Optimizing Floating Wind Turbine Design

The Role of Tower Eigenfrequency in Dynamic Loads

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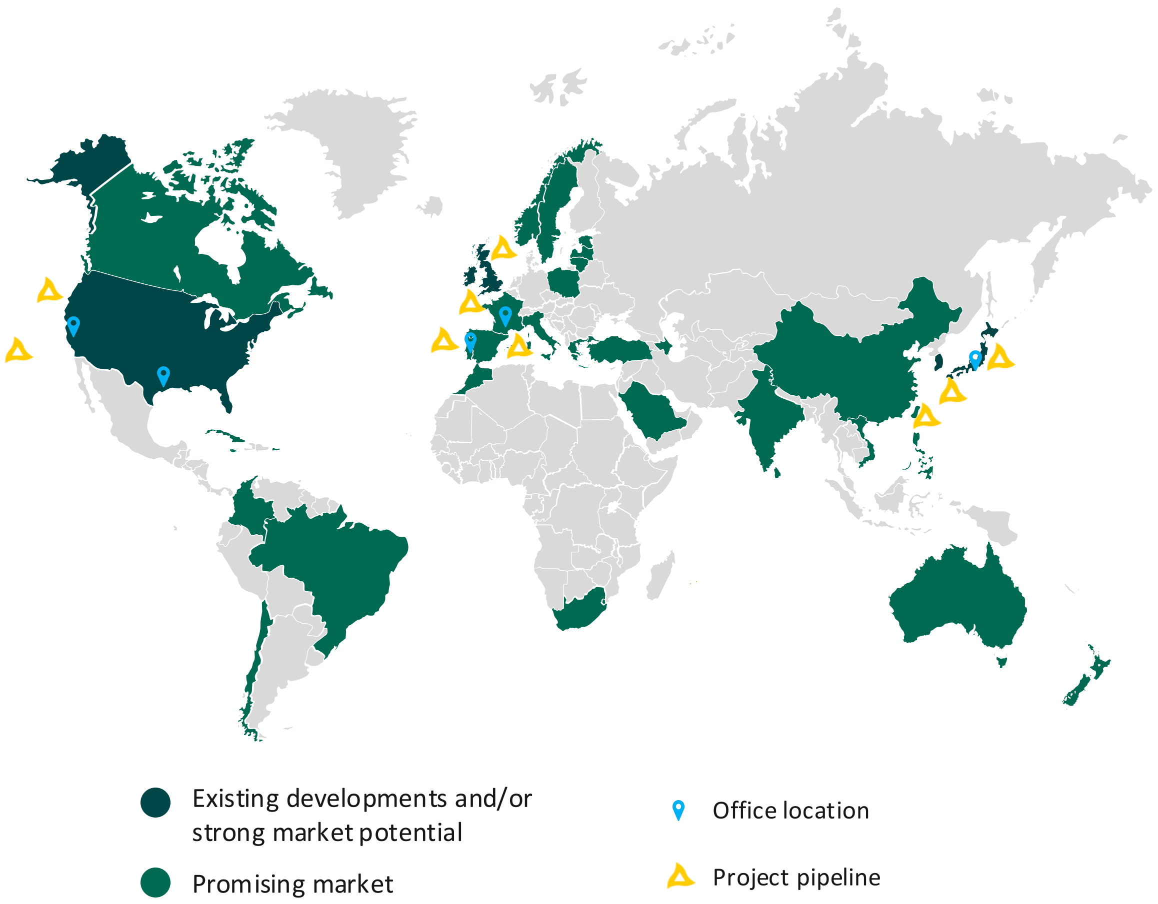

