Offshore Renewable Energy

Corso di Dottorato in Ingegneria Meccanica

Ciclo XXX

Hydrodynamics Modelling and Mooring design of floating Wave Energy Converters

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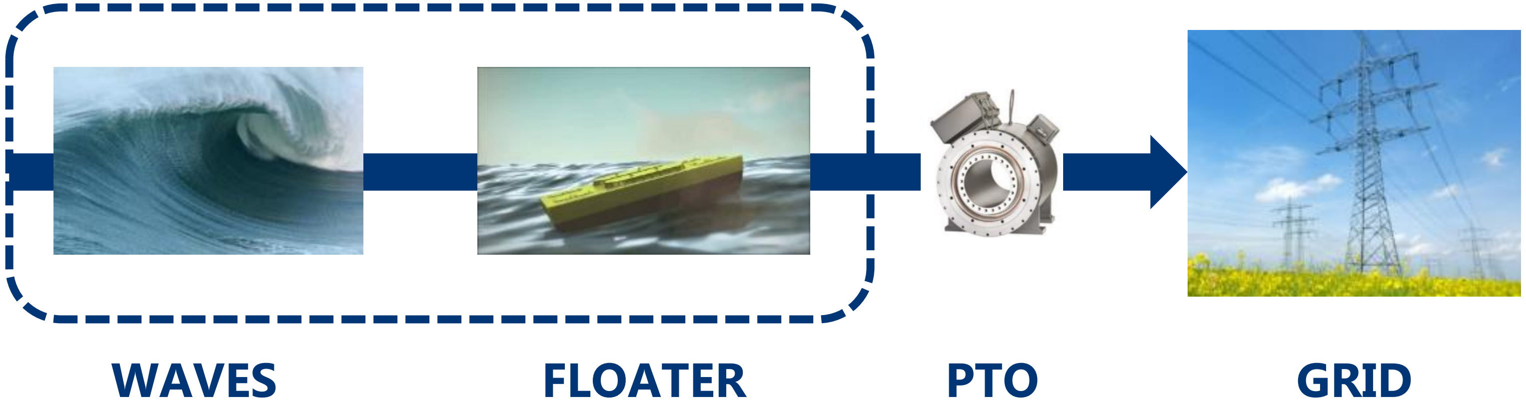
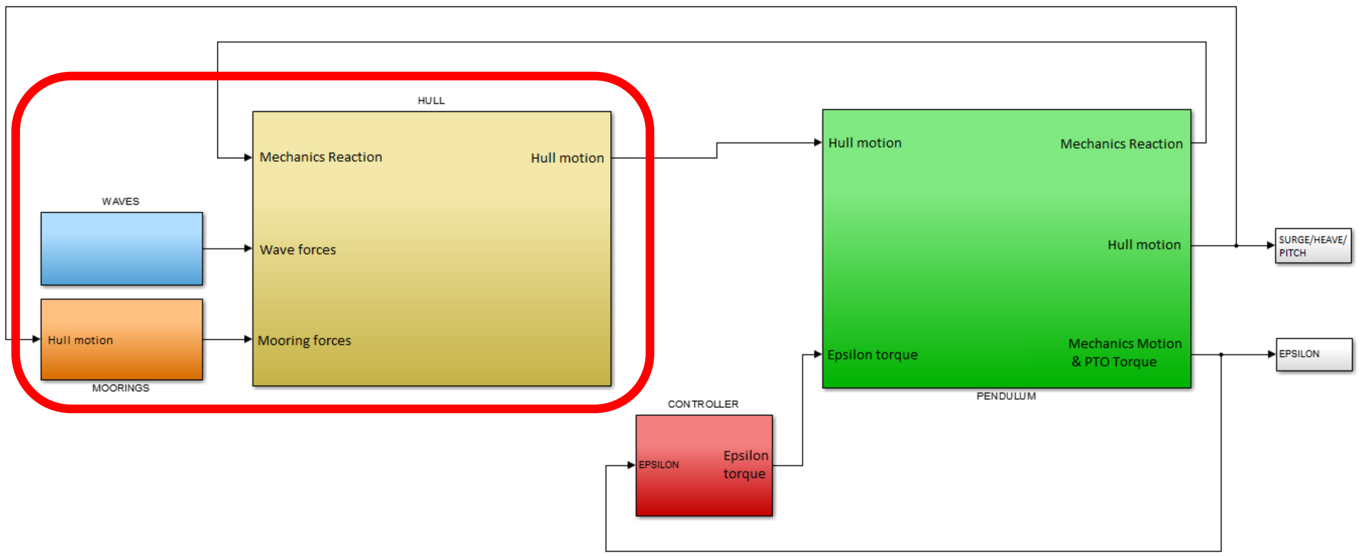
Design Tool – Simulink Wave to Wire model





Motivation

- Numerical model improvement
- Analysis of non-linear effects
- Mooring design
- Mooring influence on dynamics

Hydrodynamic interactions – Potential flow

Mathematical model – Cummins' equation

Time Domain: $(M + A_\infty)\ddot{X}(t) + \int_0^t h_{r\dot{X}}(t - t')\dot{X}(t) + KX(t) = F_w(t) + F_m(t) + F_g(t)$

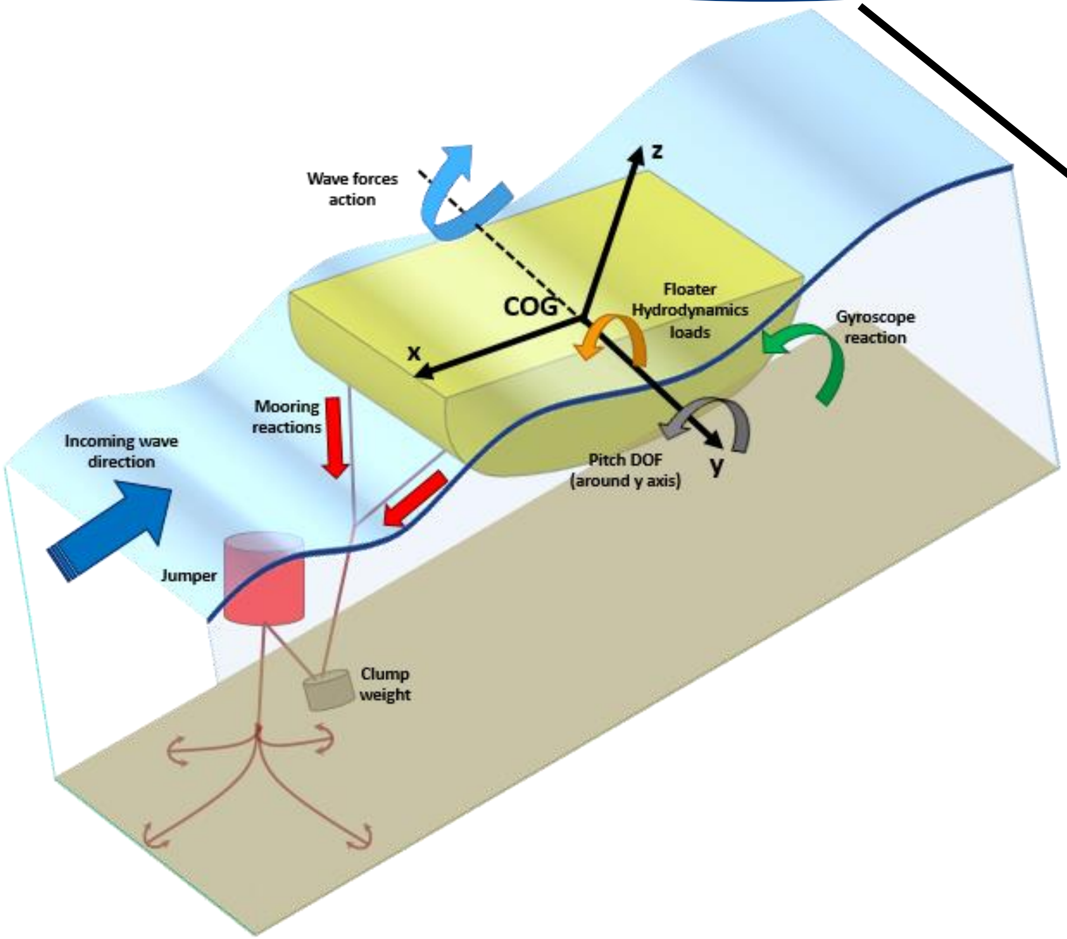
Internal Mechanical Forces

Mooring Forces

Froude-Krylov and Diffraction Forces

Restoring Forces

Radiation Forces



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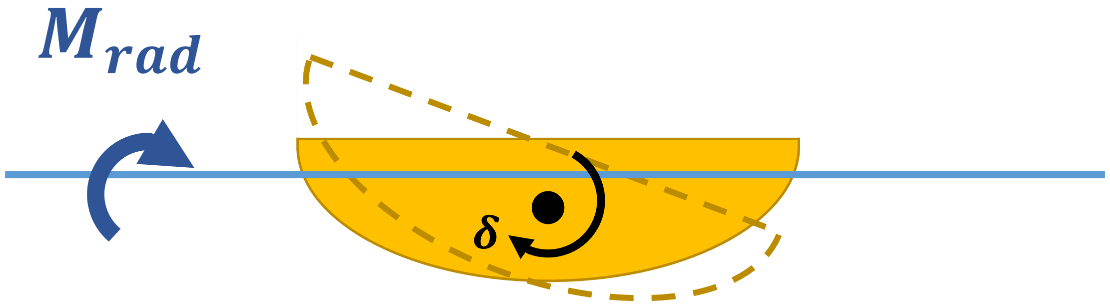
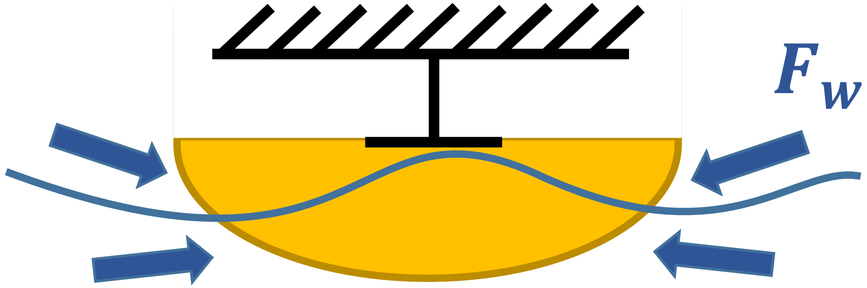
Radiation Forces

Froude-Krylov and Diffraction Forces





Frequency Domain: $\{-\omega_w^2[M+A(\omega_w)]+j\omega_w B(\omega_w) + K\}X(j\omega_w) = F_w(j\omega_w)$

Hydrodynamic interactions – Potential flow

Mathematical model – Cummins' equation

Time Domain: $(M + A_\infty)\ddot{X}(t) + \int_0^t h_{r\dot{X}}(t - t')\dot{X}(t) + KX(t) = F_w(t) + F_m(t) + F_g(t)$

Radiation Forces

Froude-Krylov and Diffraction Forces

Frequency Domain: $\{-\omega_w^2[M + A(\omega_w)] + j\omega_w B(\omega_w) + K\}X(j\omega_w) = F_w(j\omega_w)$

- Linear Model
- Potential flow theory
- Frequency domain analysis
- No mooring forces

