Effects of Motion, Waves, and Current on Heave Plate Hydrodynamics in Floating Wind Turbines

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Contents

- **Model tests with a truncated segment** of a support structure for a floating offshore wind turbine, focusing on different types of heave plates.
- Tests performed for different **forced oscillations regimes, regular and irregular waves, and current**.
- **A differential approach** is applied to isolate the effect of the heave plates in the fluid-structure interaction forces.
- **Hydrodynamic coefficients** are derived from test results and compared with the literature as a function of the Keulegan-Carpenter number.
- An empirical based formulation is proposed for correcting the hydrodynamic coefficients in the **presence of current** to account for **lift effects**.

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Case study and objectives

Case study

- **FOWT STAR1**, Sofresid Engineering

Objectives

- **characterization** of the different heave plate configurations in terms of the effects on the hydrodynamic loads

Test matrix

- **configurations:** no-plate plus two different plate designs.
- **forced oscillations:** current and no-current
- **fixed model:** regular waves, irregular waves (curr/no curr)

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Model design

- Froude Scaling: 1:45

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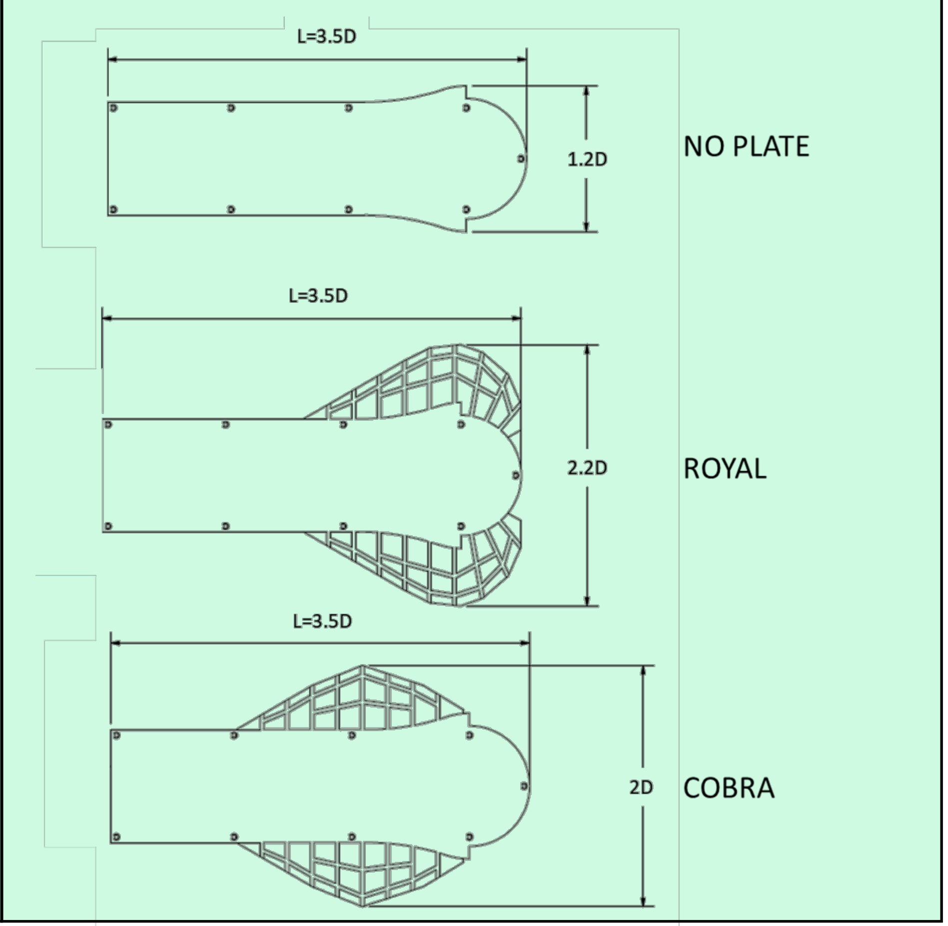
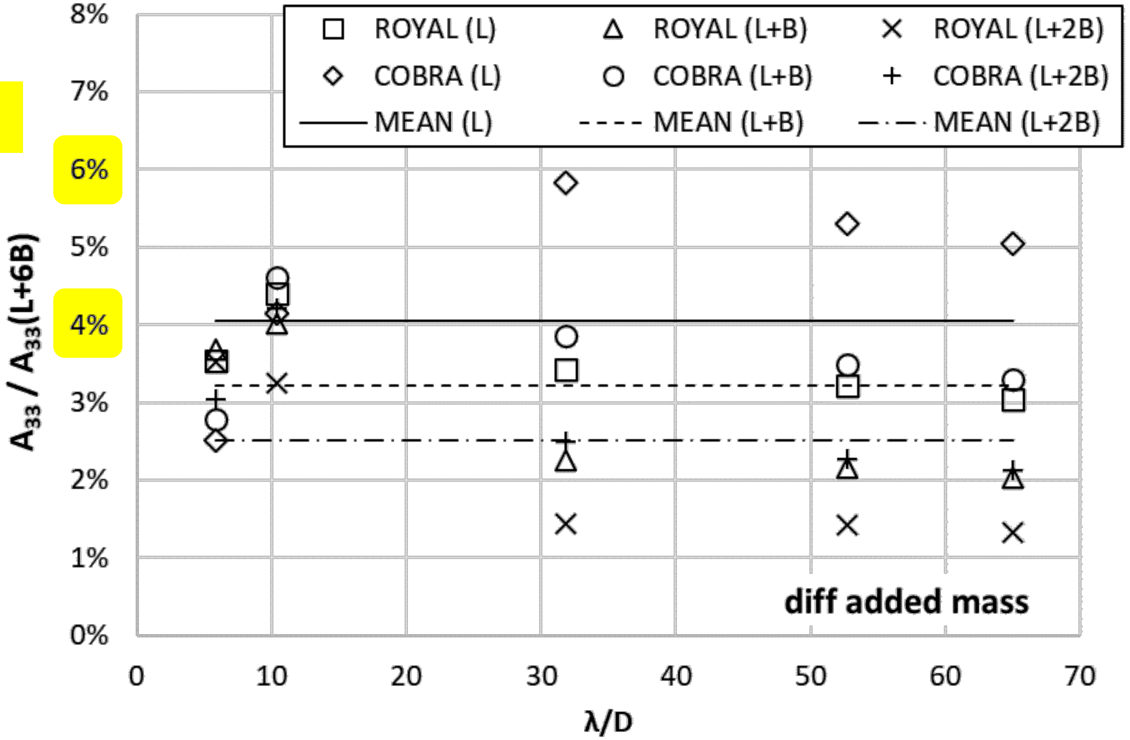
End effects?

