SHAKE THE FUTURE.

Hydrodynamic analysis and numerical modelling of heave plates dedicated to the design of FOWT

WESC2021 Mini-Symposium
25th -28th May 2021

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement N° 860879.

Introduction

> FLOAWER Project, ESR 5 (WP5-Advanced Floater Analysis)

- **Topic**

  Hydrodynamic analysis and numerical modeling of Heave Plates
- **Expected results** (2020 ~ 2023, 3yrs)

  a. Hydrodynamic database

  b. Improved engineering models

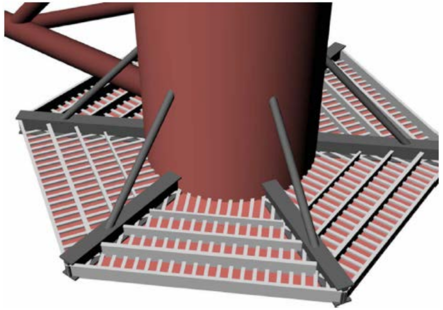


Figure 1. Heave plate on Windfloat (D. Roddier et al., 2010)

> Heave plate in Floating Wind Turbine

- Increase **Added Mass**
  - ✓ Escape from resonance period $T_3 = 2\pi\sqrt{\dfrac{m+m_a}{\rho g A_{wp} + k_m}}$.
- Increase **Total Damping**
  - ✓ Reduce the wave induced response

⬇

- Improve **Structural Design**
  - ✓ Floater, column and mooring lines
- Improve **Power Output** of Floating Wind Turbine

a. Windfloat (D. Roddier et al., 2010) b. Floatgen (Floatgen report #3.1)

Figure 2. Floating offshore wind turbine with the heave plates

Key Features

> Heave plate in Floating Wind Turbine

- **Flow Parameters**
  - ✓ Keulegan Carpenter (KC) Number

    $$KC_C = \frac{2\pi\xi_3}{D_C} \text{ or } KC_D = \frac{2\pi\xi_3}{D_D}$$

    - Classic Offshore Platform, 0.0 < KC_C < 1.2
    - Floating Offshore Wind Turbine
      ex> HiPRWind, KC_C = 2.9 in extreme condition
  - ✓ Frequency Parameter and Reynolds number

    $$\beta_C = \frac{D_C^2 f_3}{\nu} \text{ or } \beta_D = \frac{D_D^2 f_3}{\nu} \text{ and } Re = (KC)\beta$$

