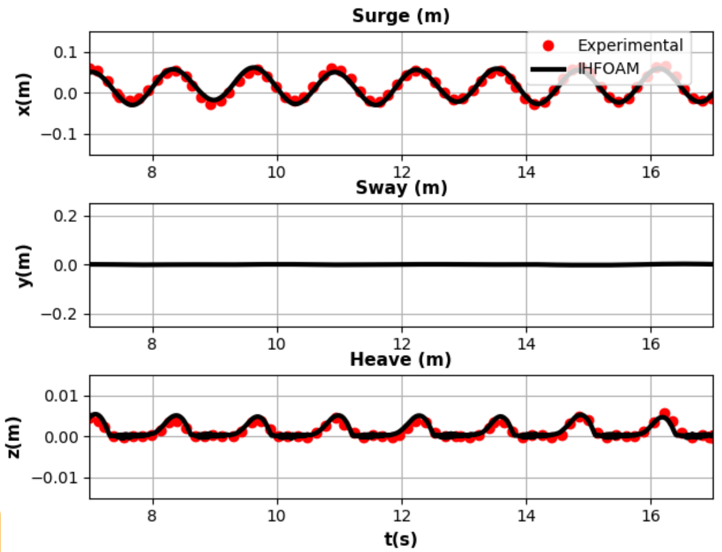
ONLY WAVES (Rahman et al., 2006).

Wave generation: Stokes II

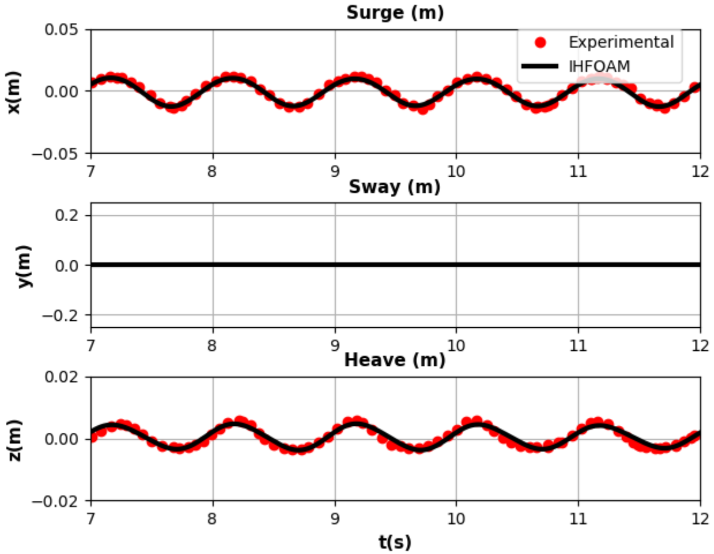
Case A: H = 7.3 cm., h = 65 cm., T = 1.3 s. Mooring system: 4 vertical mooring chains ($\theta = 90^\circ$)

Case B: H = 3.1 cm., h = 65 cm., T = 1.0 s. Mooring system: 4 inclined mooring chains ($\theta = 60^\circ$)