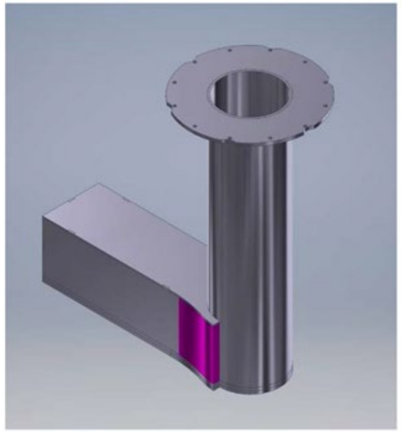
Wall effects?

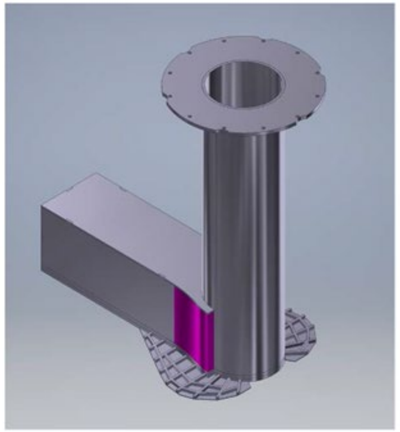
interchangeable bottom plates (same mass)

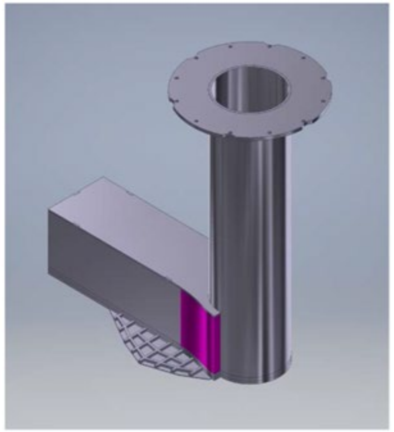


Variation of the potential flow added mass in heave induced by the heave plates with the increase of L









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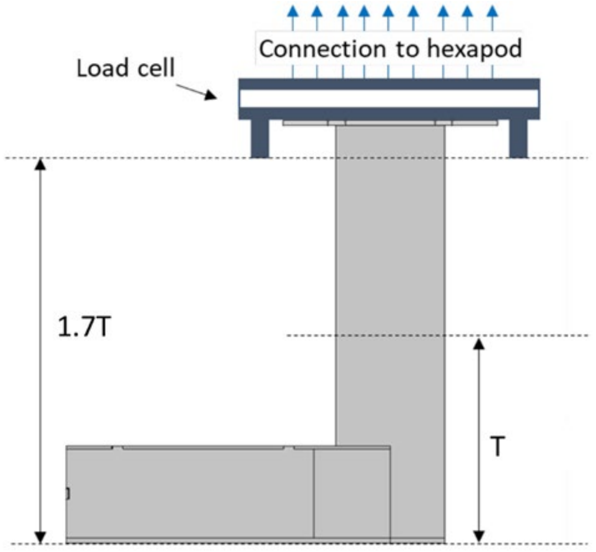
Setup and instrumentation

