EERA DeepWind Conference 2022

Installation and sub-structures
Paper number: 46

A parametric optimization approach for the initial design of FOWT's substructure and moorings in Brazilian deep-water fields

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Agenda

1) Introduction
2) Methodology
3) Optimization Framework
4) Case Study
5) Conclusions

1) Introduction

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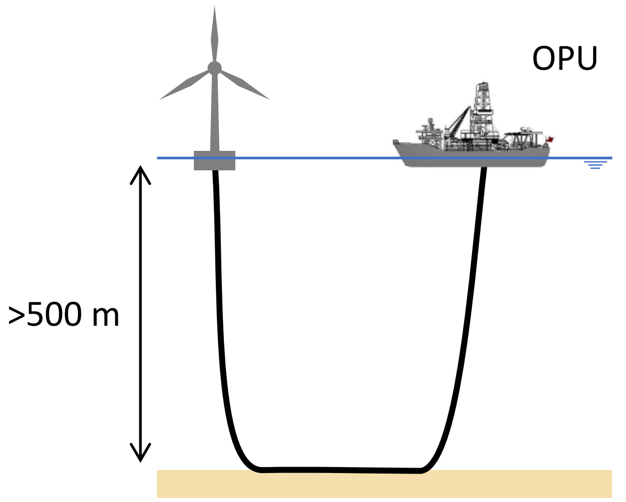
Introduction

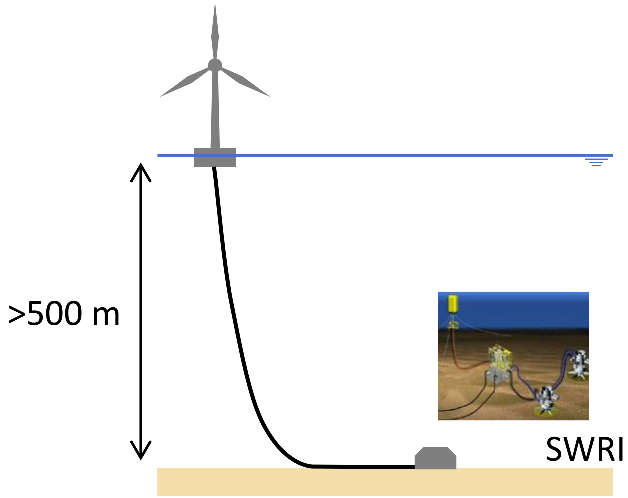
Interest from energy majors in the renewable electrification of Offshore Production Units

Offshore operations account for more than 90% of the total amount of Brazil’s O&G production

Renewable on offshore O&G operations: may help to meet the environmental regulations and maximize production.

Brazilian scenario challenges: long distances from shore and deep-water conditions (500 m – 2000 m)

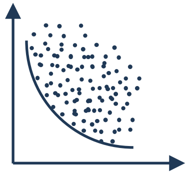




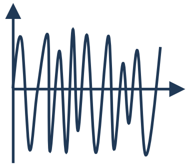
Objective

Parametric site-specific optimization of FOWT's hull and mooring systems

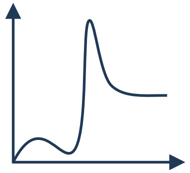
Methodology



FOWT hull and mooring design using an optimization framework based on the Multi-Niche Crowding Genetic Algorithm strategy – similar to Hall et al. (2013) and Karimi et al. (2017)



Assessment of hull-mooring coupled dynamics and fulfillment of the safety class requirements using site-specific data: adoption of long-term environmental series (12y)



Frequency domain modelling and the explicit formulation for the stiffness matrix around a generic offset position

Floater motion responses are investigated by means of nacelle horizontal acceleration RAOs at each sea state condition

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2) Methodology

3) Optimization Framework

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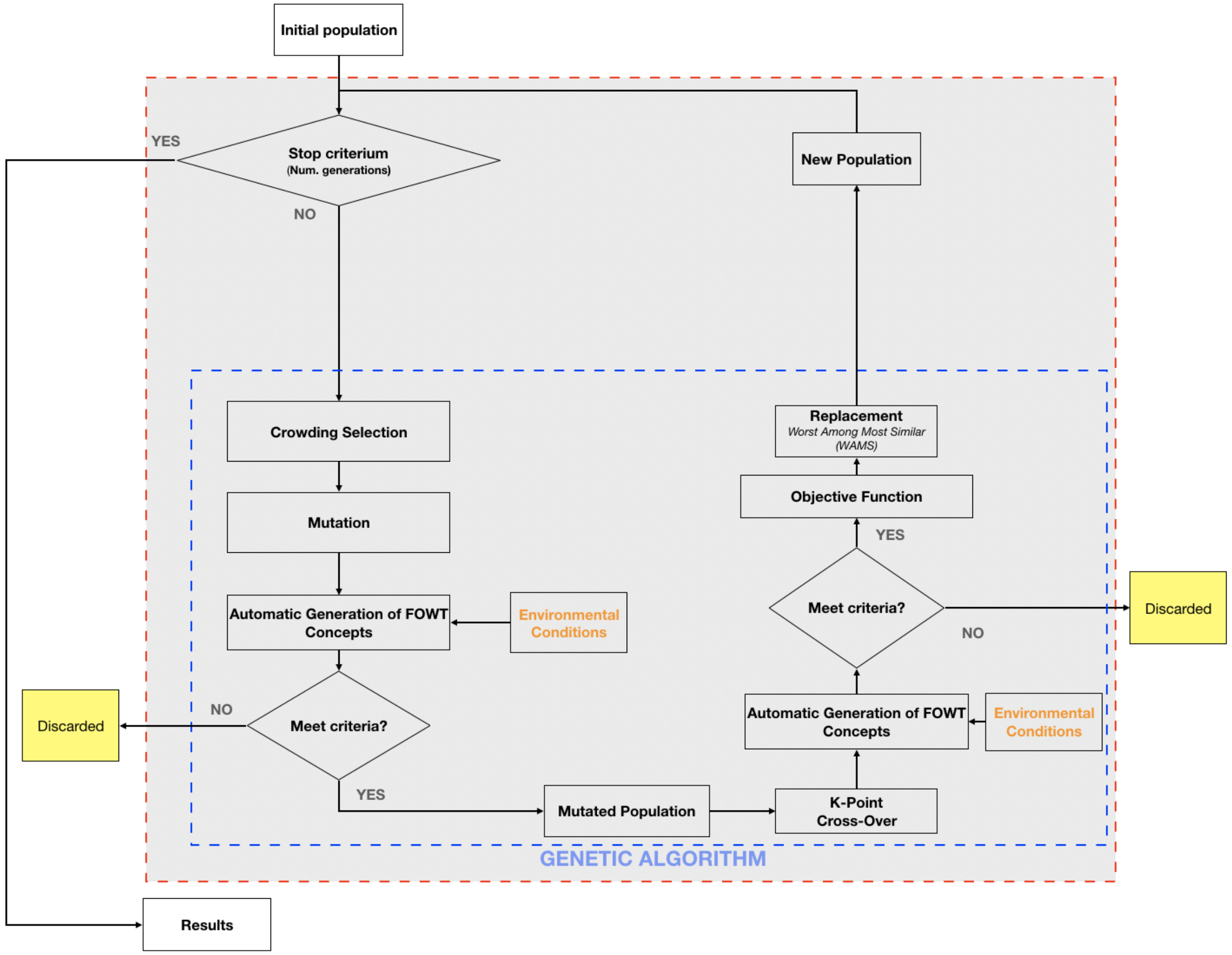
Optimization Framework (1/6)



Optimization Framework (2/6)

Cost function:

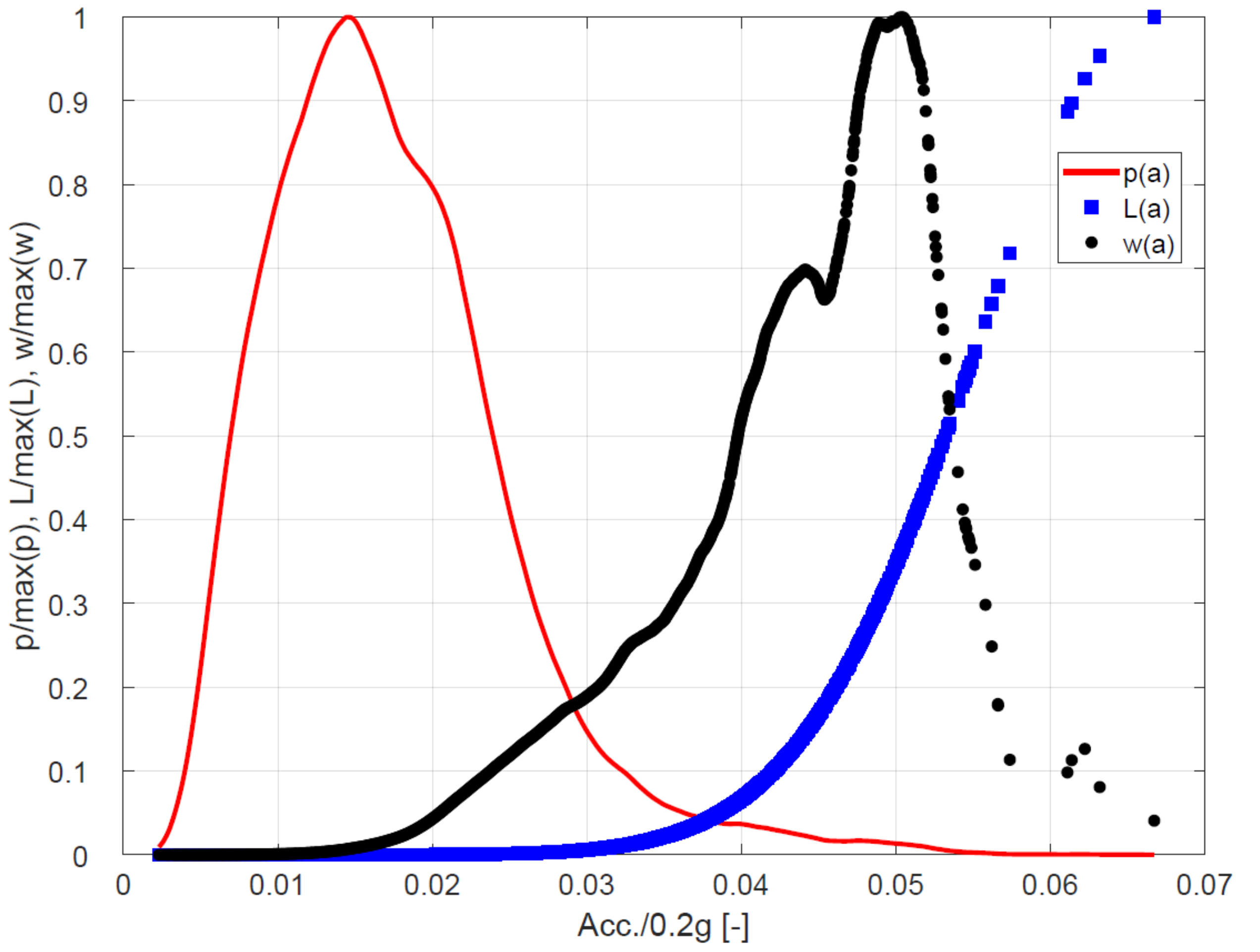
Performance evaluation:
Weighted nacelle horizontal acceleration

$$\min\{F\} = \min\left\{\left[Cost_{CAPEX}^{hull}, Cost_{CAPEX}^{mooring}, \sum_{i=1}^{N}\left(w_i \cdot \frac{a_i}{0.2g}\right)\right]\right\}$$