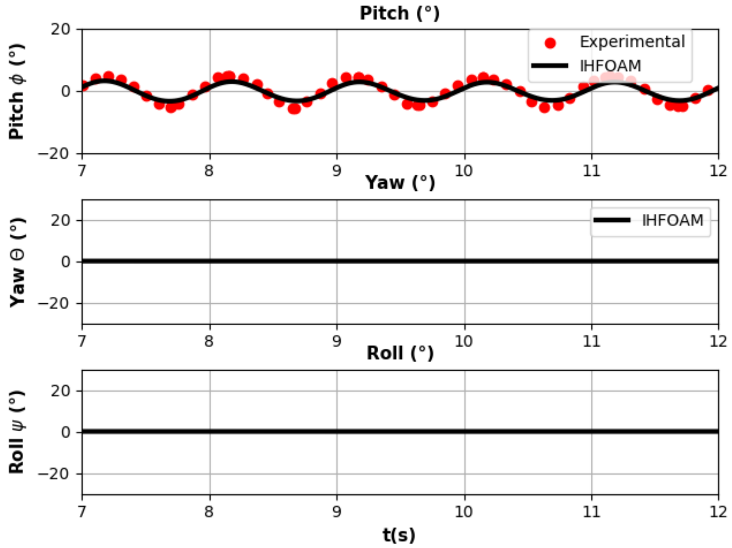
Case A



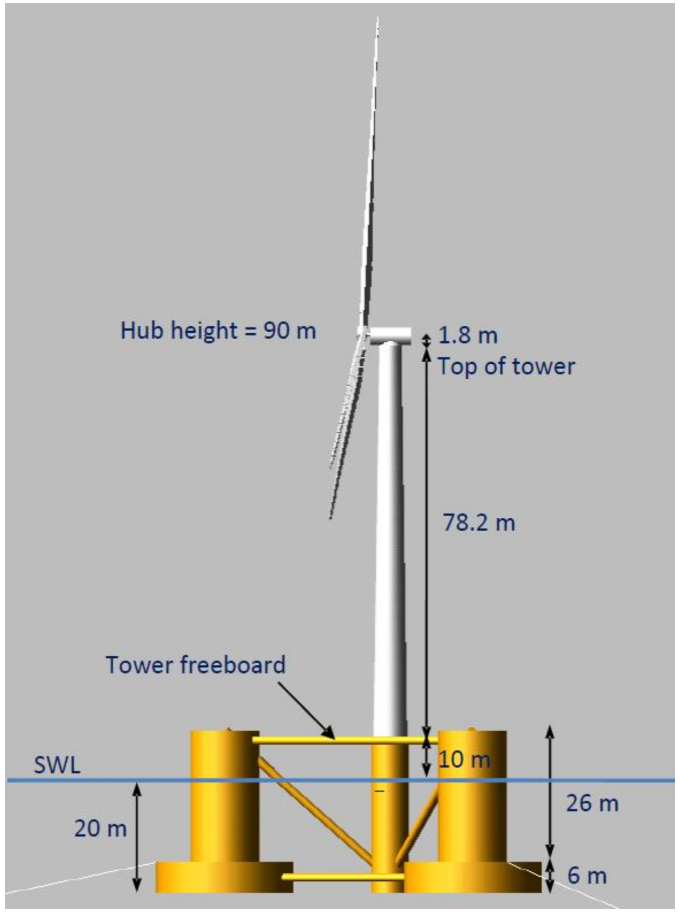
Case B

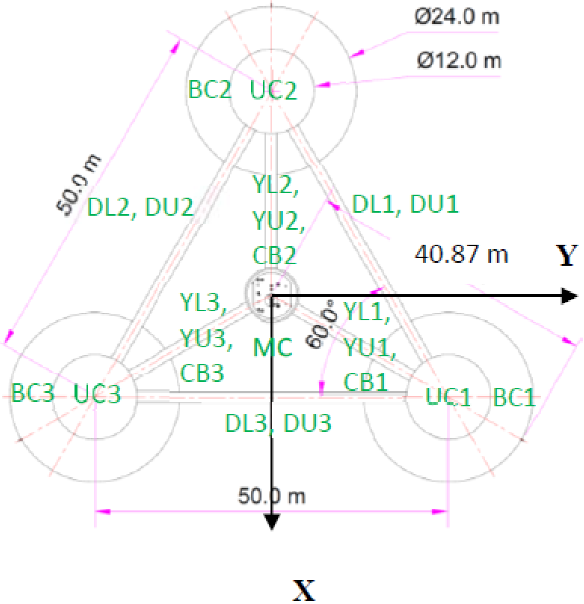


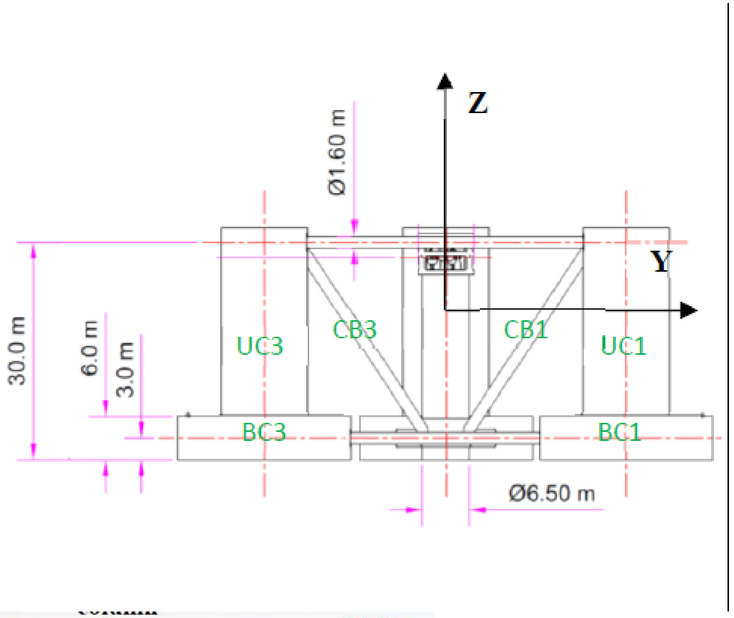
Case B

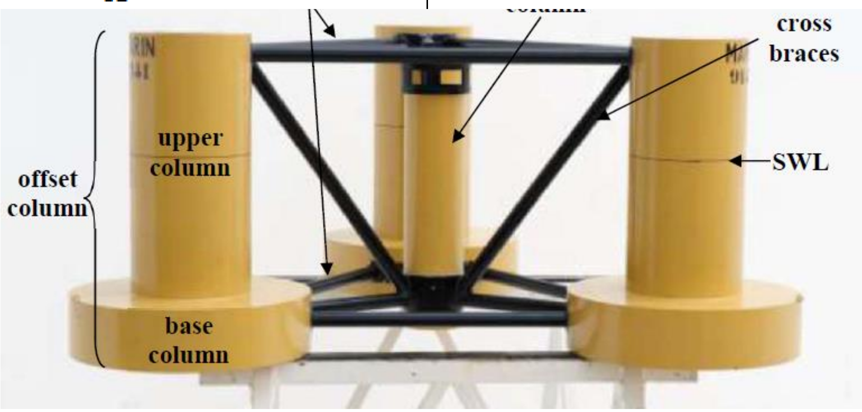


Regular waves and current interaction with a floating platform (OC5)









Reference: *"Definition of the OC5 DeepCwind Semisubmersible Floating System" A. Robertson, J. Jonkman, F. Wendt – National Renewable Energy Lab A. Goupee, H. Dagher – University of Maine*

Regular waves and current interaction with a floating platform (OC5)

Inlet: Current + waves

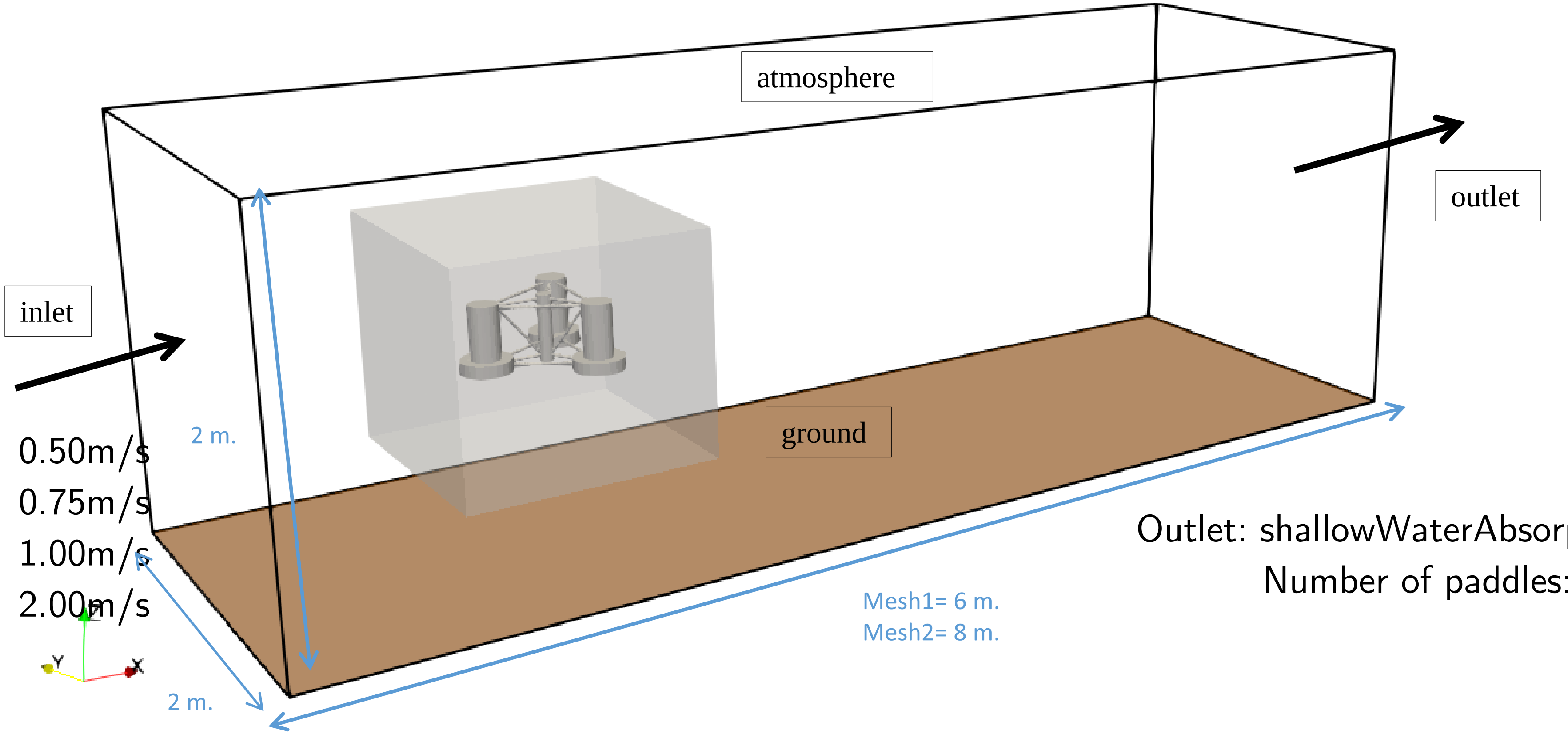
Current values: 0.25m/s

0.50m/s

0.75m/s

1.00m/s

2.00m/s



Outlet: shallowWaterAbsorption.