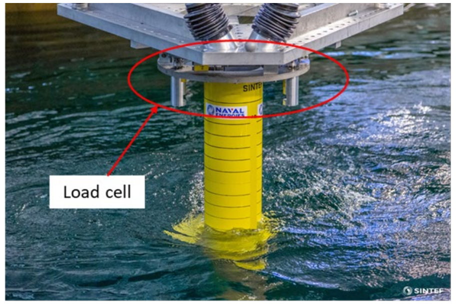
Current simulated by advancing carriage

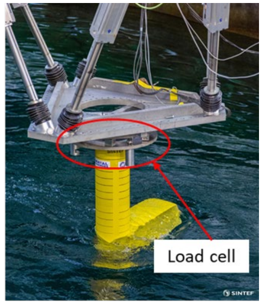
Differential approach -> inertias

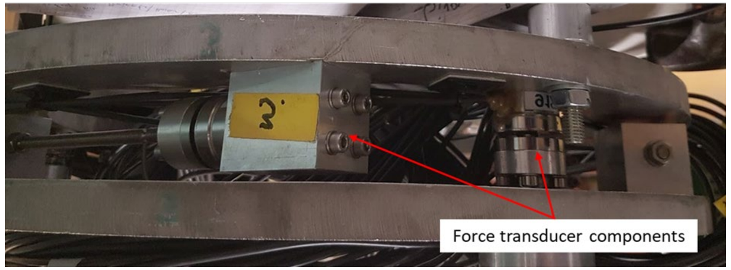
Instrumentation

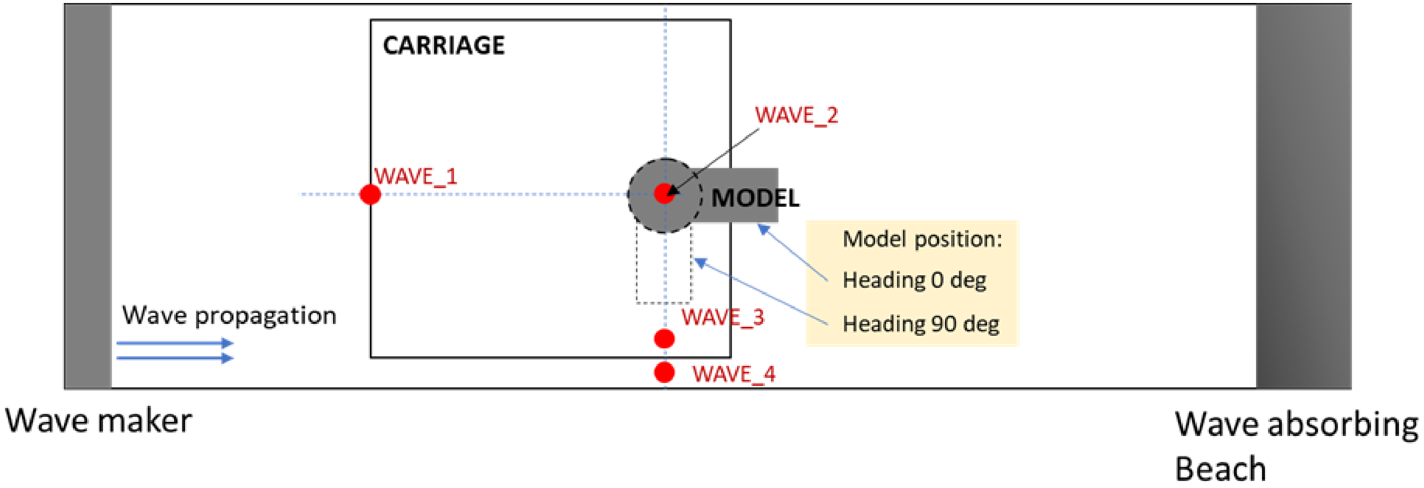
- Vertical position of the hexapod
- Acceleration at the hexapod's base and at lower plate of the load cell
- Wave probes
- Longitudinal position of the carriage (optical system)
- Speed as the derivative of the position





