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Wave Cancelling Semi-Submersible Design for Floating Offshore Wind Turbines

Frank Lemmer, Wei Yu, Kolja Müller, Po Wen Cheng

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EERA Deepwind 2019, Trondheim, Norway

SWE

WindForS
Windenergie
Forschungscluster

Motivation

Proceedings of the ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering
OMAE 2016
June 19-24, 2016, Busan, Korea

OMAE2016-54536

WIND TURBINE CONTROLLER TO MITIGATE STRUCTURAL LOADS ON A FLOATING WIND TURBINE PLATFORM

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The Science of Making Torque from Wind (TORQUE 2016) IOP Publishing
Journal of Physics: Conference Series **753** (2016) 092006 doi:10.1088/1742-6596/753/9/092006

Control design methods for floating wind turbines for optimal disturbance rejection

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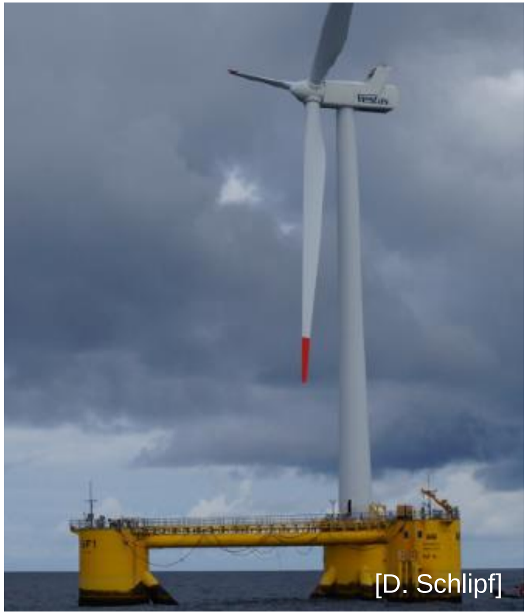
Papers of OMAE2016 and TORQUE2016 have shown:

- Wave loads are stronger than wind loads
- Wind turbine controller cannot cancel wave loads
- Wave loads are responsible for large portion of structural fatigue of platform/tower

- ➢ How to design substructures which are
  - ➢ of sustainable lightweight structures
  - ➢ „grown into their ocean environment“
  - ➢ less excited by environmental loads

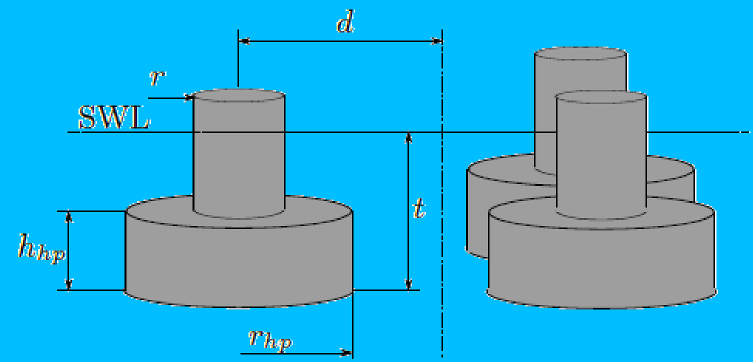


[D. Schlipf]

What we have done…

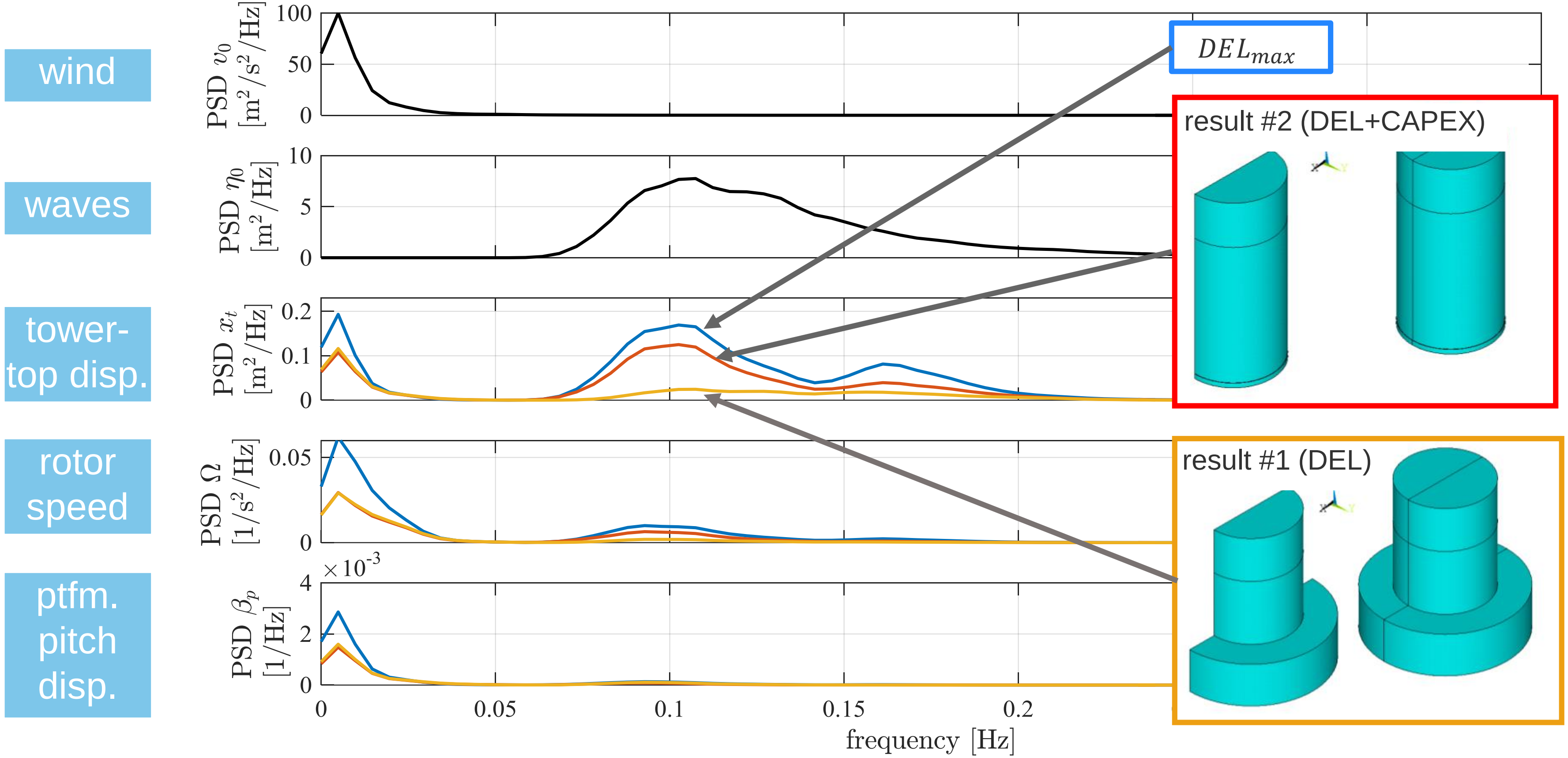
Parametric study of 3-column semi-submersibles in LIFES50+