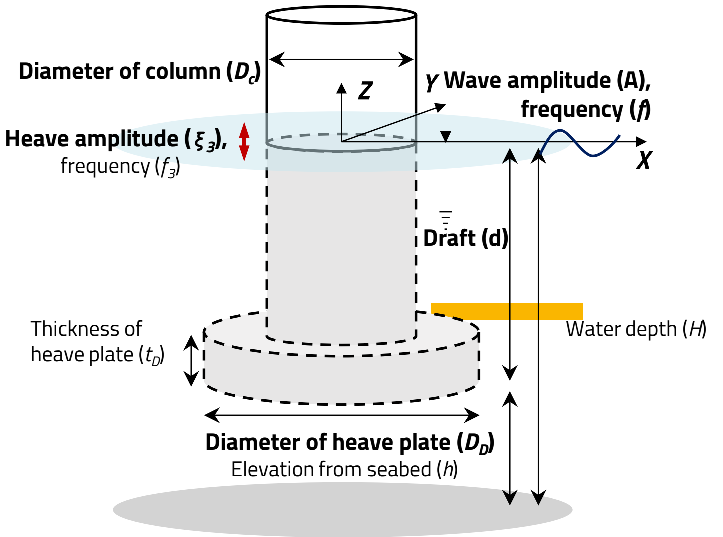


Figure 3. Definition of parameters

- **Geometrical Parameters**
  - ✓ Diameter ratio

    $$1.0 < D_D/D_C < 3.6$$

  - ✓ Draft ratio

    $$0.4 < d/r_D < 25.5$$

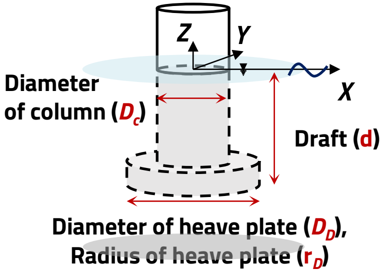
    $$where\ r_D\ is\ \frac{1}{2}D_D$$

Table 1. Floating Platform Models

Type		Semi1	Semi2	Semi3	Semi4	Spar1	Spar2	Barge
Column Dia.	D_C [m]	12.0[a]	10.5	7.0	15.8	6.5/9.4[b]	14.4	34.0
Heave Plate Dia.	D_D [m]	24.0	36.9	20.0	22.8	-	-	38.4
Draft	d [m]	20.0	18.0	15.5	22.0	120.0	78.0	7.0
Plate Thickness	t_D [m]	6.0	thin plate	0.1	thin plate	-	-	thin plate
Diameter Ratio	D_D/D_C	2.0	3.6	2.9	1.4	1.0	1.0	1.1
Draft Ratio	h/r_D	1.7	1.2	1.6	1.9	25.5[c]	10.8[d]	0.4

[a] Offset column, [b] tapered column, [c,d] Draft ratio with column diameter
< Note > Semi1: DeepCWind (OC4), Semi2: Windfloat, Semi3: HiPRWind (OC3), Semi4: OO-STAR, Spar1: Hywind, Spar2: Hywind-Scotland, Barge: Floatgen (Ideol)