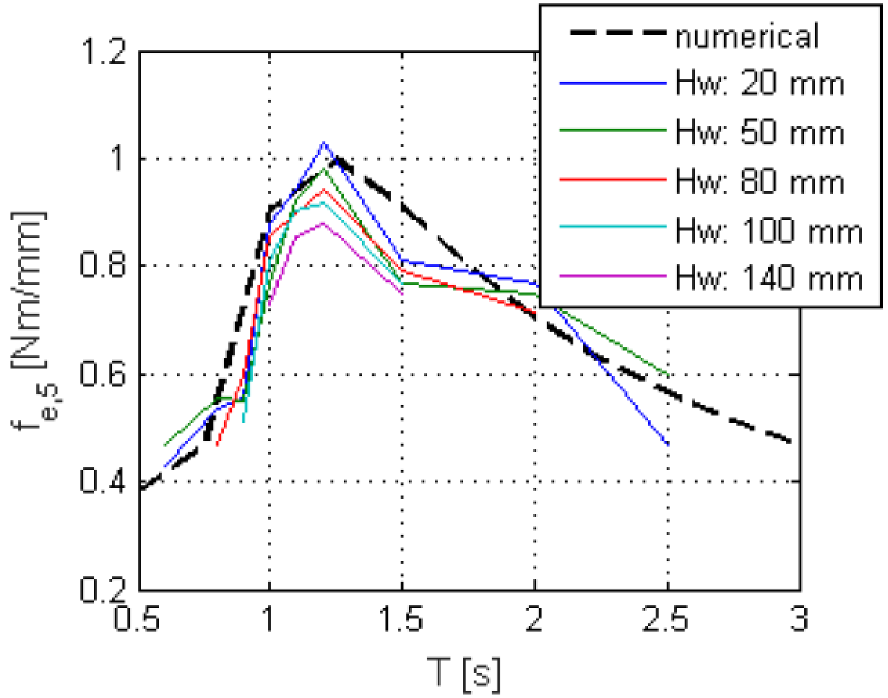
Model validation

Experimental test campaign @ Hydrodynamic and Maritime Research Centre of University College of Cork (HRMC)

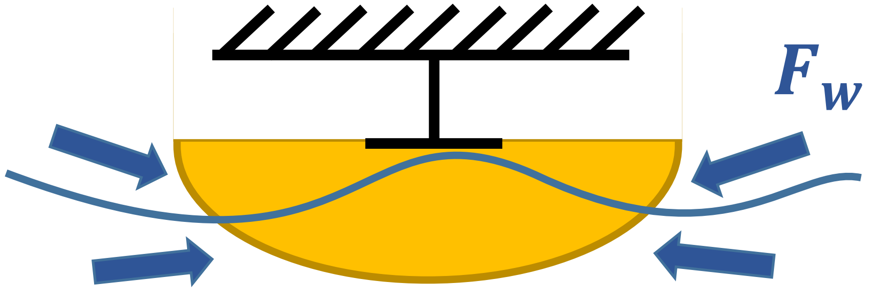
Hydrodynamic interactions – Potential flow validation

Experimental tests campaign in Cork

$$\{-\omega_w^2[M + A(\omega_w)] + j\omega_w B(\omega_w) + K\}X(j\omega_w) = F_w(j\omega_w)$$



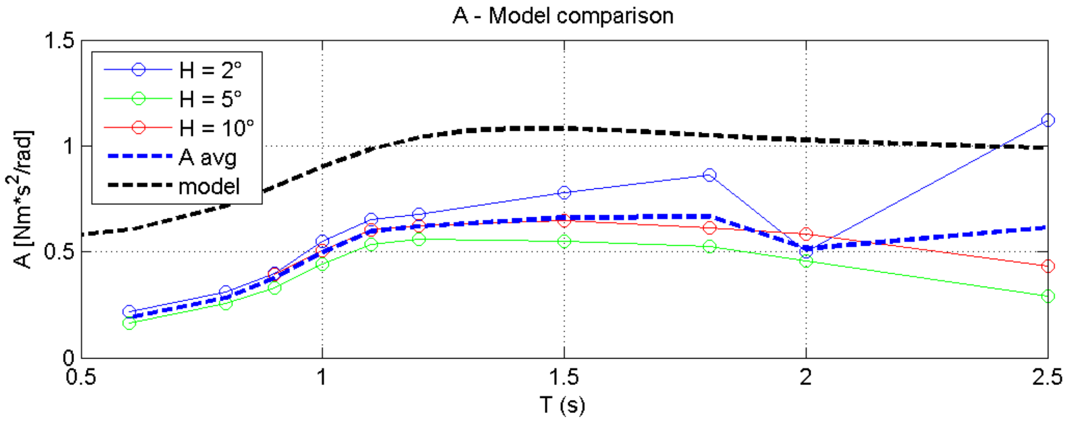
Wave Excitation Force coefficients – Froude-Krylov and Diffraction forces

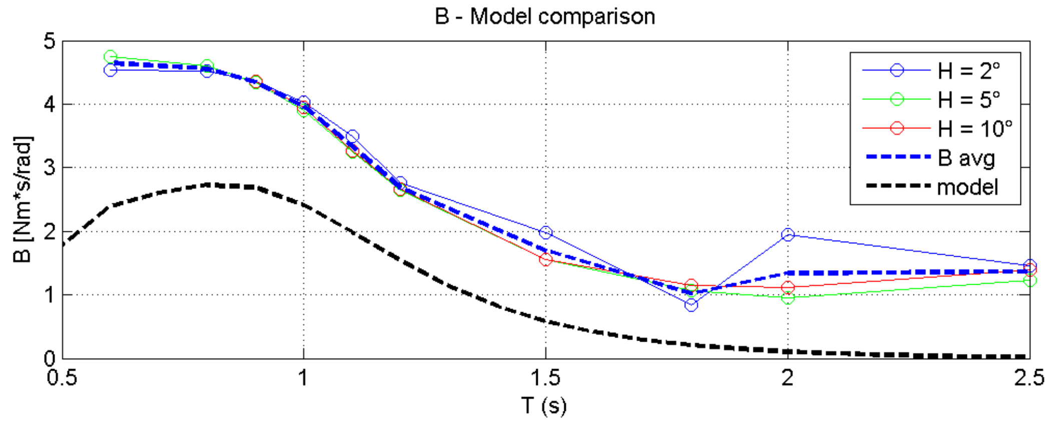


✓Good agreement

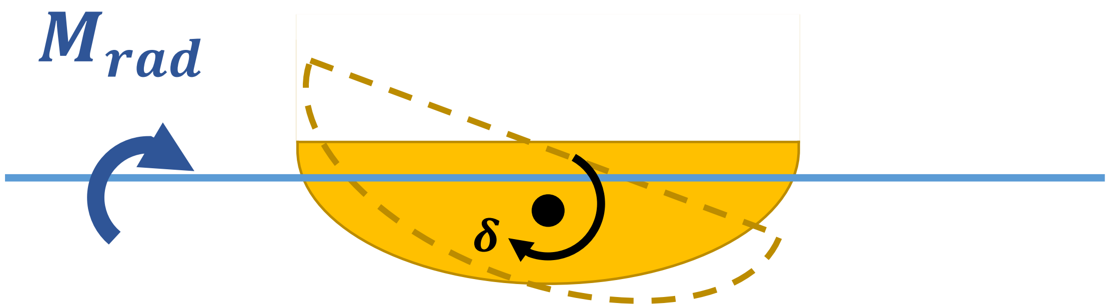
Hydrodynamic interactions – Potential flow validation

$$\{-\omega_w^2[M + A(\omega_w)] + j\omega_w B(\omega_w) + K\}X(j\omega_w) = F_w(j\omega_w)$$





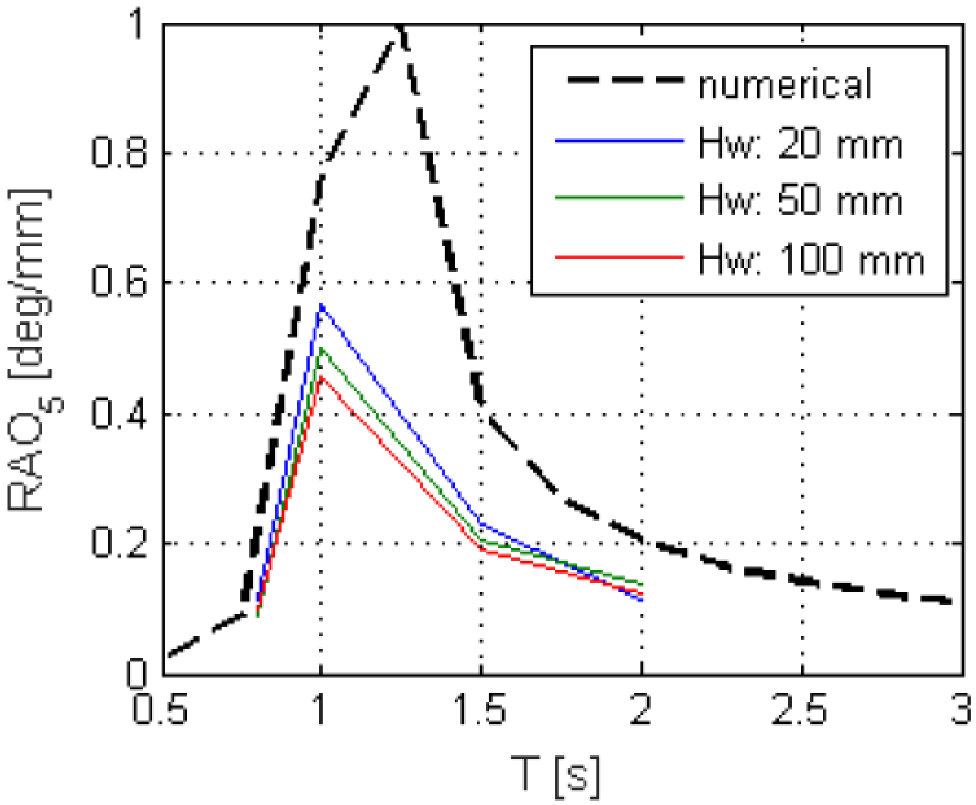
Radiation Forces



✗ **Bad agreement**

Potential Flow Limits

Pitch Response Amplitude Operator (RAO)



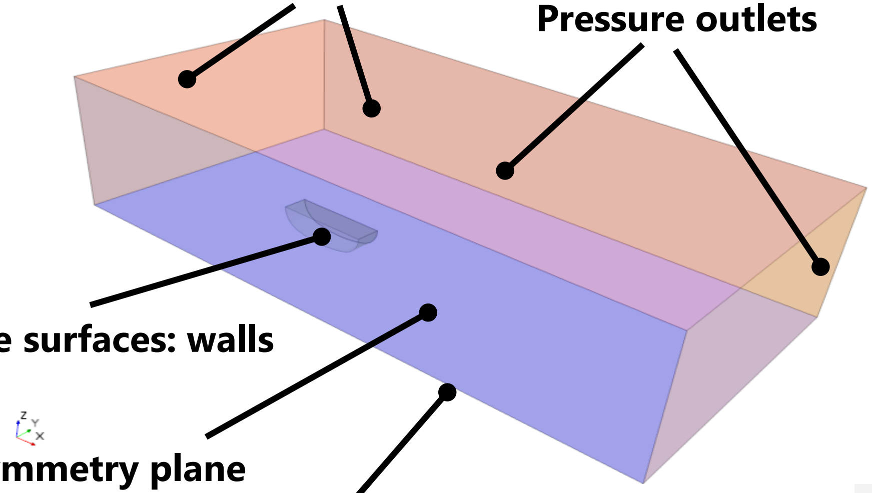
NOT CONSIDERED:

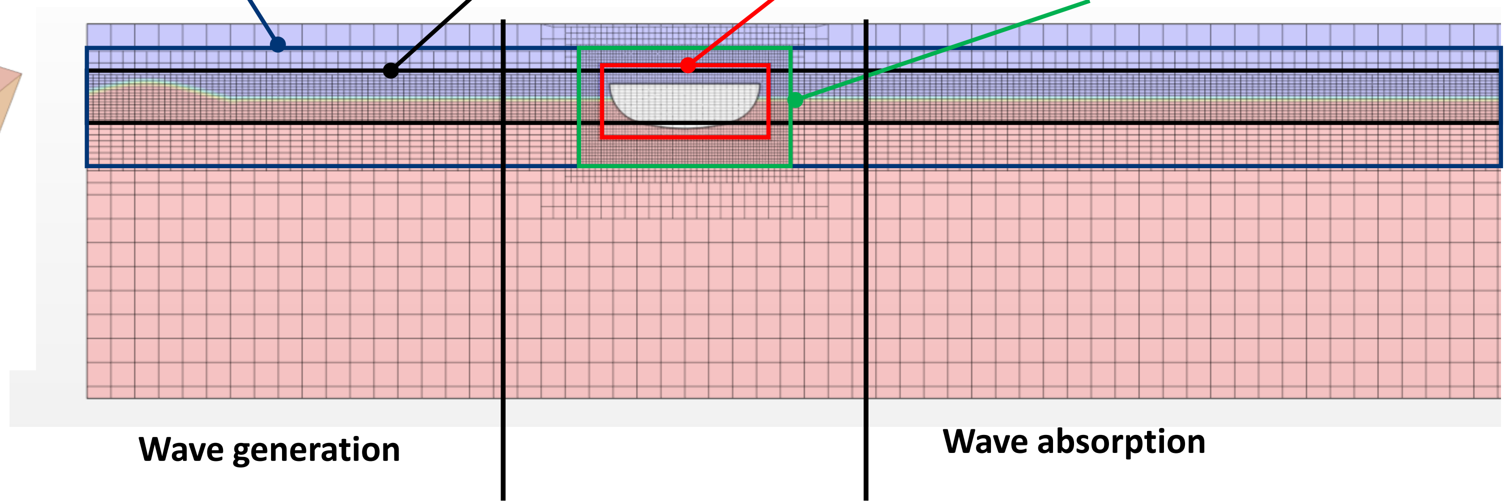
- **Viscous Forces**
- **Instantaneous Wetted Surface**

✓ **More influent at higher amplitudes**

CFD – Volume Of Fluid RANS in Star-CCM+

- Imposed Oscillatory Motion for Radiation Forces Identification
- Virtual Beach on the tank sides

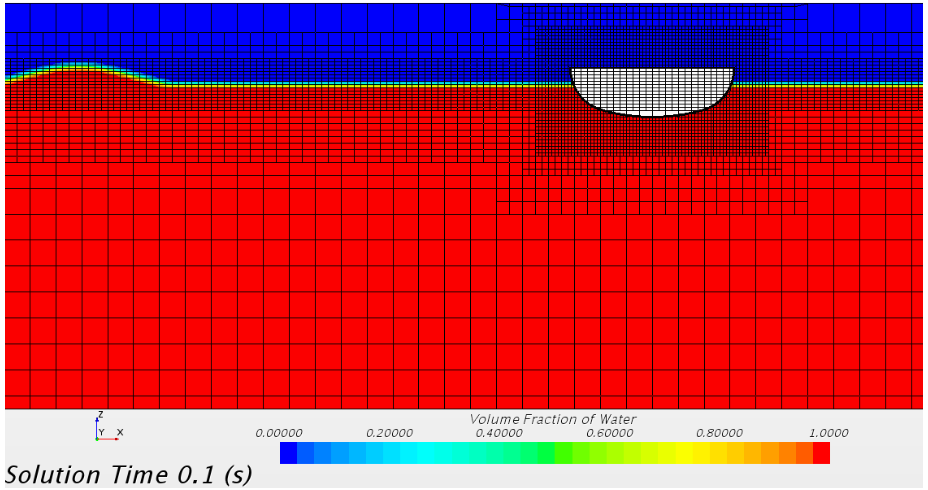


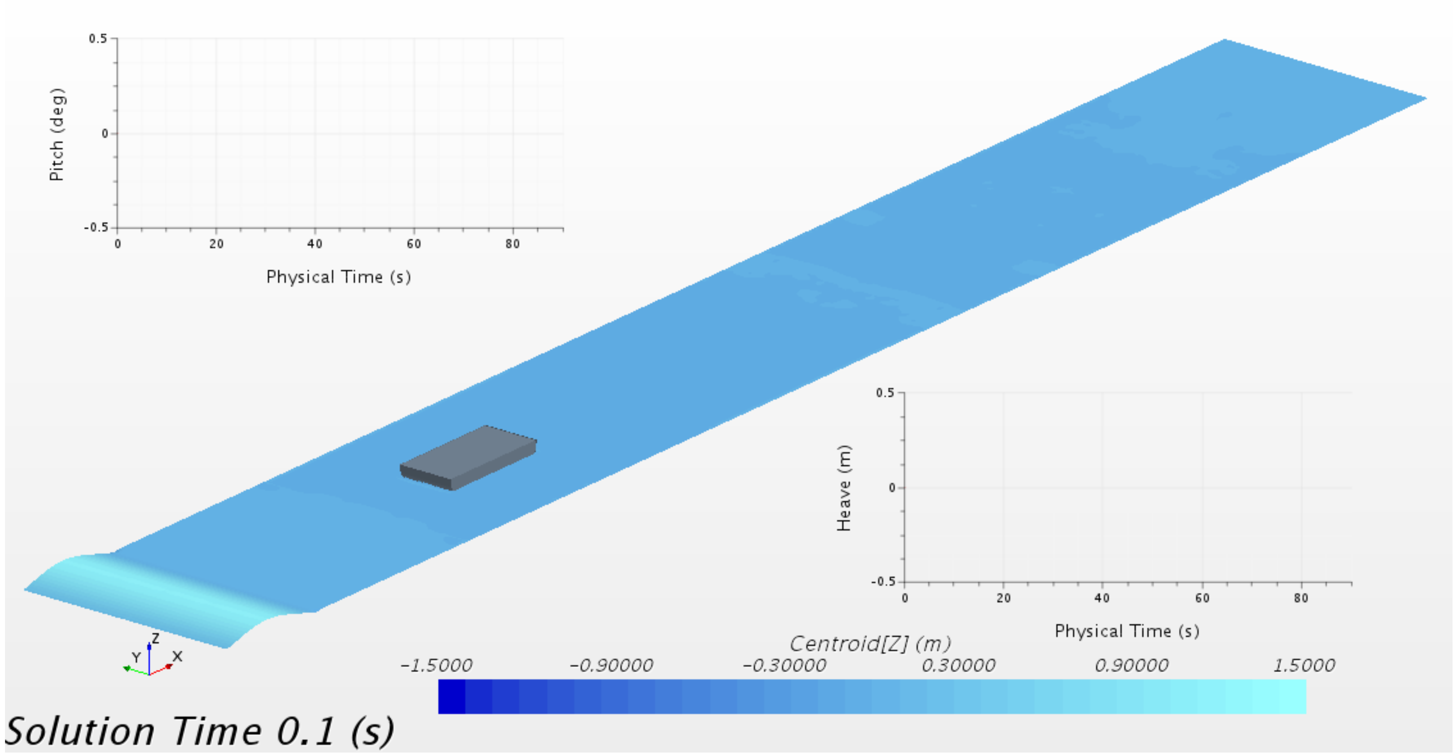


Calibration and Convergence analysis:

- Minimum computational domain
- Optimized mesh size
- Calibration on experimental and benchmark data

CFD – Volume Of Fluid RANS in Star-CCM+



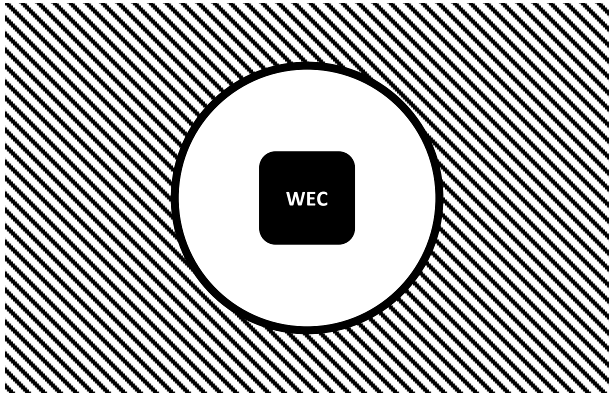


Calibration and Convergence analysis:

- **Minimum computational domain**
- **Optimized mesh size**
- **Calibration on experimental and benchmark data**

