Preliminary Sizing and Optimization of Semisubmersible Substructures for Future Generation Offshore Wind Turbines

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Introduction

- Large wind turbines and floating foundations are expected to give lower costs
- Existing reference designs constitute a good starting point, but simple upscaling may give unfeasible or overly conservative designs
- Previous studies:
  - Theoretical upscaling of the substructure geometry with some constrained dimensions and checking the static and dynamic behavior of the upscaled design
  - Parametric studies considering dynamic behavior of the substructure (using diffraction/radiation analysis)
- Current work:
  - 2D simplified model of a FWT considering rigid motions and tower bending
  - Preliminary sizing to support a **25 MW turbine upscaled from the IEA15MW RWT** [1] through a design space search using two **reference platforms**

Reference designs

IEA 15 MW UMaine VolturnUS-S [2]

INO WINDMOOR 12 MW [3]

References:

(1) Allen, C. et al. (2020). Definition of the UMaine VolturnUS-S Reference Platform Developed for the IEA Wind 15-Megawatt Offshore Reference Wind Turbine (No. NREL/TP-5000-76773). National Renewable Energy Lab.(NREL), Golden, CO (United States).
(2) Gaertner, E. et al. (2020). IEA wind TCP task 37: definition of the IEA 15-megawatt offshore reference wind turbine (No. NREL/TP-5000-75698). National Renewable Energy Lab.(NREL), Golden, CO (United States).
(3) Silva de Souza et al. (2021). Definition of the INO WINDMOOR 12 MW base case floating wind turbine.

Simplified model

Modelling assumptions:

– Only surge, heave, pitch and tower fore-aft bending
– Added mass calculated using strip theory with 2D coefficients
– Mooring stiffness based on 18 m surge offset under rated thrust

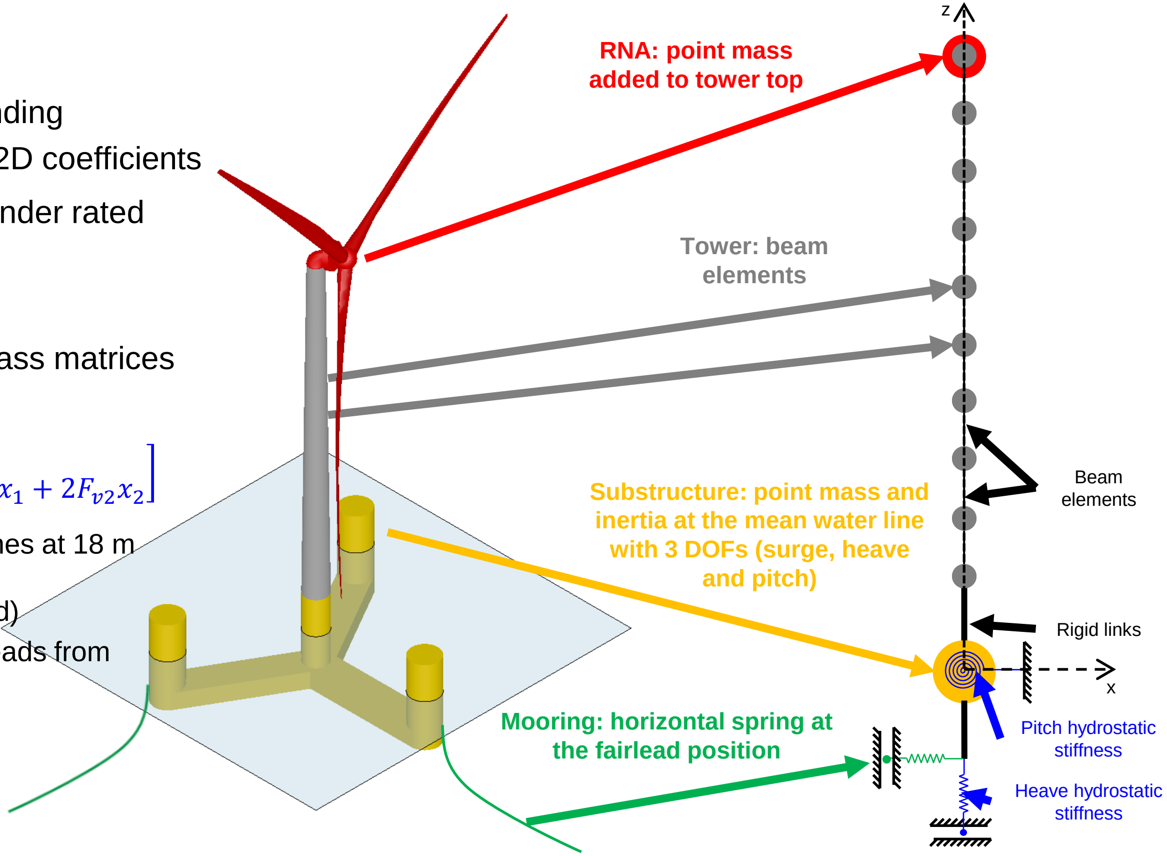
Outputs:

– Natural periods from the global stiffness and mass matrices
– Static pitch under maximum thrust:

$$\begin{bmatrix} C_{11} & C_{15} \\ C_{51} & C_{55} \end{bmatrix} \begin{bmatrix} \eta_1 \\ \eta_5 \end{bmatrix} = \begin{bmatrix} F_{thrust} \\ F_{thrust} h_{hub} - m_{RNA} x_{RNA} g - F_{v1} x_1 + 2F_{v2} x_2 \end{bmatrix}$$

F_{v1}, F_{v2}: vertical tension in the fwd and aft mooring lines at 18 m platform surge offset
(obtained from OpenFAST and theoretically upscaled)

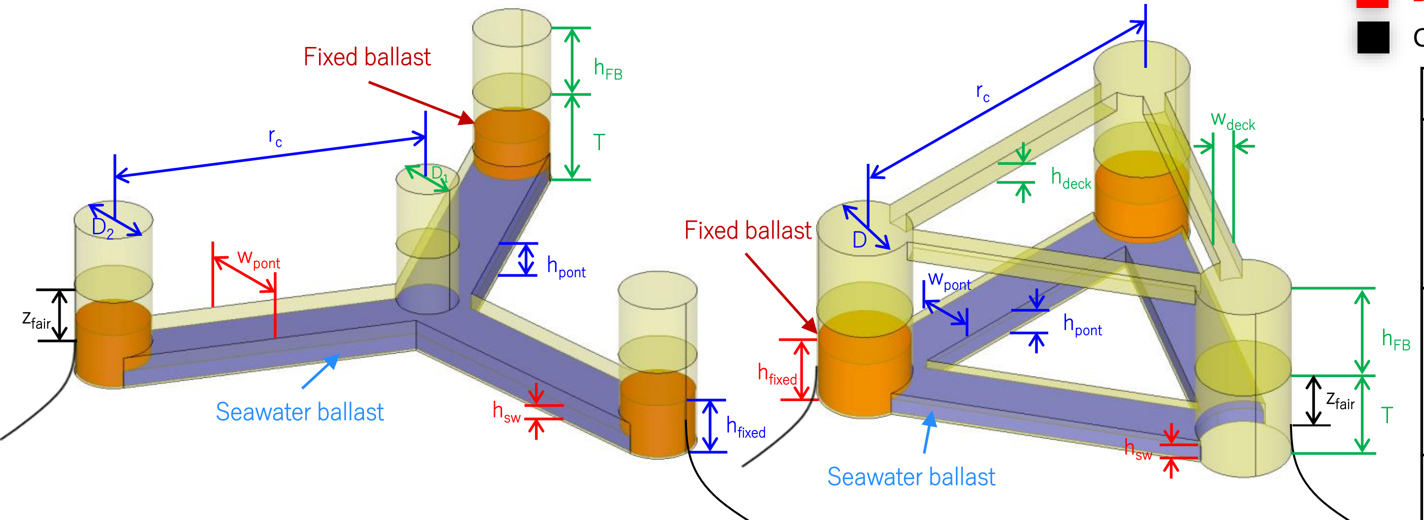
x_1, x_2 : the longitudinal distances of fwd and aft fairleads from geometric center



Parametric analysis setup

Central tower platform

Peripheral tower platform



- Theoretically upscaled (green)
- Variables (blue)
- Derived from variables (red)
- Constant (black)

Design	Constraint
Central	$w_{pont} = D_2$
	h_{fixed} varied by varying fixed to total ballast ratio
Peripheral	$\frac{D}{2} \leq w_{pont} \leq D$
	w_{pont} varied by varying w_{pont}/D
For both designs	$h_{sw} < h_{pont}$
	$h_{fixed} < T$

Assumptions:

- Constant steel thickness across all structural members (back-calculated from UMaine platform as 4.6 cm and upscaled)
- Fixed ballast (ρ = 2650 kg/m3) in side-columns (aft columns for the peripheral design) and seawater ballast in pontoons

Constraints:

- Maximum hull dimension 120 m
- Stiff-stiff tower (on the floater): $T_{towFA1} < 60/3P$
- Natural periods for rigid body motions larger than 20 s
- Mean pitch at rated wind speed below 30°

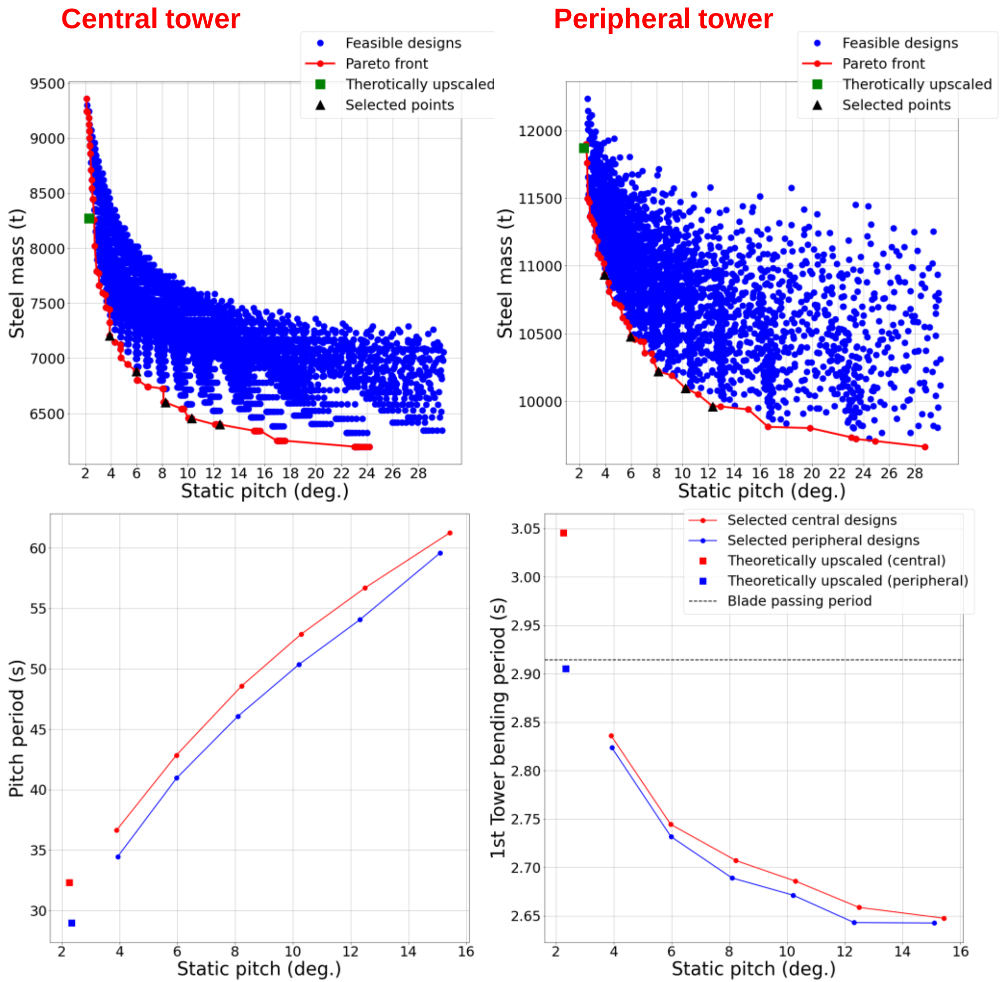
Design space exploration

- **Objective:** Find feasible designs with minimum steel mass at various max. allowable static pitch angles

- Theoretically upscaled designs
  - have over-conservative static pitch angle
  - may violate the stiff-stiff tower requirement

- A small increase in the max. static pitch angle results in:
  - Significant decrease in steel mass
  - Stiffer tower

- 6 design points for each concept at different static pitch angles were selected for coupled simulations along with the upscaled designs



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Simplified model verification

- Decay tests for the selected designs performed using OpenFAST
- Good agreement with the simplified model
- Discrepancies may be a result of the following:
  - Accuracy of added mass estimation
  - Using a linear mooring stiffness matrix in the simplified model
- More results from the coupled analyses for the turbine's performance in different environmental states will be available in the full publication