Hydrodynamic Database with Heave Plate



> List of Previsous Database

- Forced oscillation in Heave motion

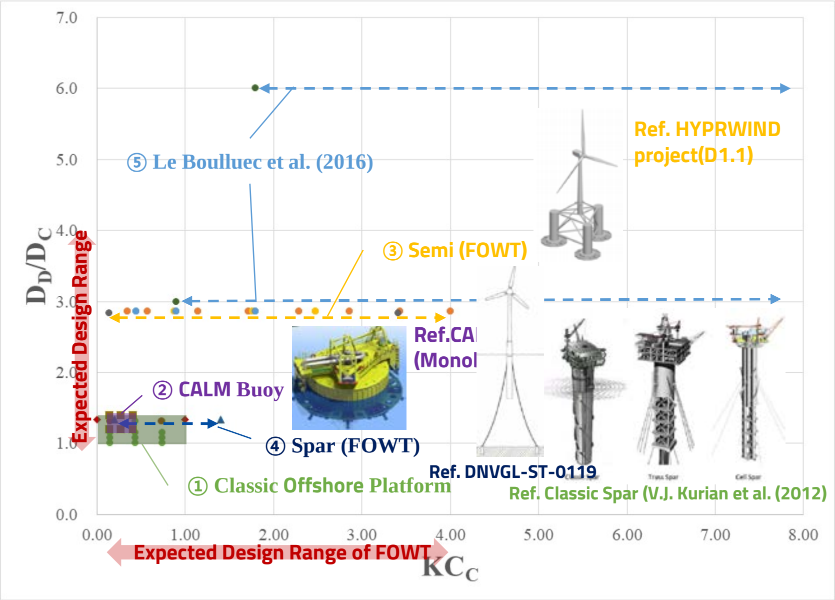


Fig 5. Hydrodynamic database with KCc vs Diameter ratio

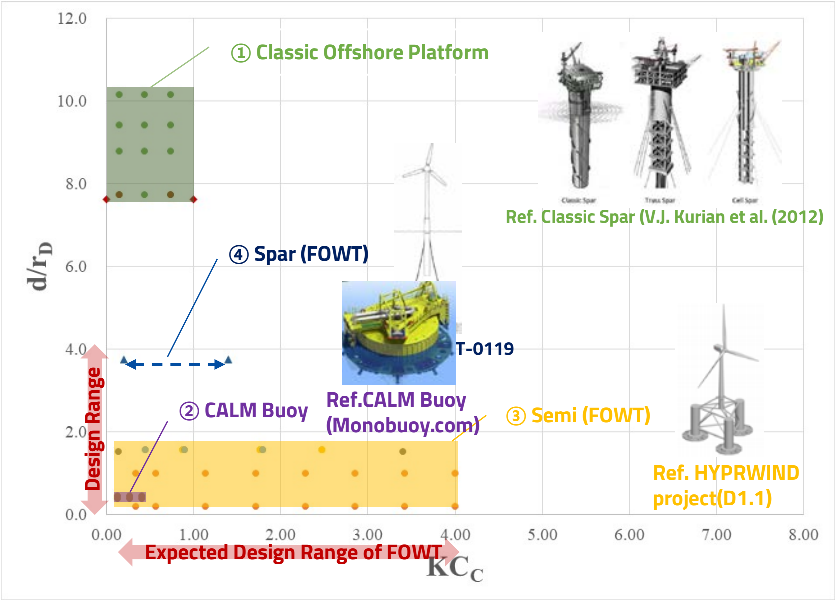


Fig 6. Hydrodynamic database with KCc vs draft ratio

*** Classic Offshore Platforms (TLP & Spar, ①):** Thiagarajan et al. (2002), Tao & Thiagarajan (2003), Tao et al. (2007)

*** CALM Buoy JIP , 2006 (**②)

*** Floating Offshore Wind: Semi-submersible (**③ Garrido-Mendoza et al. (2014), Lopez-Pavon et al. (2015), Bezunartea-Barrio et al (2019), Thiagarajan & Moreno (2020)**), Spar (**④, Zhu & Lim (2017)**), Others (**⑤, Boulluec et al. (2016))

Summary for Future Works

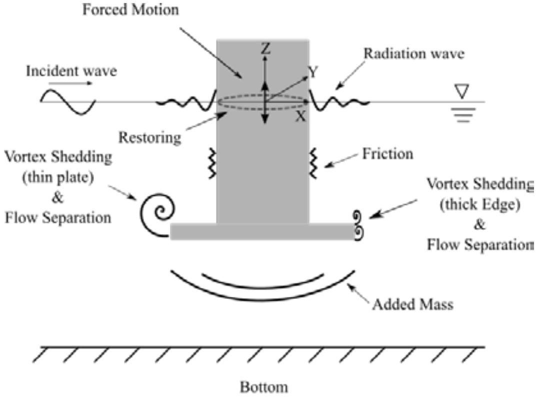
> Methodologies

- Experiment & Numerical Analysis (OpenFOAM)
- Forced oscillation and Captive Test

> Test Campaign

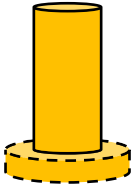
Fig 6. Ocean Engineering Tank (LHEEA) and CFD (OpenFOAM)

1.Forced Oscillation (Radiation Problem)



- Including **free surface** and **wave effect**
- **Complex motion** (regular and irregular)

< Model >

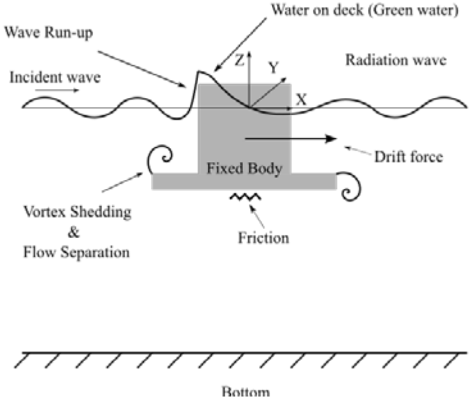


Single Column
with Heave Plate

< Output >

✓Hydrodynamic **D/B**
✓**Numerical Scheme**

2.Captive (Diffraction Problem)



- **Wave drift force**
- **Wave run-up** (with heave plate)
- Upright & **inclined** conditions

Thanks for your attention

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement N° 860879.