Cost model:
Bjerkseter and Agotnes (2013)
and Karimi et al. (2017)

CAPEX	Description	value	Units
Hull	Acquisition & Manufacturing	2.100,00	$[USD/ton]$
Mooring Chain	Acquisition	2.000,00	$[USD/ton]$
Mooring Synthetic	Acquisition	2.800,00	$[USD/MBL_{ton} \cdot m]$
Anchors	Acquisition	DEA: 100; VLA: 120; SPA: 150	$[USD/kN/un]$

Optimization Framework (3/6)



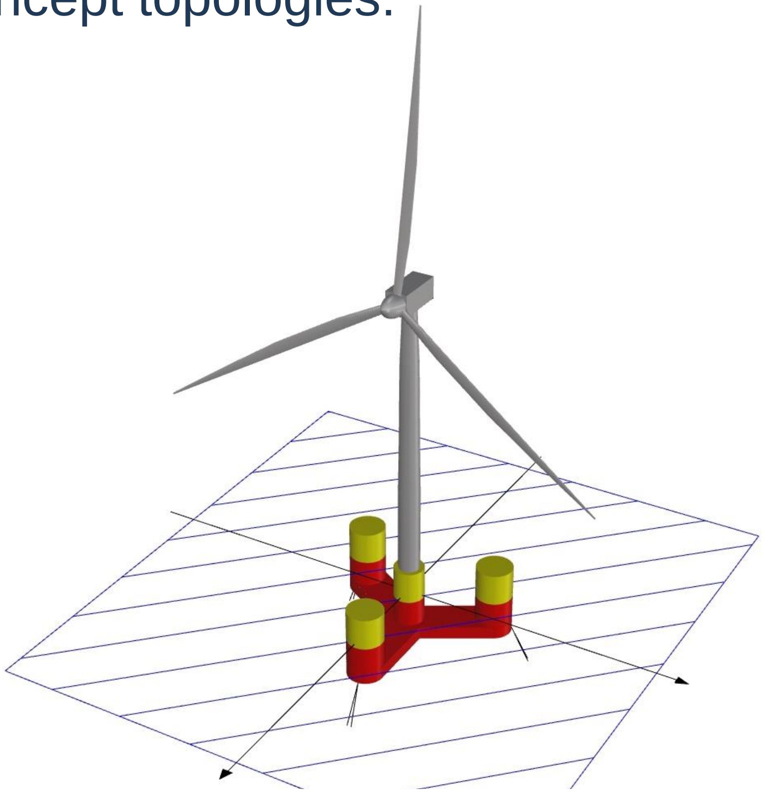
p(a): empirical probability function of occurrence of accelerations

L(a): distribution discriminating the lowest values of acceleration

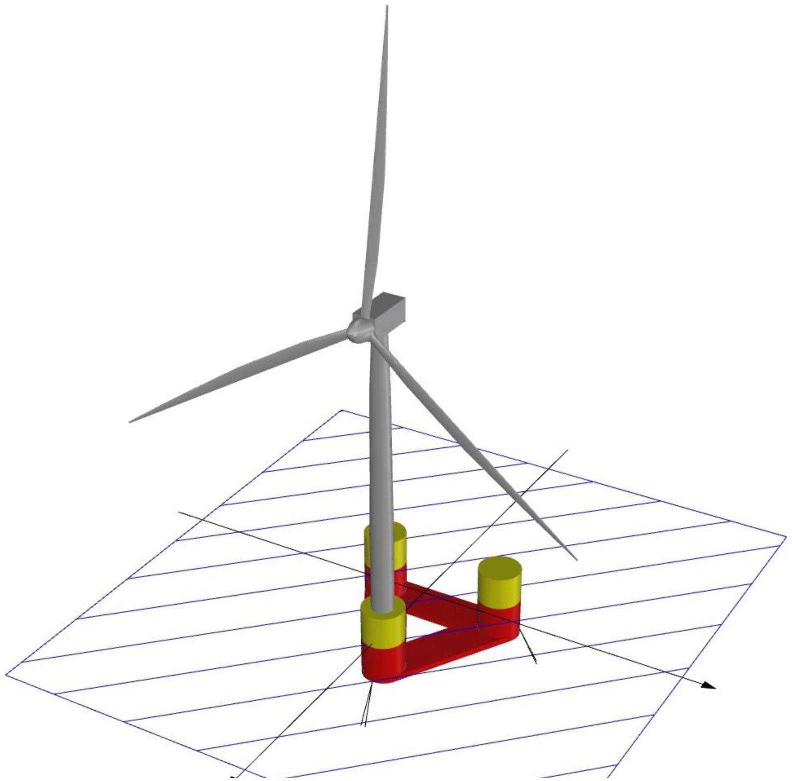
w(a): weights for each acceleration

Optimization Framework (4/6)

Hull concept topologies:



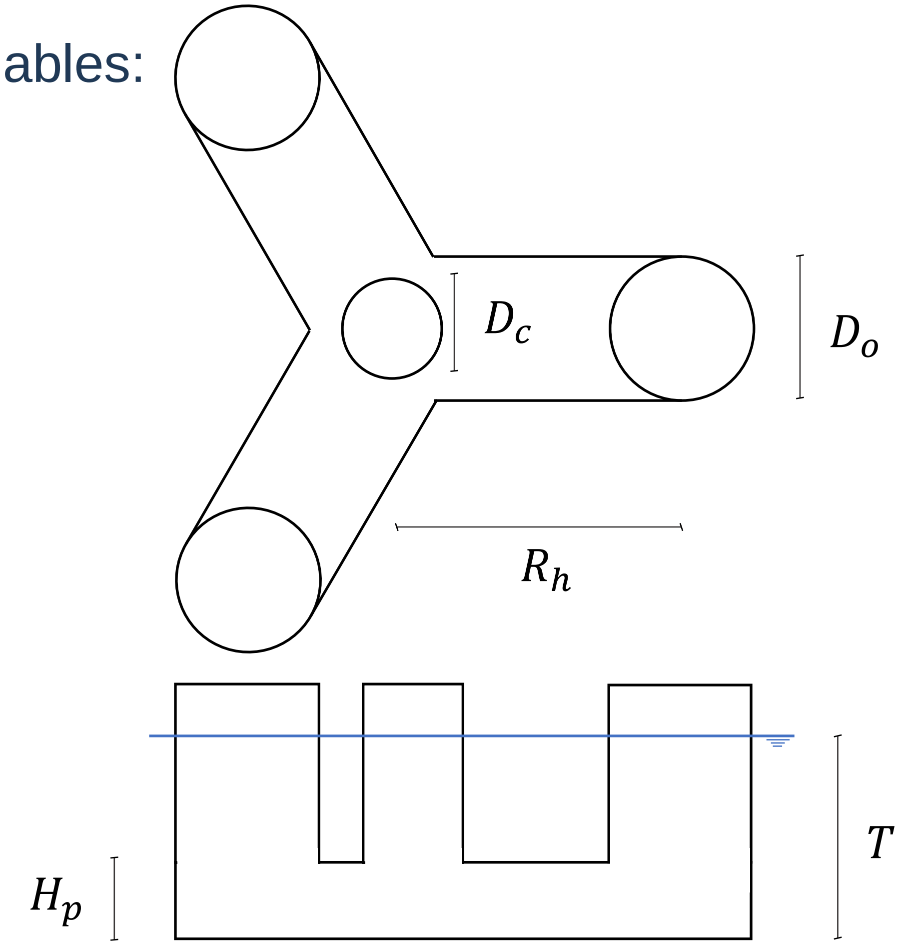
FOWTC



FOWTO

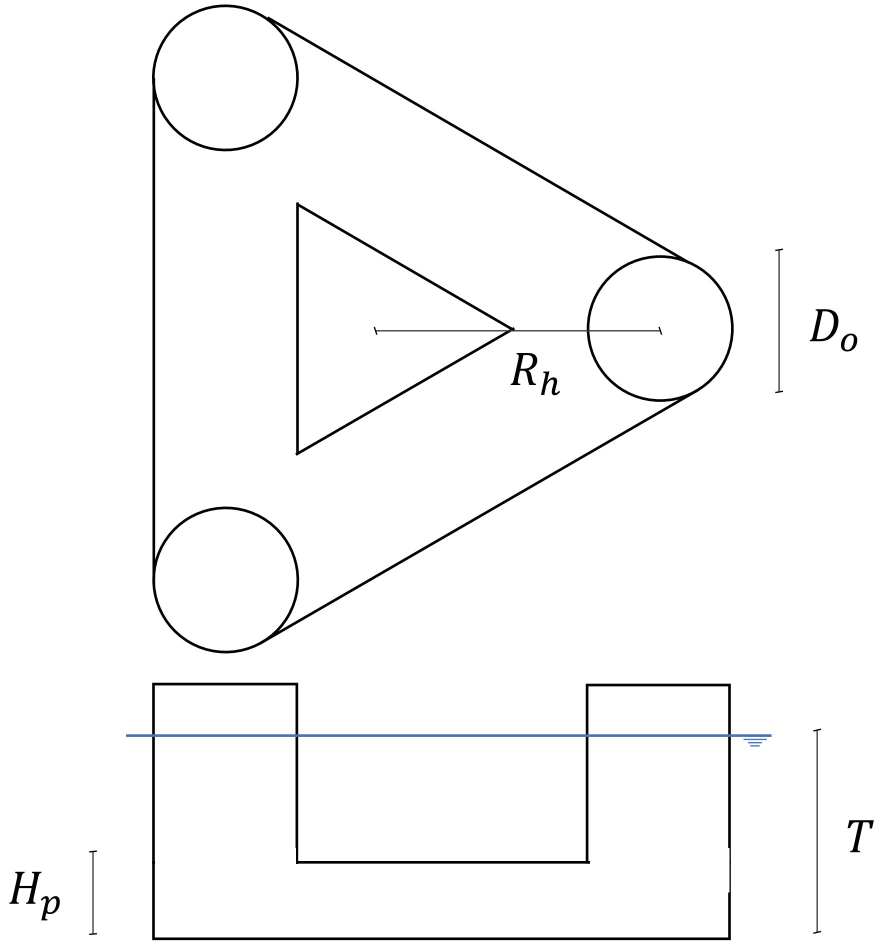
Optimization Framework (5/6)

