Design Challenges and novel Solution for Tower Designs of next generation Floating Wind Turbines

Espen Engebretsen, Anastasios Stampoultzoglou, Eystein Borgen, Sebastian Schafhirt

odfjell oceanwind

DeepWind conference, 19 January 2023, Trondheim

SIEMENS Gamesa RENEWABLE ENERGY

Fatigue loads on Floating Wind Turbines

- Fatigue loading at tower bottom is significantly higher compared to a bottom-fixed structure (assuming the same turbine size)
- Fatigue loads are driven by wind, waves, and the resonance due to the excitation of the blade passing frequency (3p)
- Wave-induced fatigue is determined by the design of the floating sub-structure (e.g. size of underwater structure)
- Fatigue loads due to excitation of 3p depend on the separation between the first global tower bending frequency and the rotor velocity (rpm) of the turbine

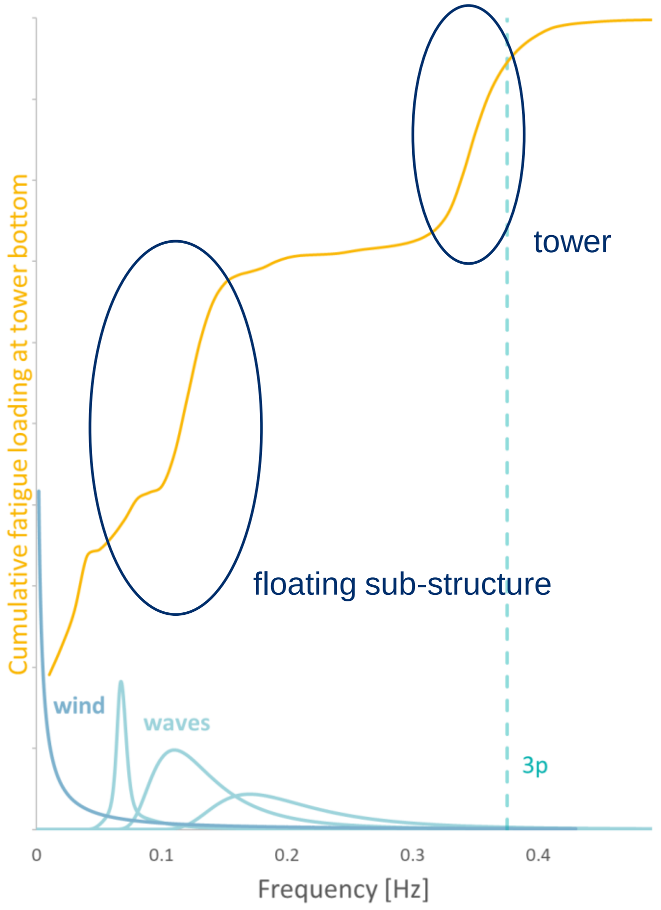


Figure 1: Frequency-dependent fatigue accumulation for a typical FWT

Design options for the global tower bending frequency of a FWT

- Soft-stiff design: the first tower bending frequency is placed between the 1p and 3p rotor harmonics
- Stiff-stiff design: the first tower frequency is placed above 3p