Number of paddles: 4

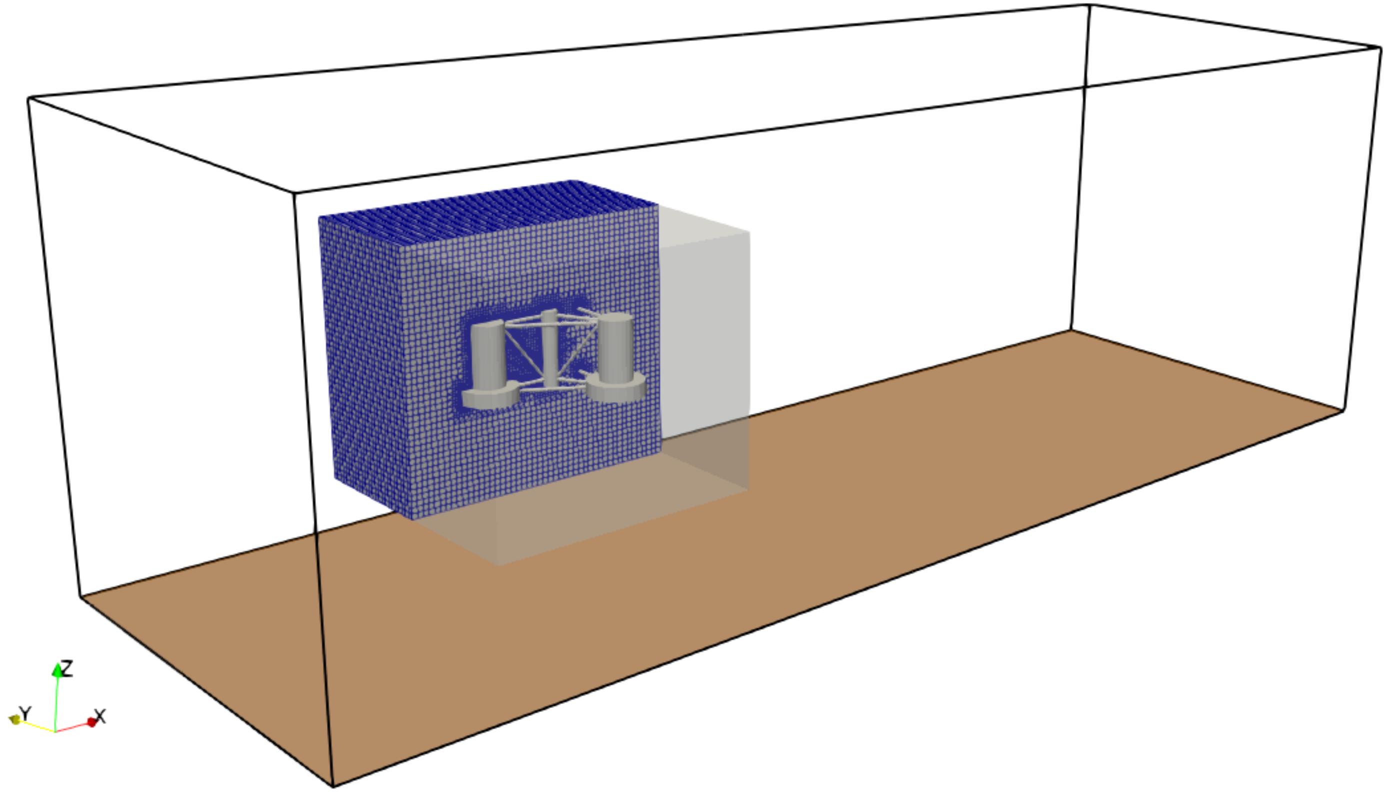
Regular waves (Stokes II)

Hs = 0.12 m.

T = 3.0 s.

h = 1.0 m.

Regular waves and current interaction with a floating platform (OC5)



overset Mesh:

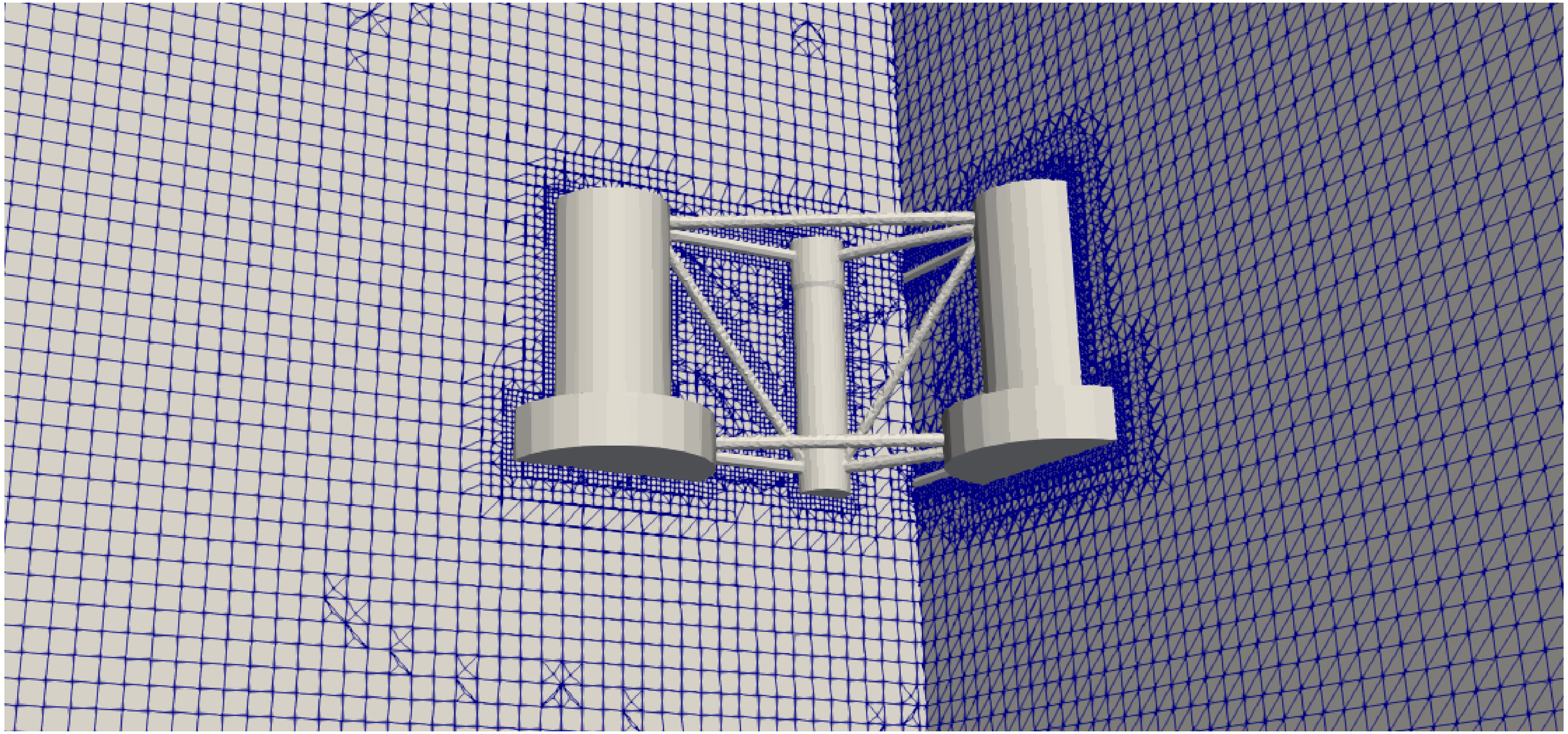
Numerical Domain: x=1.2 m., y= 1.2 m., z=1.1 m.

Numerical Discretization: dx=0.025m, dy=0.025m, dz=0.025m.

Refinamente Zones: 2

Number of Cells: 0.217 M.

Regular waves and current interaction with a floating platform (OC5)



Background:

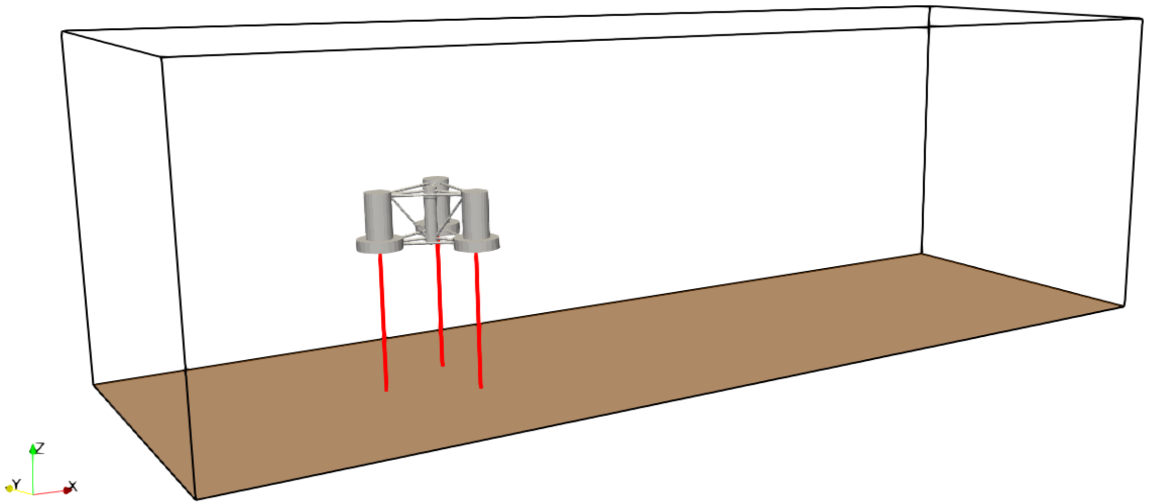
Numerical Domain: x=8.0 m., y= 5.0 m., z=3.0 m.