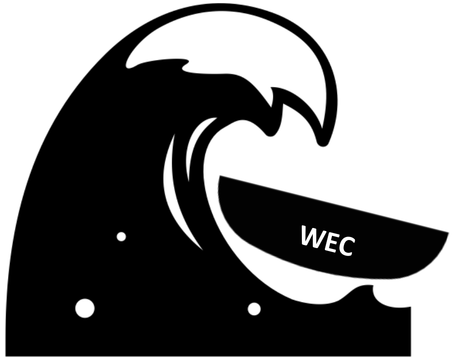
Moorings requirements

Station keeping

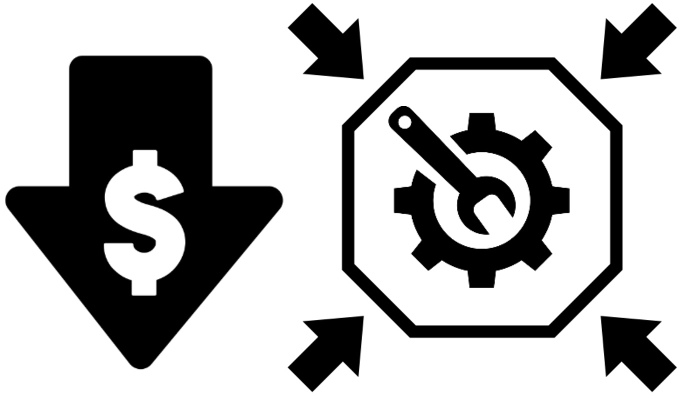


Compliance

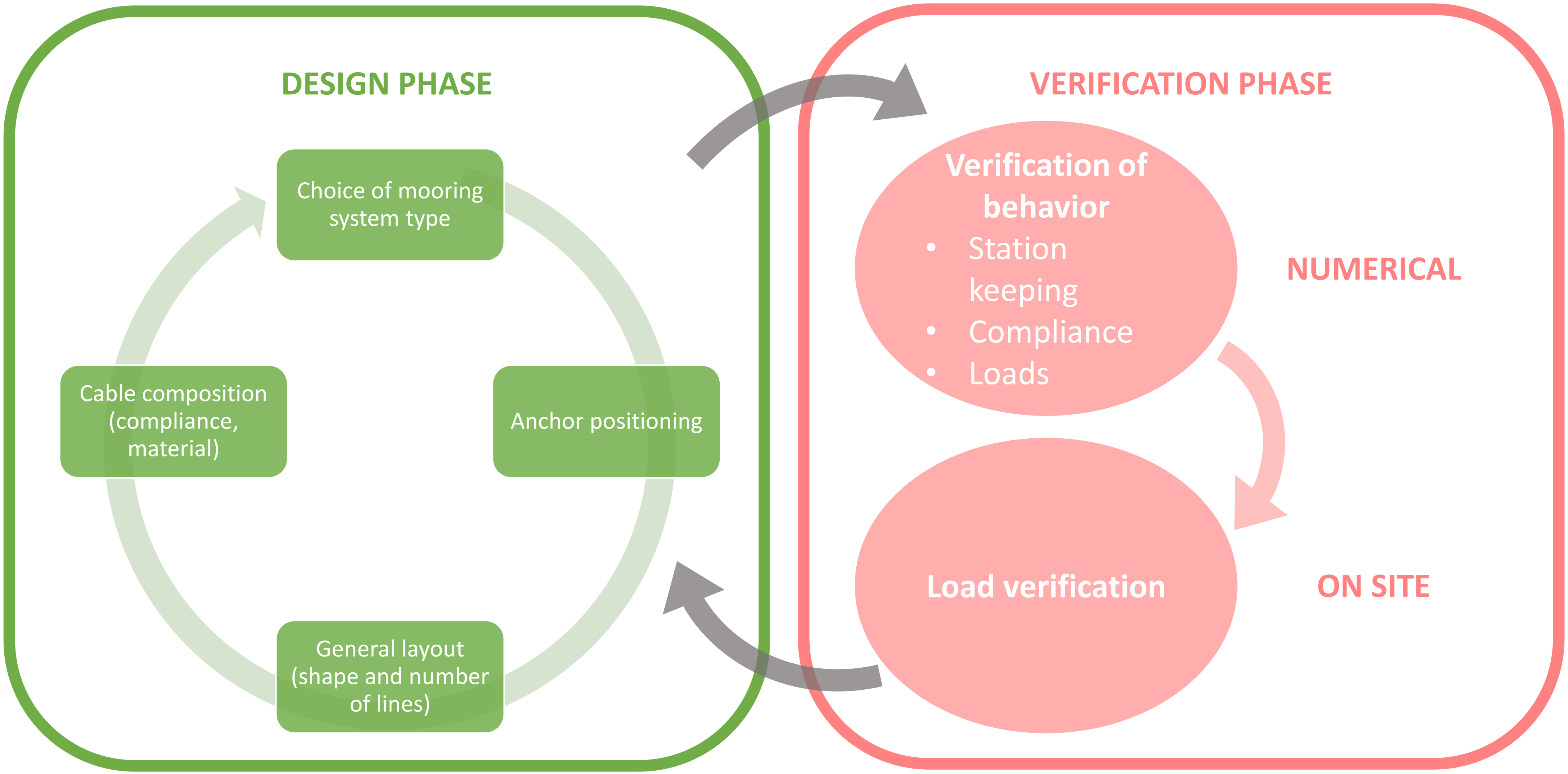
Survivability



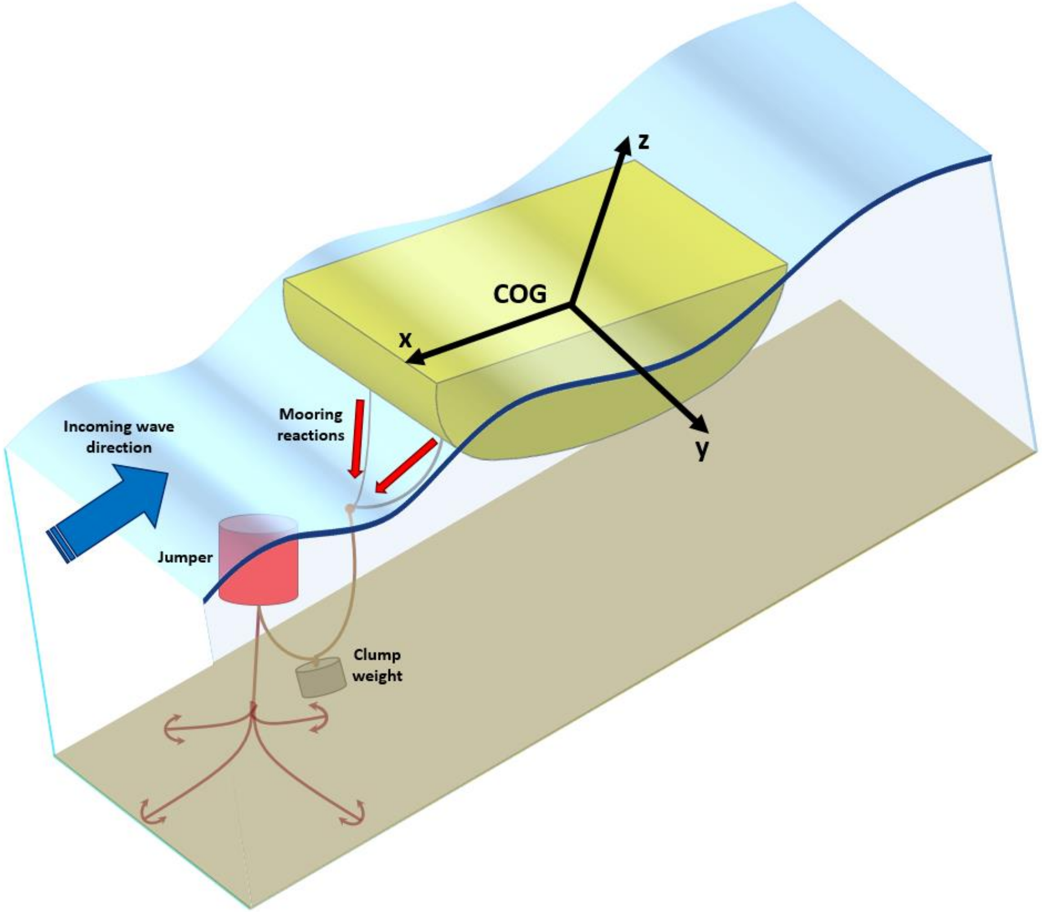
Low Maintenance

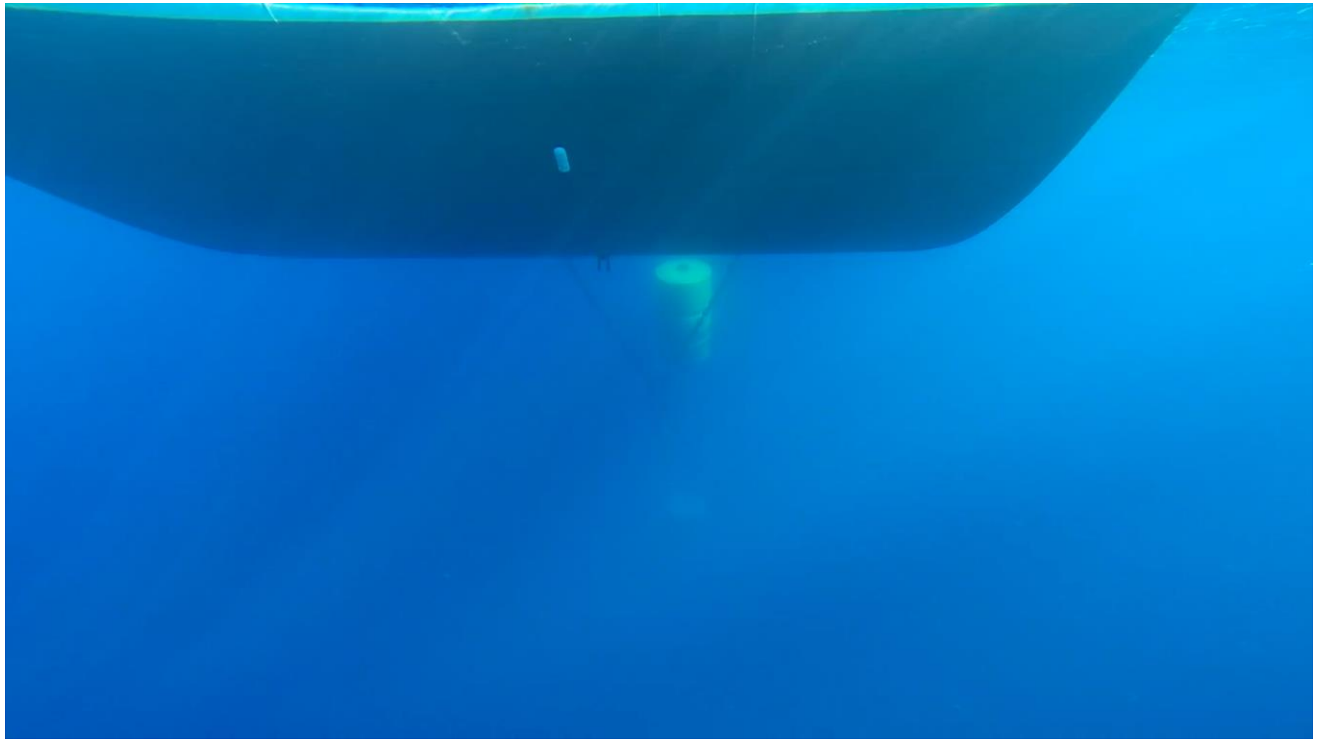