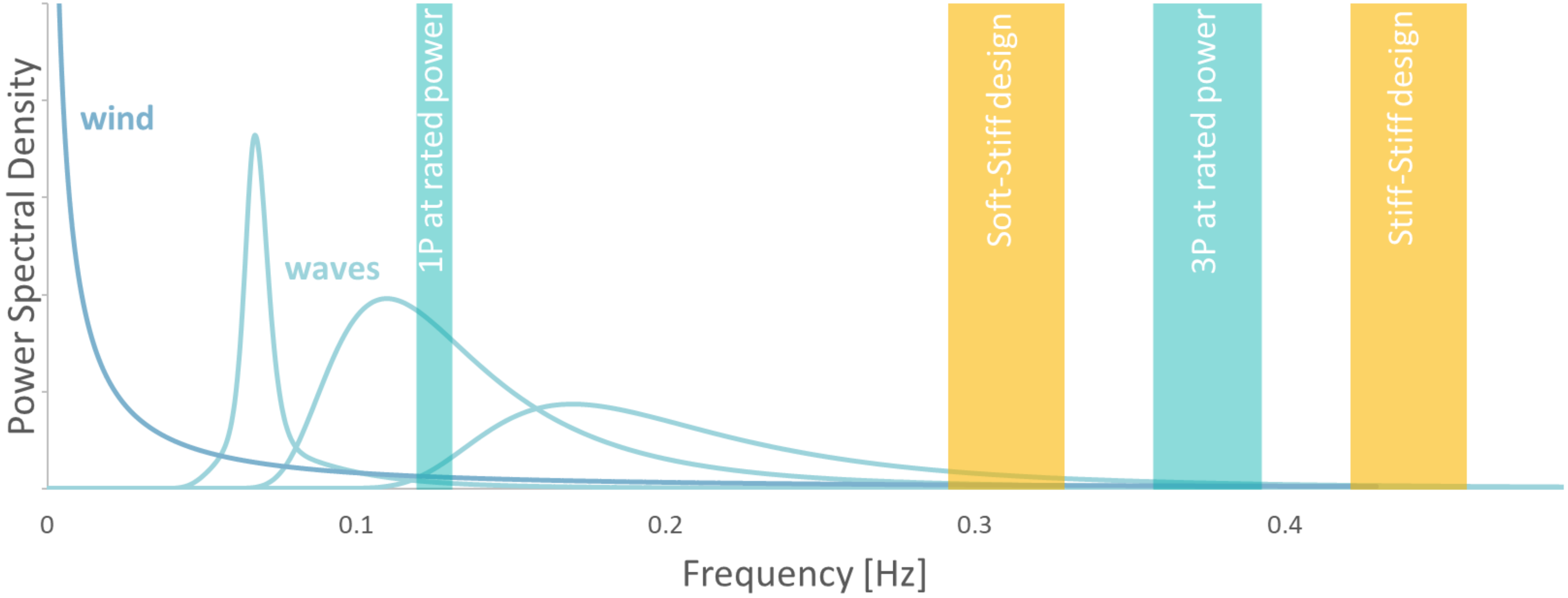


Figure 2: Typical structural and environmental frequency ranges for a state-of-the-art offshore wind turbine

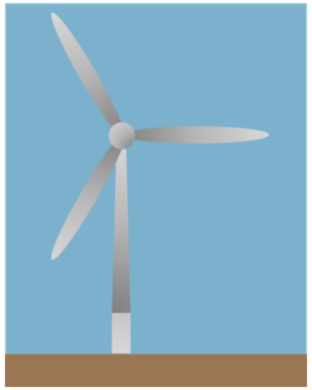
odfjell oceanwind

SIEMENS Gamesa RENEWABLE ENERGY

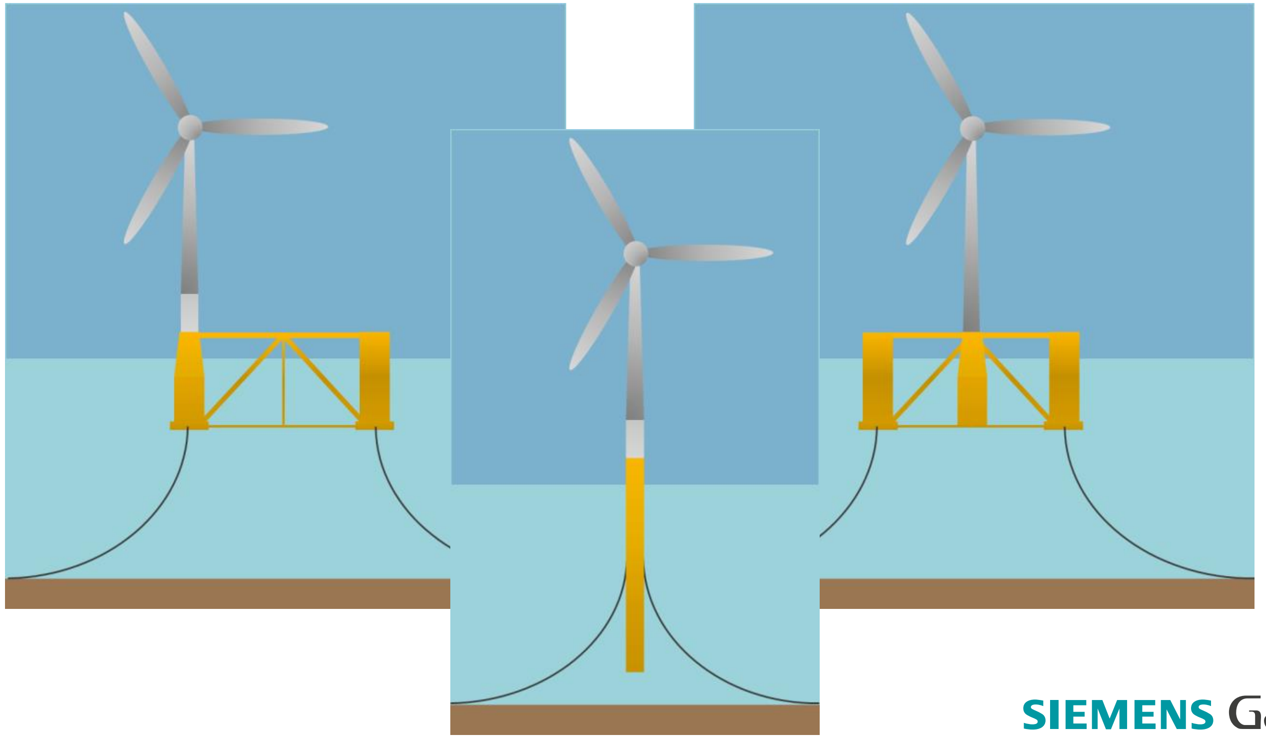
Impact of floating sub-structure design on global tower bending frequency