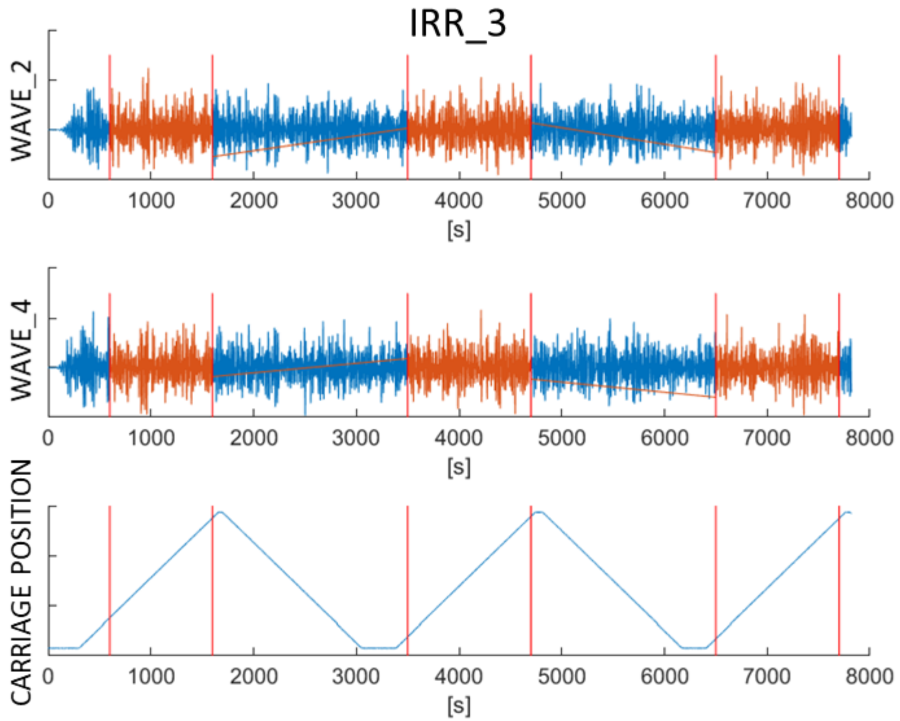


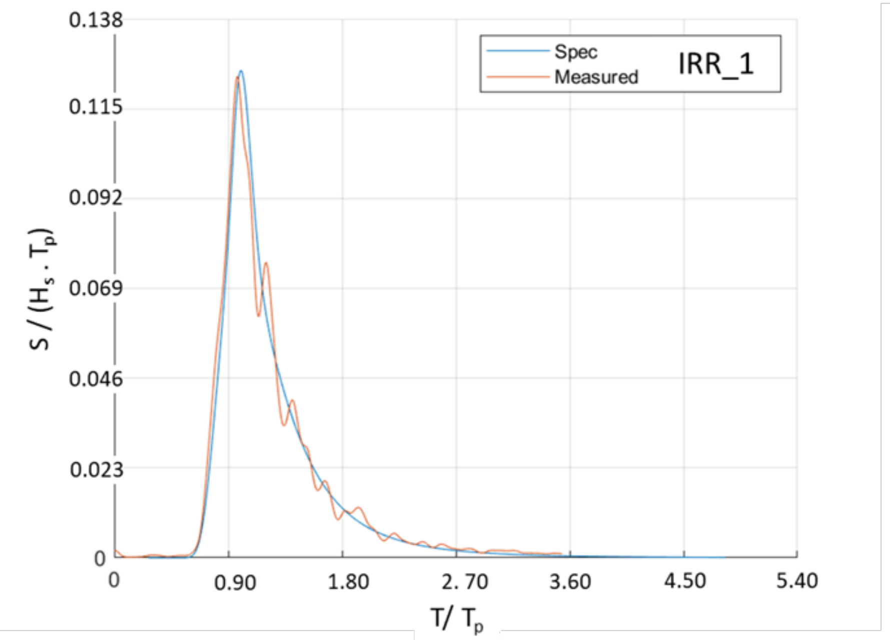




Environment calibration

- 3-hour JONSWAP
- effective length of the section of the towing tank that was used is limited
- Segmented runs
- statistical parameters be equivalent to a continuous run





Problem formulation and analysis procedure

Morison Equation → $F_H = \rho C_A \dot{u} + \frac{1}{2}\rho A_P C_D u|u|$

Differential approach → $F_P^H \cong F_P^T - F_B^T$

Added mass and Drag coefficient → $f(C_A, C_D) = F_P^H - \rho C_A \dot{u}(t) - \frac{1}{2}\rho A_P C_D u(t)|u(t)| \cong 0$

Relative undisturbed velocity

- Regular waves → $u(t, P_c) = \omega A e^{kz_c} \cos(kx_c - \omega t)$ → P_c = centroid of the plate; X_c = offset relative to the measurement point
- Irregular waves

discrete Fourier transform of the time series of the wave elevation measured by WAVE_2 ($\mathcal{F}$) → complex vertical velocity and acceleration →

$U(\omega, P_c) = \omega \mathcal{F} e^{i\left(\frac{\pi}{2} - kx_c\right)} e^{kz_c}$