Moorings design and analysis



Starting point: Pantelleria Mooring system





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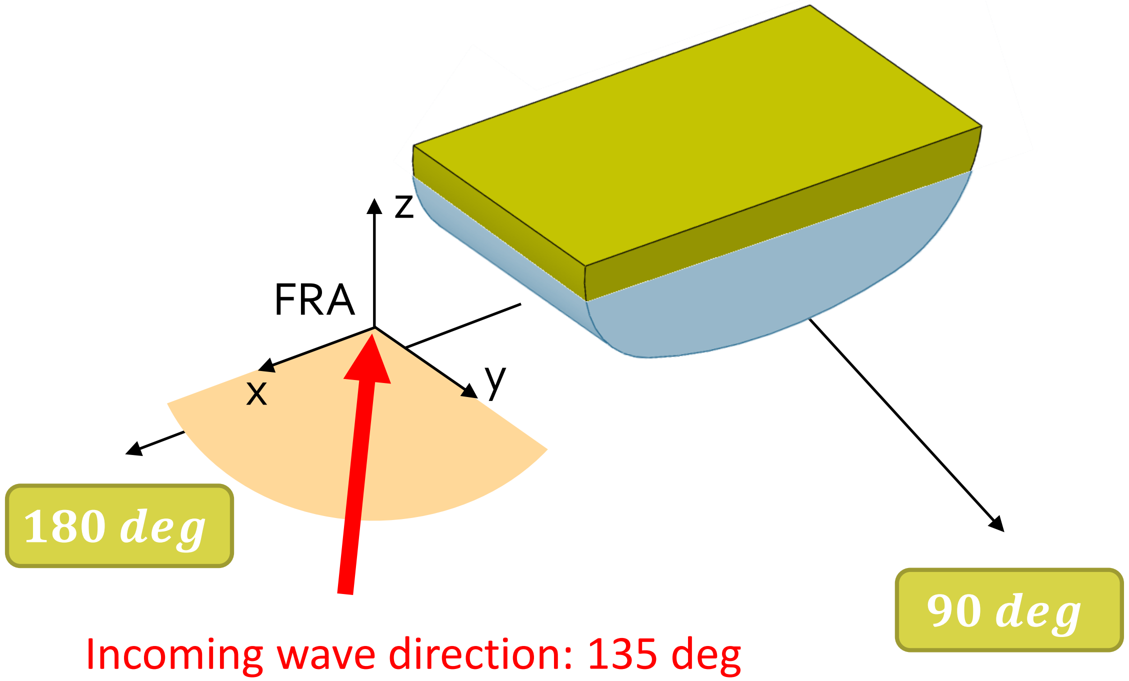
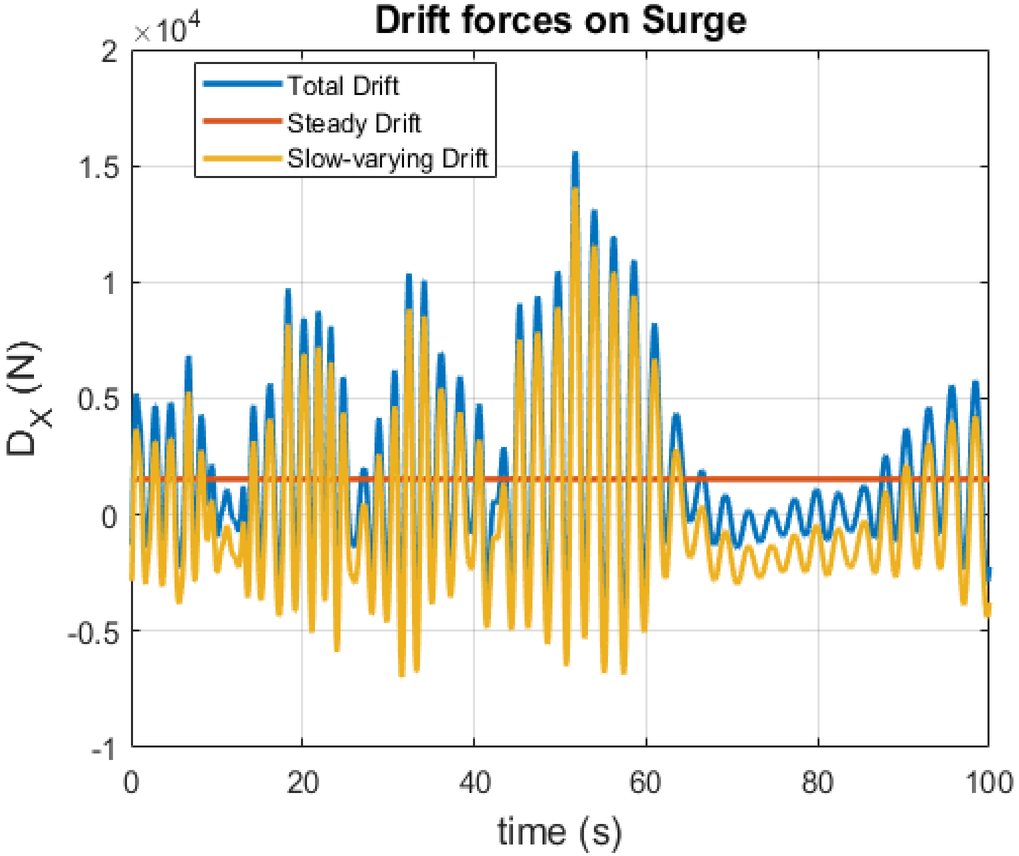
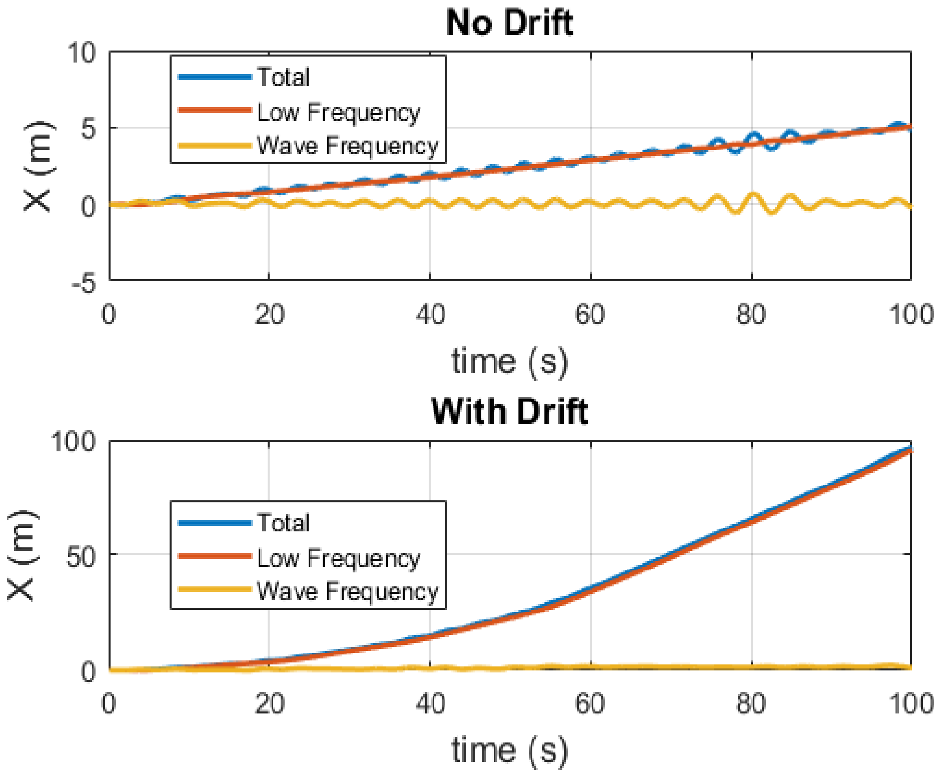