- The global tower bending frequency increases (compared to a tower clamped at bottom) when mounted on a semi-submersible or spar-type floater [1]

- The increase depends on the type and design of the floating sub-structure



Tower bending frequency increases typically around 25% to 40%



odfjell oceanwind

SIEMENS Gamesa RENEWABLE ENERGY

Design objective and constraints

Objective

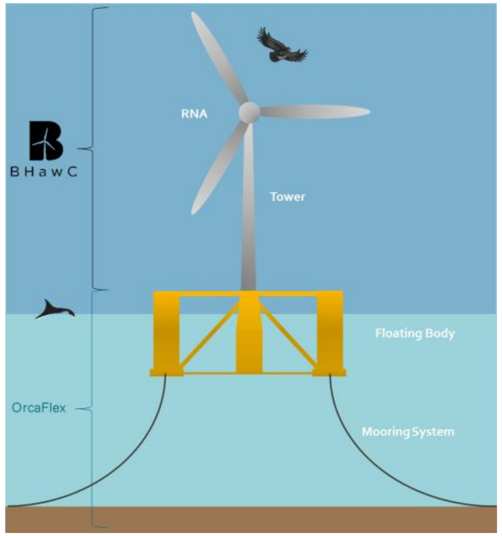
Reduce LCOE for floating wind turbine

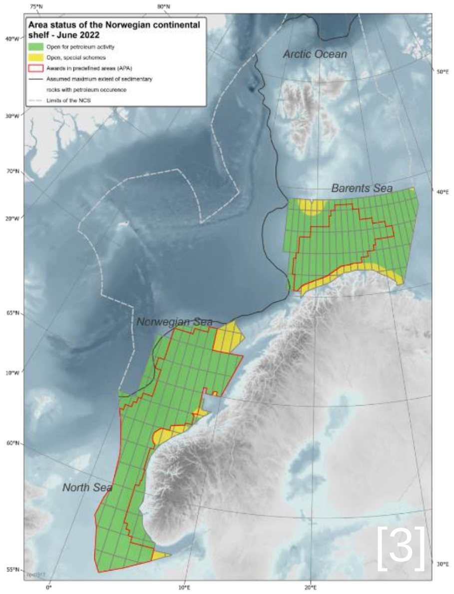
Constraints

- Keep standard tower bottom diameter (it is not just a shell)
- 1st global tower bending mode below 3p
- Feasible design for a lifetime of 25 years

Floating Wind Turbine model

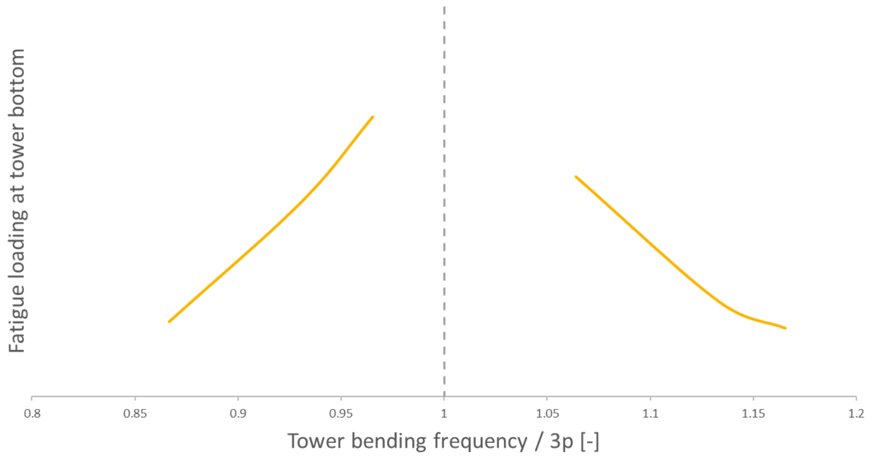
- Turbine: 15MW with 236m rotor diameter
- Tower design with bottom diameter of 8m
- Floating sub-structure: semi-submersible with turbine on center column
- Turbine and tower modelled in BHawC (SGRE's inhouse aeroelastic solver)
- Floating sub-structure (rigid body) and mooring lines modelled in OrcaFlex
- BHawC and OrcaFlex are coupled via BHawCLink [2]
- FLS assessment based on 7000 simulations (DLC12 + DLC64), representative for a lifetime of 25 years in harsh environment (NCS)