APPENDIX A – Formula for Added Mass Coefficients

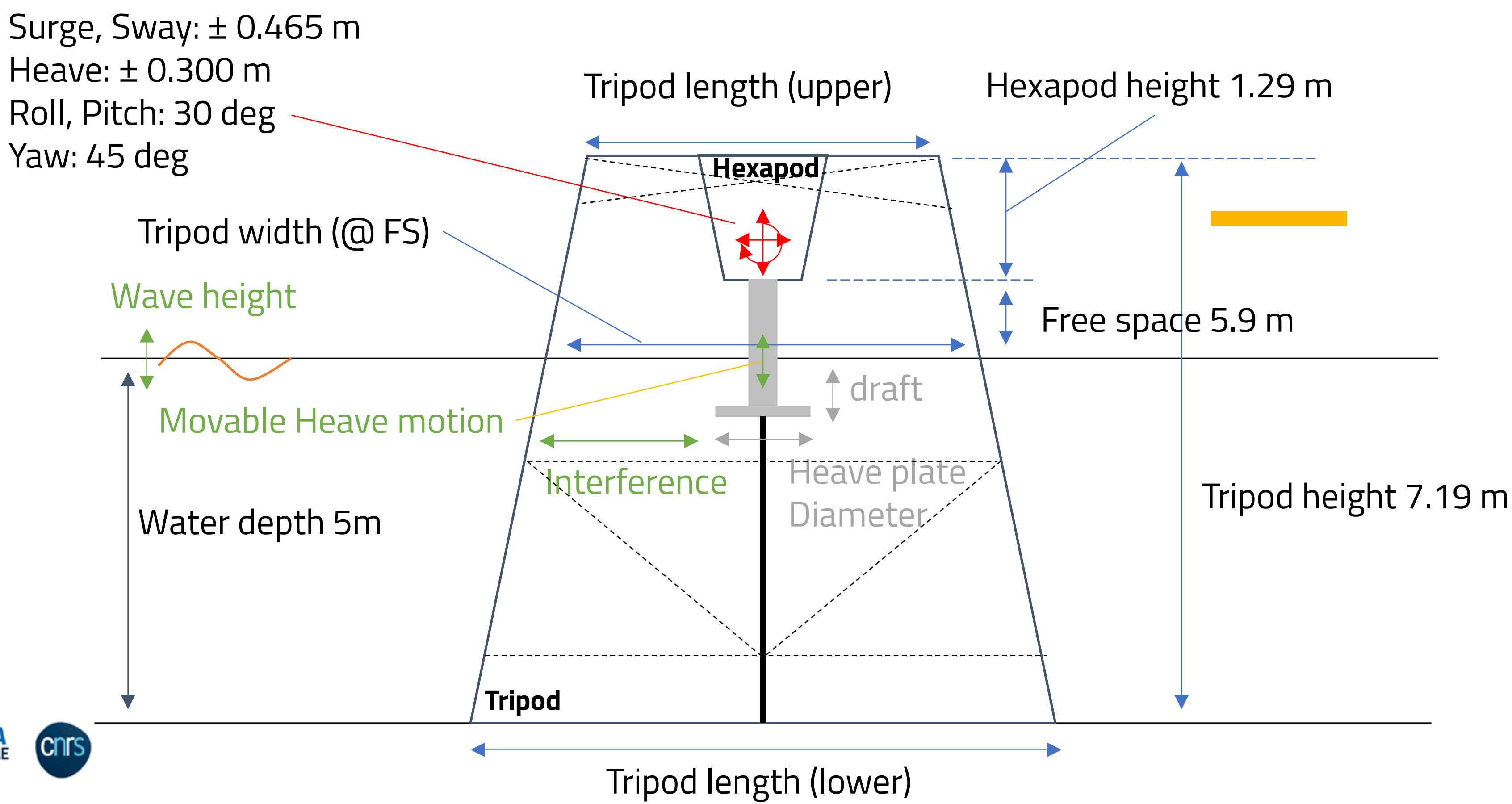
Configuration	Section	Added mass (or coefficient)	Ref.
Isolated heave plate	Cir.	$m_a = \frac{1}{3}\rho D_d^3$	[11]
A cylinder with heave plate	Cir.	$C_a = \frac{1}{3}\frac{2D_d^3+3\pi D_d^2 z-\pi^3 z^3-3\pi D_c^2 z}{\pi(D_d^2 t_d+D_c^2 t_c)}$, $z = \frac{1}{\pi}\sqrt{D_d^2 - D_c^2}$	[19]
	Cir., Oct., Rec.	$C_a = f_{r1}\left(k^3 - \frac{1}{4}\left[3r_d^2\sqrt{k^2-r_d^2} + \left(k-\sqrt{k^2-r_d^2}\right)^2\left(2k+\sqrt{k^2-r_d^2}\right)\right]\right)$, $k = k_1 \cdot k_2, \quad k_1 = 1 + 0.2KC, \quad k_2 = \begin{cases} 1.00; & \text{Circular heave plate} \\ 0.95; & \text{Octagonal heave plate} \\ 0.75; & \text{Square heave plate} \end{cases}$ $f_{r1} = \frac{1}{3}\rho D_d^3 / \left(\frac{1}{4}\pi(D_d^2 t_d + D_c^2 t_c)\right)$	[20]
A cylinder with multiple heave plates	Cir.	$C_a = \frac{1}{12}\frac{8D_d^3-12\pi D_c^2 z-12\pi D_c^2 L+12\pi D_d^2 z-4\pi^3 z^3+12\pi D_d^2 L-\pi^3 L^3}{\pi(2D_d^2 t_d+D_c^2 t_c)}$	[19]
	Cir., Oct., Rec.	$C_a = \begin{cases} f_{r2}\left(2k^3 - \frac{1}{4}\left[3r_d^2\sqrt{k^2-r_d^2} + \left(k-\sqrt{k^2-r_d^2}\right)^2\left(2k+\sqrt{k^2-r_d^2}\right)\right] - \frac{1}{16}\left[12\pi r_d^2 r_L + (2k-\pi r_L)^2(4k+\pi r_L)\right]\right); & \text{for } r_L \leq 2k/\pi \\ f_{r2}\left(2k^3 - \frac{3}{4}\left[3r_d^2\sqrt{k^2-r_d^2} + \left(k-\sqrt{k^2-r_d^2}\right)^2\left(2k+\sqrt{k^2-r_d^2}\right)\right]\right); & \text{for } r_L > 2k/\pi \end{cases}$ $f_{r2} = \frac{1}{3}\rho D_d^3 / \left(\frac{1}{4}\pi(2D_d^2 t_d + D_c^2 t_c)\right)$	[20]