Hull variables:



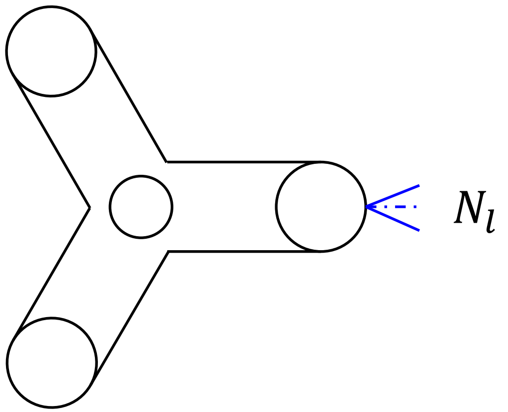
Top view

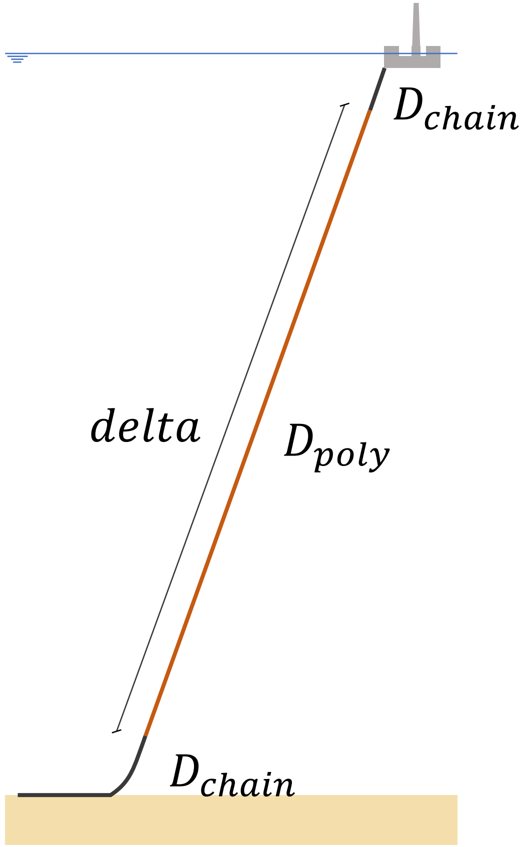
Elevation

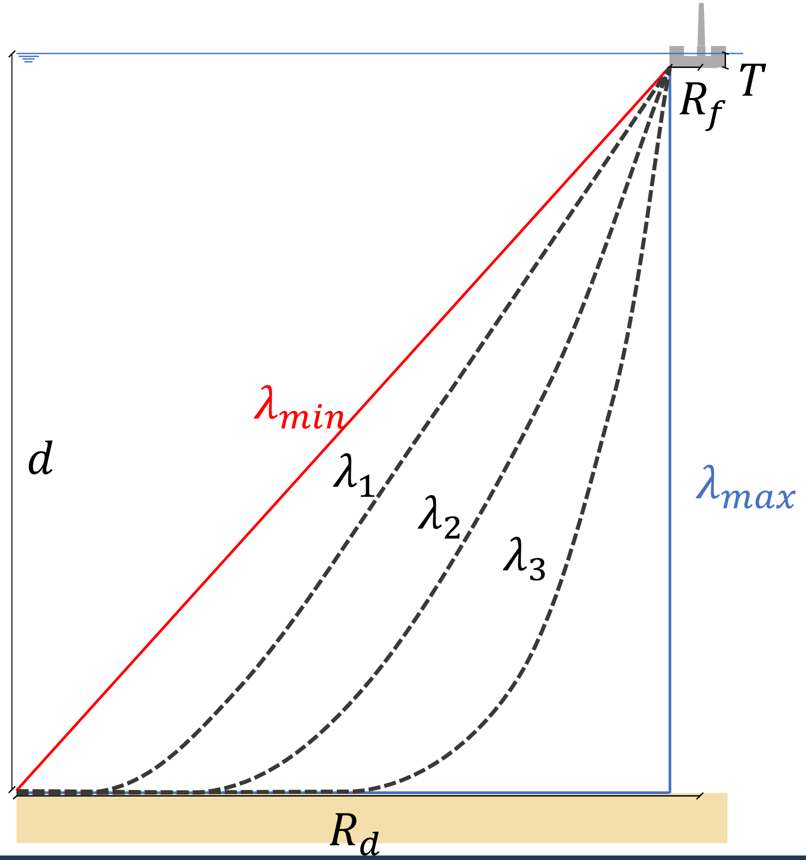


Optimization Framework (6/6)

Mooring system variables:



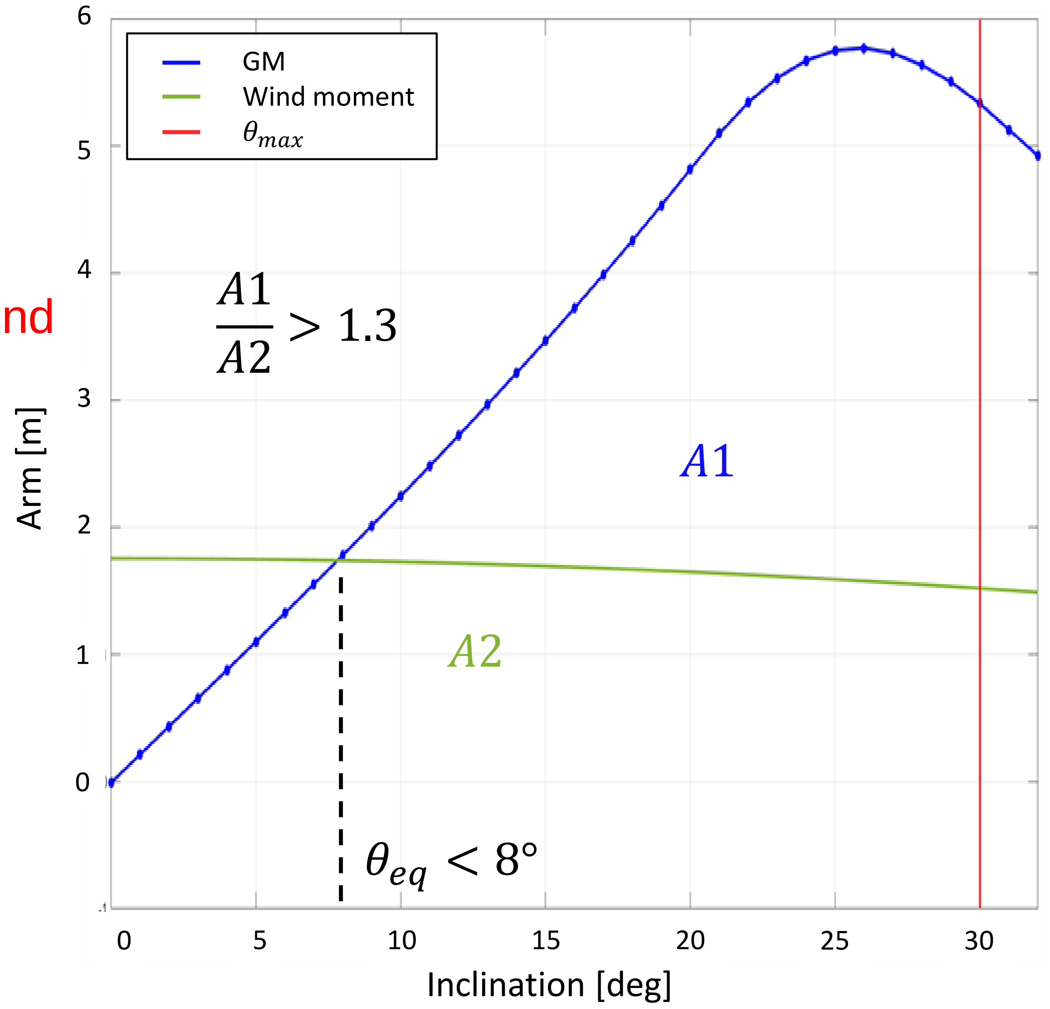




Optimization Framework (7/7)

Constraints and Criteria:

- Intact stability and maximum heeling angle due to wind
- Heave period
- Bending stress
- Maximum offset
- Mooring lines safety factor



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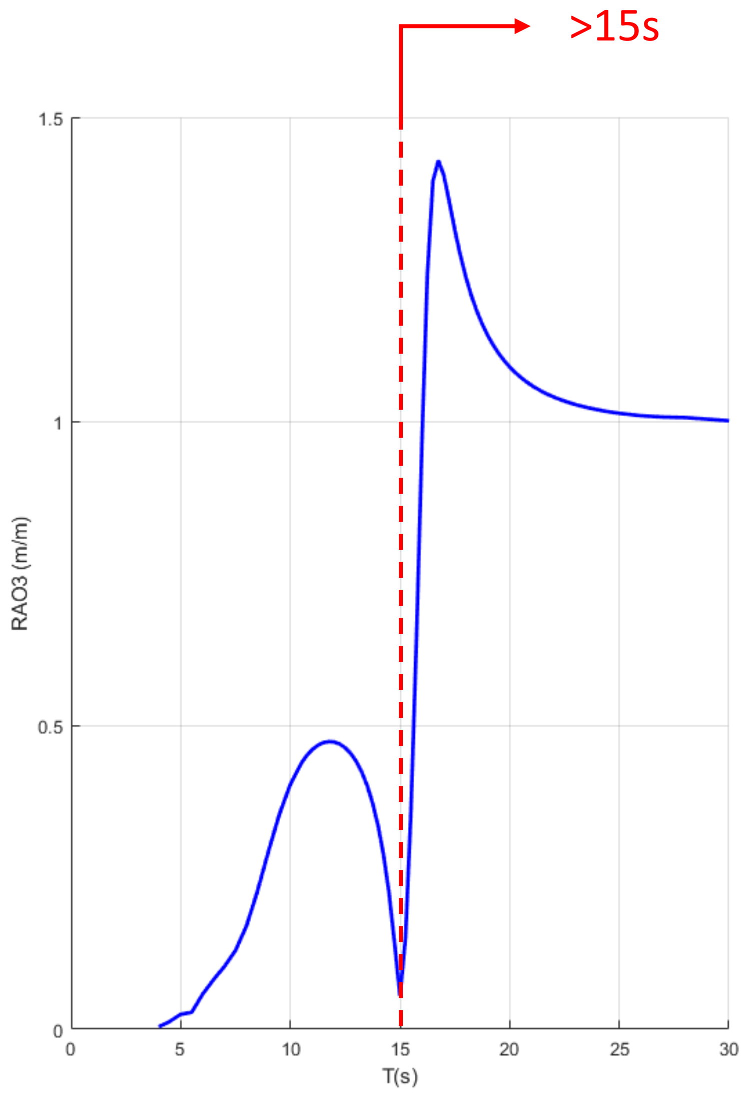

