Rational upscaling of a semi-submersible floating platform

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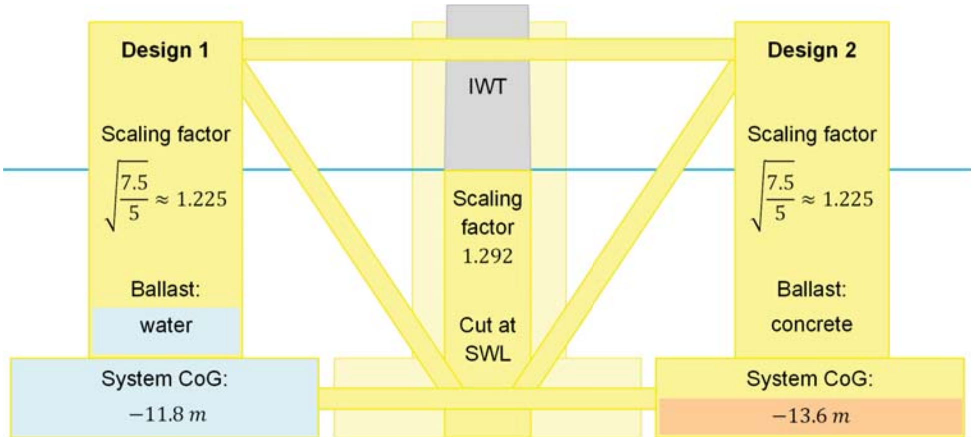
Abstract: Technological progress, design changes and additional factors that floating structures have to deal with - like large motions and motion coupling, low frequency modes, radiation and diffraction, mooring system and damping interaction - make basic scaling based on the turbine rating insufficient. Thus, the objective of this work is to develop a rational upscaling process for a semi-submersible structure in order to find a reasonable design of a platform, which would fit a predefined wind turbine, is producible, and represents realistic dynamic behavior.

Methodology

Original design	→	Upscaled design
NREL 5MW	→	Fraunhofer IWT-7.5-164
DeepCwind semi-submersible	→	Rational upscaled semi-submersible



Upscaling procedure and main criteria:

- Main scaling based on power rating
- Main column has to fit tower base
- Unchanged hub height
- Ballasting with main focus on floatability and stability
- Unchanged water depth
- Unchanged mooring parameters

Platform performance analysis:

- Based on hand and HydroD computations
- Focus on stability limit in pitch, natural periods in heave and pitch, nominal pitch at rated power, frequency-dependent hydrodynamic behavior

Results

- **Design 1:** less stiff
  → higher pitch natural period
- **Design 2:** stiffer
  → higher stability
  → less nominal pitch

	Design 1	Design 2	Upscaled
$T_{\mathrm{n,heave}}$	$19.12\ s$	$19.12\ s$	$21.12\ s$
$T_{\mathrm{n,pitch}}$	$42.20\ s$	$38.71\ s$	$33.11\ s$
$\theta_{nominal}$	$3.67°$	$3.03°$	$2.31°$

Added mass limits:

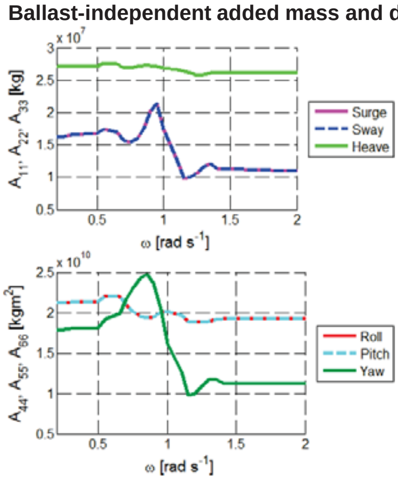
- Equation-based approximation [1,2] gives poor results

$$\widetilde{A_{33}} = \frac{\rho}{3} D_d^3 - \left[\frac{\pi\rho}{8} D_c^2 \left(D_d - \sqrt{D_d^2 - D_c^2}\right) + \frac{\pi\rho}{24}\left(D_d - \sqrt{D_d^2 - D_c^2}\right)^2 \left(2D_d - \sqrt{D_d^2 - D_c^2}\right)\right]$$