Numerical Discretization: dx=0.025m, dy=0.025m, dz=0.025m.

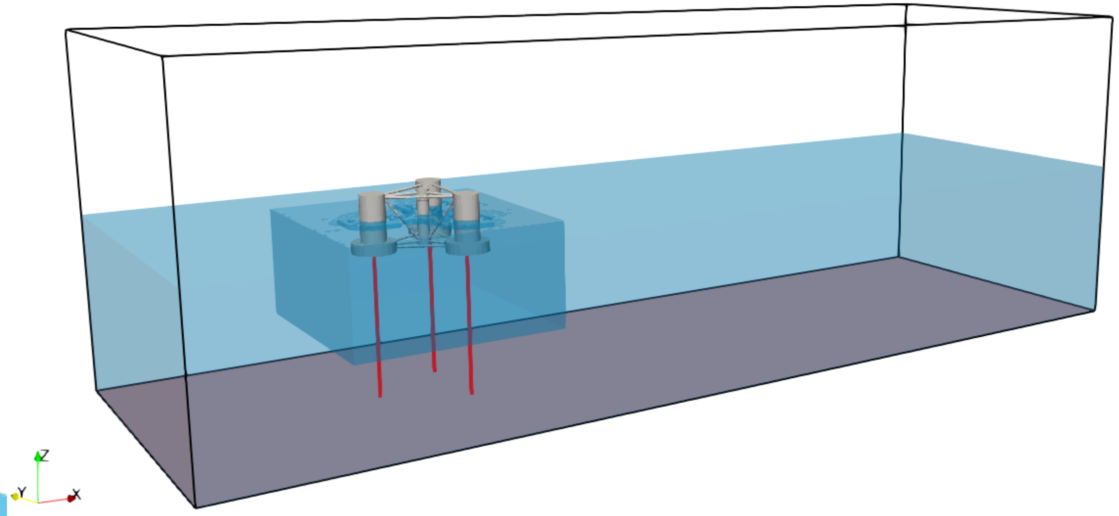
Number of Cells: 2.26 M.

Regular waves and current interaction with a floating platform (OC5)

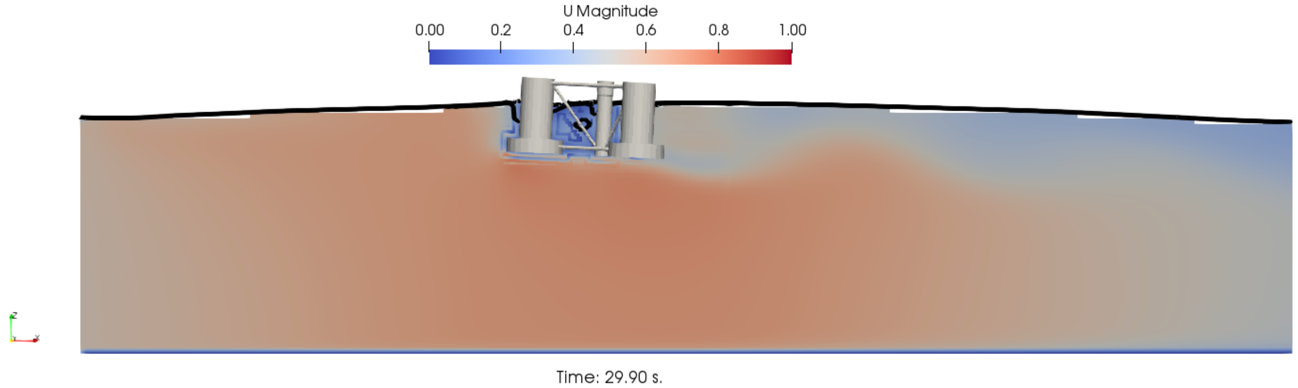
Define 3 mooring lines (taut)

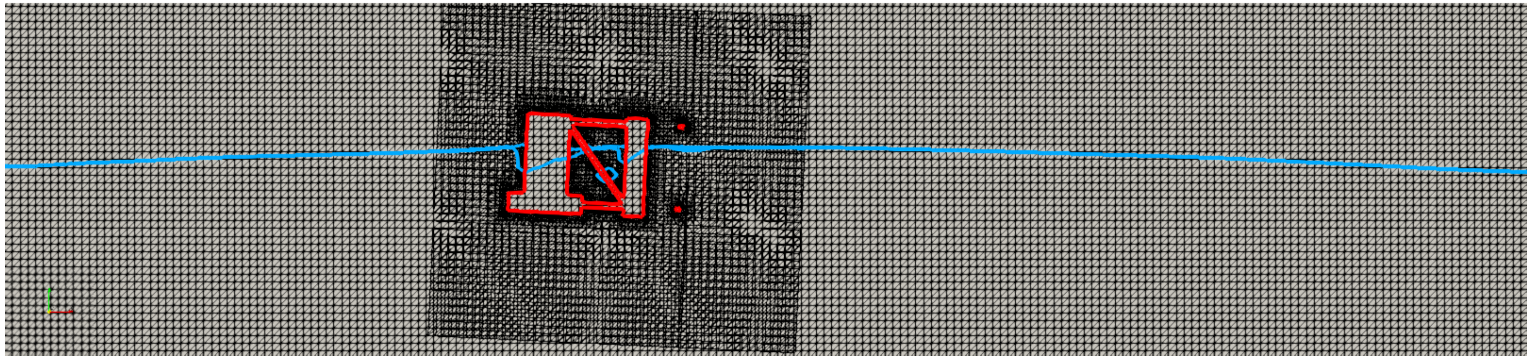


Set initial water conditions



Regular waves and current interaction with a floating platform (OC5)





Solver: overInterDyMFoam (**OpenFOAM-v1812**)

Boundary conditions: currents (t<10s) & currents + regular waves (t>10s)

Turbulence Model: kEpsilon (Larsen & Fuhrman)