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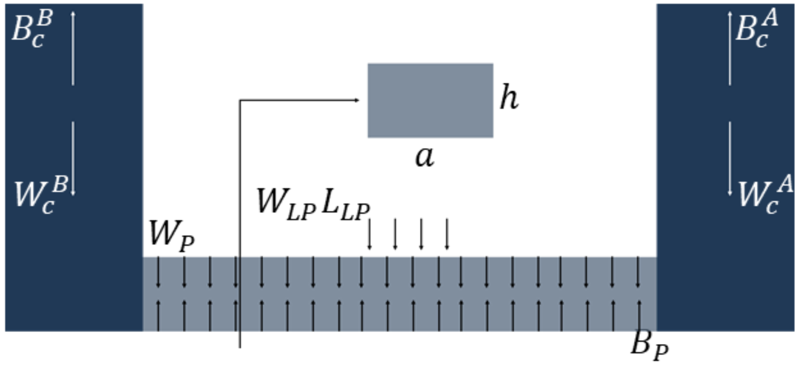

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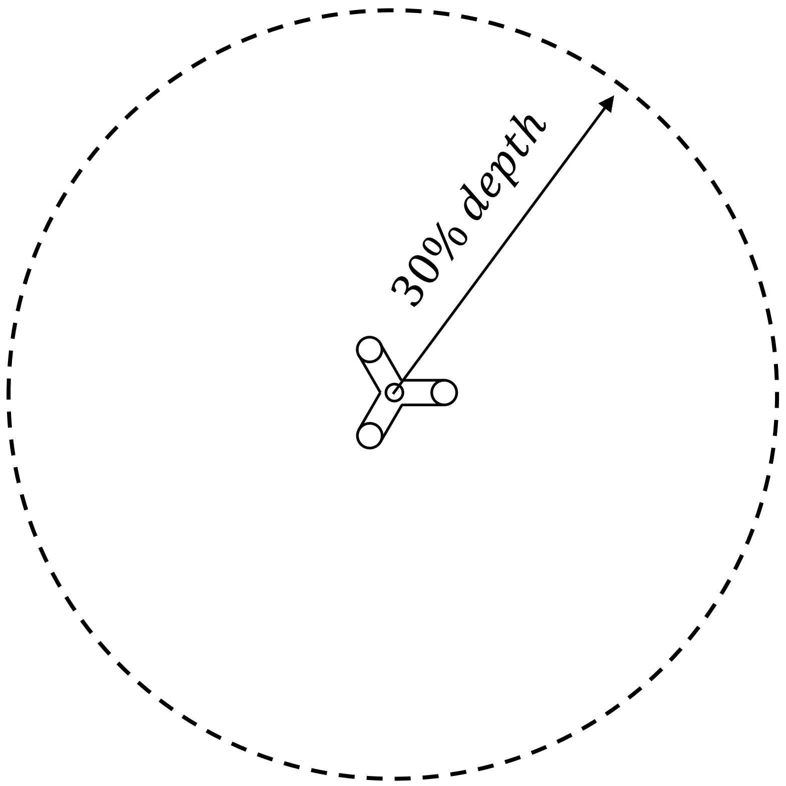

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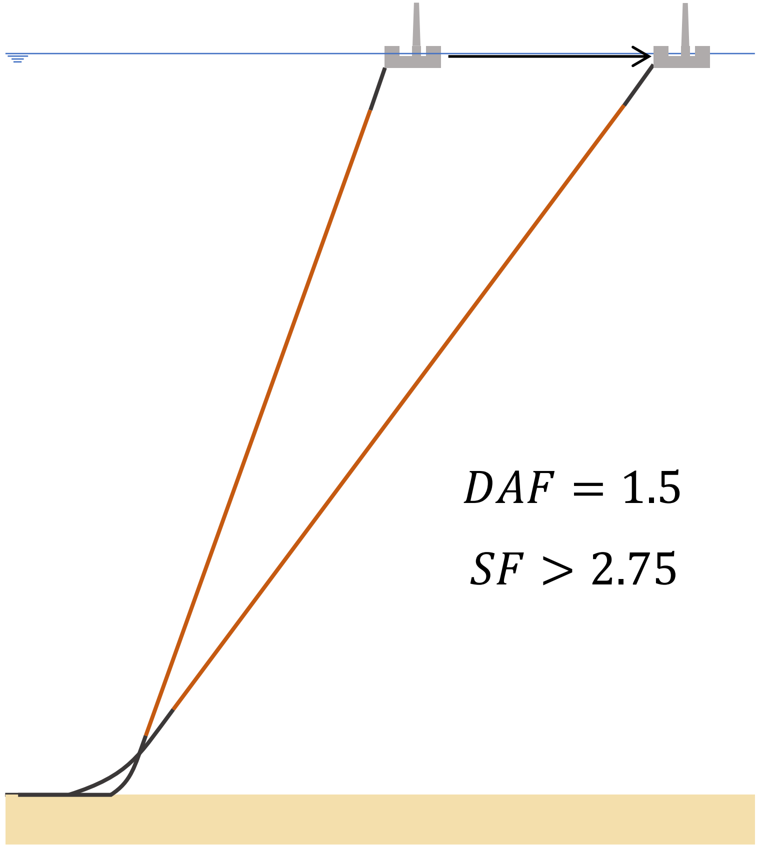