LHEEA CENTRALE NANTES cnrs

APPENDIX B – Formula for Drag Coefficients

Configuration	Section	Drag coefficient	Ref.
Isolated heave plate	Cir.	$C_{d(form)} = A(KC)^n$ $A = \begin{cases} 11.8 \\ 5.7 \end{cases}, n = \begin{cases} -1/3 & \text{for flat plate} \\ 0 & \text{for diamond cylinder} \end{cases}$	[23]
A cylinder with heave plate	Cir.	$C_{d(form)} = A(KC)^n$ $A = \begin{cases} 0.15 \\ 2.5 \\ 4.0 \end{cases}, n = \begin{cases} -3/4 & \text{for independent vortex shedding} \\ -1/5 & \text{for interactive vortex shedding} \\ -1/4 & \text{for uni-directional vortex shedding} \end{cases}$	[24]
	Cir., Oct., Rec.	$C_d = min\left\{1.7 r_t^{-1/3.7} (KC)^{-1/k_3}, 12\right\}$ $k_3 = \begin{cases} 2.5; & \text{Circular heave plate} \\ 2.5; & \text{Octagonal heave plate} \\ 3.0; & \text{Square heave plate} \end{cases}$	[20]
A cylinder with multiple heave plate	Cir., Oct., Rec.	$C_d = \begin{cases} min\left\{1.7\left(r_{t,d1}^{-1/3.7} + r_{t,d2}^{-1/3.7}\right)(KC)^{-1/k_3} - 3.7k_2 + 2.9r_L, 24\right\}; \\ \text{for } r_L \leq 2k_2/\pi \\ min\left\{1.7\left(r_{t,d1}^{-1/3.7} + r_{t,d2}^{-1/3.7}\right)(KC)^{-1/k_3}, 24\right\}; \\ \text{for } r_L > 2k_2/\pi \end{cases}$	[20]

APPENDIX C – Test Set-up



APPENDIX D – Time series

From Geometry

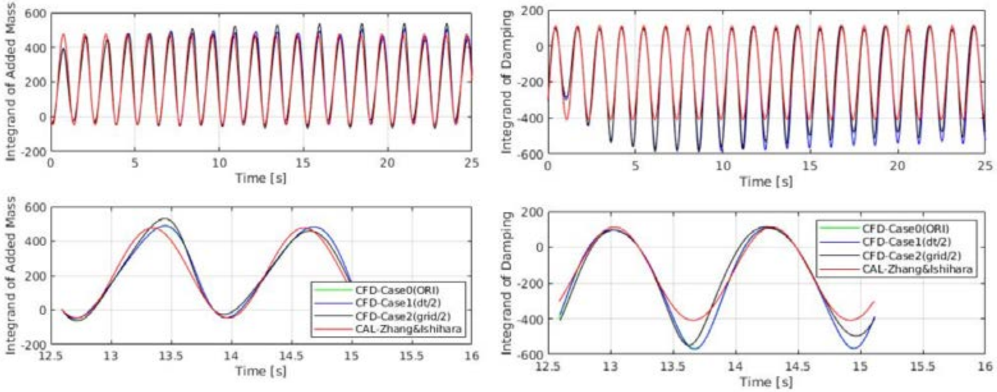
$$F_{measured} = -M_a \ddot{x}(t) - B_{eq}\dot{x}(t) - \rho g A_w x(t) + \rho g \nabla$$