- variable column spacing
- variable column diameter
- variable heave plate height



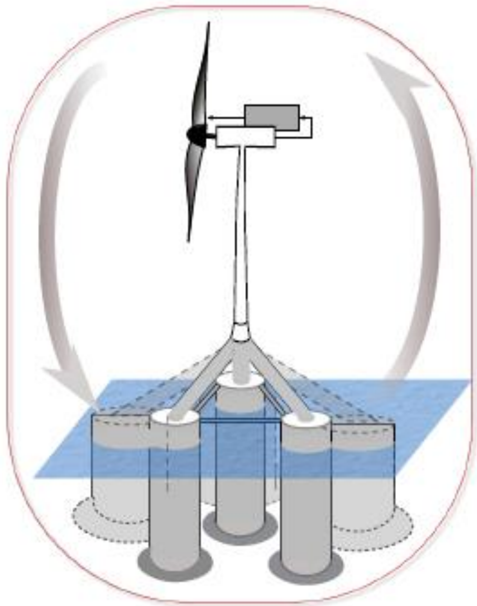
Lemmer, F., Müller, K., Yu, W., Faerron-Guzmán, R., & Kretschmer, M. (2016). LIFES50+ D4.3: Optimization framework and methodology for optimized floater design.

Past study



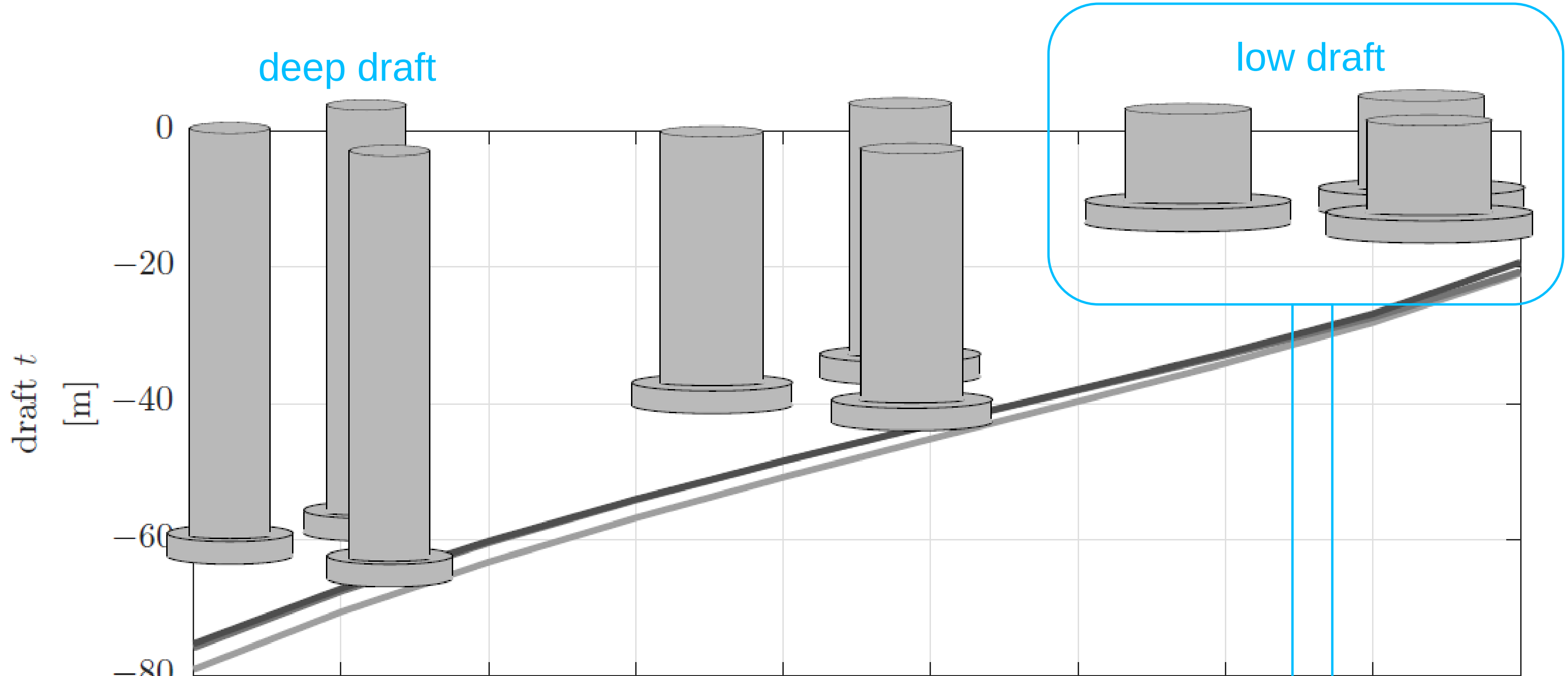
➢ Existing characteristic of wave cancellation at ~0.1Hz!