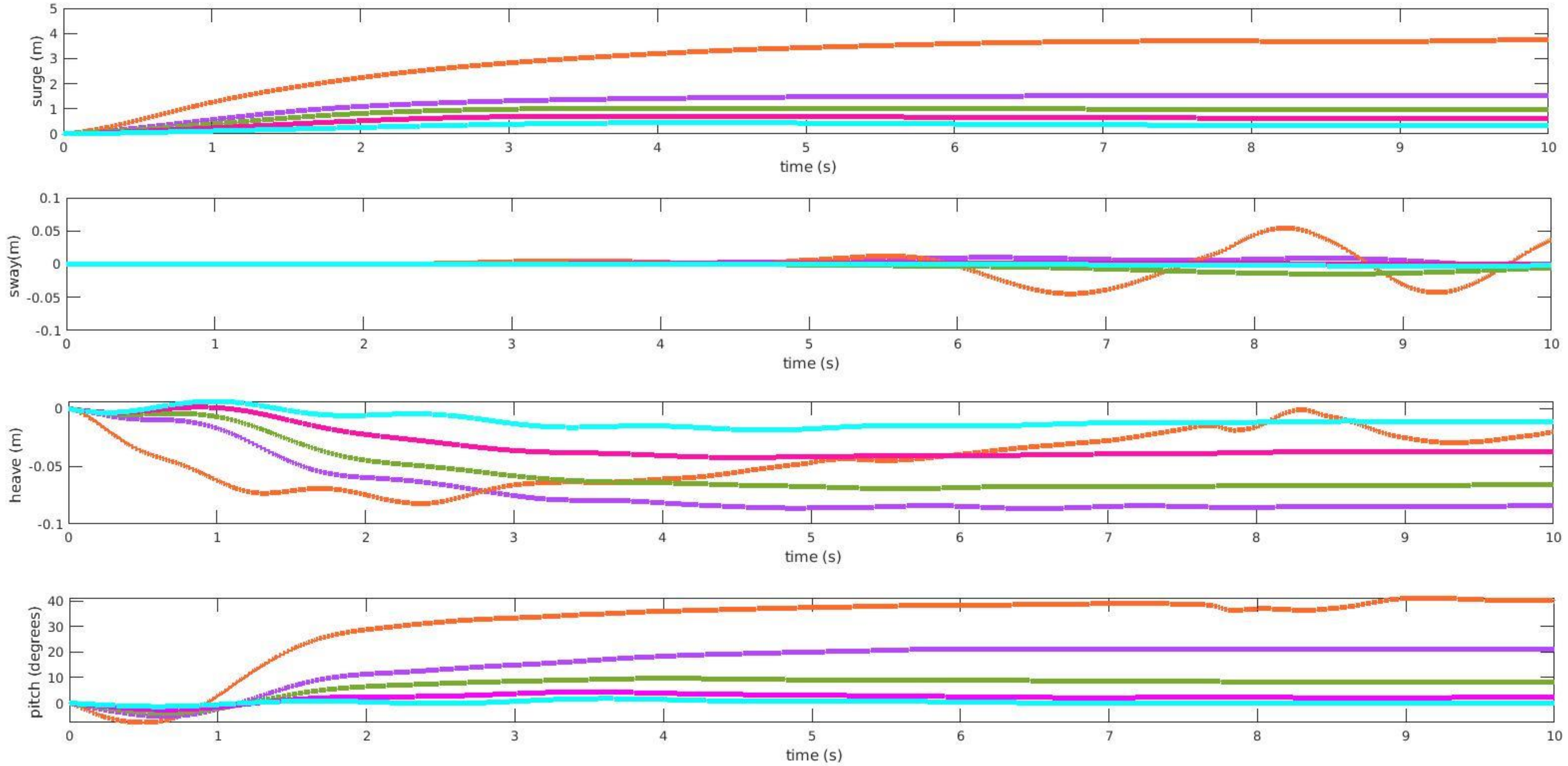
Number of Cells: 2.26M

Number of PE’s: 16

Numerical Simulation: 40 s. (200h of real computational time)

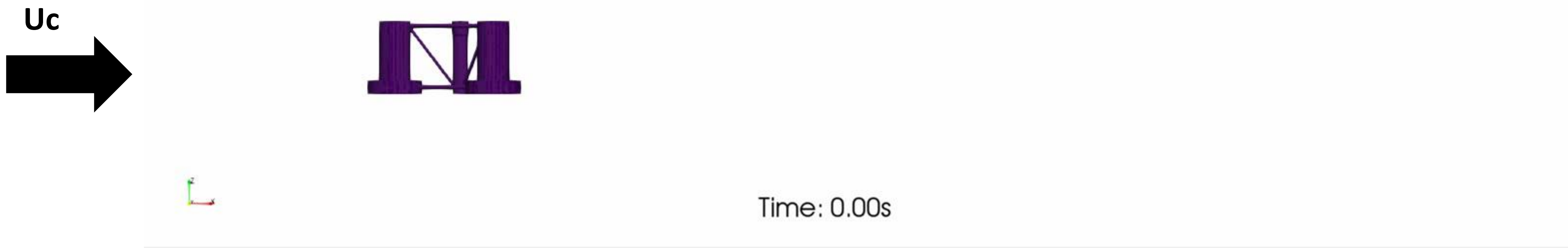
Regular waves and current interaction with a floating platform (OC5)

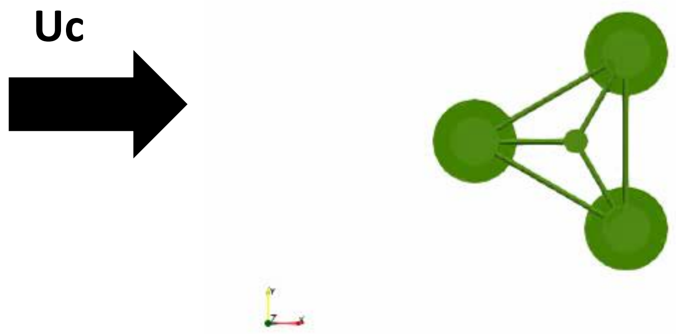
Displacement of the floating structure under a constant current. Case Uc=[0.25 m/s, 0.50 m/s, 0.75 m/s, 1.00 m/s, 2.00 m/s].



Regular waves and current interaction with a floating platform (OC5)

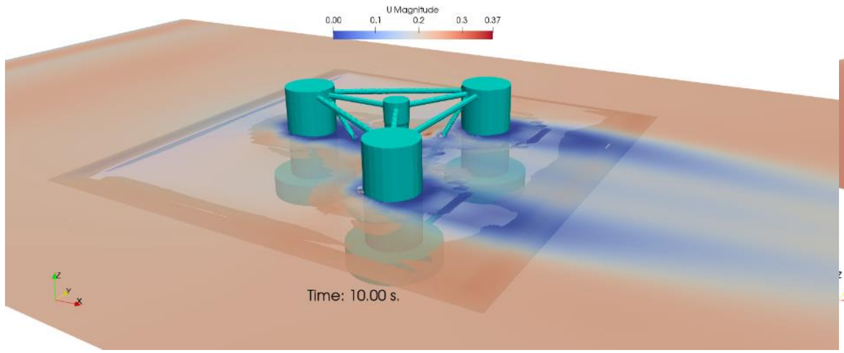
Displacement of the floating structure under a constant current. Case Uc=[0.25 m/s, 0.50 m/s, 0.75 m/s, 1.00 m/s, 2.00 m/s].



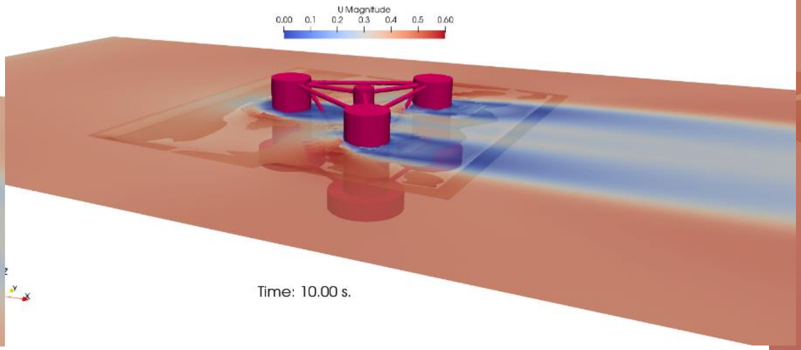


Regular waves and current interaction with a floating platform (OC5)

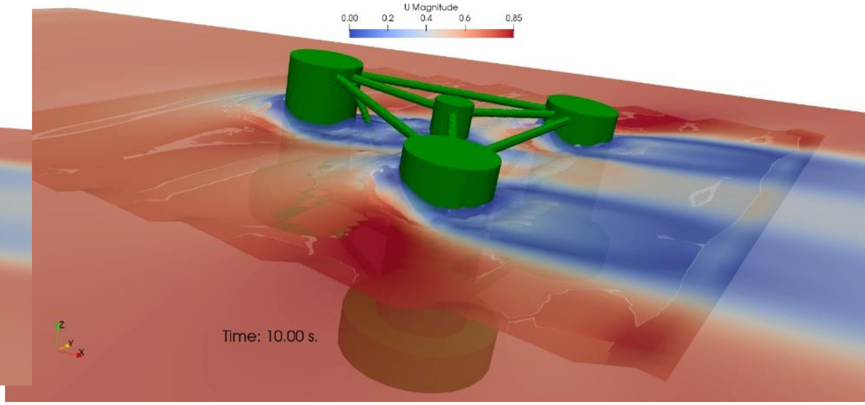
Velocity magnitude on the FreeSurface (VoF=0.5) at t=10.00s, Case Uc=[0.25 m/s, 0.50 m/s, 0.75 m/s, 1.00 m/s, 2.00 m/s].