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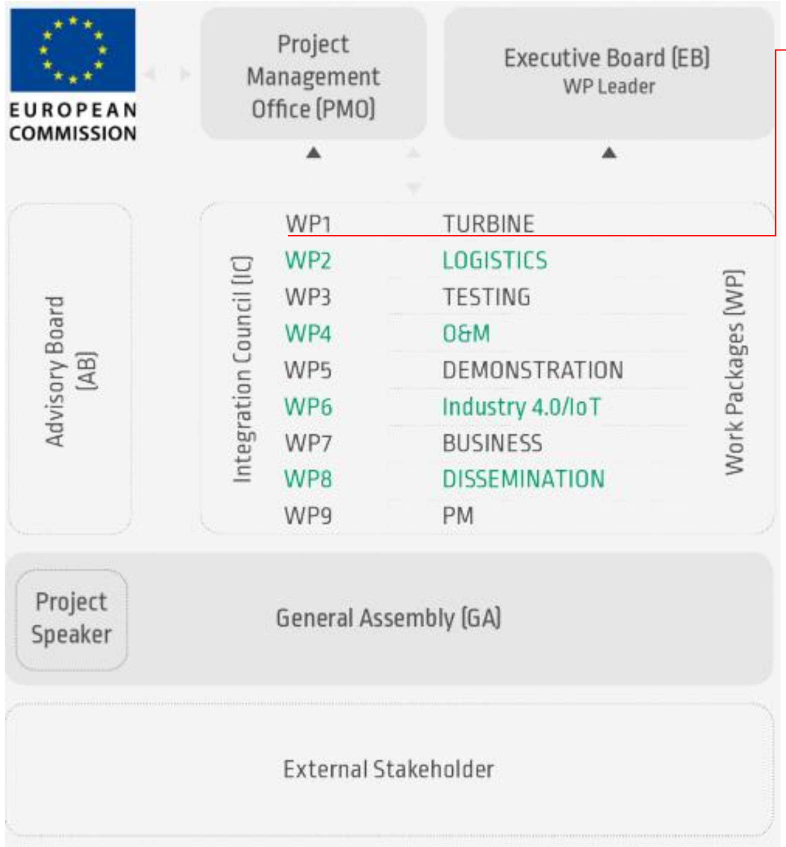
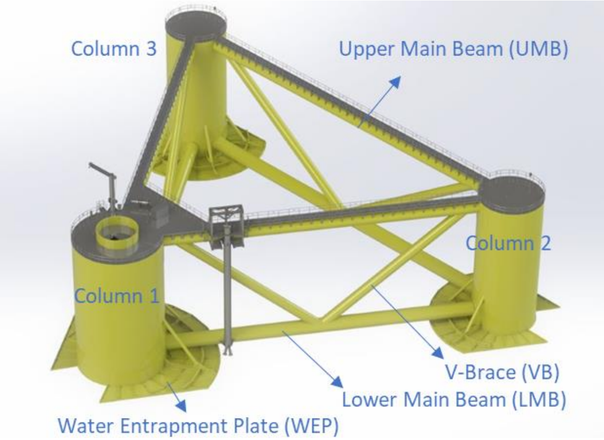
RealCoE – Objective: To reduce WECs electricity prices

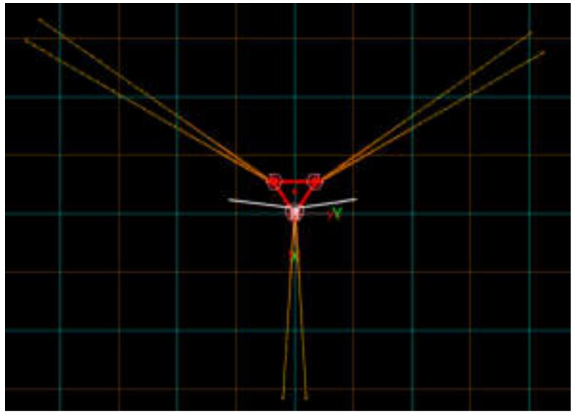
ReaLCoE is an **EU-funded project** to develop more efficient offshore wind energy converters (WECs). These WECs will produce clean energy at a lower cost than conventional and other renewable sources. By increasing the capacity of WECs to 14-16 MW, ReaLCoE aims to **achieve electricity prices as low as 35-50 €/MWh**. This would reduce energy costs and boost the European energy sector, leading to sustainable growth and job creation.



WP1.3 - Floating conceptual design key objectives were:

- Define the design basis for the floating concept study (WindFloat-T concept).
- Design a preliminary WindFloat platform with a 15+MW turbine, with a catenary mooring system.
- Benchmark simulation tools (HAWC2 and Orcaflex) to assess loads on the turbine and platform.

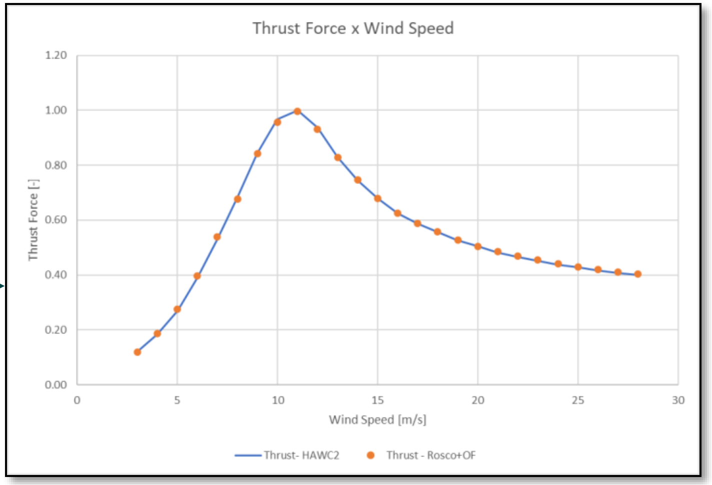




RealCoE – Overview WP1.3 – Main Configuration and Process

Wind turbine and tower modelling

- Fixed condition model.
- Eigenfrequency calculation.
- Wind turbine benchmark with HAWC2.