Present study



- Automated preprocessing of panel code coefficients
- Parametric low-order model (SLOW)
- Automatically adjusted controller
- KC-dependent heave-plate drag http://dx.doi.org/10.3390/jmse6040118

Present study

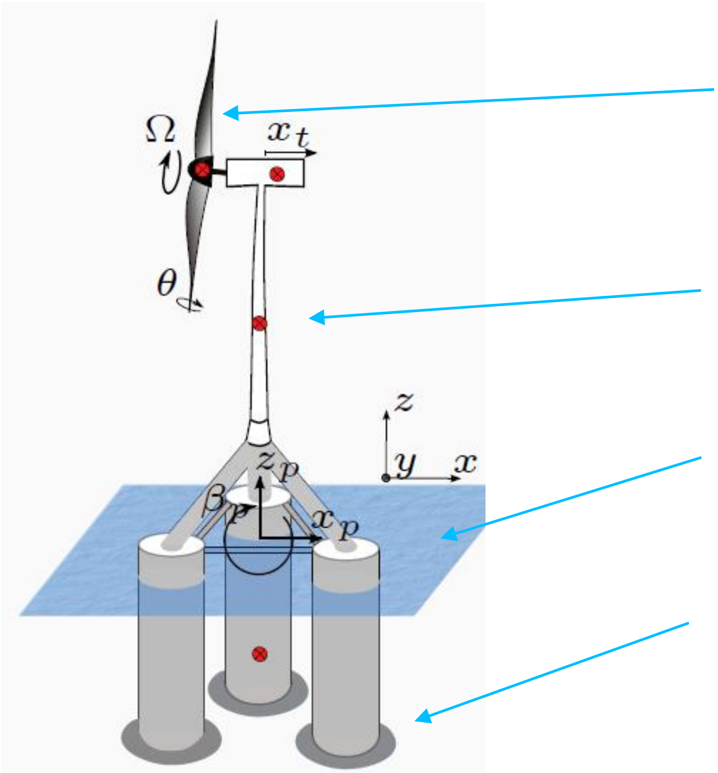


- >30% smaller tower-base bending damage than deep draft
- Electrical power shows no response to 1st order waves

Why do we end up with the low draft configuration?

Linear system analysis

SLOW – Simplified Low-Order Wind turbine model

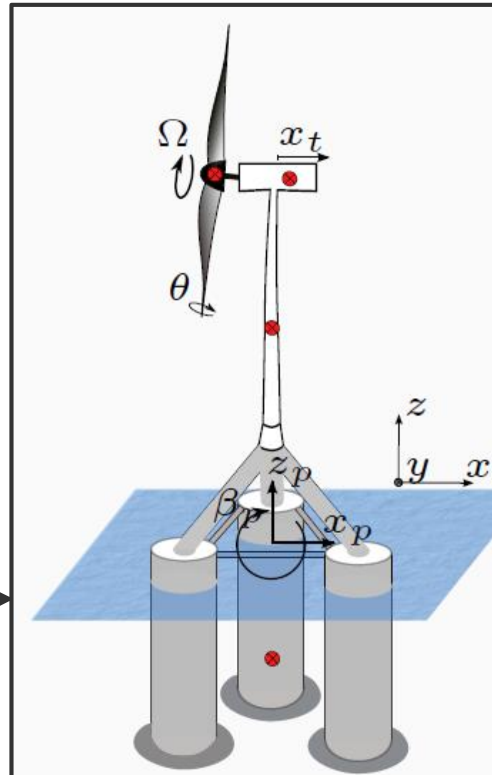


- Linearized aerodynamics, including controller
- Multibody dynamics, including elastic tower
- Linear potential flow hydrodynamics
- Linearized Morison drag (Borgman) with parametric heave plate drag
- 2D motion

Linear system analysis

RAO using SLOW

Unit wave ζ:



Platform displacements

Tower bending

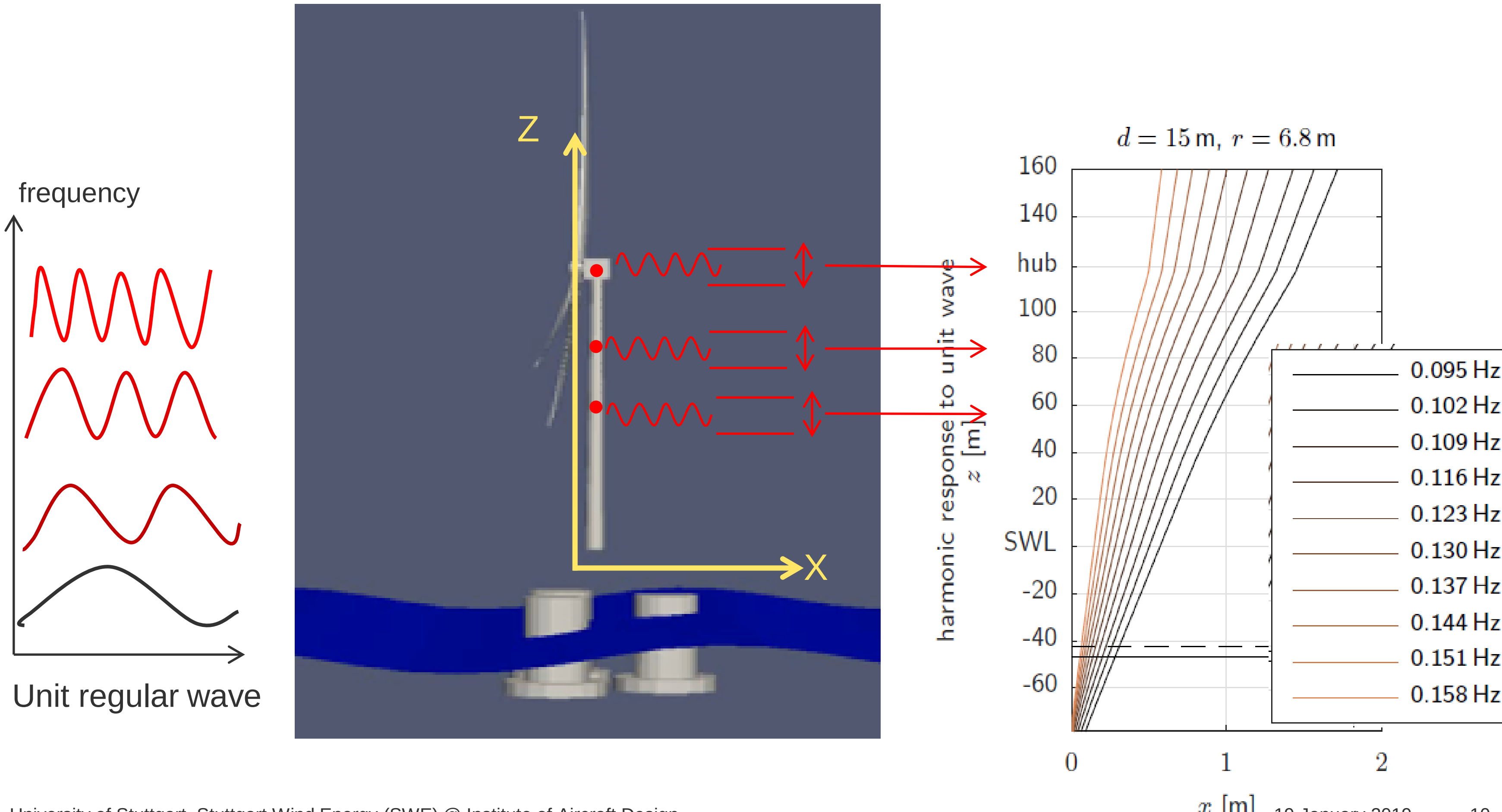
Rotor speed, power

Blade pitch angle

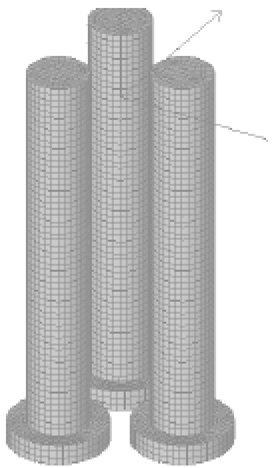
Mooring tensions

etc.