Importance of Drift Forces

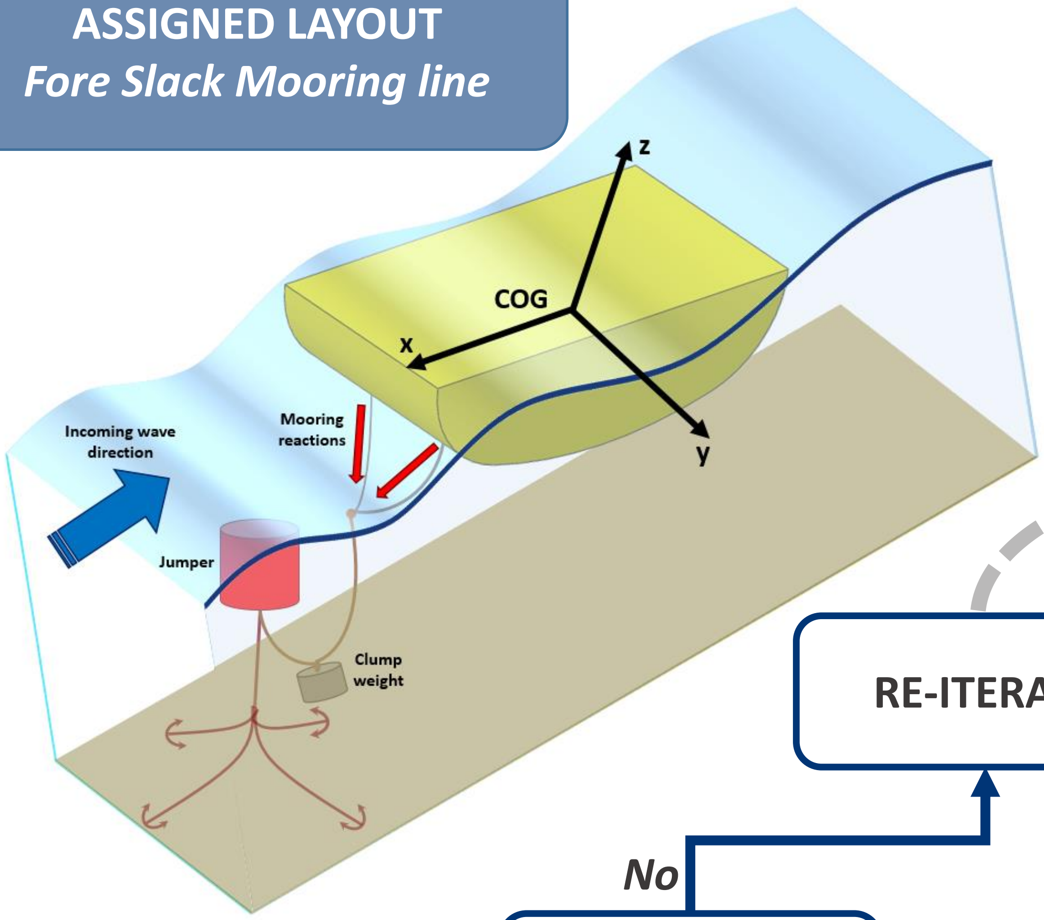
Potential Flow Second Order effects





Mooring design workflow

ASSIGNED LAYOUT
Fore Slack Mooring line



A — **INSTALLATION SITE CHARACTERISTICS**
Extreme wave
From Resource Analysis

B — **HYDRODYNAMIC LOAD CALCULATION**
Time domain simulation
ANSYS AQWA

C — **MOORING LINE SIZING**
Chain Diameter
Market Data

D — **STATIC CHARACTERISTIC DESIGN**
Jumper & Clump Weight
Quasi Static Code

E — **MOORING LINE TENSION VERIFICATION**
Time domain simulation
ANSYS AQWA

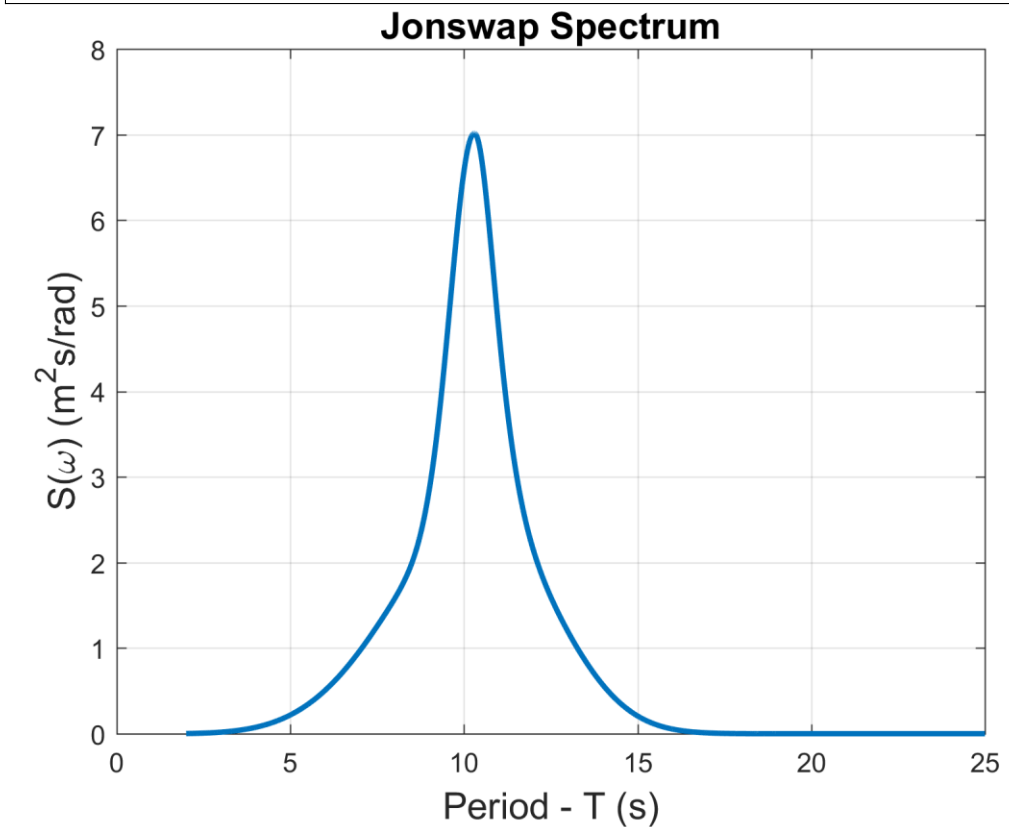
VERIFIED?
No → **RE-ITERATE**
Yes

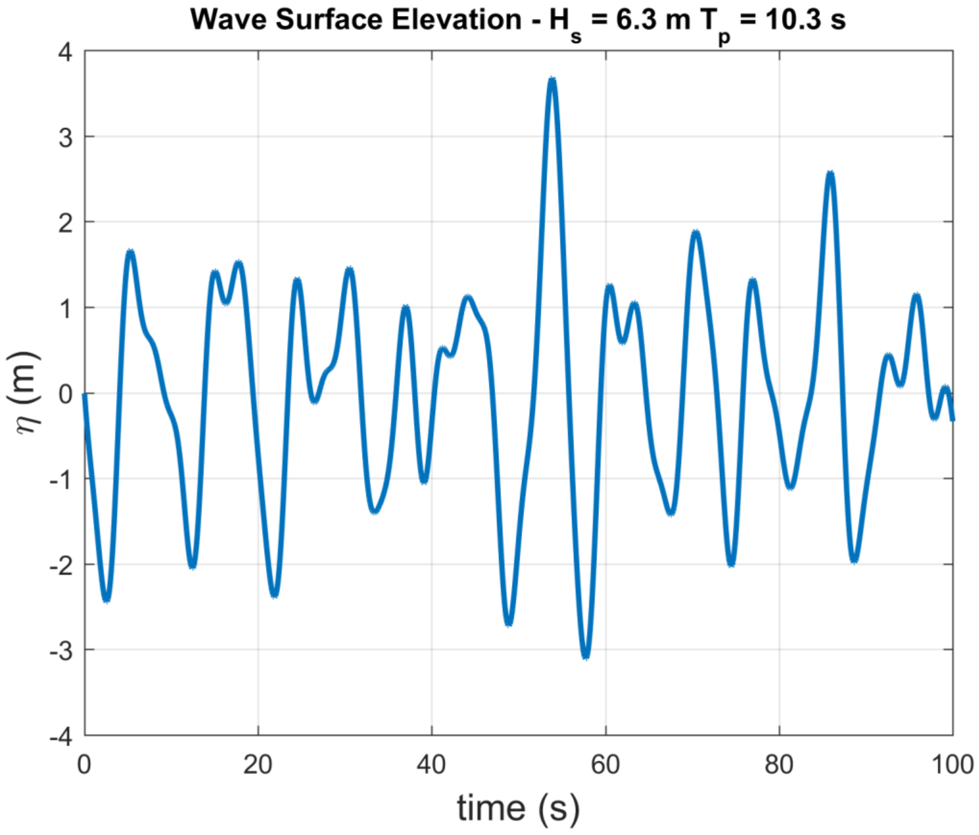
Irregular Wave Properties		
Significant Height	(m)	6.3
Peak Period	(s)	10.3
Simulation time	(s)	100

Secular wave properties

A

Irregular Wave Properties		
Significant Height	(m)	6.3
Peak Period	(s)	10.3
Simulation time	(s)	100

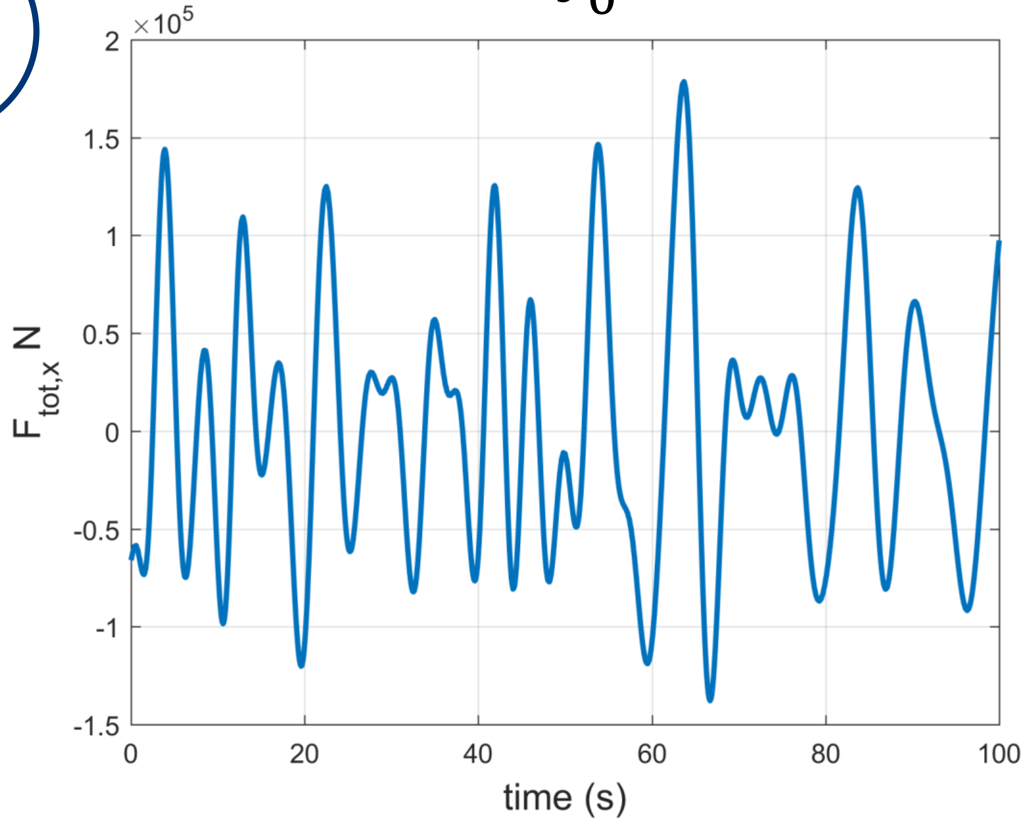




B

Time domain with no moorings and no gyroscope (Surge DOF):

$$(M + A_\infty)\ddot{X} + \int_0^t h_{r\dot{X}}(t - t')\dot{X}dt' + KX = F_{FK} + F_{diffraction} + F_{drift}$$



$$F_{tot,max} = 180\ kN$$

Mooring line sizing

C

Chain properties from supplier catalogue

Mass per unit length	(kg/m)	14.8
Chain Diameter	(mm)	26
Equivalent Cross Sectional Area	(m^2)	0.0069
Axial Stiffness per unit length	(kN)	57730
Working Load	(kN)	278
Breaking Load $(B.L.)$	(kN)	389

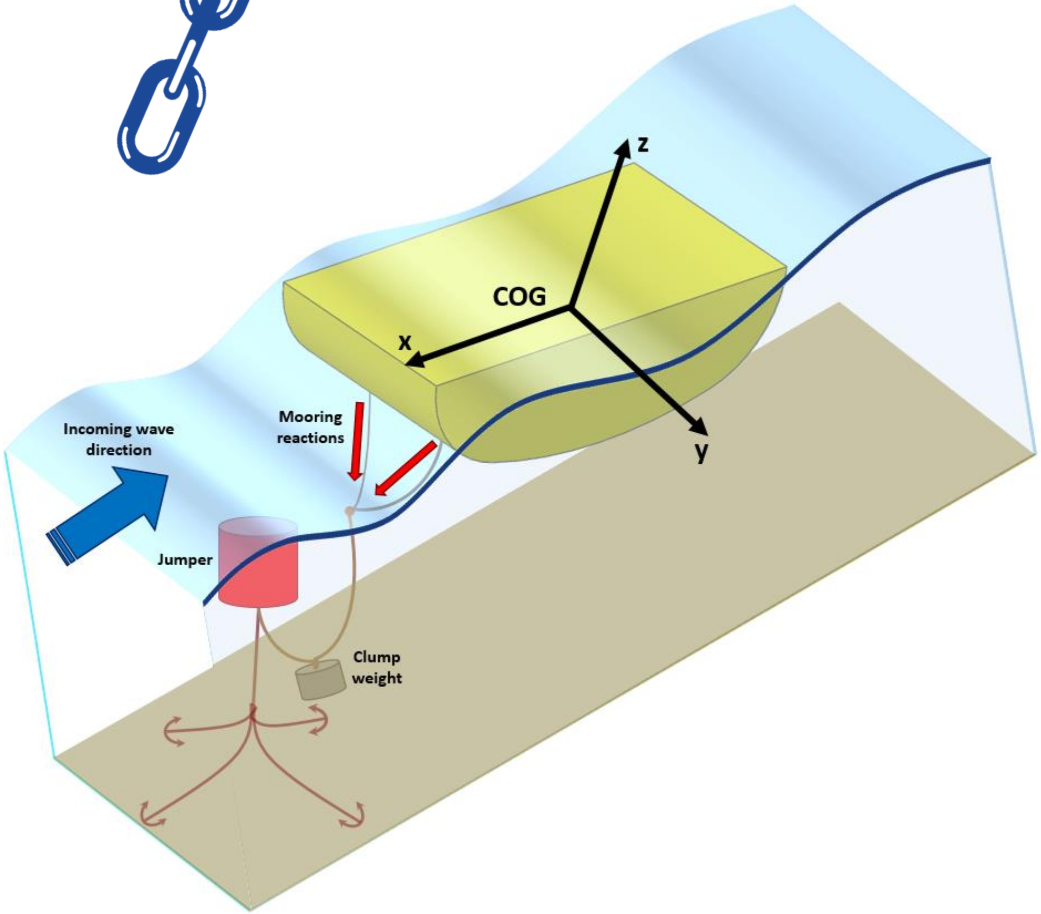
$$H = \boldsymbol{AE}\sqrt{\left(\frac{T}{AE}+1\right)^2 - \frac{2\boldsymbol{w}Z}{AE}} - AE$$