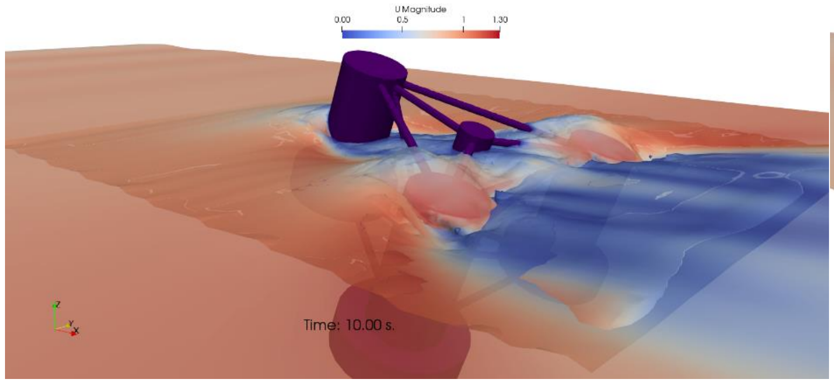
Uc=0.25m/s.



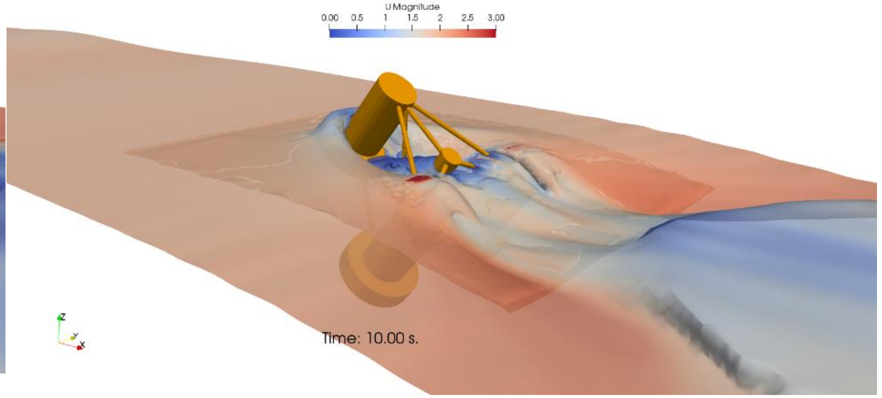
Uc=0.50m/s.



Uc=0.75m/s.



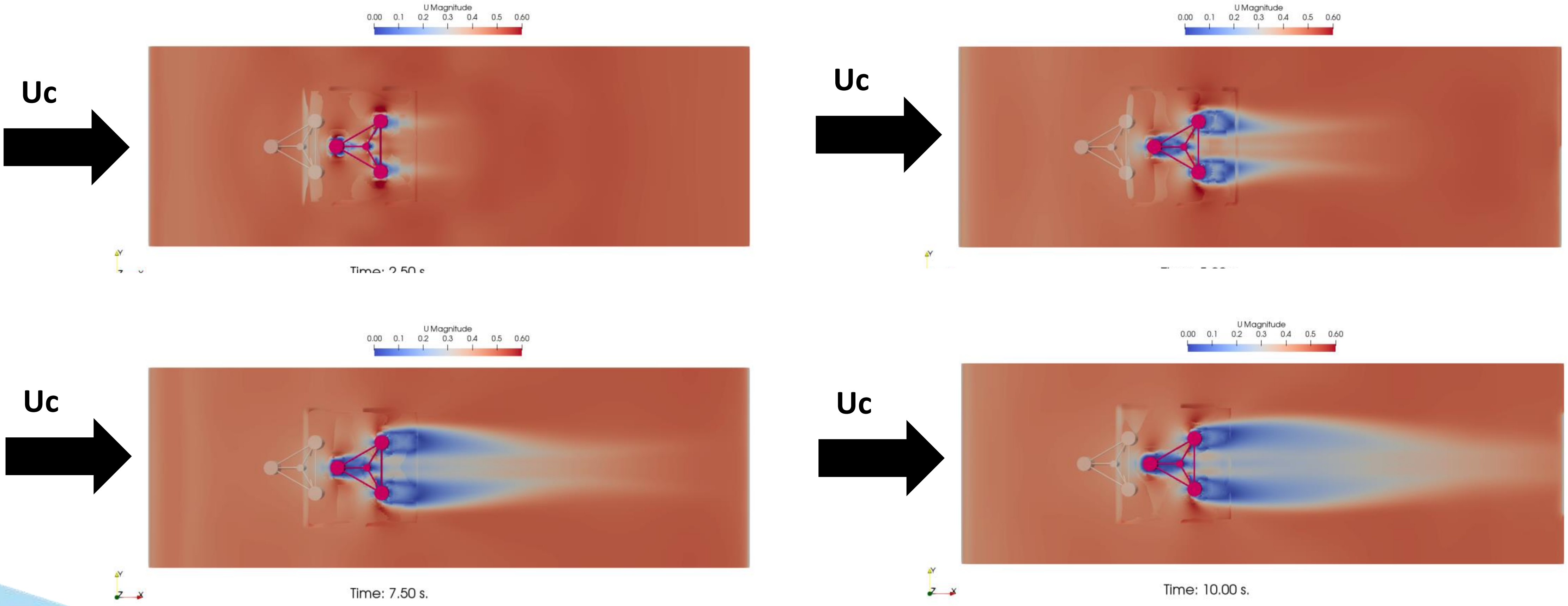
Uc=1.00m/s.



Uc=2.00m/s.

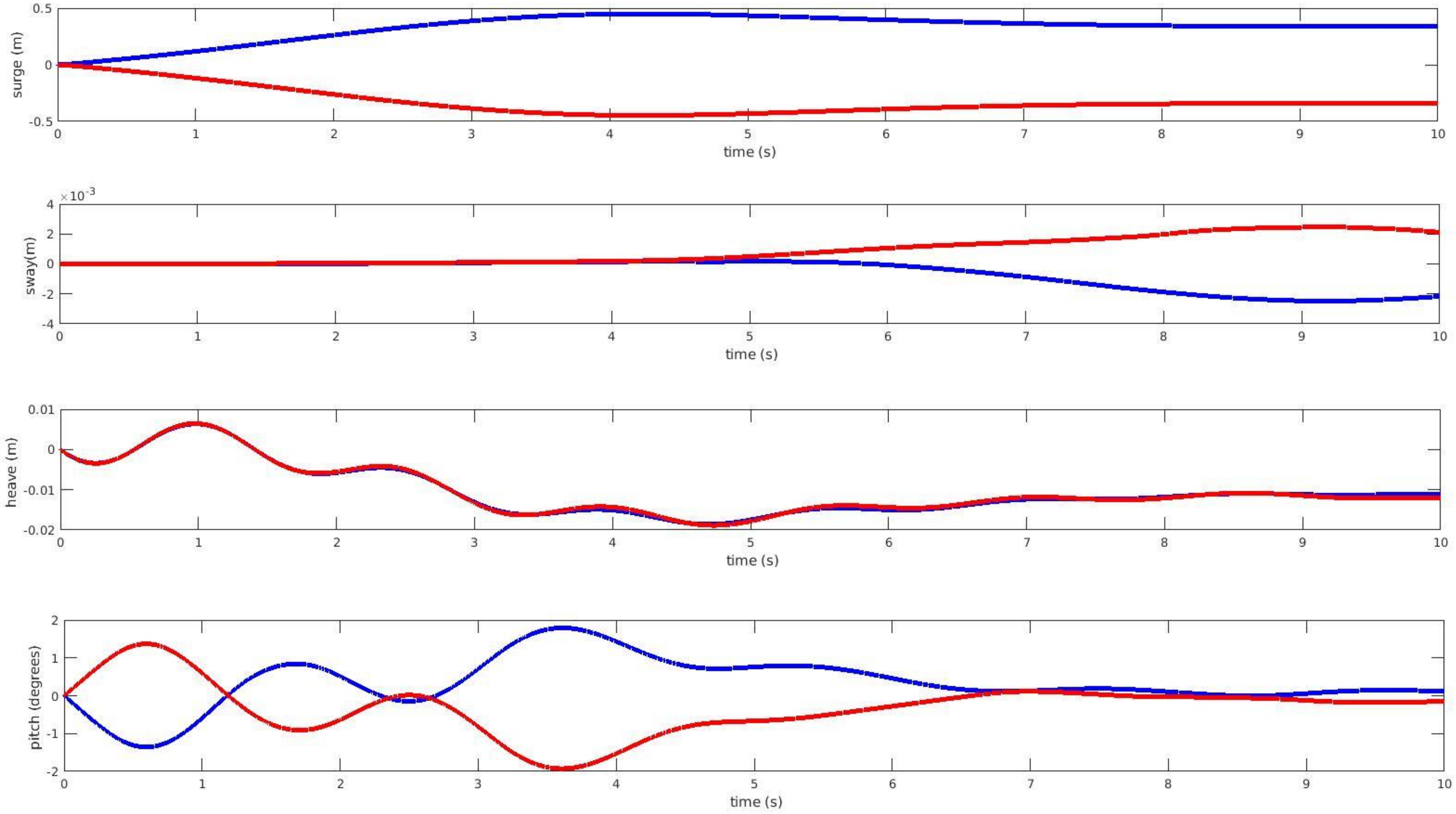
Regular waves and current interaction with a floating platform (OC5)