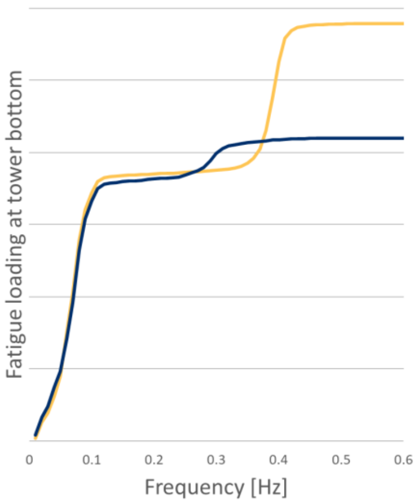


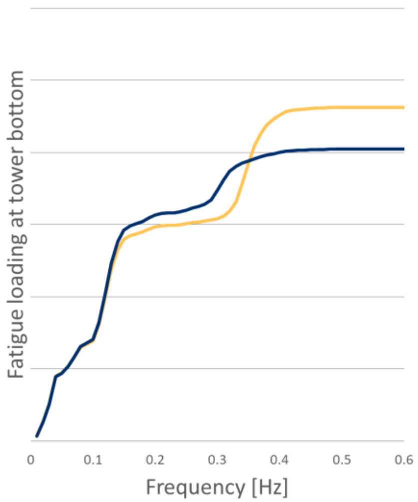


Design choices and their impact on tower bottom fatigue loading

- Fatigue increases for tower designs close to 3p
- Fatigue accumulated in the wave-frequency range is quite independent of the tower design
- A floating sub-structure not fully optimized for wave-loading might lead to significant reduction in the first tower bending frequencies







Design challenge

- High fatigue capacity at tower bottom

-> larger tower bottom wall thickness

-> higher tower bending frequency

-> increase in rotor-induced fatigue loads due to 3p ressonance

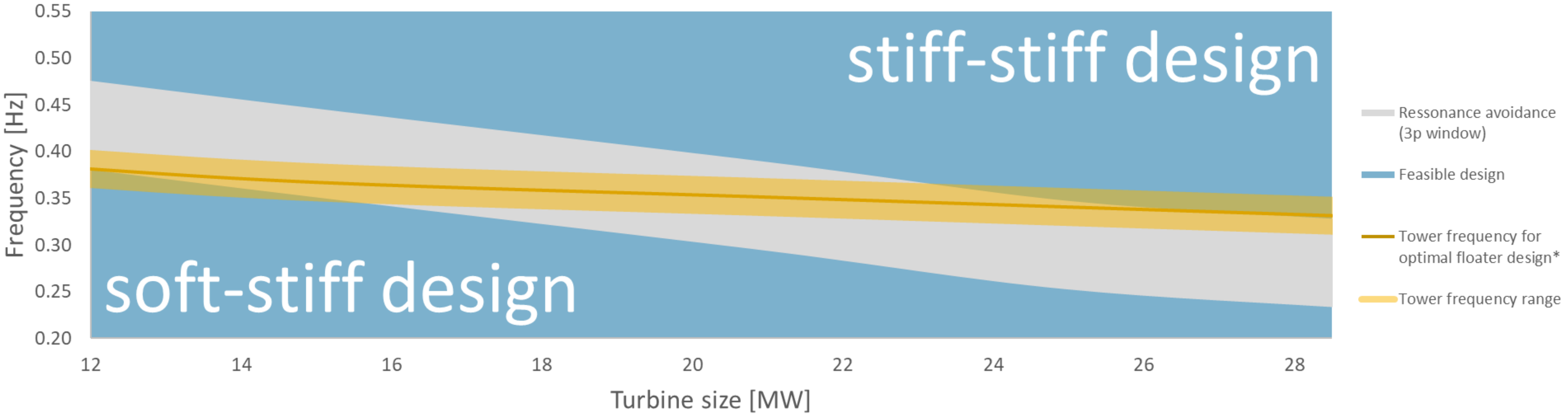
- Reduce wave-induced fatigue loading / floating sub-structure optimized for reduced hydrodynamic loading