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2) Methodology

3) Optimization Framework

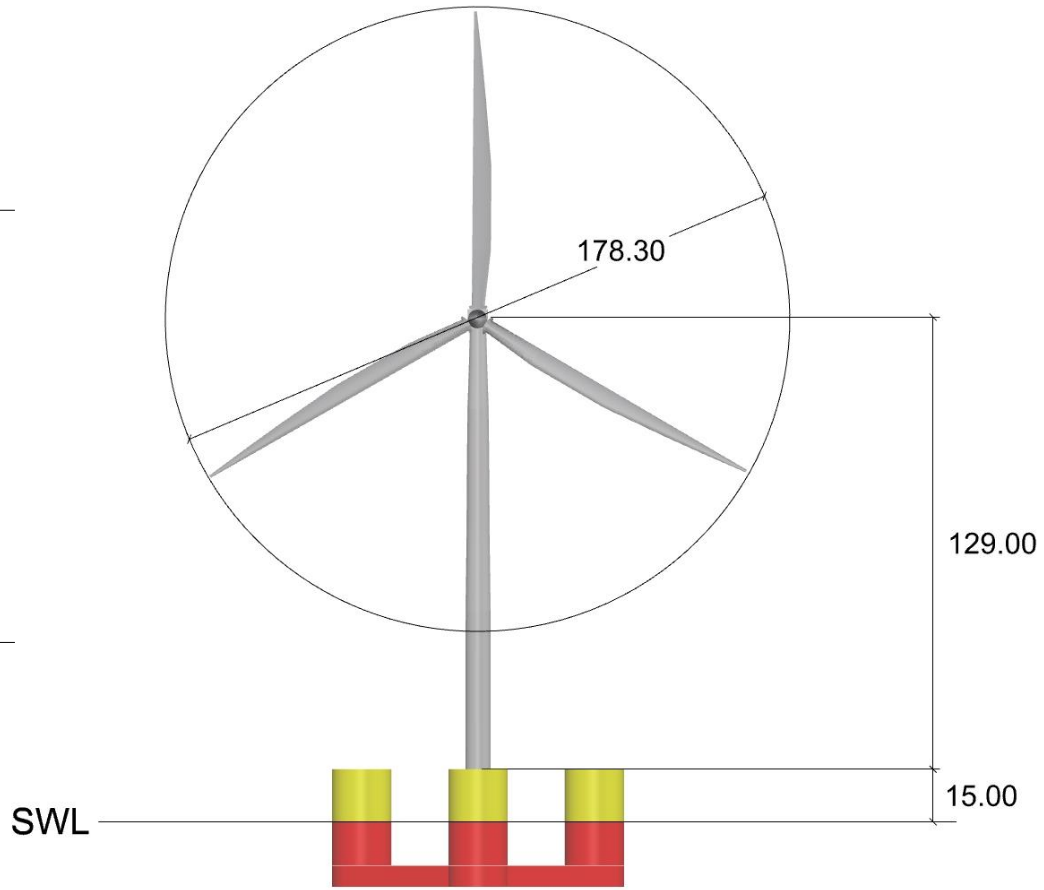
4) Case Study

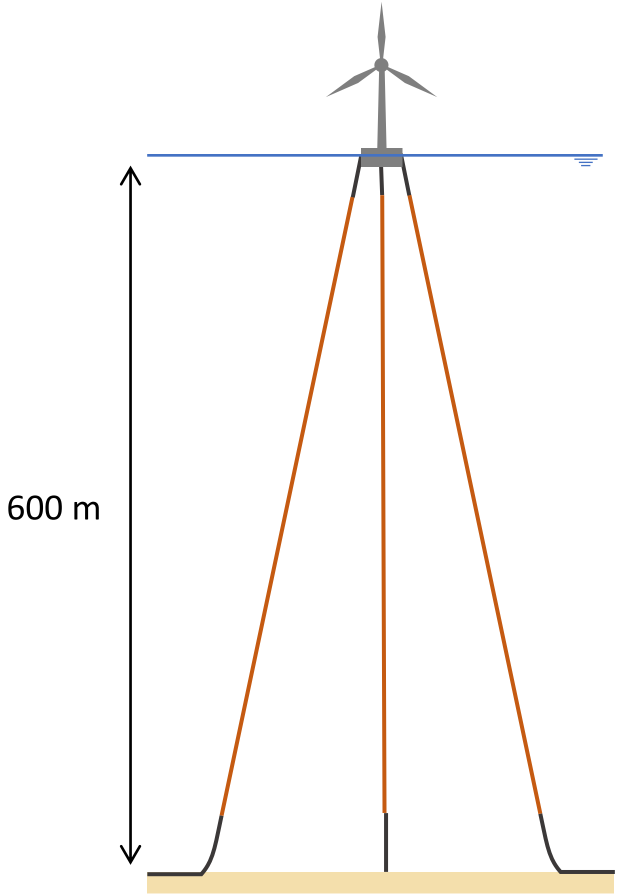
5) Conclusions

Case study: Wind turbine and depth

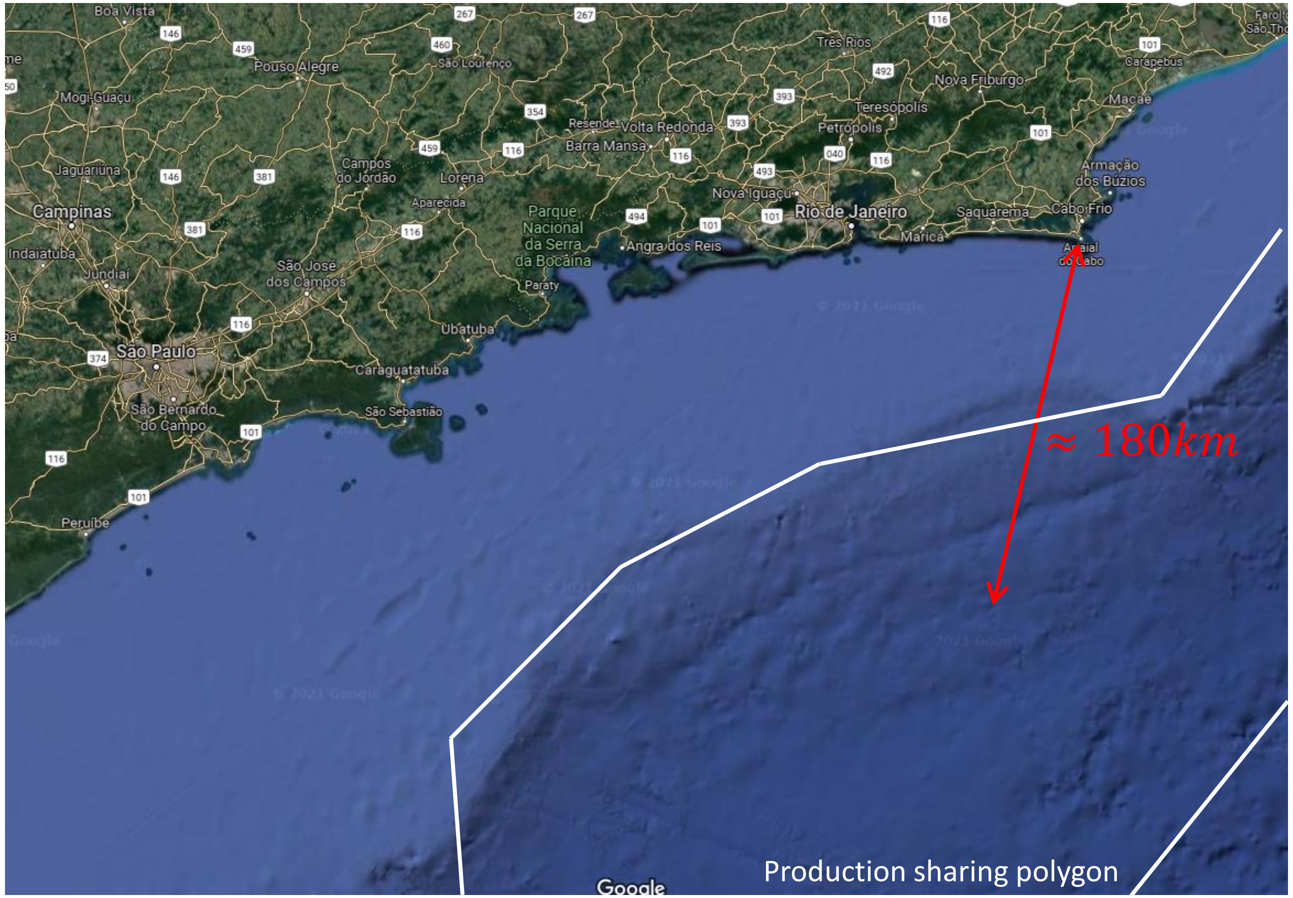
Parameter	Value	Units
Cut-in wind speed	4	[m/s]
Cut-out wind speed	25	[m/s]
Rated wind speed	11.4	[m/s]
Rated power	10	[MW]
Rotor speeds	6 – 9.6	[rpm]
Number of blades	3	[-]
Rotor diameter	178.3	[m]
Hub diameter	5.6	[m]
Hub height	129	[m]
Rotor mass	227,962	[kg]
Nacelle mass	446,036	[kg]

Specifications of the DTU 10MW Wind Turbine



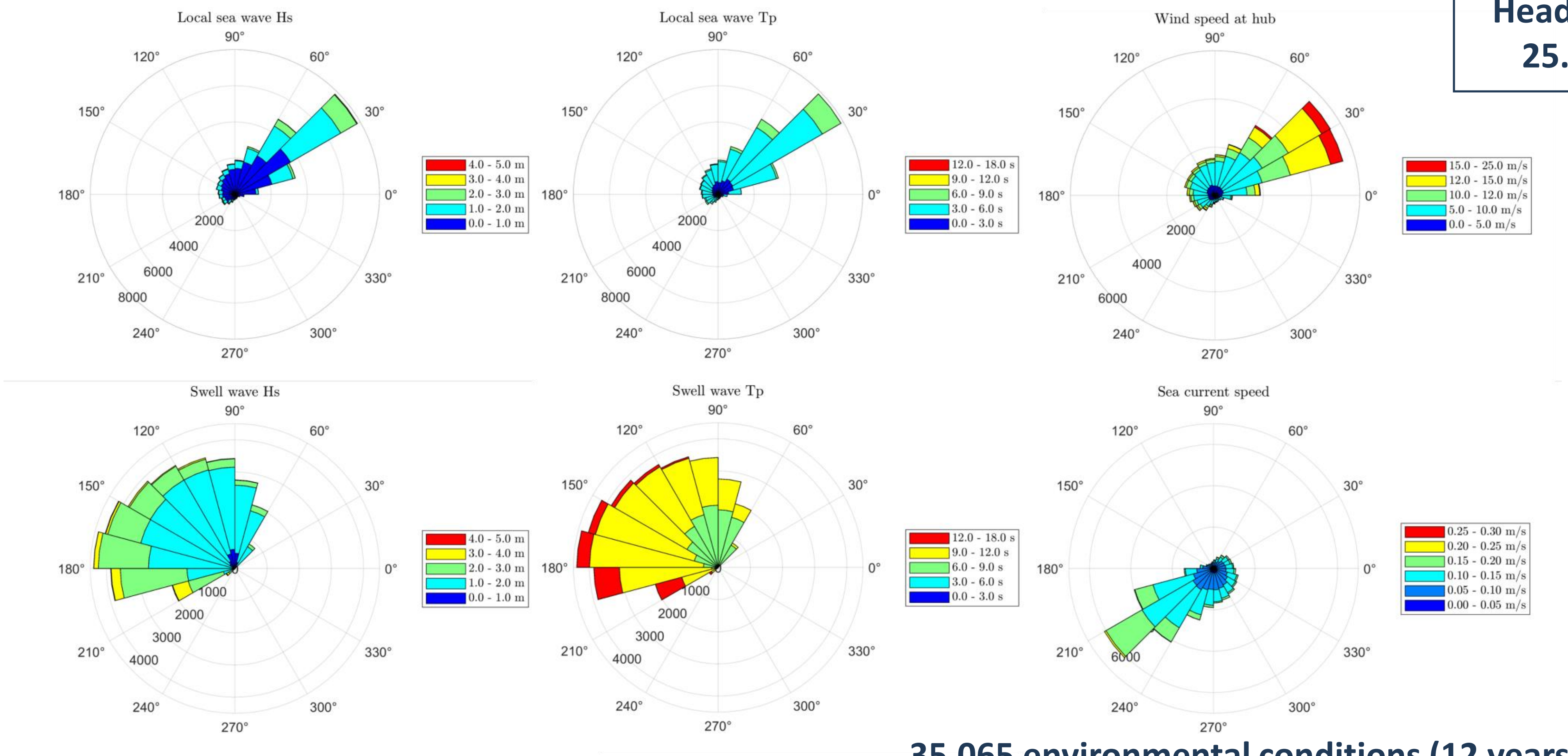


Case study: Location



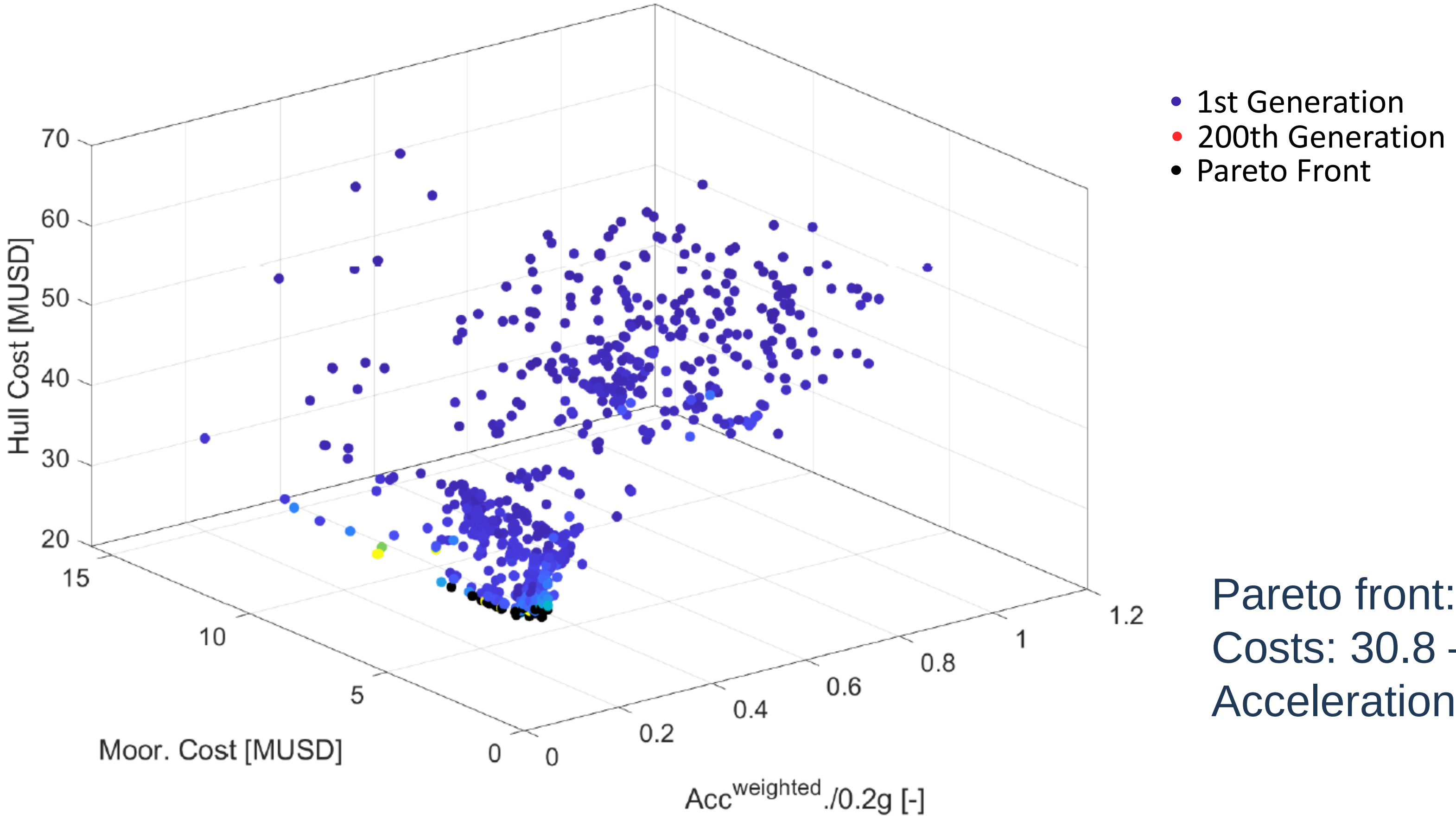
Case study: Metocean

Heading: 25.7°



35,065 environmental conditions (12 years/3h-long)