Iteration

$$X = \frac{H}{w}\sinh^{-1}\left(\frac{wL}{H}\right) + \frac{HL}{AE}$$

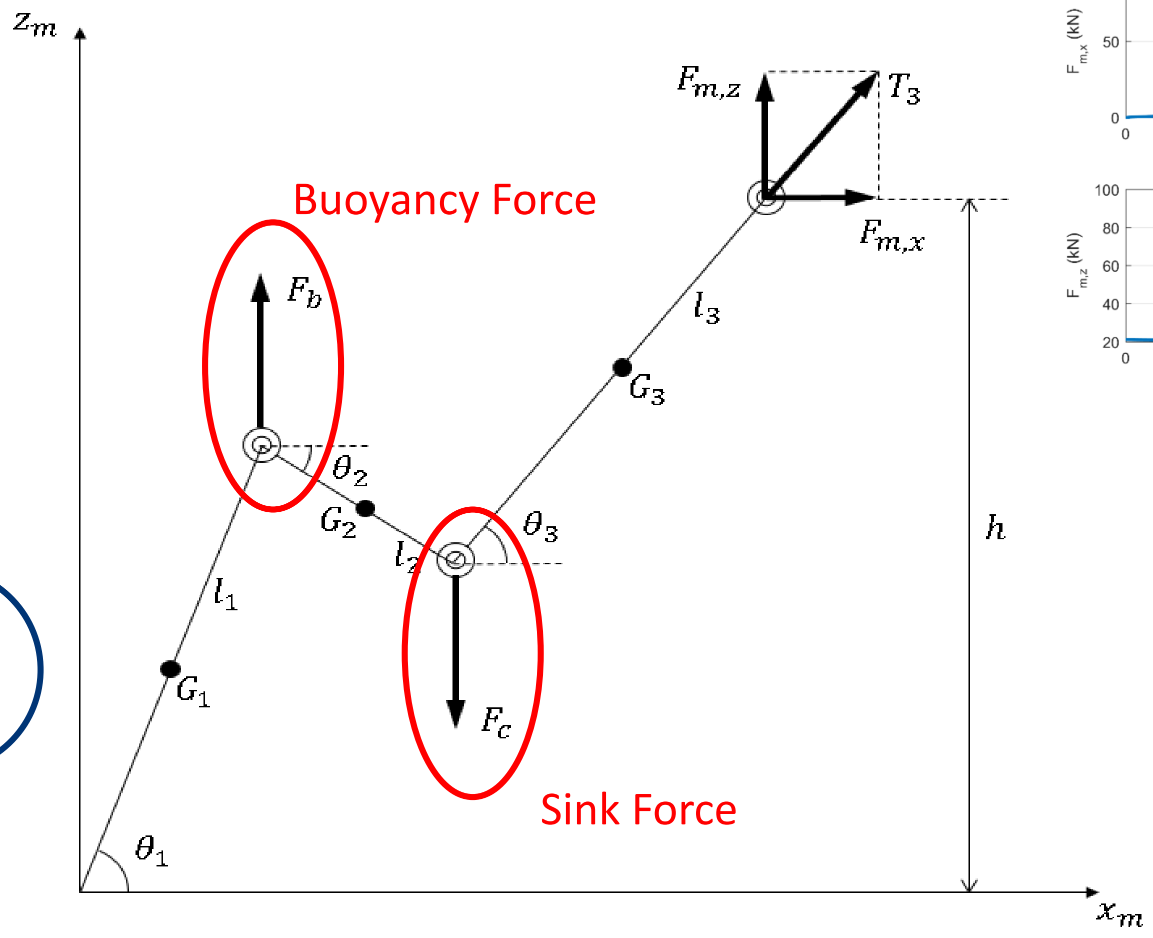
$$V = wL$$

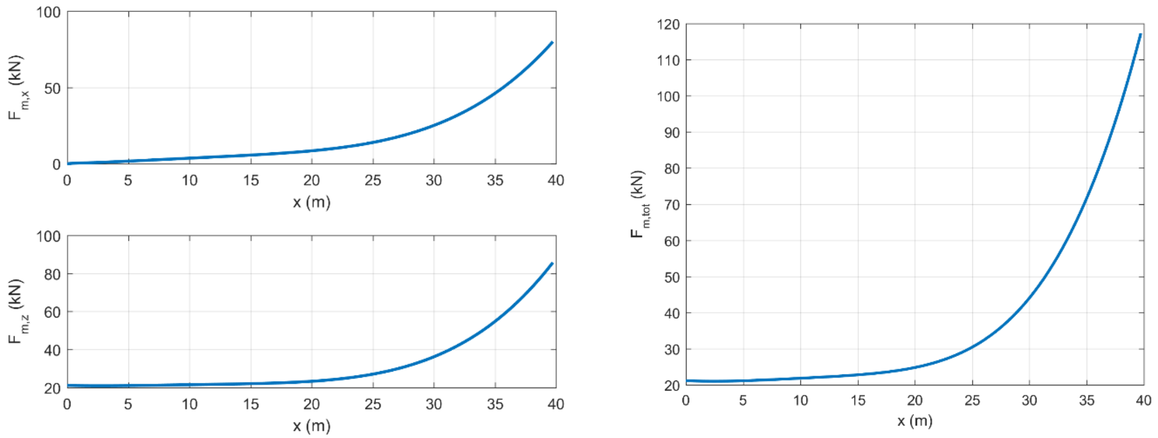
$$\boldsymbol{T = \sqrt{H^2 + V^2}}$$



Static characteristic design

D





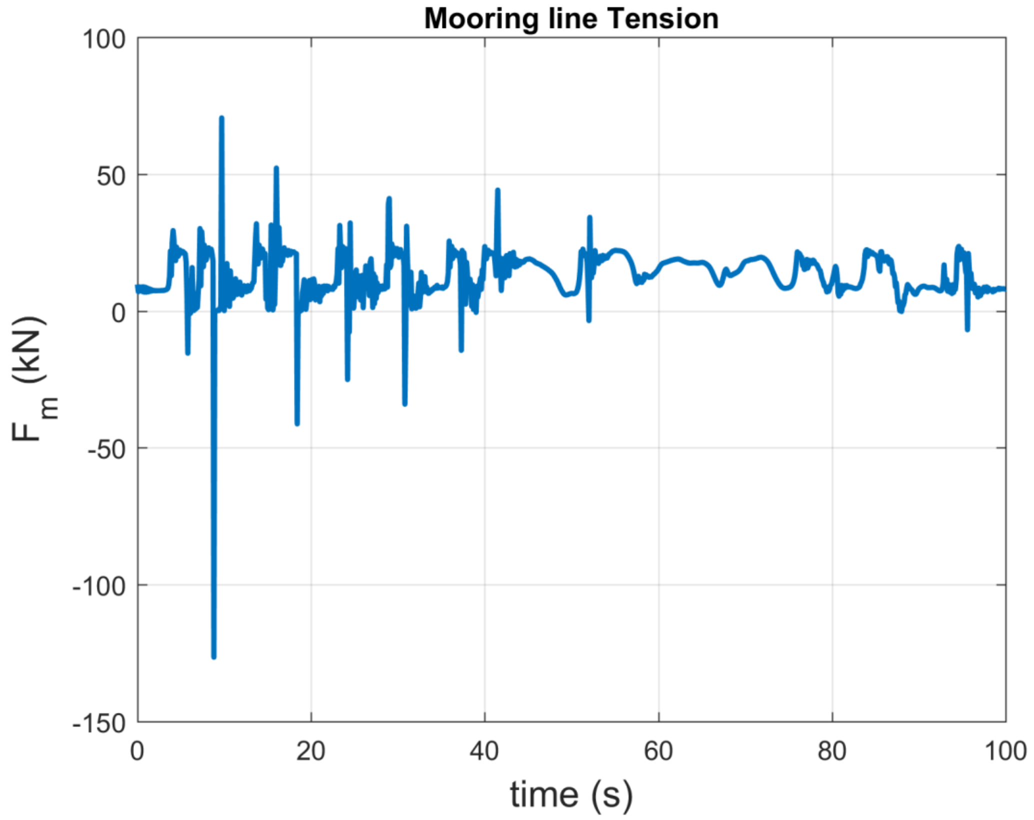
Design parameters

- Buoyancy Force
- Clump weight
- Lines lengths

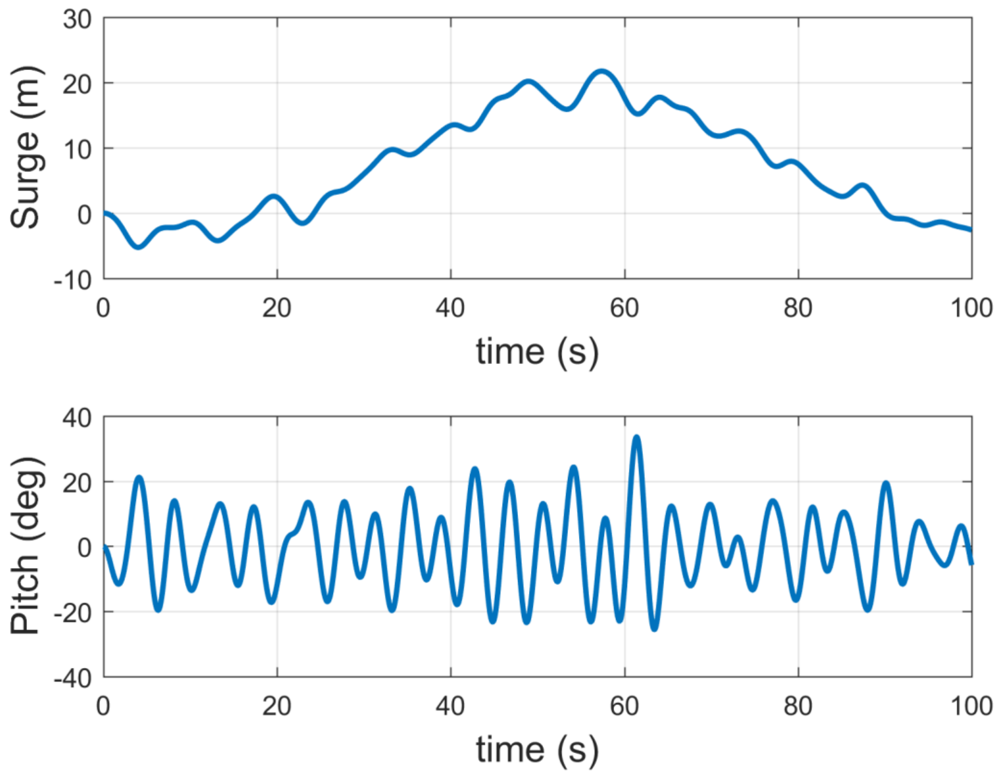
GOALS

✓ Non-linear behavior
✓ Small loads

Mooring line tension verification



Floater dynamics with mooring actions



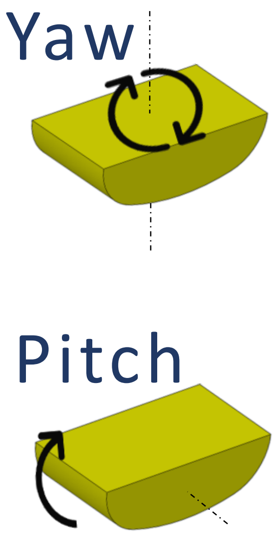
E

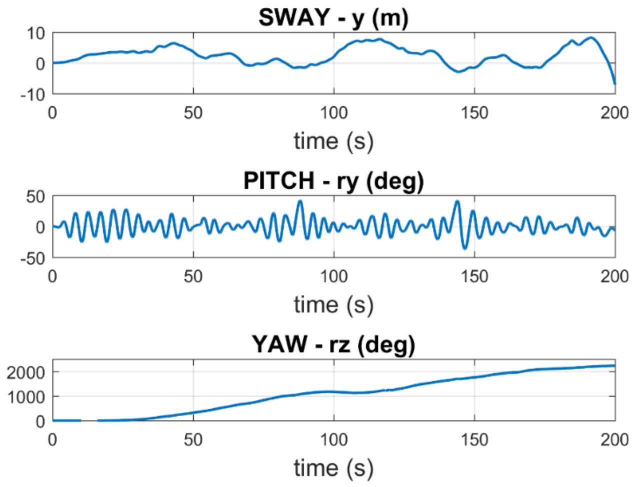
$$F_{m,max} = 126\ kN$$

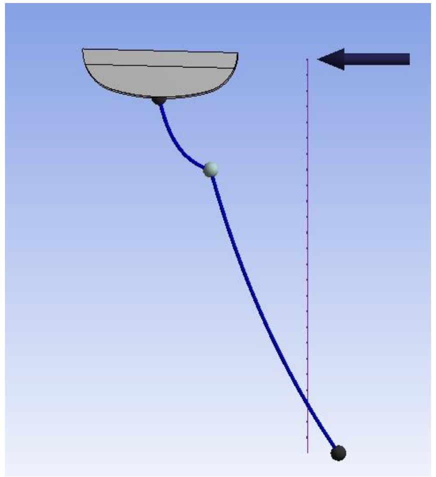
✓ Structural sizing verified with a safety factor of

$$B.L./F_{m,max} = 3$$

Weathervaning problem: wave and current

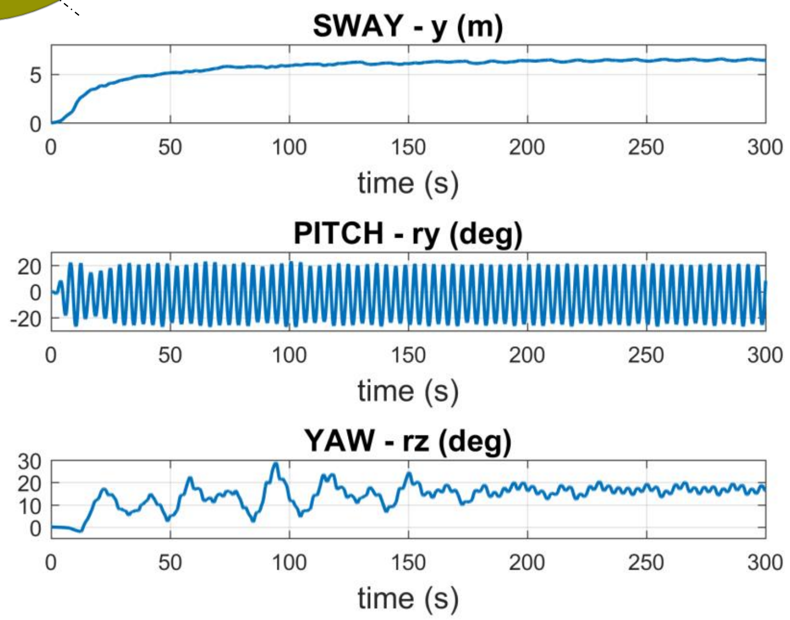


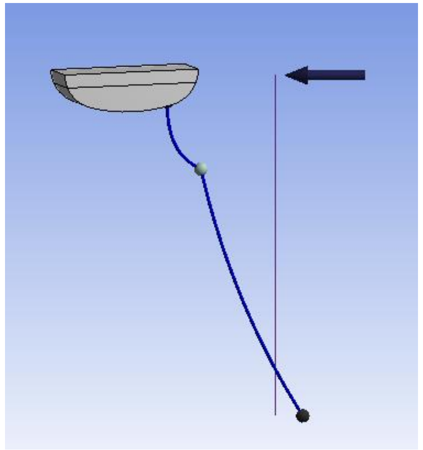




Central connection point

- ✓ Minimize mooring loads
- ✓ Best solution for joint connection
- ✗ Yaw and Sway motions diverge
- ✗ Pitch motion strongly irregular