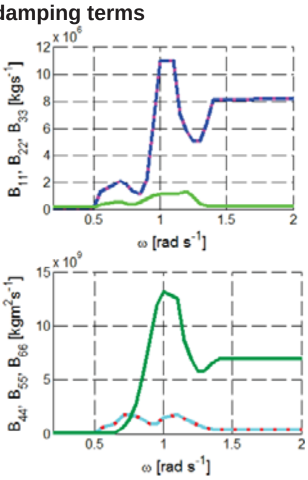
$$\widetilde{A_{55}} = C_a \rho \pi r^2 \left[\frac{(d-h)^3}{3} + \overline{KG}^2 (d-h) + \overline{KG}(d-h)^2\right]$$

- Better approximation by upscaling of original added mass matrix with main scaling factor (1.225^3 for heave, 1.225^5 for pitch)

Ballast-independent added mass and damping terms



Diagonal added mass matrix terms

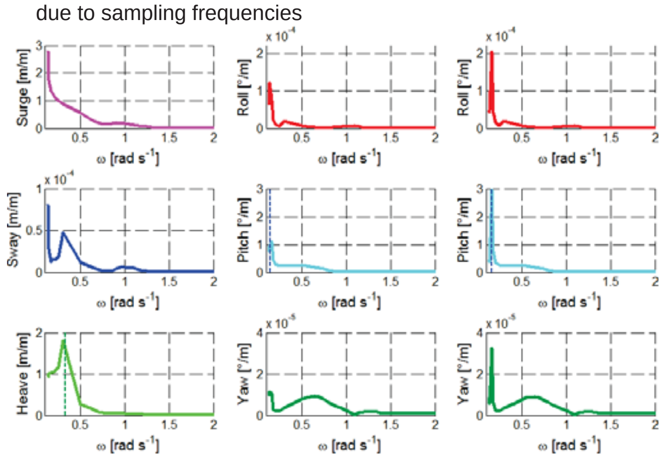


Diagonal damping matrix terms

References:
[1] L. Tao, S. Cai. Heave motion suppression of a Spar with a heave plate. Ocean Engineering, 31:669-692, 2004.
[2] P. Ghadimi, H.P. Bandari, A.B. Rostami. Determination of the Heave and Pitch Motions of a Floating Cylinder by Analytical Solution of its Diffraction Problem and Examination of the Effects of Geometric Parameters on its Dynamics in Regular Waves. International Journal of Applied Mathematical Research, 1(4):611-633, 2012.

Response amplitude operators:

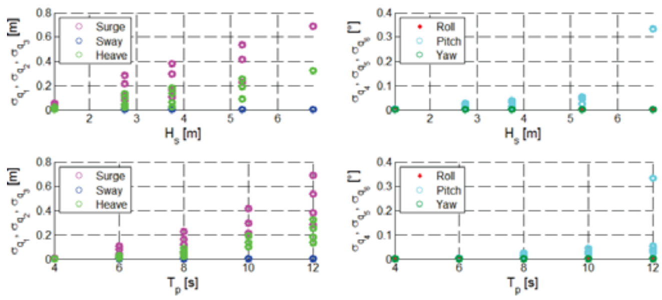
- Main response in surge, heave and pitch (without mooring)
- Design 1 and 2 show different peaks in RAOs for rotational DoFs due to sampling frequencies



RAOs in translational DoFs Design 1 and 2 | RAOs in rotational DoFs Design 1 | RAOs in rotational DoFs Design 2

Standard deviations:

- Based on FD-analysis of 15 representative sea states
- Similar for both designs
- Main dynamic response in surge, heave and pitch
- Increasing dynamic response with more severe sea states
- Dynamic pitch motion up to 10% of nominal mean displacement



Outlook

- Detailed stability analysis needed, for example in Modelica
- Higher natural periods by allowing different geometrical upscaling (e.g. smaller upper column diameter, larger base column diameter)
- Optimized balance between stability and natural frequencies by adjustment of ballasting
- Inclusion of mooring system stiffness and mooring line tension