Case study: FOWTC multi-objective optimization (1/4)

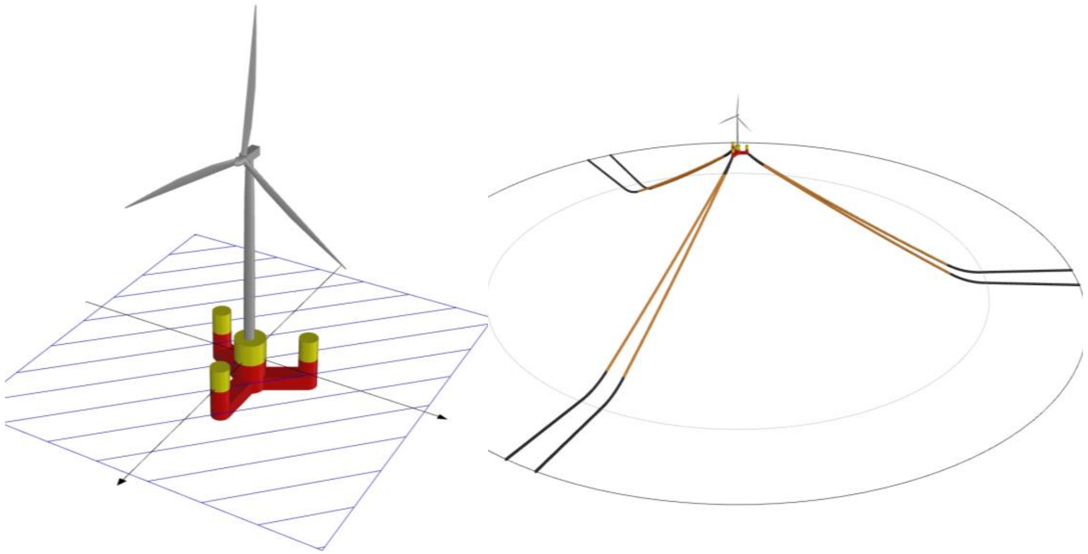


Pareto front: 25 concepts
Costs: 30.8 – 33.3 MUSD
Accelerations: 0.14 – 0.16

Case study:
FOWTC multi-objective optimization (2/4)

FOWTC-I concept

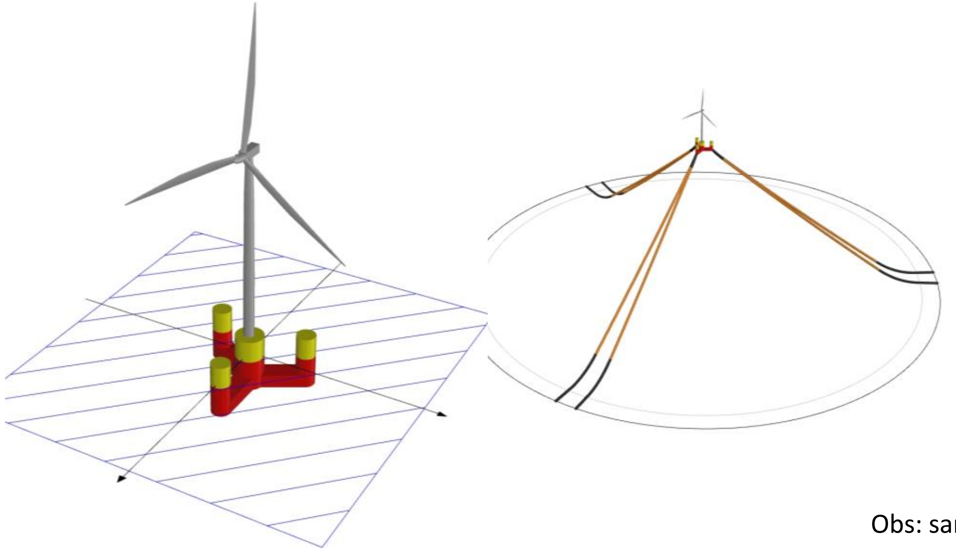
No vertical tension at the anchor



Displacement	25,850 ton
Draft	21.7 m
Mooring length	1,564.6 m

FOWTC-II concept

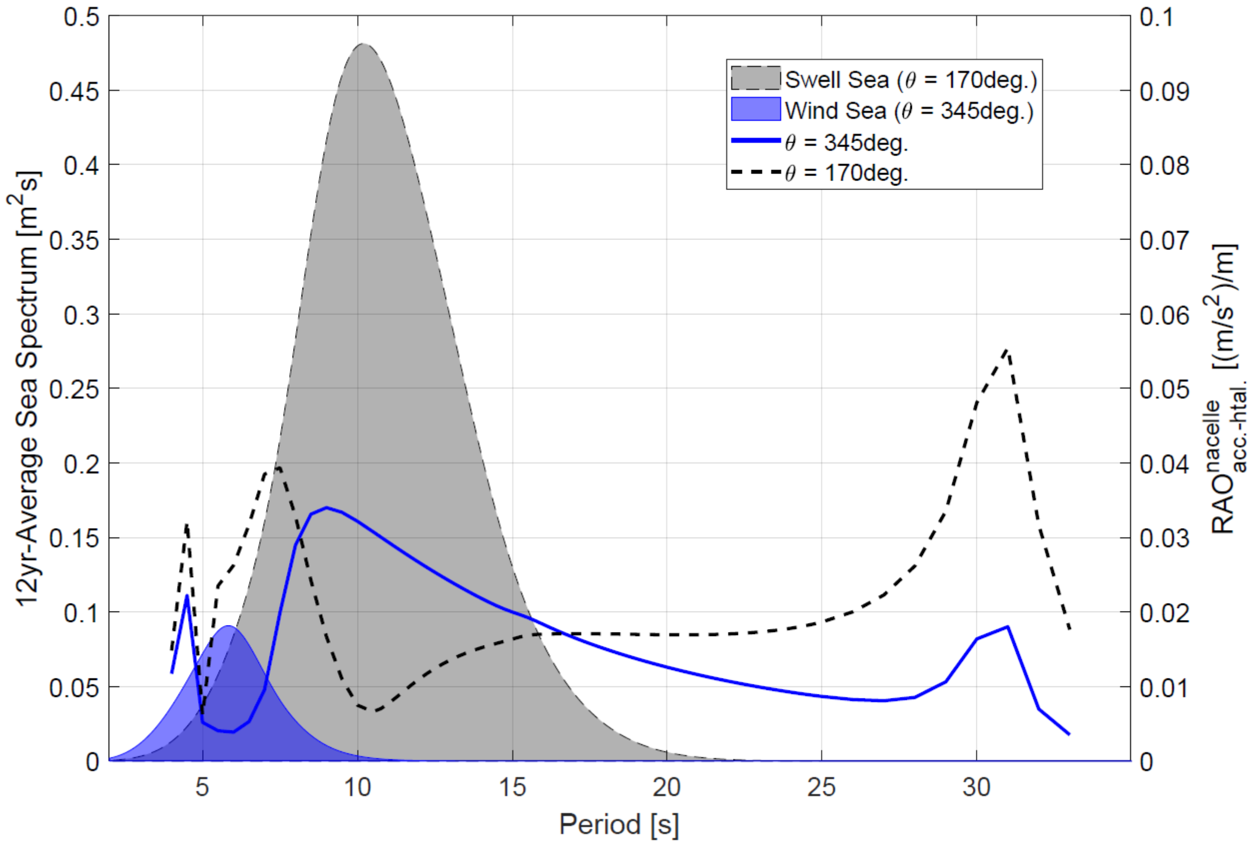
Vertical tension at the anchor



Obs: same scale

Displacement	24,681 ton
Draft	21.7 m
Mooring length	1,106.6 m

Case study:
FOWTC multi-objective optimization (3/4)