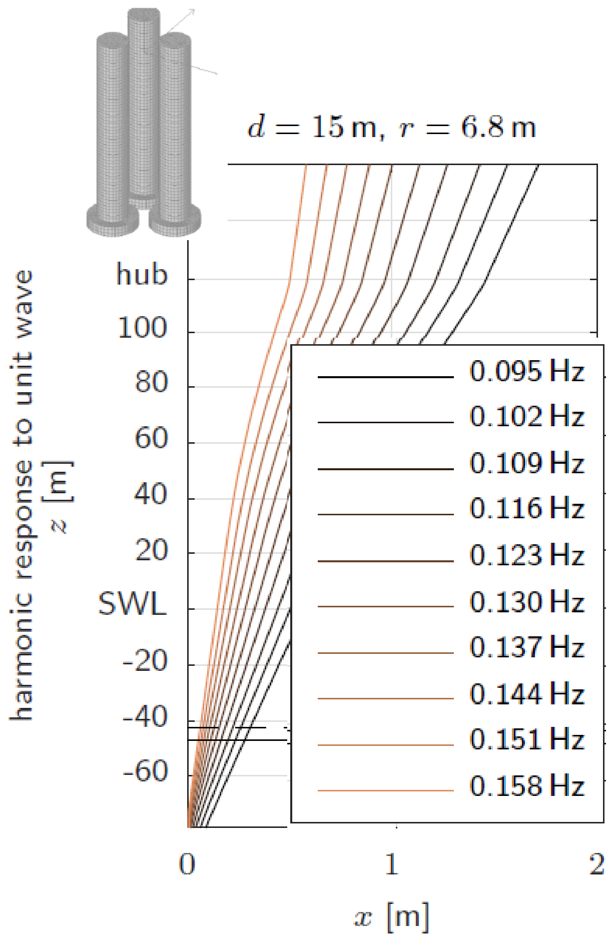
Harmonic Response to Wave

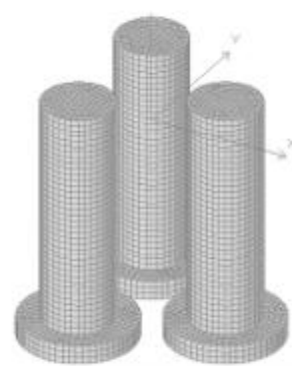


Harmonic Response to Wave

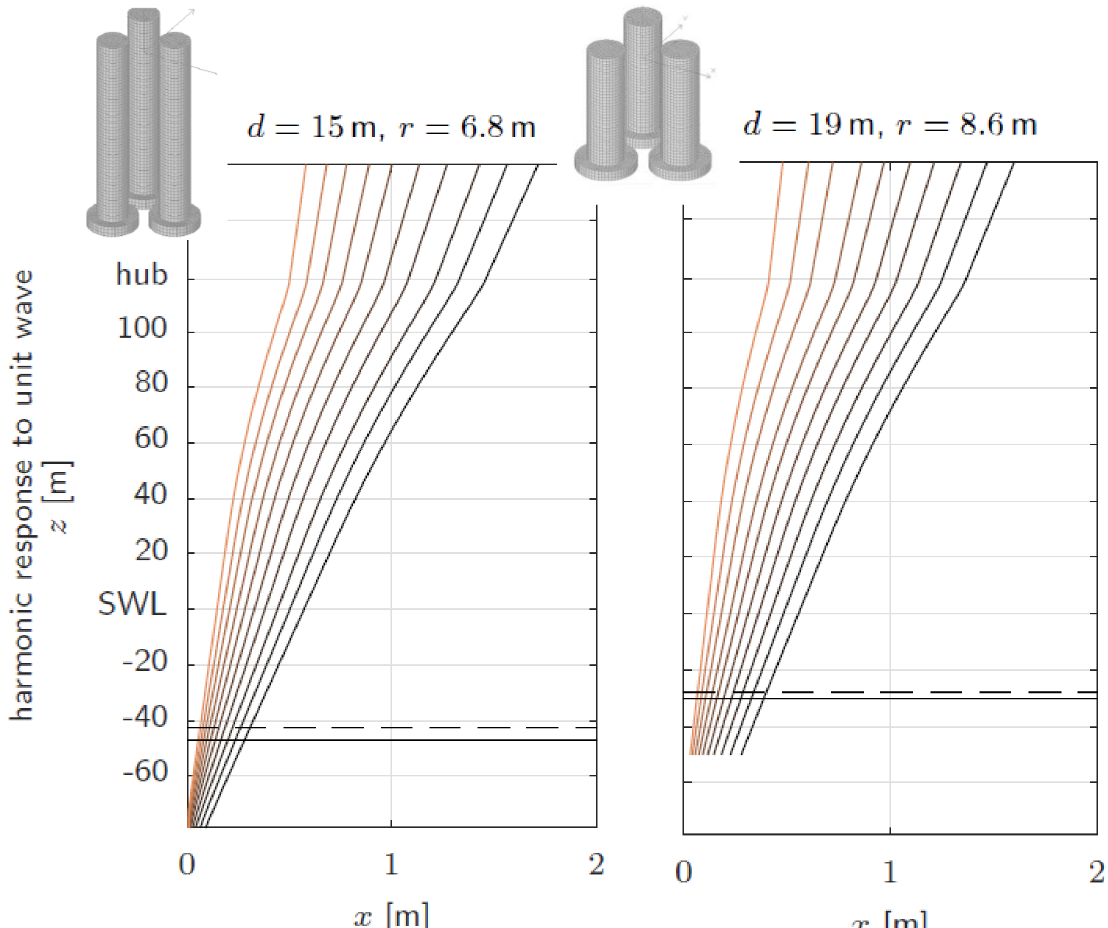


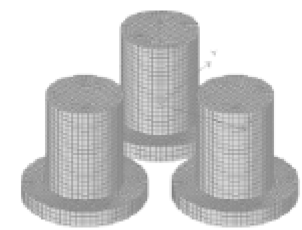
Harmonic Response to Wave