$\dot{U}(\omega, P_c) = \omega e^{i\left(\frac{\pi}{2}\right)}$

→ inverse discrete Fourier → u, $\dot{u}$

Identification of the hydrodynamic coefficients

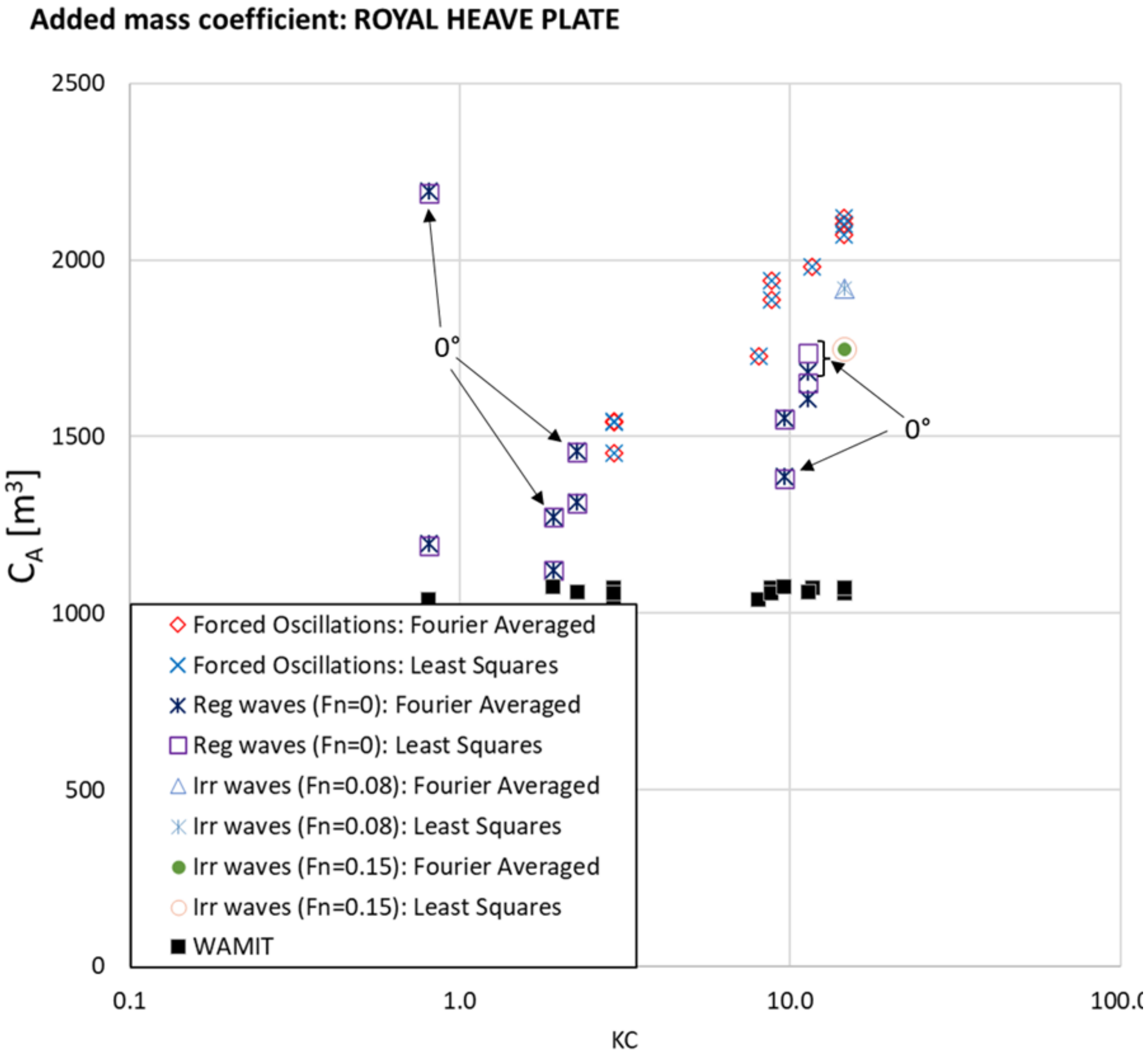
Keulegan-Carpenter number

- $K_C = \frac{2\pi A}{w_s}$
- $A = amplitude$
- $A = \eta_0 e^{kd}$

Identification of coefficients

- Fourier averaging
- Levenberg-Maquardt method for Non-Linear Least Squares (LM)