-> higher relative increase of tower bending frequency

-> increase in fatigue loads due to 3p ressonance

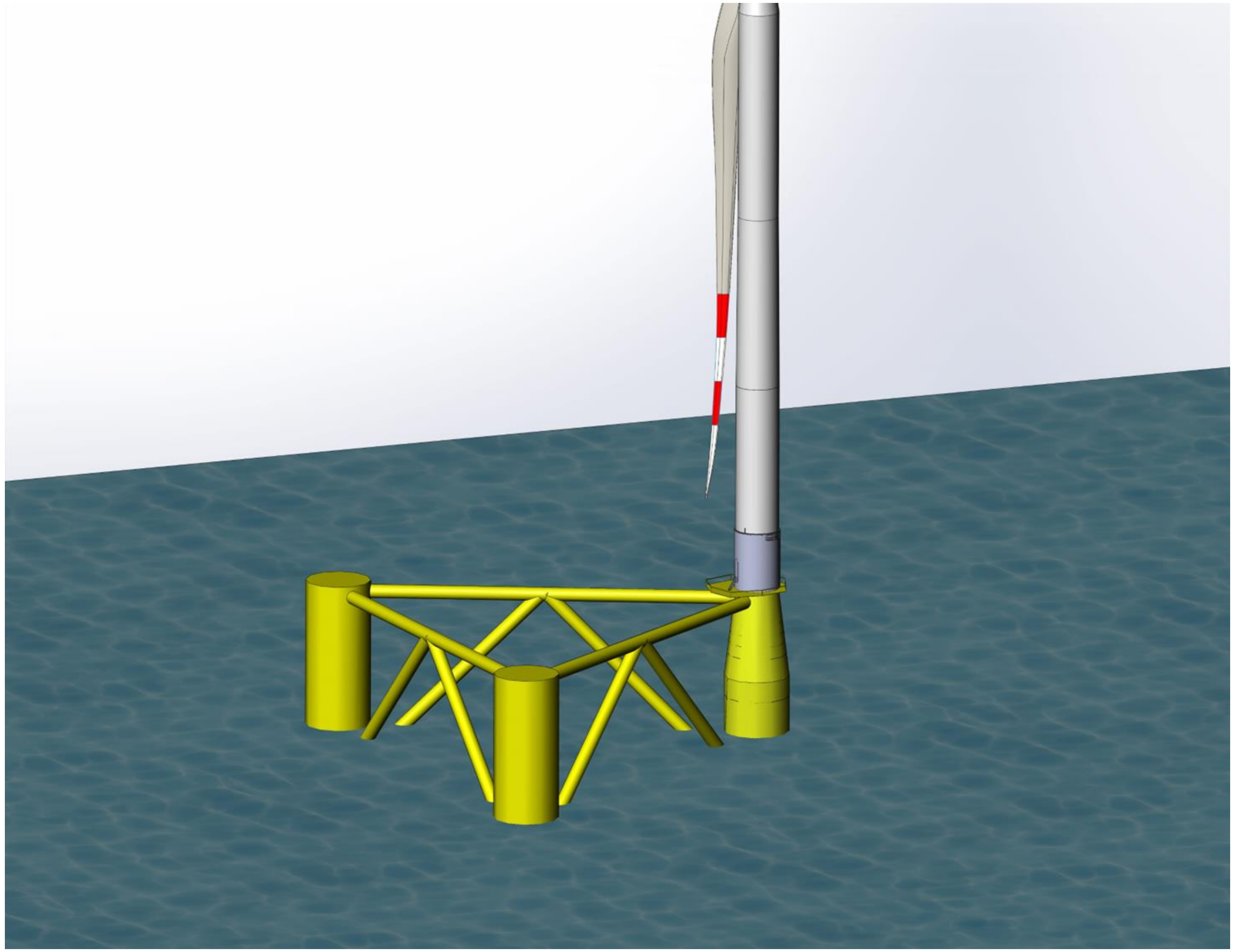
Next Generation of Floating Wind Turbines

- Increase in rotor size leads to a lower generator speed (rated rpm)
- The frequency range for the first tower bending mode (considering an optimized floater design) stays fairly constant
- For Turbine sizes between 16MW to 23MW it becomes particularly difficult to separate the tower bending from the blade passing frequency (3p)