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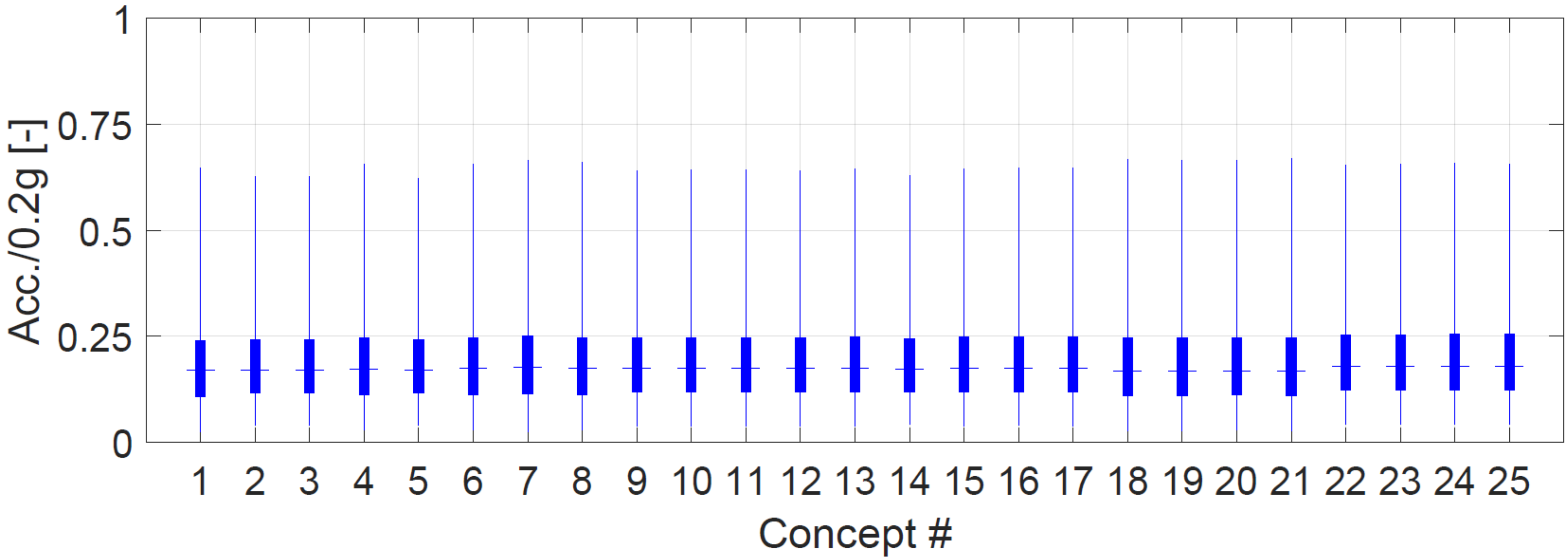
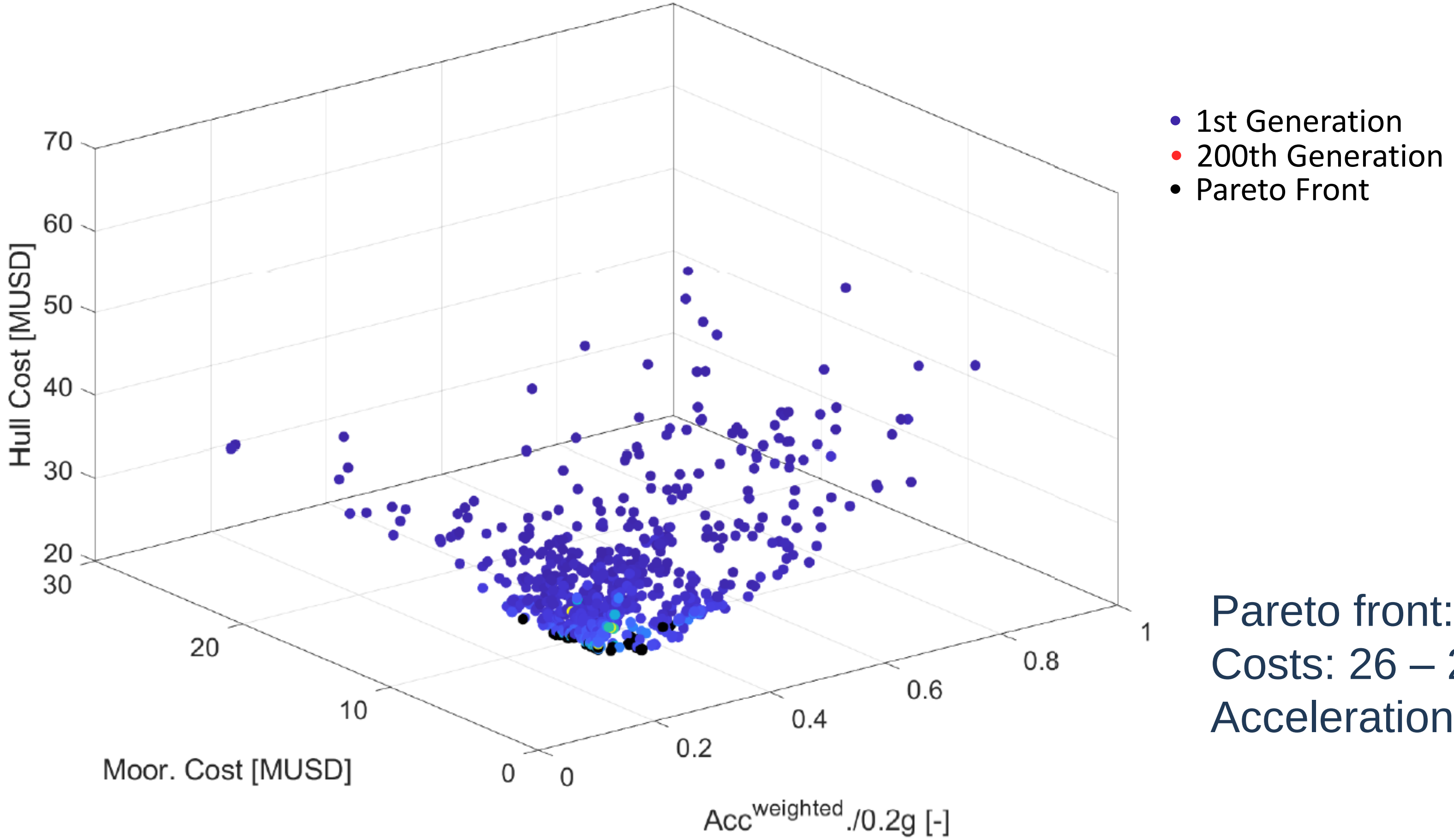
Case study: FOWTC multi-objective optimization (4/4)



Skip FOWTO results

Case study:
FOWTO multi-objective optimization (1/4)

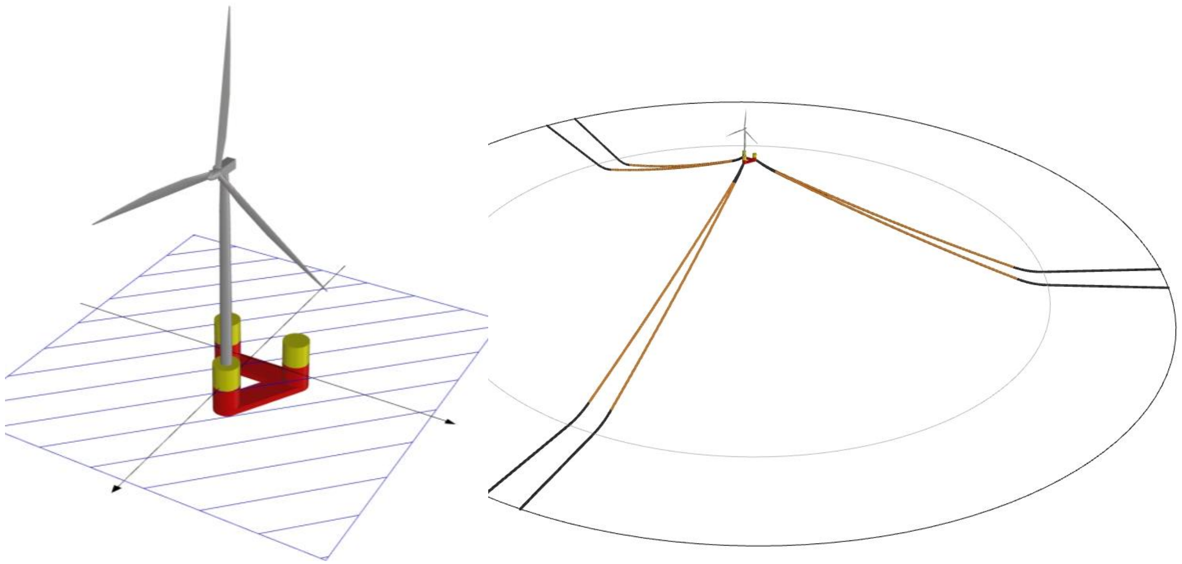


Pareto front: 23 concepts
Costs: 26 – 28 MUSD
Accelerations: 0.15 – 0.40

Case study:
FOWTO multi-objective optimization (2/4)