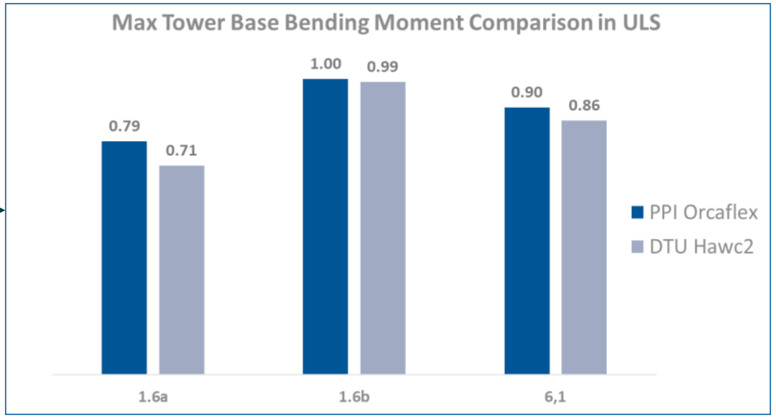
Floating model

- Floater sizing.
- Eigenfrequency calculation.
- ULS/FLS analysis.
- Mooring system development.

DLC	Turbine Status
1.2	Production
1.6	Production
5.1	Emergency shutdown
6.1	Parked

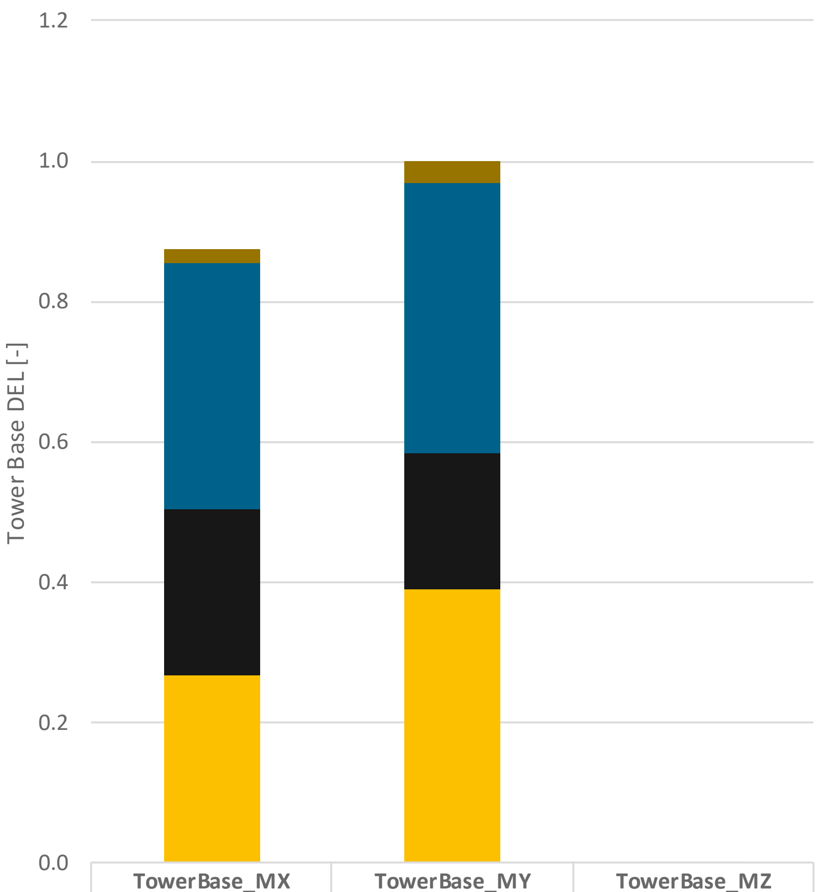
Post-processing

- Compare results with HAWC2.
- Controller analysis and improvements.
- Analysis in mooring configurantion.