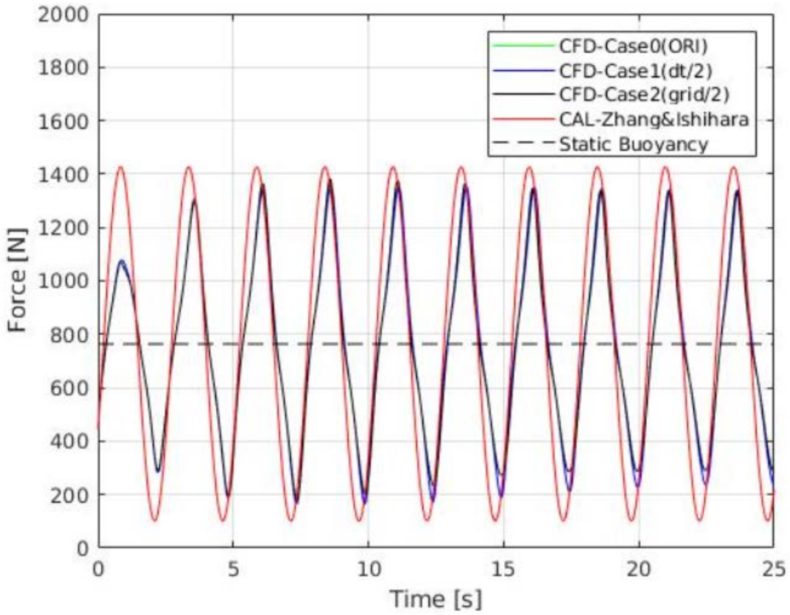
Computed by Zhang & Ishihara formula

< Integrand for Added mass and Damping >

$$\int_t^{t+T} a\omega^2 M_a \sin\omega t \sin\omega t dt - \int_t^{t+T} a\omega B \cos\omega t \sin\omega t dt = \int_t^{t+T} F_{hyd}(t) \sin\omega t dt$$

$$\int_t^{t+T} a\omega^2 M_a \sin\omega t \cos\omega t dt - \int_t^{t+T} a\omega B \cos\omega t \cos\omega t dt = \int_t^{t+T} F_{hyd}(t) \cos\omega t dt$$





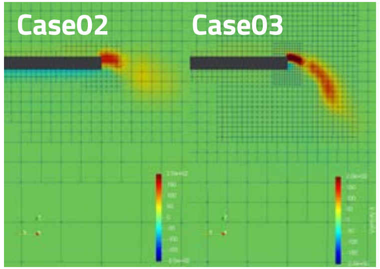
APPENDIX E – Vorticity Fields

< Main Dimensions >

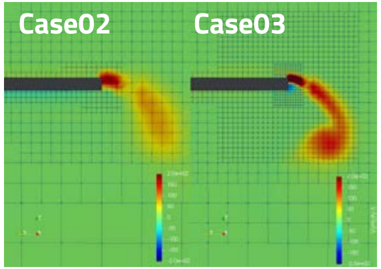
Nomenclature	Unit	Value	Note
Dc	m	0.350	Column diameter
h	m	0.775	Draft of floater
Dd	m	1.000	Disc diameter (heave plate)
td	m	0.005	Disc thickness
Amplitude	m	0.140	Heave amplitude
Period	s	2.519	Heave period
KC	-	0.866	KC number
Beta	-	411738	frequency parameter

< Test Cases for convergence >

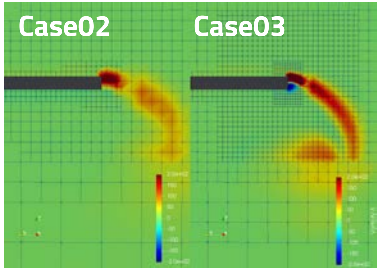
	Case01	Case02	Case03
Turbulence Model	kOmegaSST		
Motion	Moving wall velocity		
Freesurace	Volume of Fraction		
Time Step	0.002	0.001	0.002
Number of Grids	0.8M	0.8M	1.6M