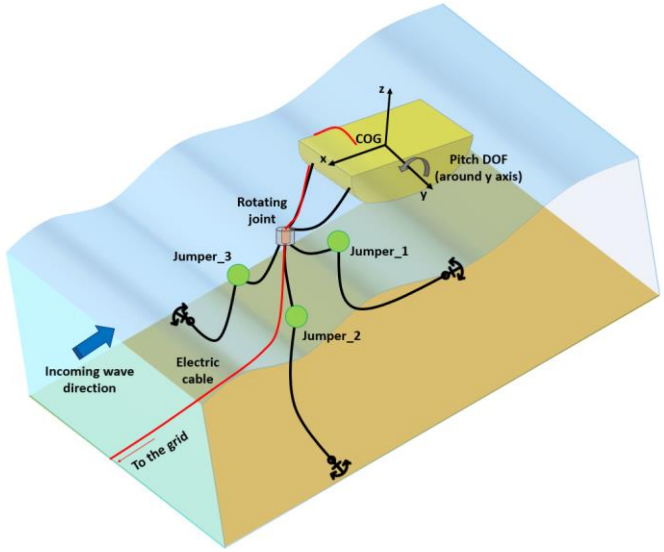


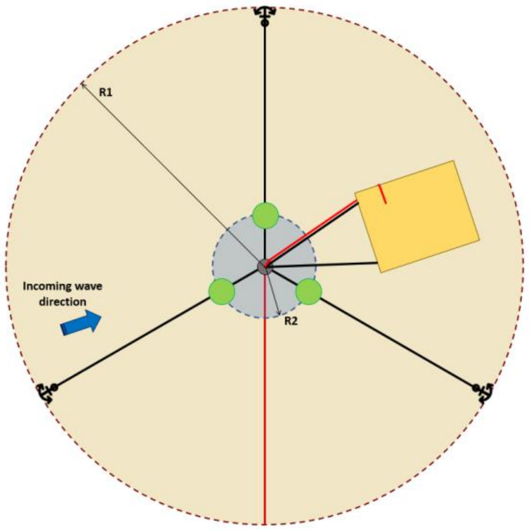
Fore connection point

- ✓ Yaw and Sway motions stable
- ✓ Regular Pitch motion
- ✗ Higher mooring recall force
- ✗ More complex moorings layout

POLITECNICO DI TORINO

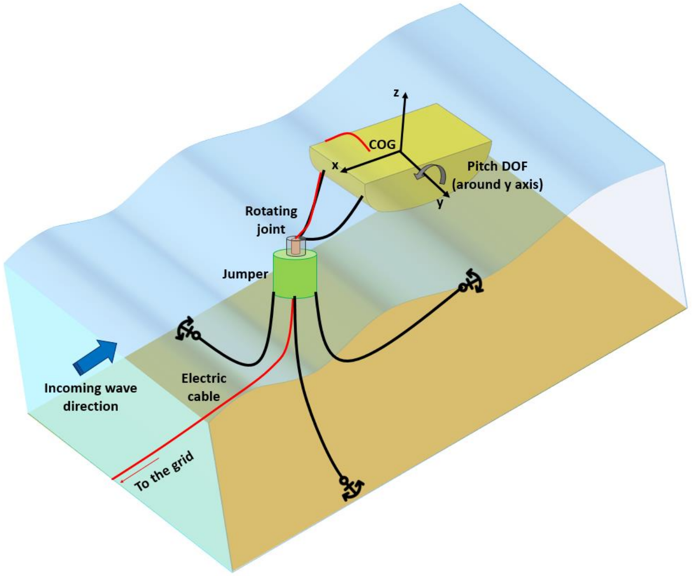
New moorings systems: grid connection & weathervane

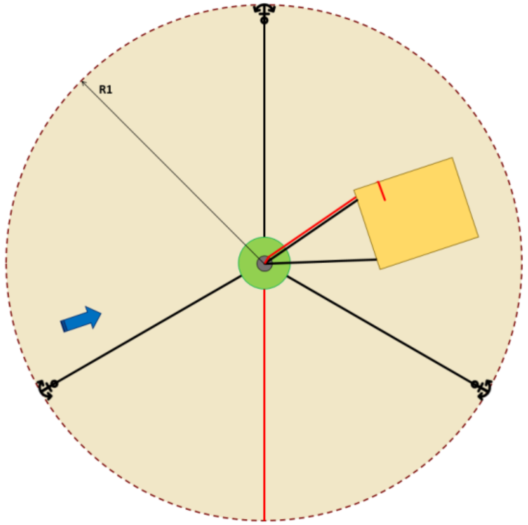




Configuration 1

- 3 jumpers
- Free joint motion

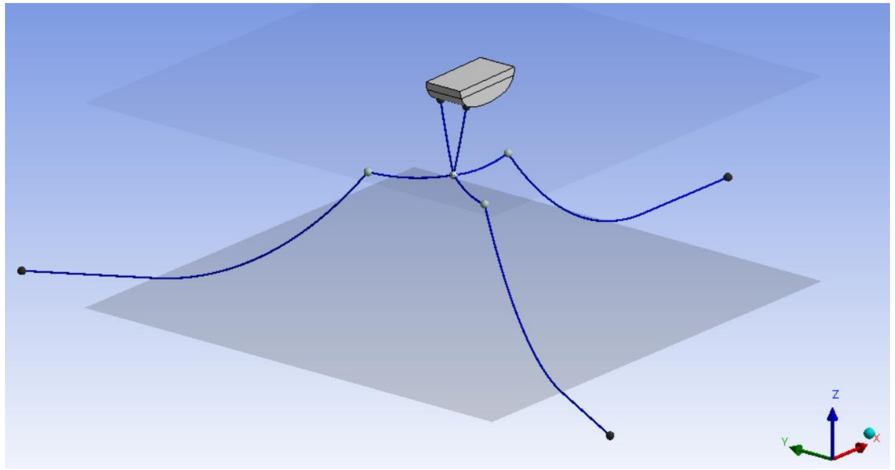


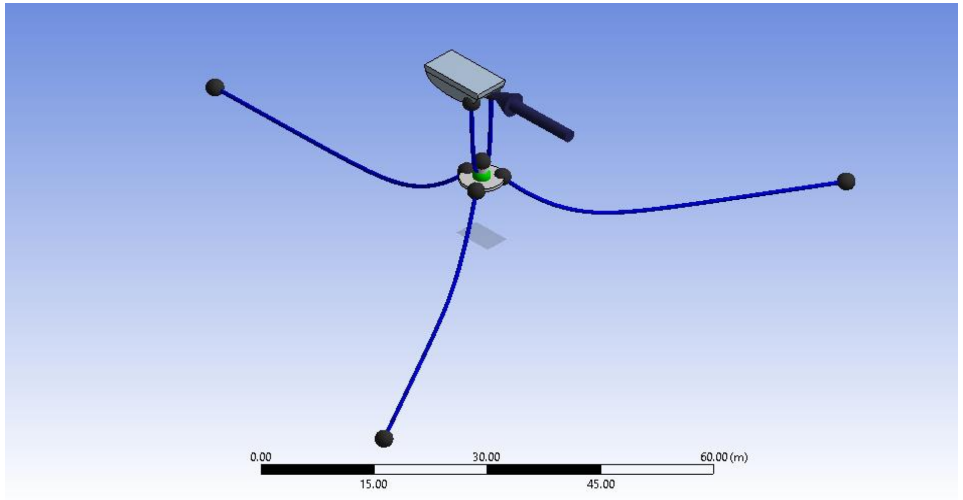


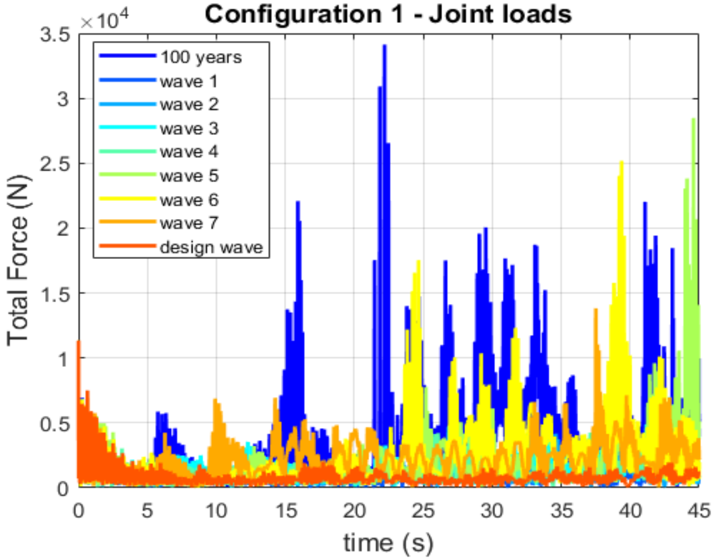
Configuration 2

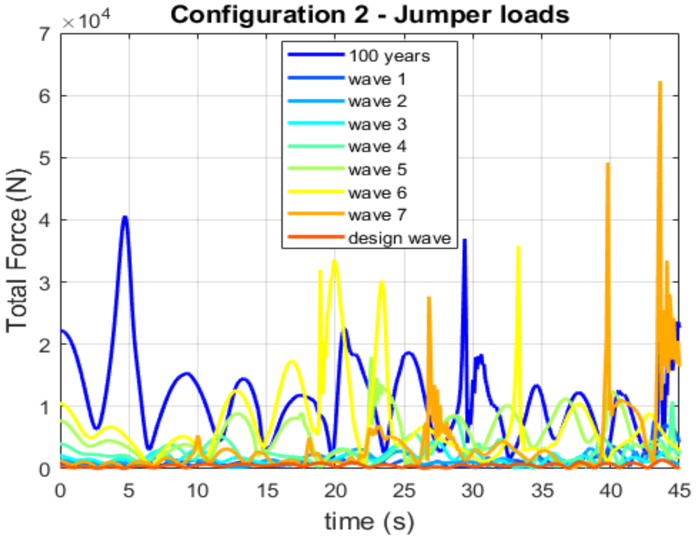
- Single jumper
- Joint follows the jumper

New moorings systems: grid connection & weathervane









Conclusions

- Numerical wave tank modelling
  - Possibility to run tests at reduced costs
  - Identification of non-linear phenomena involved in the floater-waves dynamics
  - 6 DoF simulations in irregular waves

- Mooring modelling and design
  - Wave to wire model expansion with 3 DoF quasi-static modelling
  - Modelling of dynamic mooring system with multiple lines
  - Design of slack mooring systems for floating WECs

Thank you