3P Impact in The Tower Damage Equivalent Load - ReaLCoE

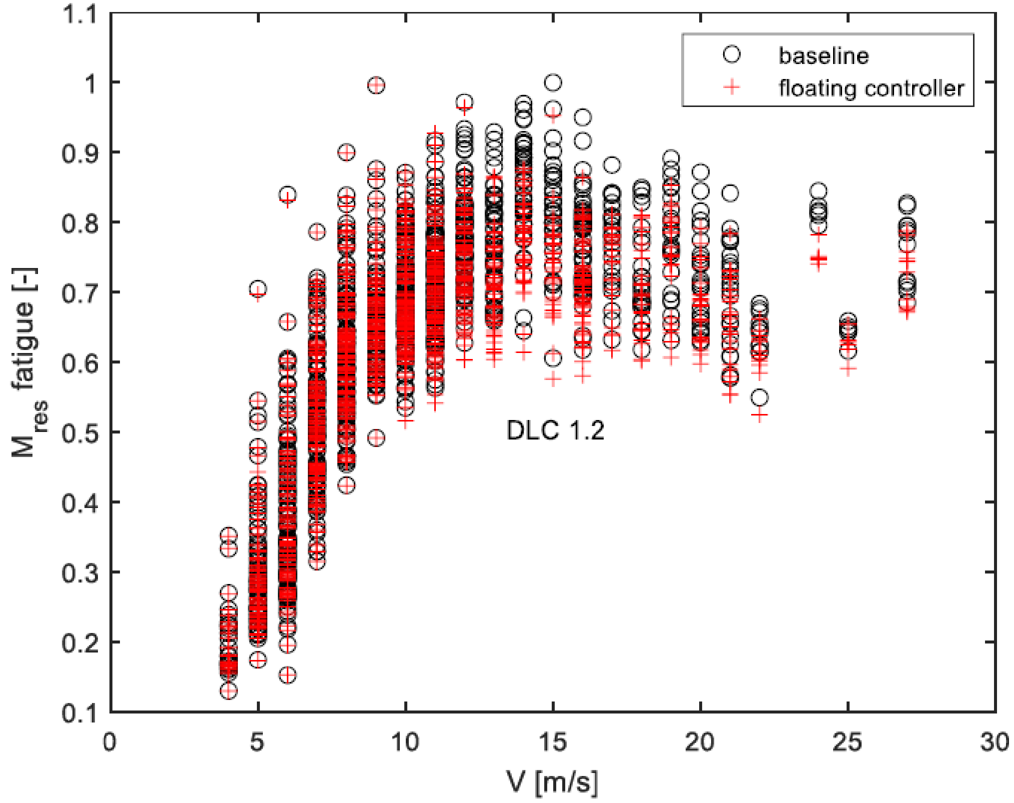
Tower Damage Equivalent Load



	TowerBase_MX	TowerBase_MY	TowerBase_MZ
Rem	0.02	0.03	0.00
3P	0.35	0.39	0.00
WF	0.24	0.19	0.00
LF	0.27	0.39	0.00

LF WF 3P Rem

- Damage Equivalent Load coming from wind turbine is significant.
- DTU and PPI have tuned the controller for floating conditions, but schedule was relatively short to develop new controllers.
- It would be beneficial to explore further tuning options to potentially reduce FLS and ULS loads.



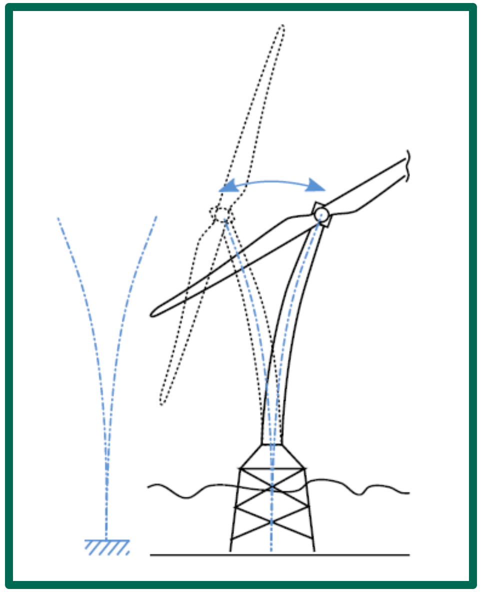
- LF: Low Frequency
- WF: Wave Frequency
- 3P: Blade Passing Frequency
- Rem: Remainder Frequency

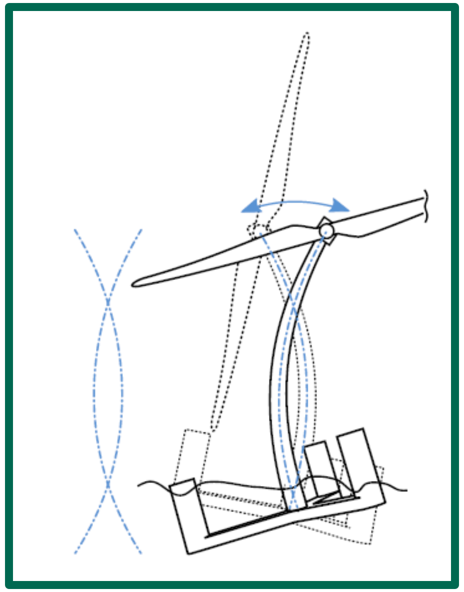
Tower Eigenfrequency increases in Floater Configuration

Tower EF is affected by:

- Its foundation:
  - The tower system of a floating turbine **behaves like an unfixed beam** that can oscillate freely in all directions.
  - **The natural frequency of the tower increase**s when comparing a floating turbine with a fixed turbine.
  - The equation shows the effect of the change in the first tower mode, assuming a constant homogeneous beam.*
- Varying the tower **diameter and thickness**.
- The **mass/inertia of the RNA.**
- Need to consider the **mass/inertia of the floater** and, the stiffness of the system.
- The **flexibility of the floater.**
- E.g.in ReaLCoE:

RealCOE	
Mode	**EF Difference between fixed and float condition [%]**
Side-Side	22.2%
Fore-Aft	31.5%





$$\omega_0 = (\lambda l)^2 \sqrt{\frac{EI}{\rho A l^4}},$$

Eigenvalue

Bending Stiffness

Length

Density

Cross-section Area

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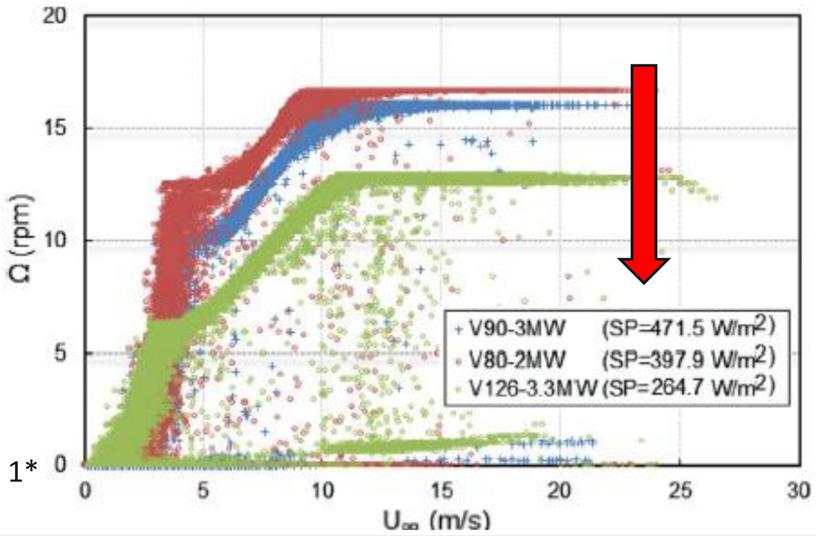
*Ref: Fabian Anstock et al 2023, Increased tower eigenfrequencies on floating foundations and their implications for large two and three-bladed turbines.

Larger wind turbines have rotated at lower speed



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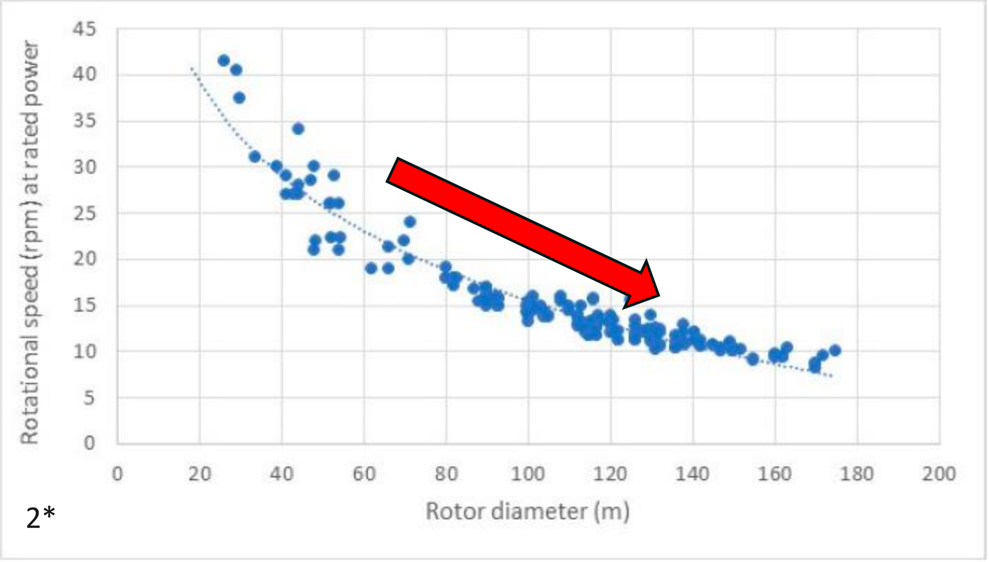
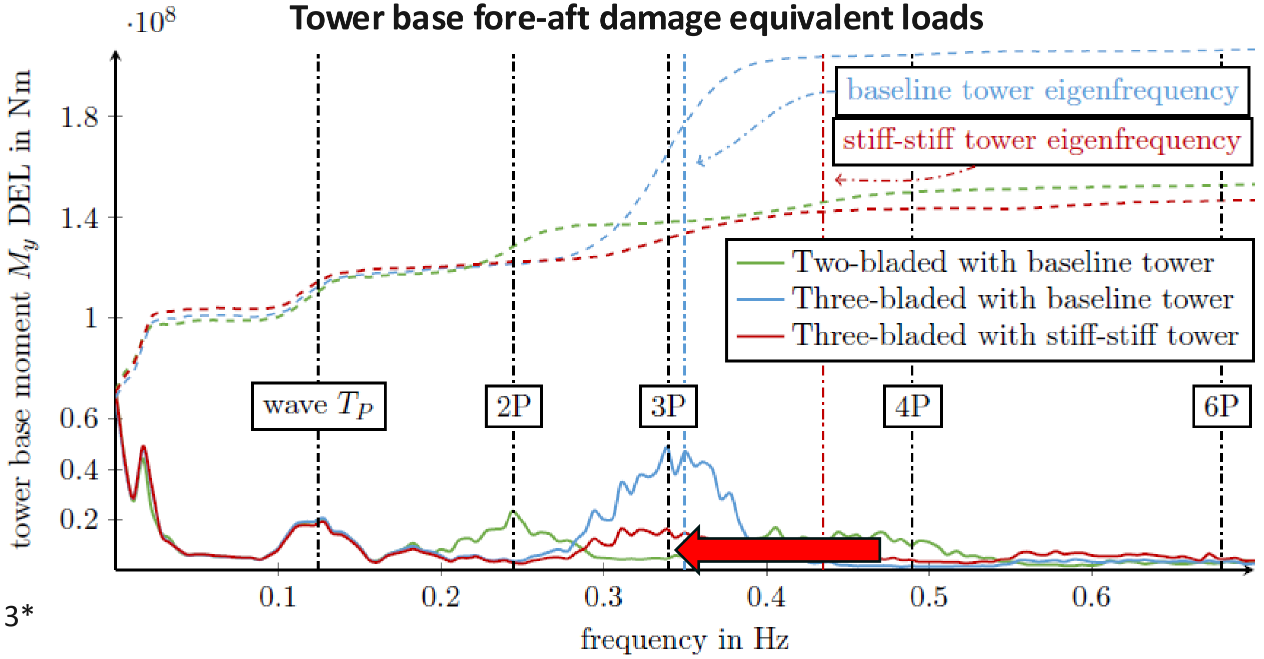