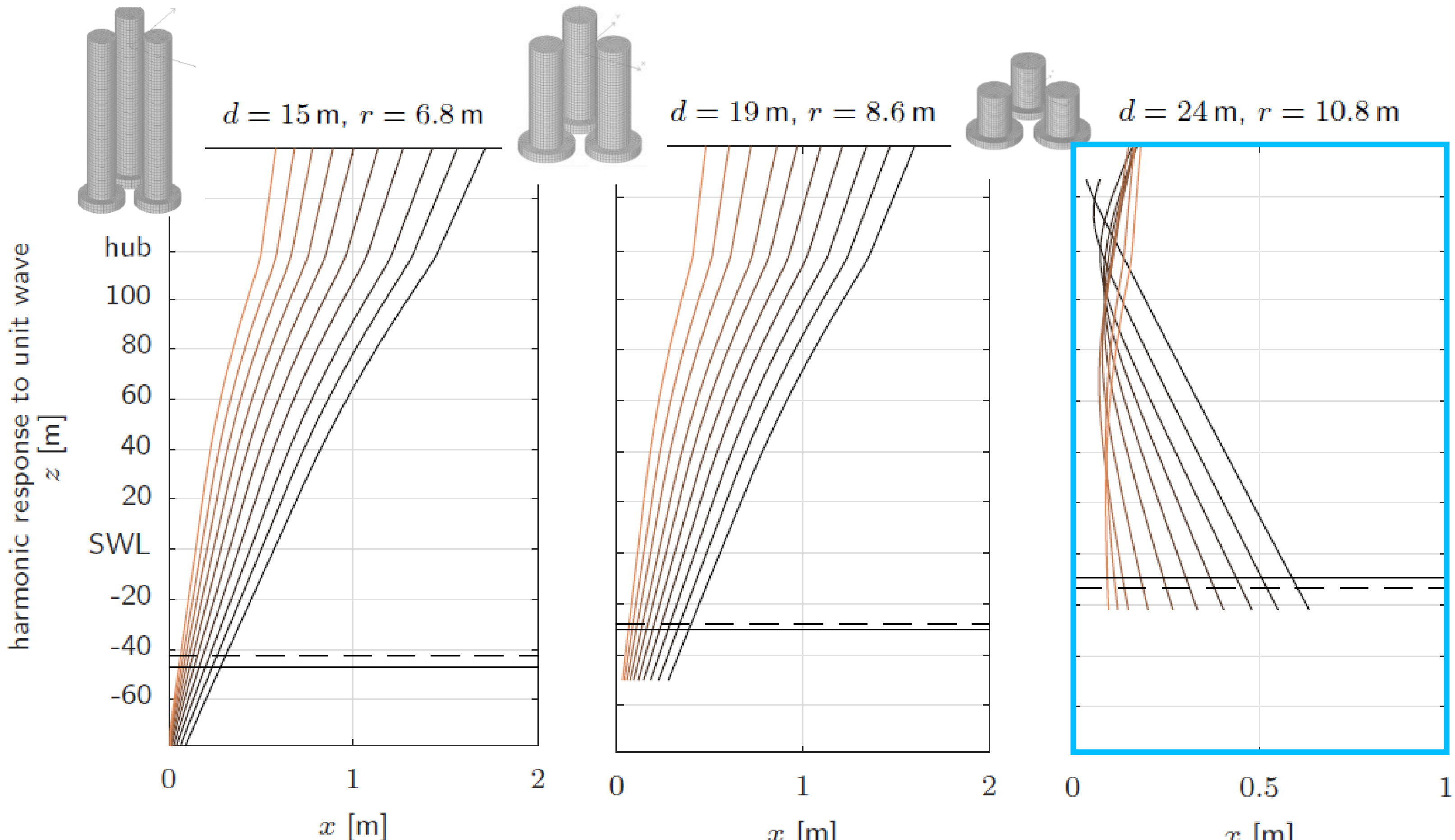


Harmonic Response to Wave



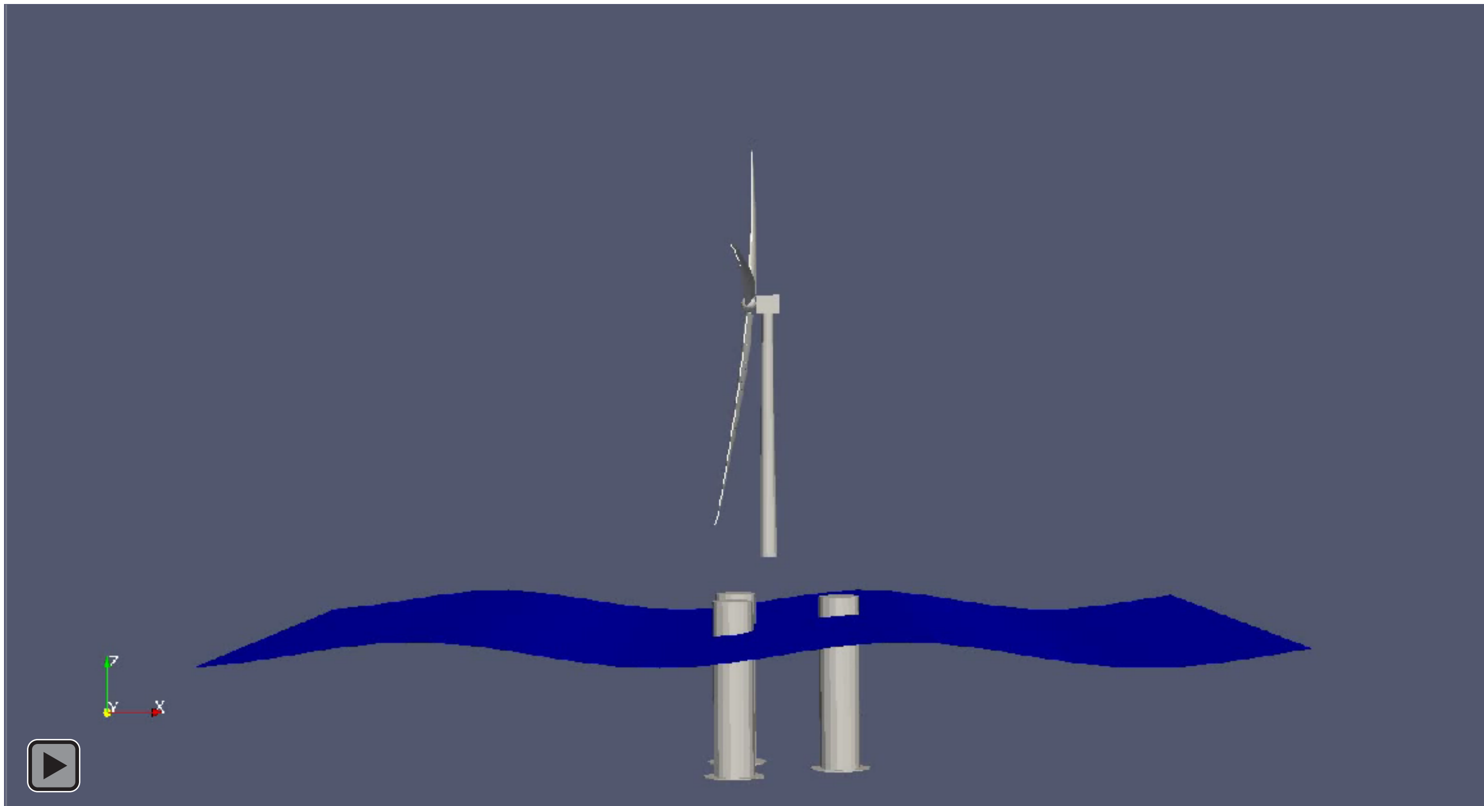


Harmonic Response to Wave



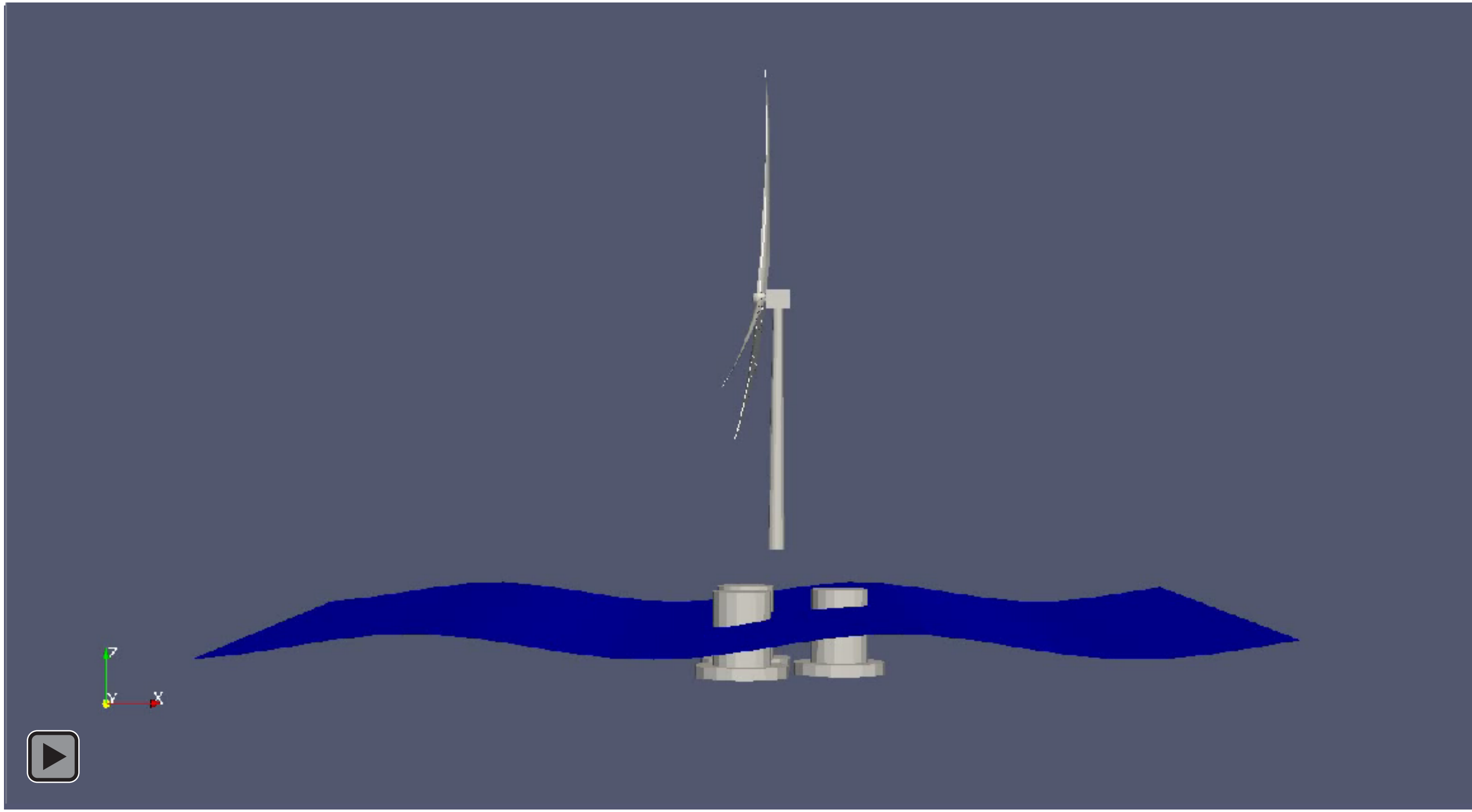
Response to regular waves

Reference design: TripleSpar



Response to regular waves