Velocity magnitude on plane XY (z=0.95m), Case Uc= 0.50 m/s.



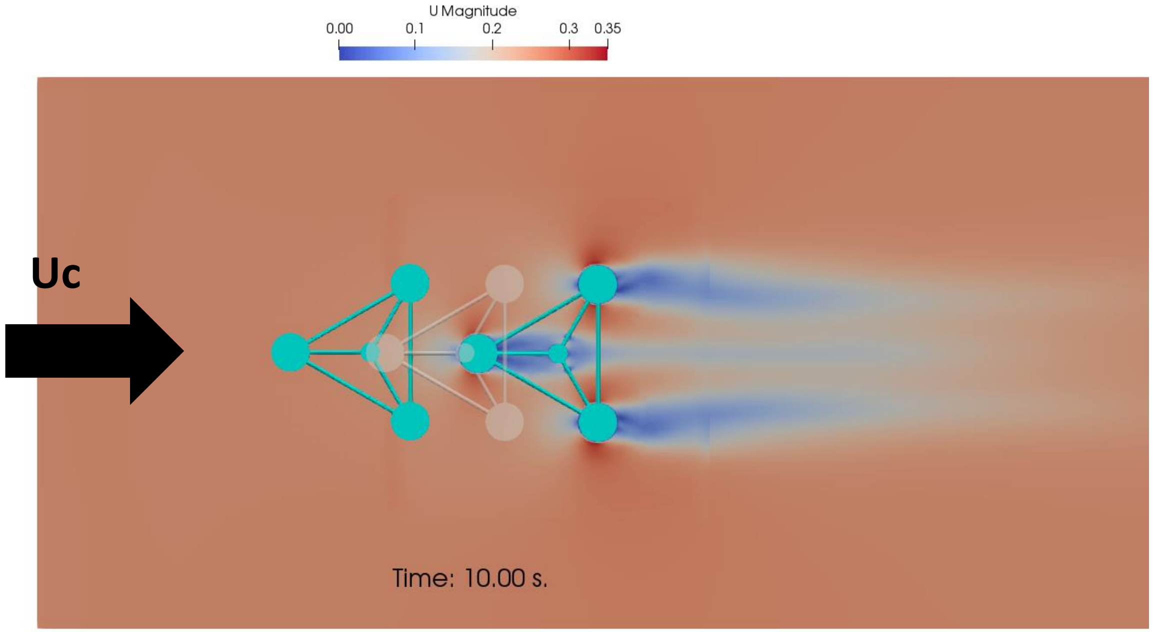
Regular waves and current interaction with a floating platform (OC5)

Traslations (surge, sway and heave) and rotation (pitch), Case Uc= [0.25 m/s., -0.25 m/s.]

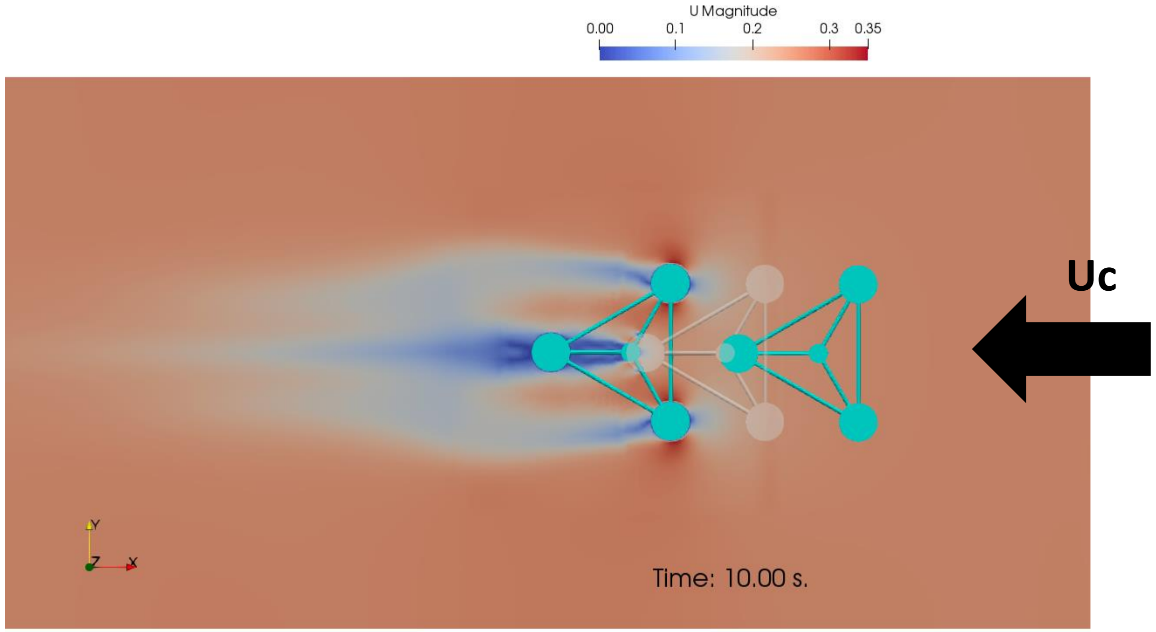


Regular waves and current interaction with a floating platform (OC5)

Velocity magnitude on plane XY (z=0.95m), Case Uc= [0.25 m/s., -0.25m/s.]