2*

- Historically, larger wind turbines have **rotated at lower speeds**.
- As a result, the WTM 15+MW **reduces the soft-stiff zone window** in floater conditions. However, this increases the margin of the stiff-stiff towers solutions.
- The stiff-stiff solution needs to be addressed with lightweight platforms designed for stiff conditions.

Tower base fore-aft damage equivalent loads



3*

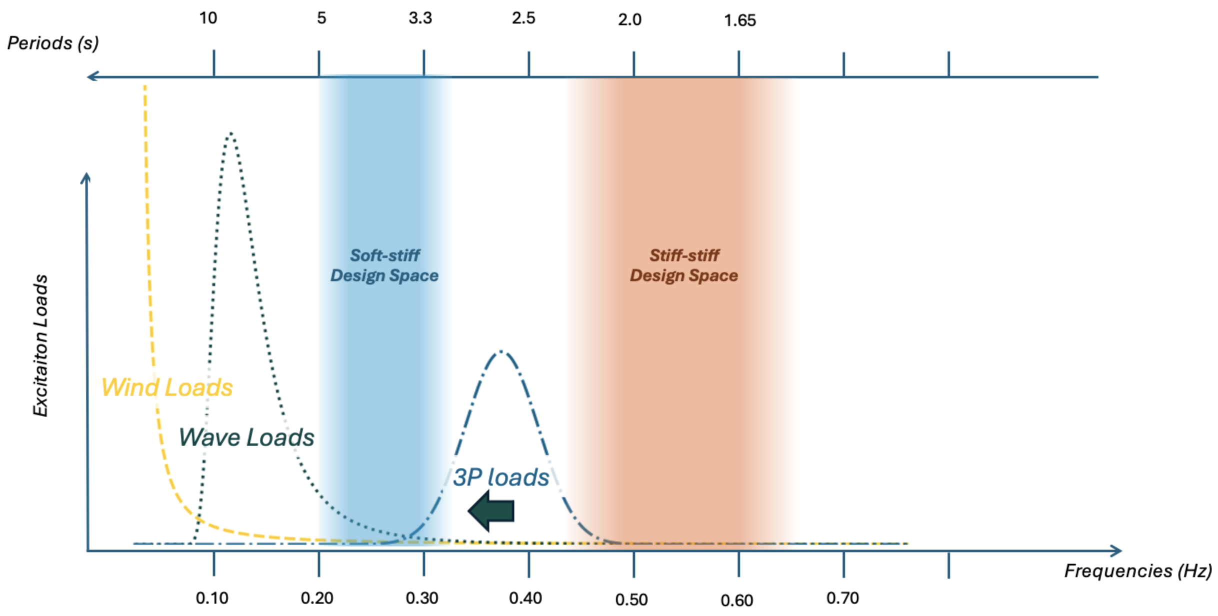
Public

1) Mehmet Bilgili et all, 2020, "Effect of Growth in Turbine Size on Rotor Aerodynamic Performance of Modern Commercial Large Scale Wind Turbines" 2) van den Berg, Frits et all, 2024, "Development of Sound Power of Onshore Wind Turbines including Its Spectral Distribution"; 3) Fabian Anstock et al 2023, Increased tower eigenfrequencies on floating foundations and their implications for large two and three-bladed turbines.