Optimal design: column spacing 24m, column diameter 21.6m

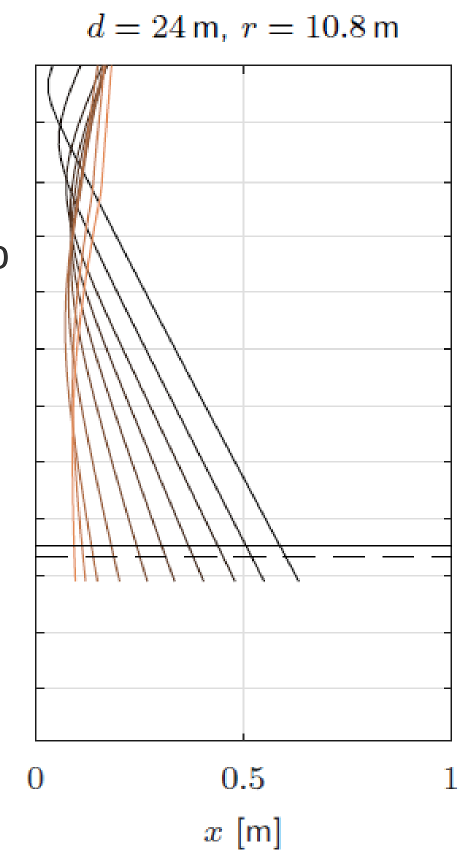


Counter-Phase Pitch Response

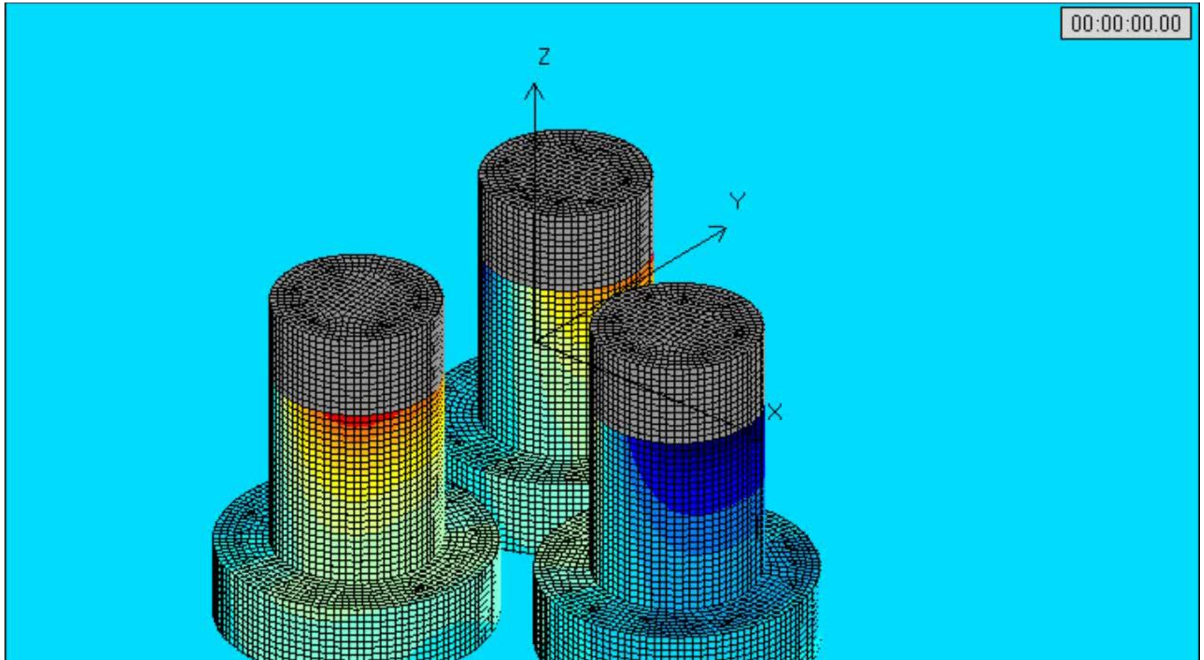
is caused by a favorable design for a given range of peak spectral frequencies