FOWTO-I concept

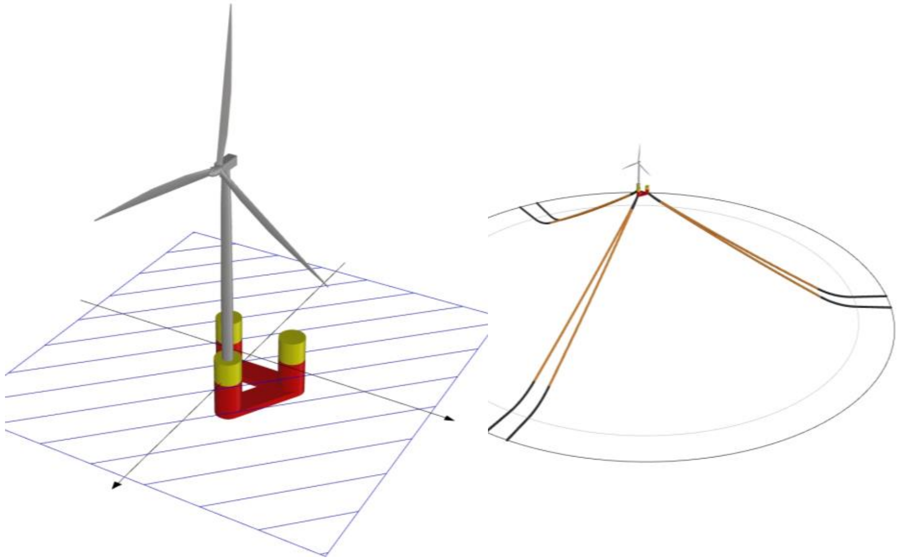
No vertical tension at the anchor



Displacement	18,919 ton
Draft	18.4 m
Mooring length	1,935.0 m

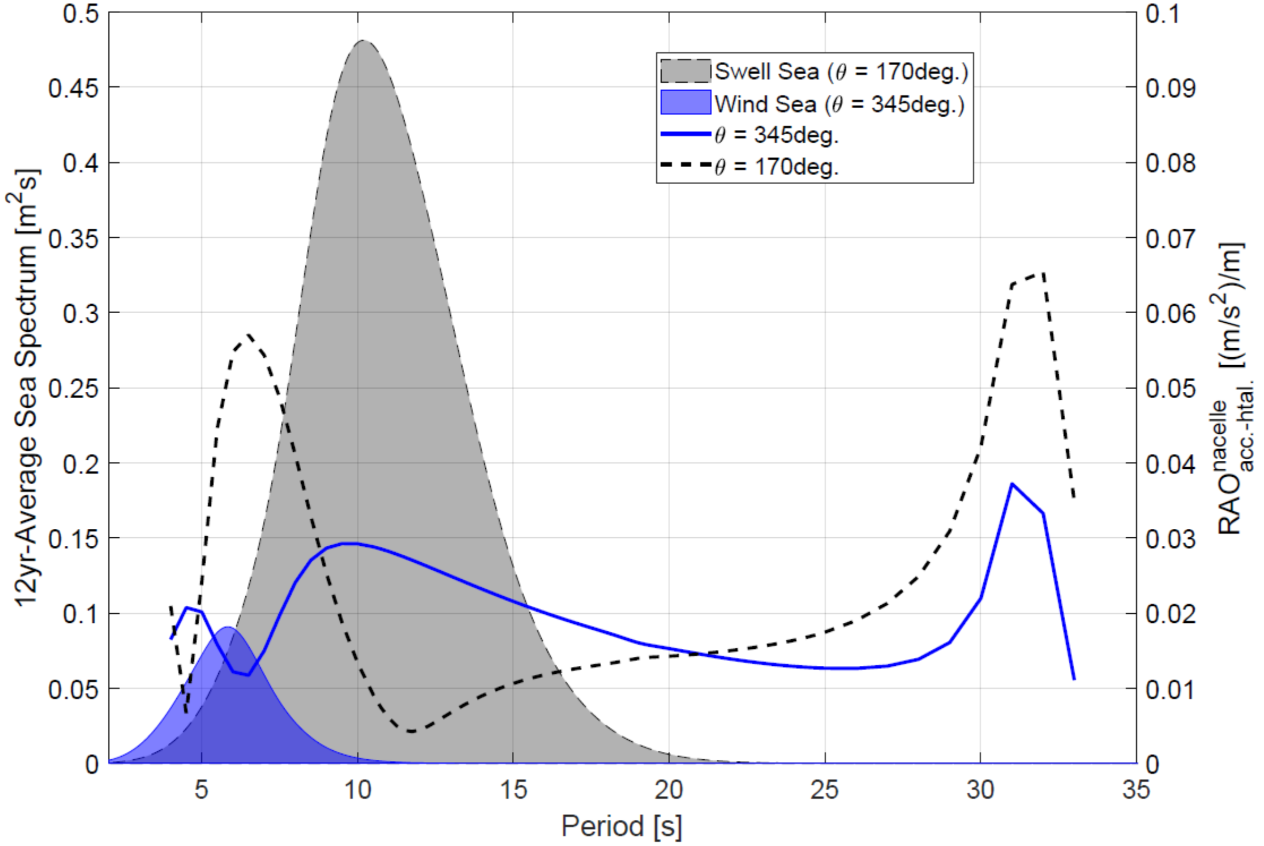
FOWTO-II concept

Vertical tension at the anchor



Displacement	22,828 ton
Draft	24.9 m
Mooring length	1,320.9 m

Case study: FOWTO multi-objective optimization (3/4)



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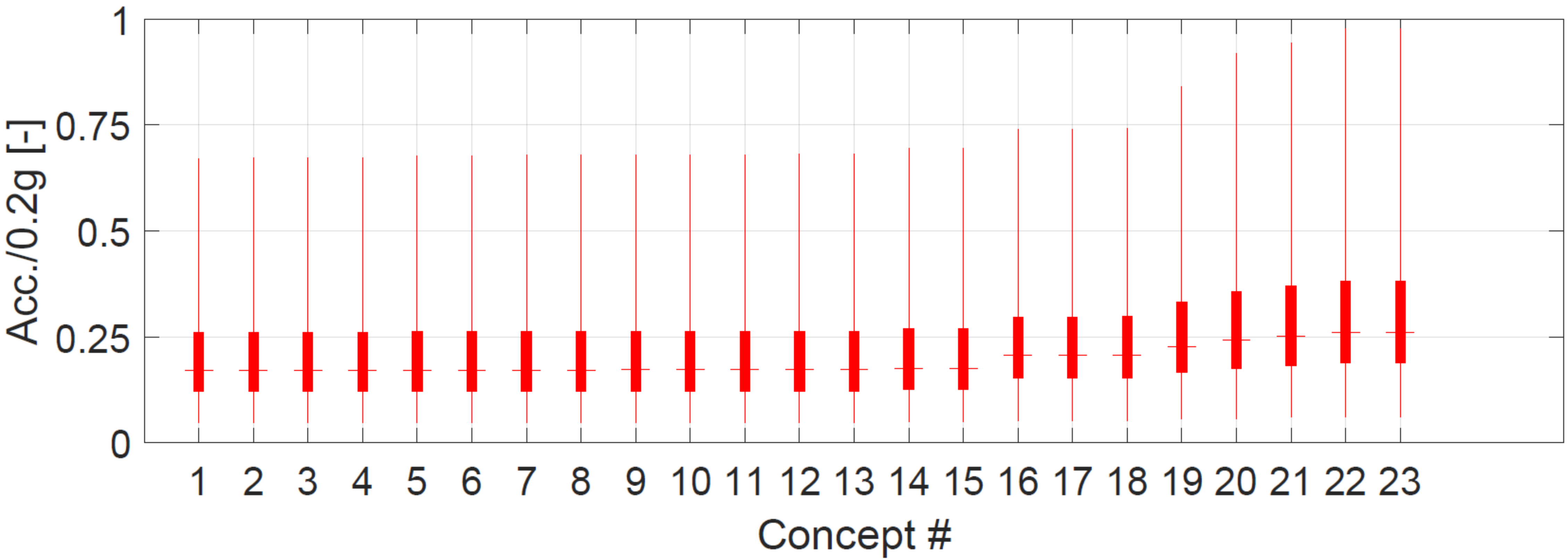
Case study:
FOWTC multi-objective optimization (4/4)



1) Introduction

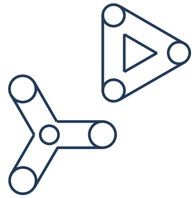
2) Methodology

3) Optimization Framework

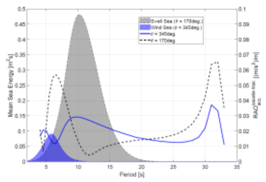
4) Case Study

5) Conclusions

Conclusions



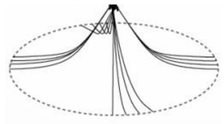
FOWT site-specific optimization for two topologies of semisubmersible platforms, using a 10MW wind turbine



Pareto fronts show a clear trend to minimize the nacelle's acceleration responses within the frequency range featured the largest (wind and swell) sea energy

Optimization results show trade-off between the maximum horizontal accelerations and the costs of the hull and mooring systems

- Largest hulls are characterized with robust mooring systems and small accelerations



Mooring system robustness is conditioned by diameter and number of lines per column

- Different combinations may result in systems with similar safety factors → not-fit results
- Inclusion of mooring installation costs may help to overcome this problem

Thank you!

Acknowledgments

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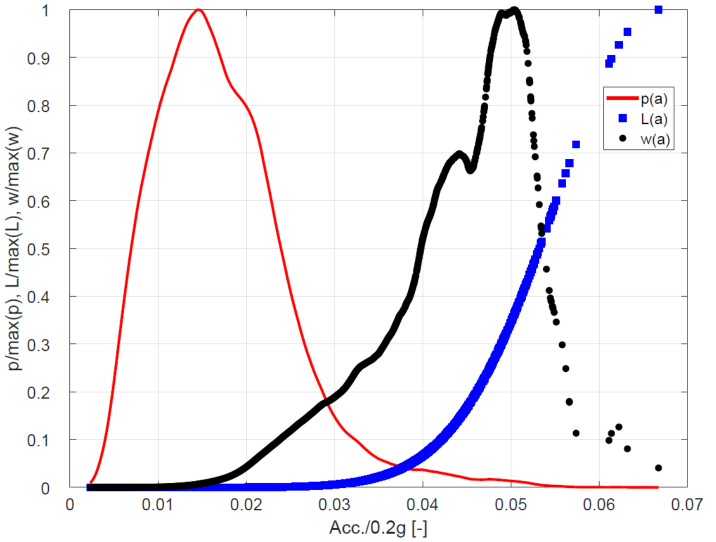
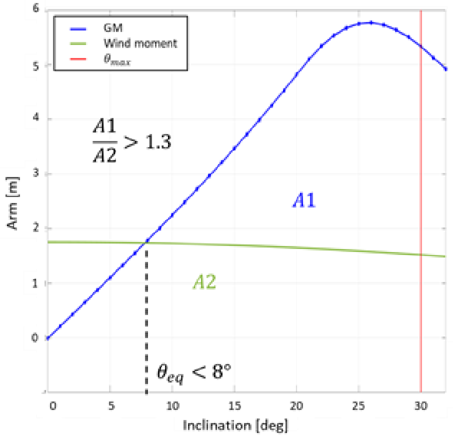
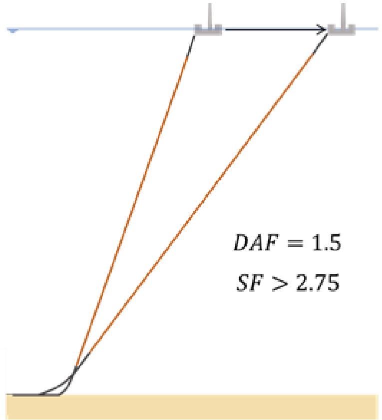
Optimization Framework

Weighting Function



Restrictions





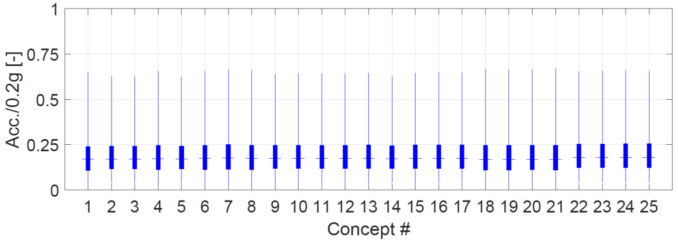
Cost function

Performance evaluation:
Weighted nacelle horizontal acceleration

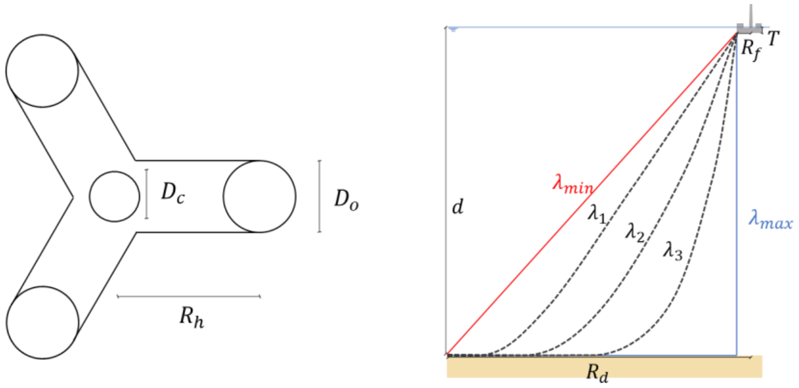
$$\min\{F\} = \min\left\{\left[Cost_{CAPEX}^{hull}, Cost_{CAPEX}^{mooring}, \sum_{i=1}^{N}\left(w_i \cdot \frac{a_i}{0.2g}\right)\right]\right\}$$

Cost model:
Bjerkseter and Agotnes (2013) and Karimi et al. (2017)

Concepts accelerations



Optimization Framework



accelerations RAOS x Mean Sea Energy