Added Mass


Added mass coefficient: ROYAL HEAVE PLATE
C_A [m³]
KC
0°
0°
Forced Oscillations: Fourier Averaged
Forced Oscillations: Least Squares
Reg waves (Fn=0): Fourier Averaged
Reg waves (Fn=0): Least Squares
Irr waves (Fn=0.08): Fourier Averaged
Irr waves (Fn=0.08): Least Squares
Irr waves (Fn=0.15): Fourier Averaged
Irr waves (Fn=0.15): Least Squares
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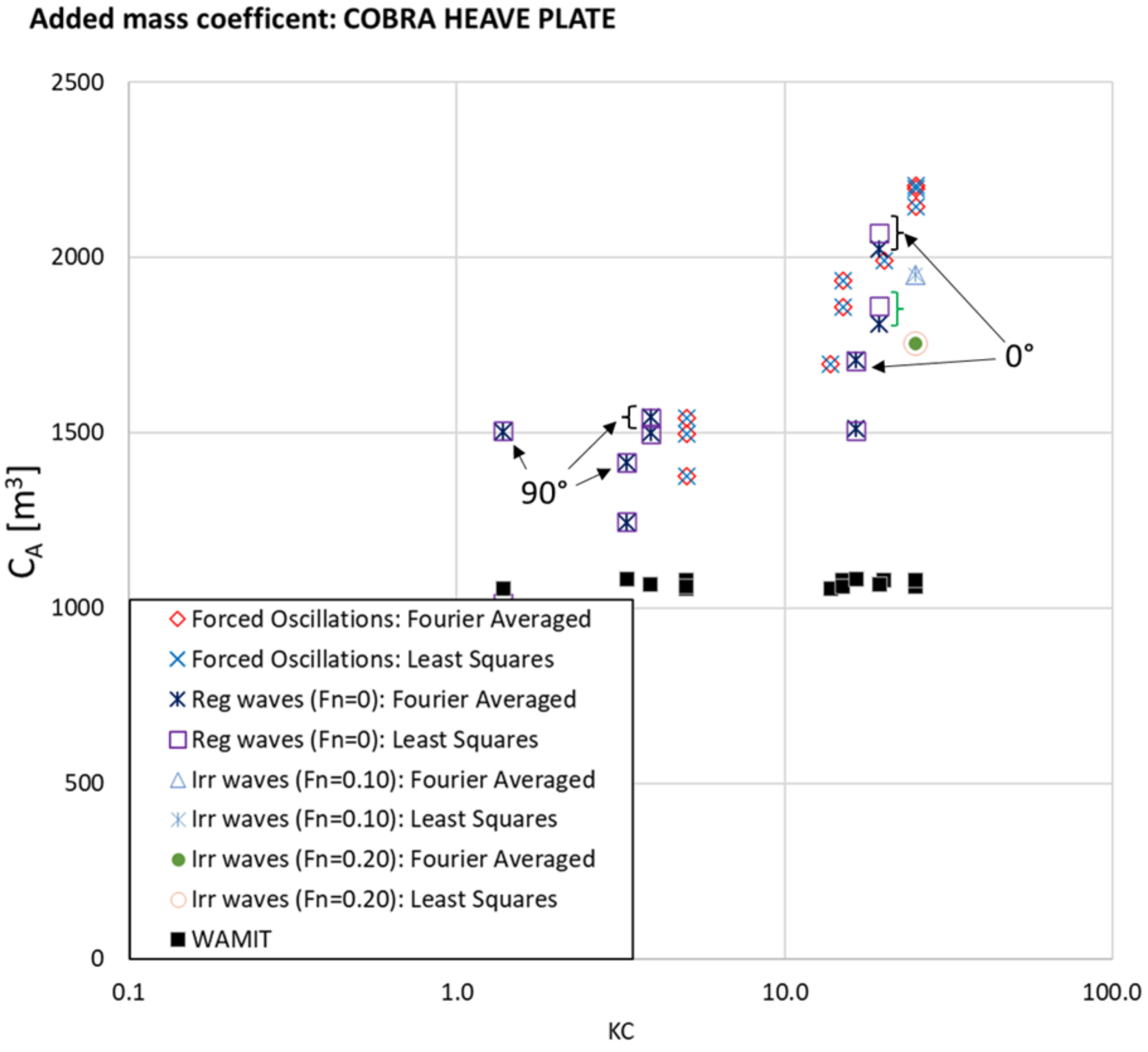
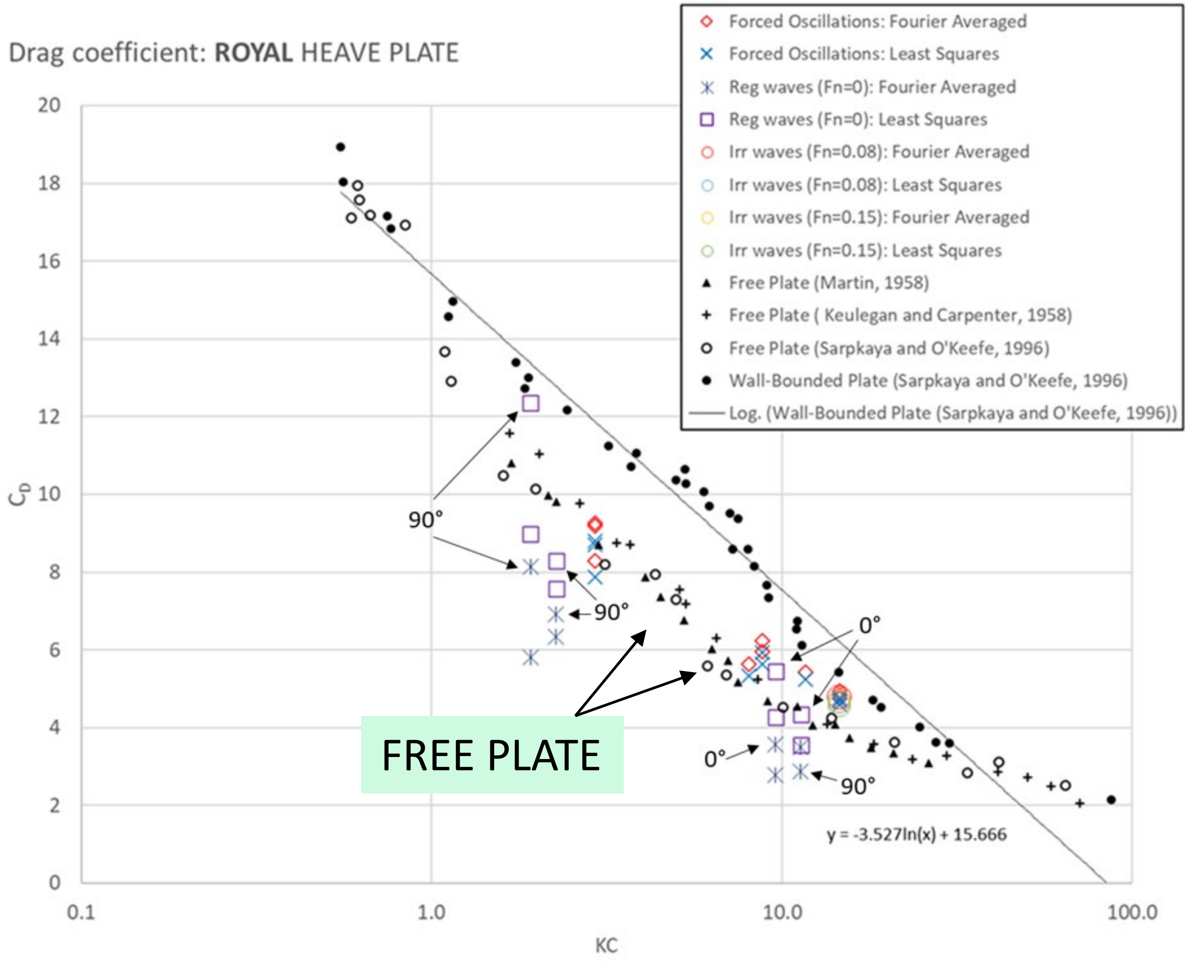
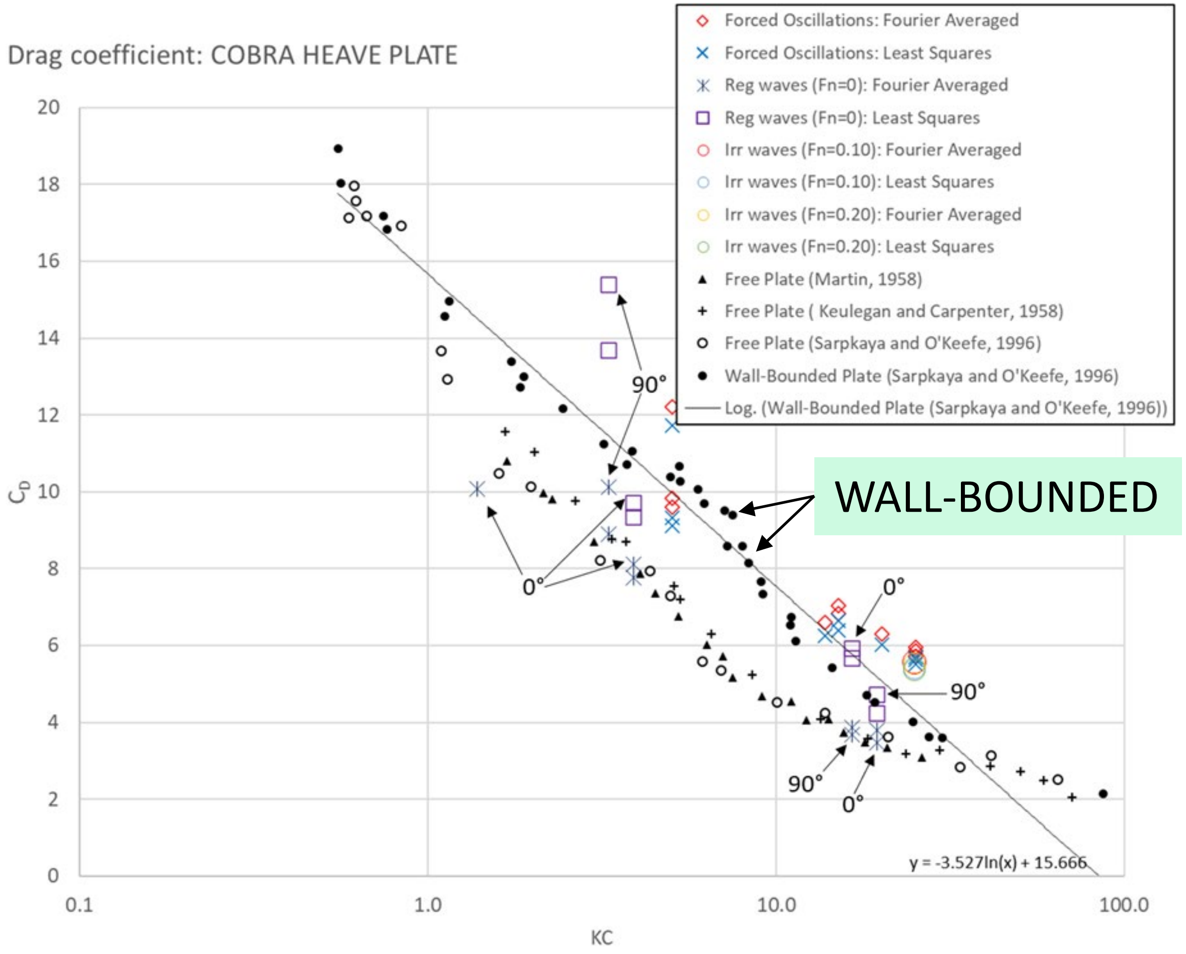