- Platform pitches negatively (into the wind) when surge-velocity is positive
- Turbine pitching about instantaneous center of rotation close to the hub

> ➢ Nacelle does not oscillate in fore-aft direction due to wave loads
> ➢ Waves have almost no effect on power production
> ➢ Tower-base fatigue is reduced by 30%, compared to TripleSpar, slightly larger than for onshore turbines



Counter-Phase Pitch Response



- Spatial magnitude phase distribution of mainly FK-forces yield the desired behavior for given frequencies and system dynamic properties
- Integrated Froude-Krylov+diffraction forces and phases are tailored for the system properties to yield the desired forced-response behavior

Counter-Phase Pitch Response

- Behavior used to be known for TLPs:

Proceedings of the ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering
OMAE2016
June 19-24, 2016, Busan, South Korea

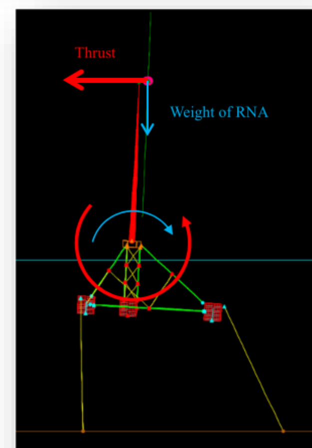
OMAE2016-54961

A NOVEL TENSION-LEG APPLICATION FOR FLOATING OFFSHORE WIND: TARGETING LOWER NACELLE MOTIONS

Cécile Melis
François Caille
SBM Offshore
Monaco, Monaco

Timothée Perdrizet
Yann Poirette
Pauline Bozonnet
IFP Energies Nouvelles
Solaize, France

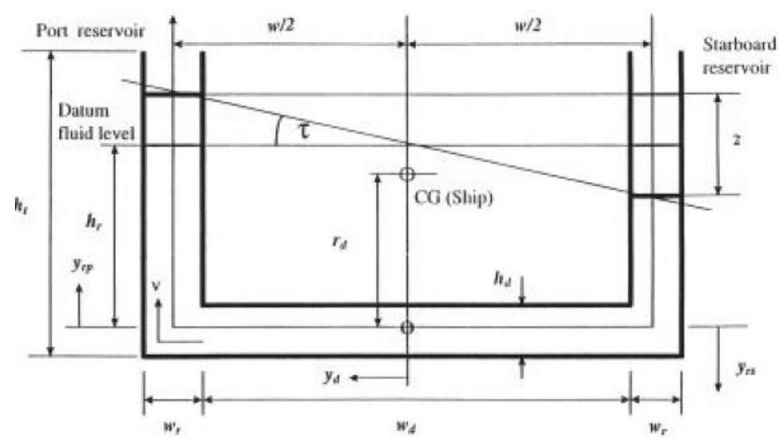
- TLP tendon kinematics impose center of rotation



➢Here, the same effect is shown for semi-subs with catenary mooring lines

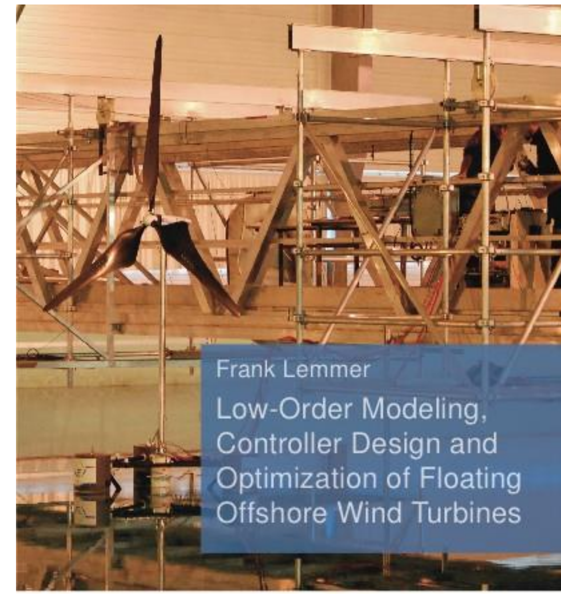
Conclusions

- Although controller cannot mitigate large wave loads, a good design can cancel the wave forces, giving a favorable response behavior
- A good hull shape, combined with a favorable controller, offers the possibility for new, lightweight platforms, which experience little fatigue and extreme loads using less material
- Further measures can improve the global response:
  - Tuned liquid column dampers (see Yu, OMAE2019)
  - Multivariable control (Lemmer, TORQUE2016)
  - Lidar-assisted control (Schlipf, ISOPE2013)



More details…

- Lemmer, F. (2018). *Low-Order Modeling, Controller Design and Optimization of Floating Offshore Wind Turbines*. University of Stuttgart.
  ISBN: 978-3-8439-3863-1
- Lemmer, F., Müller, K., Yu, W., & Cheng, P. W. (2019). Semi-submersible wind turbine hull shape design for a favorable system response behavior (submitted, revised version under preparation). *Marine Structures*.



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Thank you!

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