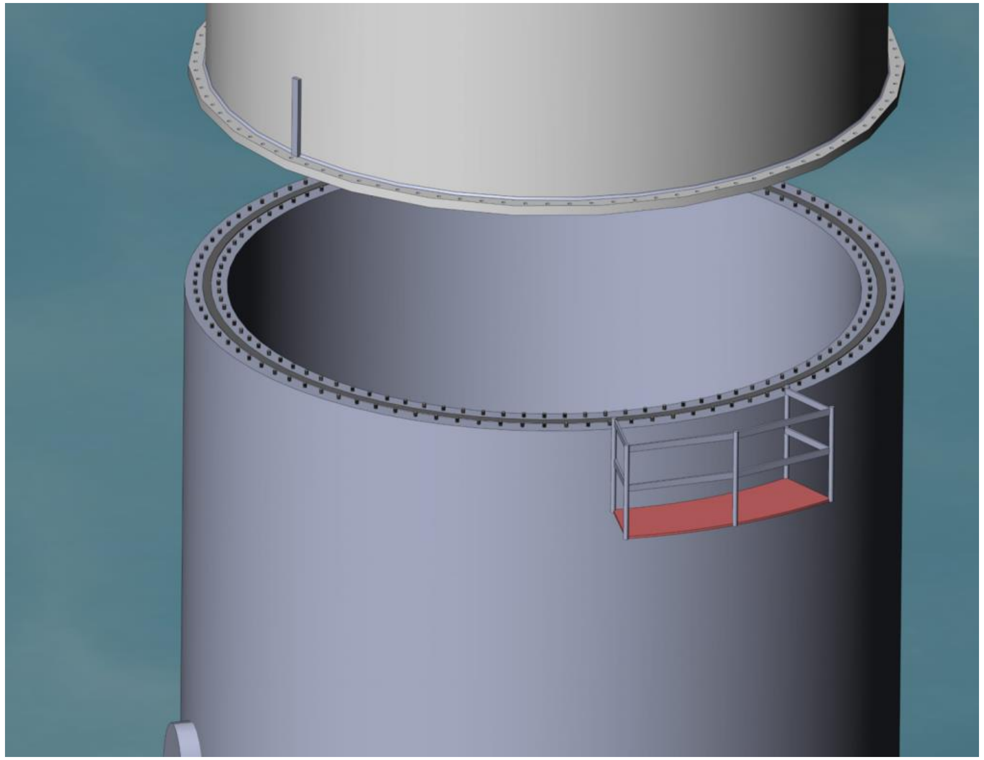
*tower frequency for optimal floater design when disregrading 3p window/exclusion zone

OOW's HybridTower solution incorporates a flexible glass fiber section in the lower part of the steel tower or in the hull structure