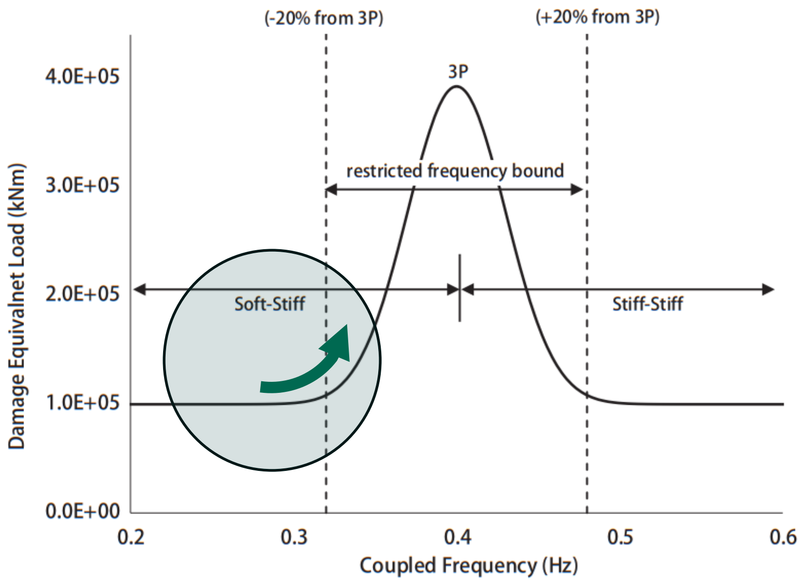
Design space for 15+ MW wind turbines

300 X 30

- **Design Space for Floating Wind Turbines**
  - So-called "soft-stiff" or "stiff-stiff" design space.
  - Defined by where the coupled system eigenfrequency (EF) lies.
  - For any WTG / platform design, keeping a safety margin between these frequencies is crucial to avoid a resonant response of the system, which could lead to severe fatigue damage.
  - As the WTG size increases, the soft-stiff design space decreases as 3P loads frequency decreases (WTG spinning slower)



- **Wind Turbine Manufacturer's Challenge**
  - The WTG **soft-stiff** approach exposed to risk of a vicious cycle of increasing stiffness and thereby increasing fatigue loads
    - Manageable with right tools and contingencies upfront
  - Soft-stiff diverging design spiral:
    - If system shows high fatigue loads (EF too close to 3P)
    - Then, add reinforcements, increasing stiffness and increasing EF
    - Then, higher fatigue loads requires adding more reinforcements



Design space for 15+ MW wind turbines

▪ Design Space for Floating Wind Turbines

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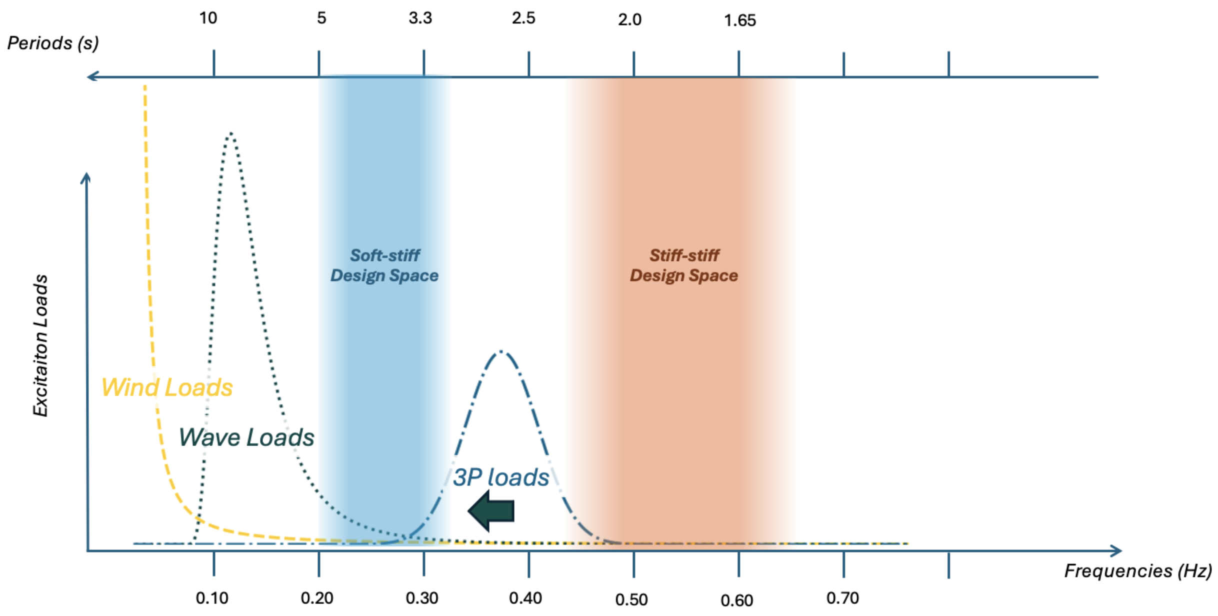
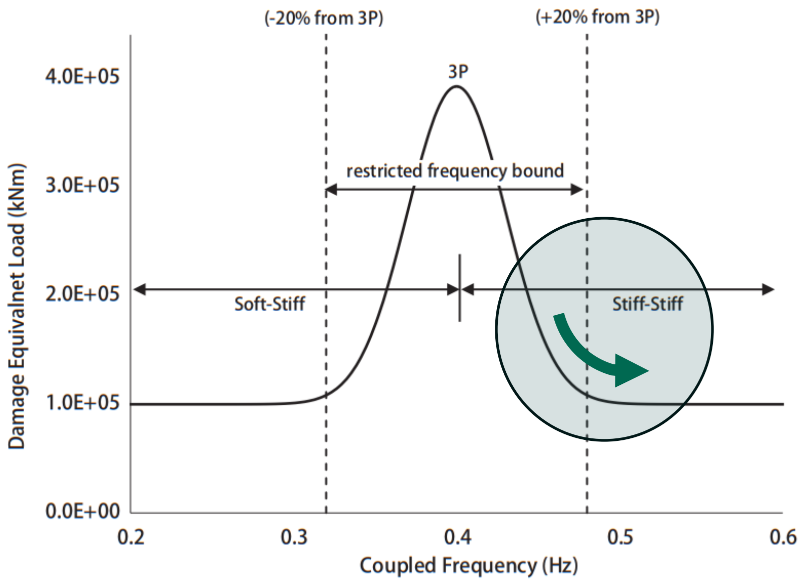