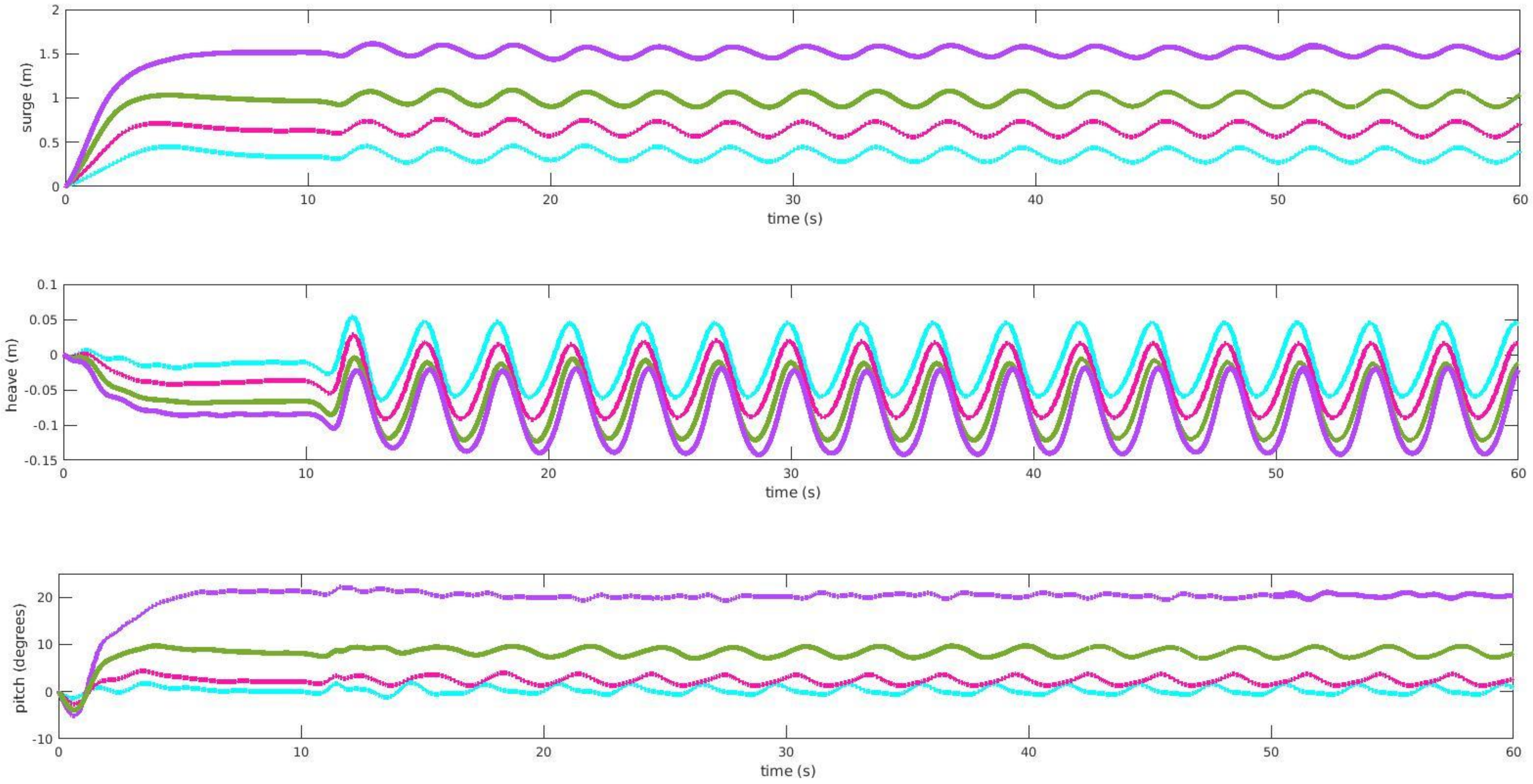
Uc=+0,25m/s.



Uc=-0.25m/s.

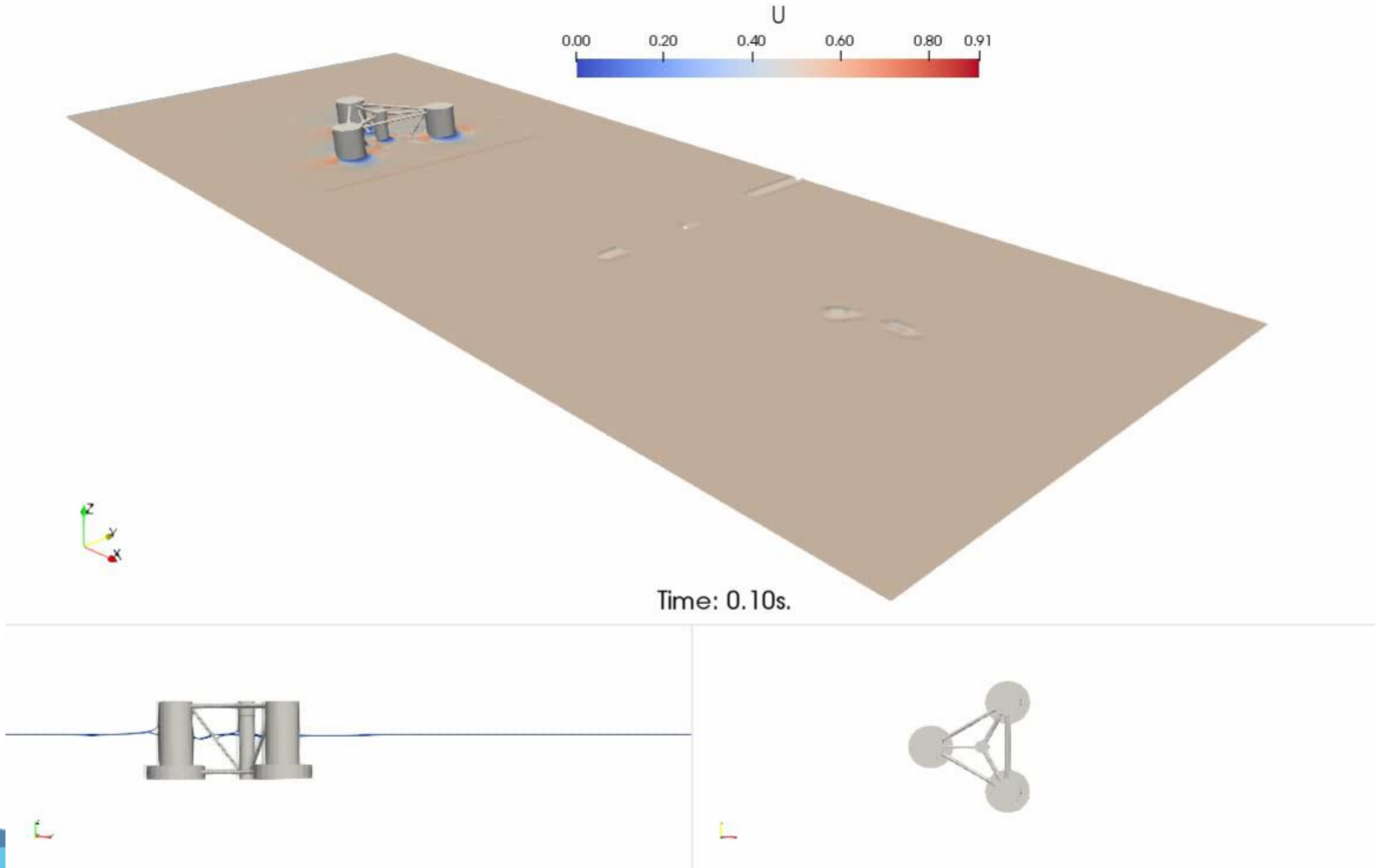
Regular waves and current interaction with a floating platform (OC5)

Traslations (surge, heave) and rotation (pitch), Case Uc= [0.25 m/s, 0.50 m/s, 0.75 m/s, 1.00 m/s,] for t<10s .
Currents and regular waves (stokesII, H=0.12m. , T=3.0s, h=1,0m), for t>10s.



Regular waves and current interaction with a floating platform (OC5)

Velocity magnitude on the free Surface (VoF=0.5), Case Uc= [0.50 m/s] and regular waves (stokesII, H=0.12m. , T=3.0s, h=1,0m)



Conclusions

- Two validations were shown for OpenFOAM:
  - waves and current interaction
  - waves interaction with a moored floating object

- A realistic application related to coastal and offshore engineering were shown:
  - It can be observed that the presence of current modifies the wave height
- - It can be observed that fluid-structure interaction can be solved very accurately.
  - Performing the Overset mesh, high dynamic mesh motion stability has been achieved for all the cases.

Future Work

- The main focus for the future is to implement real mooring systems in order to address real wave-current structure interaction.

- Reduce computational costs.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Thank you for your attention!