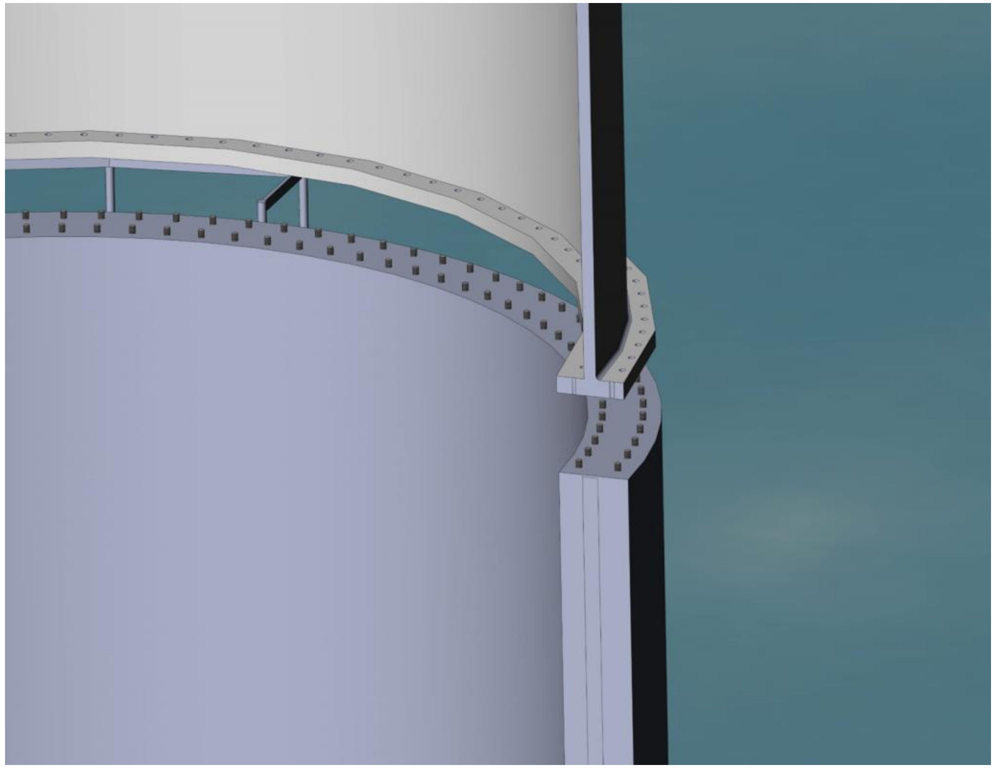


- Lower the tower bending frequency, thereby avoiding the 3P frequency and lowering tower fatigue loads
- The composite material high ULS and FLS strength will not compromise structural integrity
- Lighter weight and similar unit costs to steel section, for equal strength
- Resistant to offshore environment
- If positioned in the tower door opening zone (as shown here) the challenging large wall thickness steel in this area is avoided
- Virtually any floating substructure can be designed without the tower bending frequency as a constraint

Glass fiber section (proposed design)

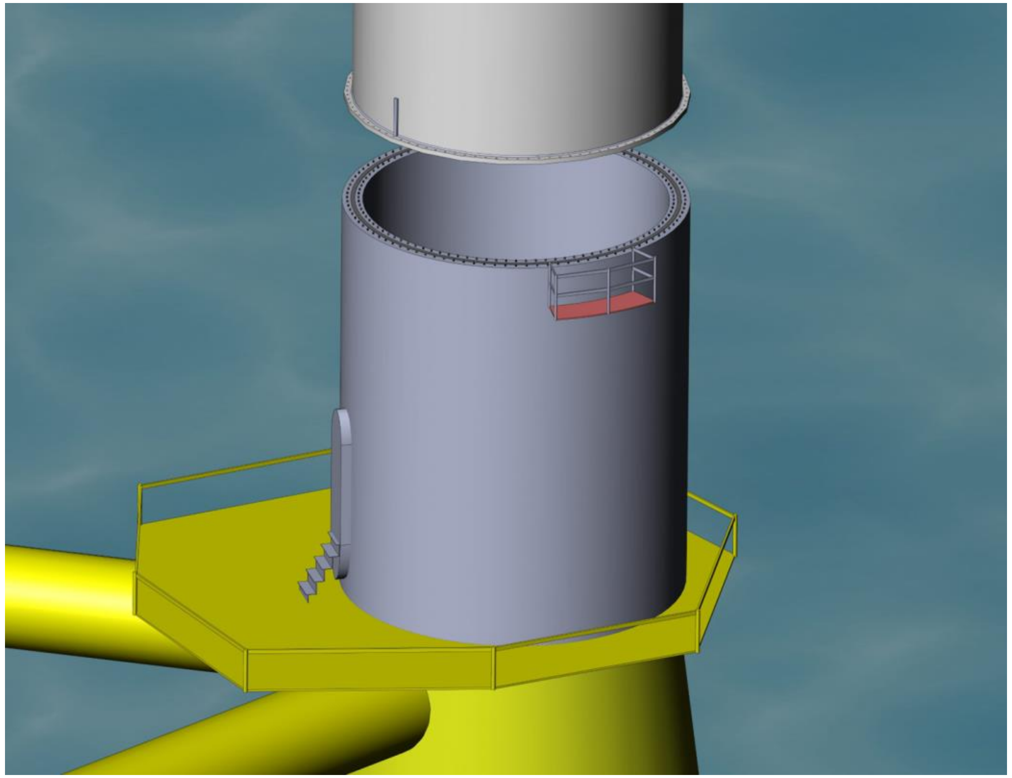


Similar known design principles and connection method as for a rotor blade-to-hub design