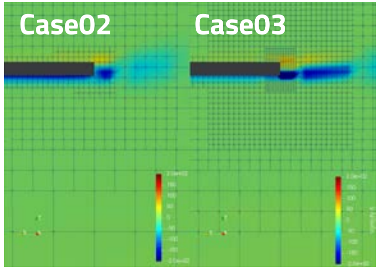
a. t/T=8.69



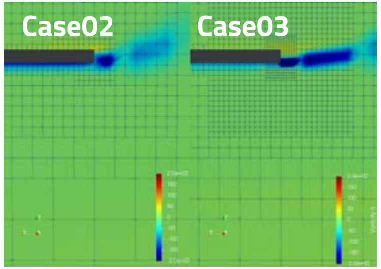
b. t/T=8.73



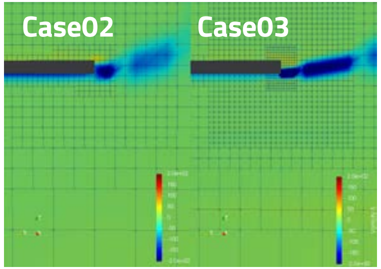
c. t/T=8.77



d. t/T=9.21



e. t/T=9.25



f. t/T=9.29

APPENDIX F – Experiment (C.Lopez)

< Main Dimensions >

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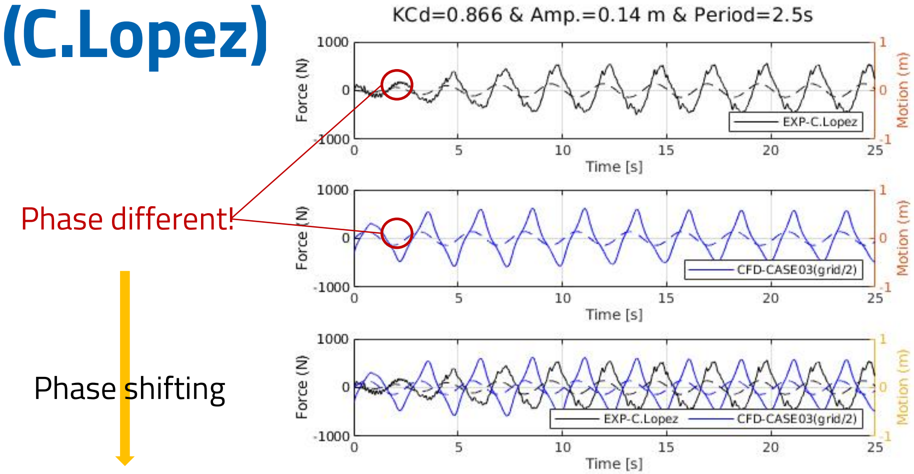
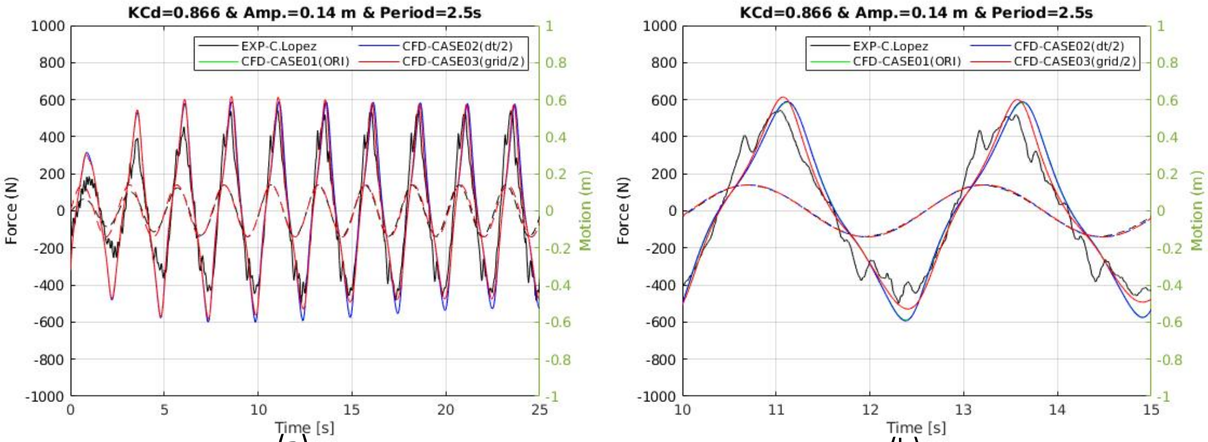
Number of Grids	0.8M	0.8M	1.6M





(a) (b)

Fig. Force time history comparison (EXP vs CFD) (a) Full time history and (b) Zoom in