Added mass coefficent: COBRA HEAVE PLATE
C_A [m³]
KC
90°
0°
Forced Oscillations: Fourier Averaged
Forced Oscillations: Least Squares
Reg waves (Fn=0): Fourier Averaged
Reg waves (Fn=0): Least Squares
Irr waves (Fn=0.10): Fourier Averaged
Irr waves (Fn=0.10): Least Squares
Irr waves (Fn=0.20): Fourier Averaged
Irr waves (Fn=0.20): Least Squares
WAMIT

Drag coefficient





Current effect

Estimated hydrodynamic coefficients for forced motion tests with and without current.

Heave plate	H/D	λ/D	K_C	Fn	C_A	C_D
Royal	2.08	33.25	14.61	0.0	2101	4.60
Royal	2.08	33.25	14.61	0.05	1919	4.62
Royal	2.08	33.25	14.61	0.1	1746	4.54
Cobra	2.08	33.25	25.13	0.0	2206	5.53
Cobra	2.08	33.25	25.13	0.1	1951	5.39
Cobra	2.08	33.25	25.13	0.2	1755	5.34

Period   Current

$$C_A = C_A^{NC} - 0.0942\left(\frac{T}{2} A_P U_C\right) C_D^{NC}$$

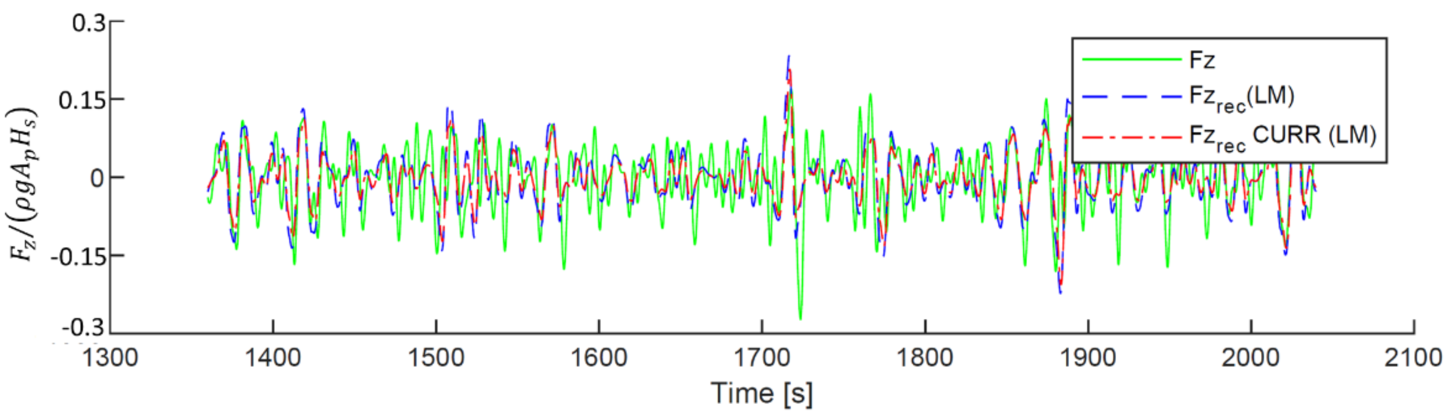
Area

Kc

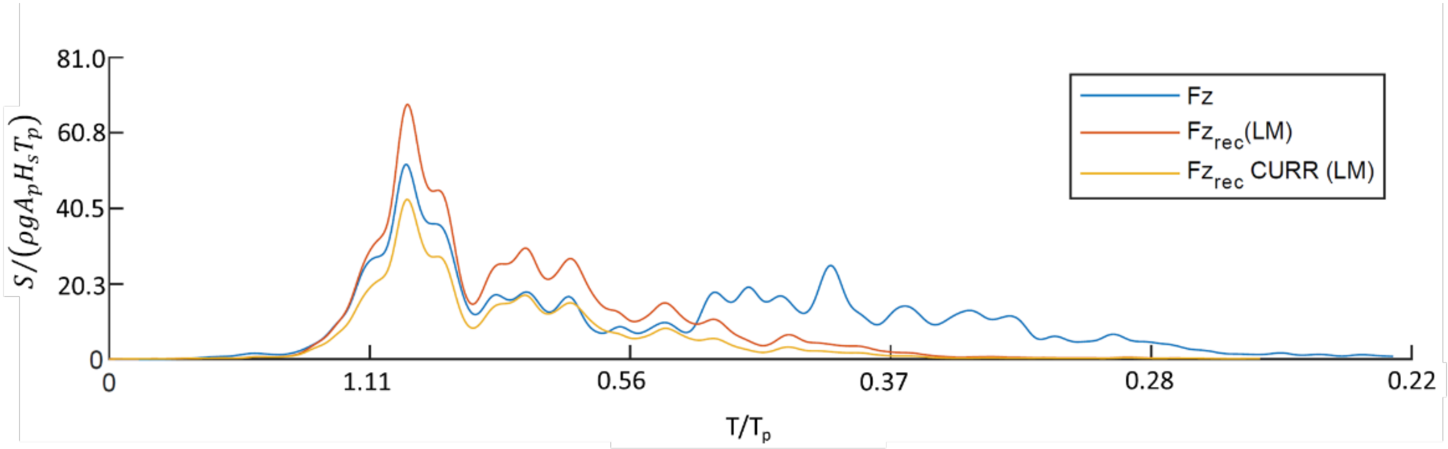
drag effects (normal)

Irregular waves
Current correction

IRR_2 , ROYAL



IRR_2 , ROYAL



Conclusions

- Drag coefficients from forced motion tests are consistent with the existing literature.
- Estimating the coefficients from the regular waves tests is not as robust as with the forced motions.
- There is no significant modification of the drag coefficient due to the presence of current.
- There is a small, but non negligible, modification of the added mass coefficient when in presence of current. This is attributed to the occurrence of lift effects.
- A correction term to account for the presence of current was formulated

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