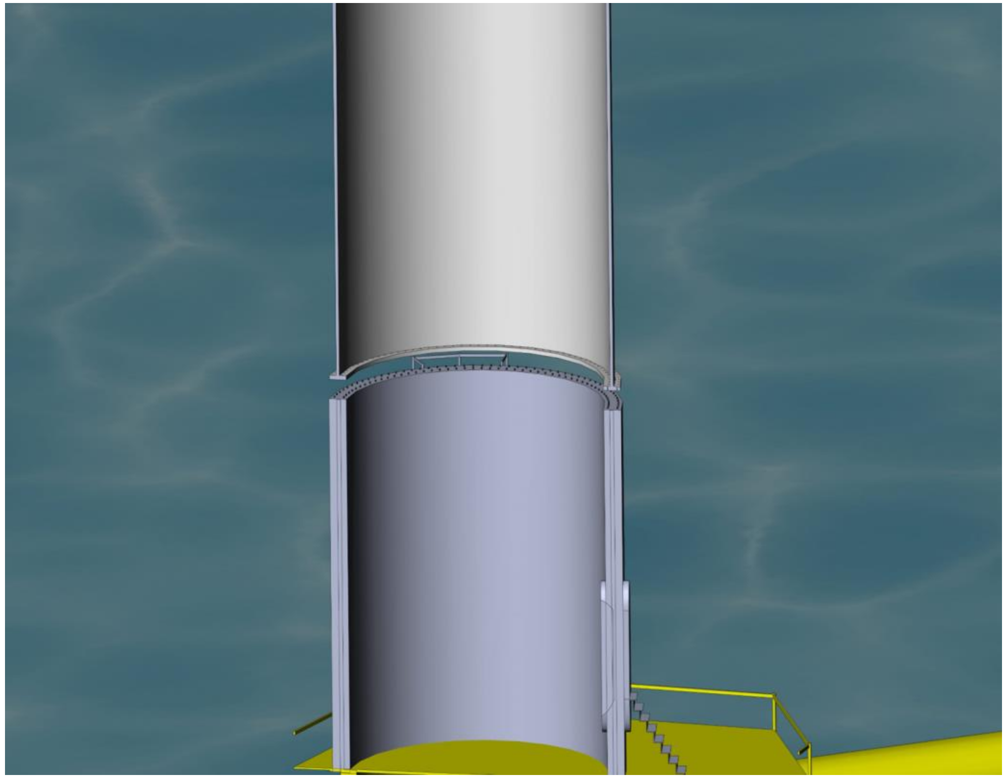


A T-flange is able to transfer the global loads, and at the same time avoid local bending

Glass fiber section (proposed design)

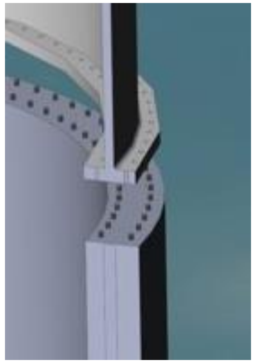


T-flange with access to external bolt row from hanging movable platform ("window cleaner")



Thick walled "root section" allows for low stresses in door opening

Outlook on the feasibility based on preliminary results



- Design feasibility
  - Manufacture of thick sandwich laminates with (balsa) core feasible
- Connection feasibility
  - Bolted connection (double row) – feasibility for 8m standard tower bottom diameter for 15MW
- Economic feasibility expected for a 20MW floating wind turbine:
  - Expected 200-250mt of steel saving in the tower above the glass fiber section compared to a "stiff-stiff" tower design. Total approximately 400mt lighter tower
  - Blade tip / tower clearance: No need for additional thrust peak shaving/reduction in power curve (which would be necessary for a large(r) diameter stiff-stiff tower design)
  - Floater can be designed with an optimal underwater body with less wave-driven loads, with 400-1200m3 less requirement for buoyancy compared to a "stiff-stiff" tower design and without restrictions from 3P issues

Conclusion

- The study suggest that conventional design methods will not allow for a soft-stiff design for the next generation of floating wind turbines
- A stiff-stiff design can become a feasible solution, but is expected to be expensive (high CAPEX and reduction of annual power production)
- Adding a glass fiber section at the bottom of the tower will allow to design the floating sub-structure independent of the turbine properties (rpm and tower bending frequency)
- The fesability study (design, connection, and economics) is currently ongoing, but shows promising results
- Finding the optimial solution for the design of a floating wind turbine does require a strong collaboration between floater designer and wind turbine supplier

References

[1] Yamaguchi, Atsushi, Subanapong Danupon, and Takeshi Ishihara. "Numerical Prediction of Tower Loading of Floating Offshore Wind Turbine Considering Effects of Wind and Wave." Energies 15.7 (2022): 2313.

[2] Arramounet, V., et al. "Development of coupling module between BHawC aeroelastic software and OrcaFlex for coupled dynamic analysis of floating wind turbines." Journal of Physics: Conference Series. Vol. 1356. No. 1. IOP Publishing, 2019.

[3] www.norskpetroleum.no