▪ The WTG stiff-stiff approach

- The coupled system EF needs to be significantly increased
- Drivers are stiffness and mass/inertia



WindFloat® central platforms are preferred for stiff-stiff towers

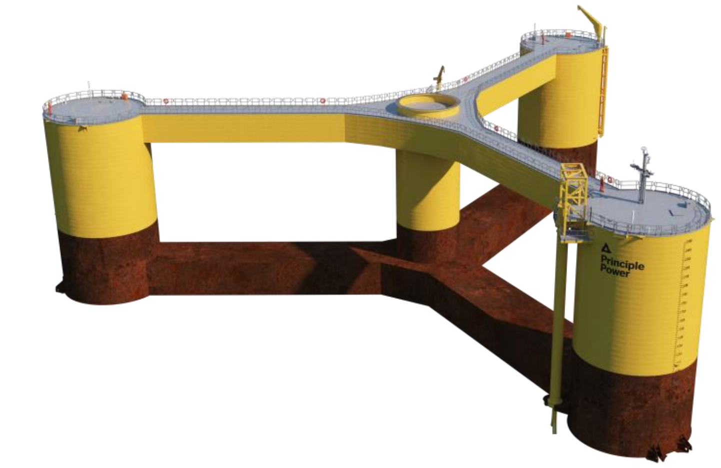


Illustration of WindFloat TC

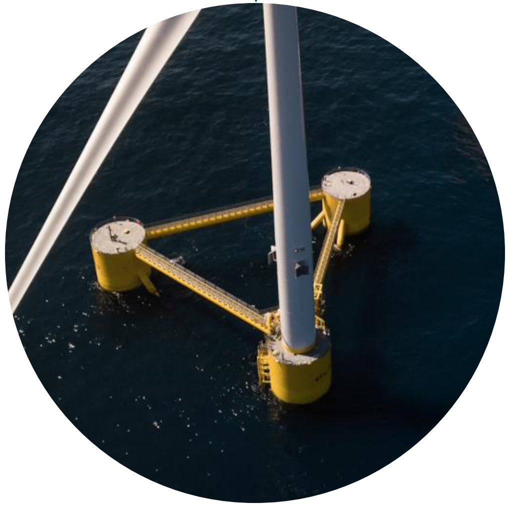
Illustration of WindFloat FC

Bankable from the beginning: natural evolution from WindFloat® product line	▪ Central turbine designs leverage four generations of WindFloat® heritage ▪ Platforms rearranges bankable modules: • WTG supported by continuous diameter shaft that reaches keel level for structural continuity (from WindFloat T); • Columns from WindFloat T & F • Pontoons and UMB (from WindFloat F)
Central-column, pontoon-based design for weight-efficient & flexible design	▪ Compact configuration minimizes column size & footprint ▪ Pontoon enables integration in shallow water ports (>8m); ▪ Symmetry reduces destabilizing yaw moment and direction-independent EF. ▪ Flexibility to manage any late weight deviations in as-designed or as-built system
Columns and major components enable access to tubular or flat panel supply chains	▪ Identical geometries and fabrication methods to WindFloat T (e.g., Tubular columns) and WindFloat F (e.g., hexagonal columns) ▪ Compatible with existing automated tubular and flat-panel fabrication lines ▪ Welded connections for long reliable lifetimes in harsh offshore environments
Optimized for Industrialized delivery	▪ Modular "block" subcomponent philosophy for columns, pontoons, and box braces ▪ Blocks manufactured indoor in serial lines for high throughput and quality ▪ Simple geometries for high density transportation and wet/dry storage
Hull Trim System	▪ Fully redundant, closed loop system to transfer water ballast between columns ▪ Maximizes AEP and reduce WTG structural loads versus passive systems

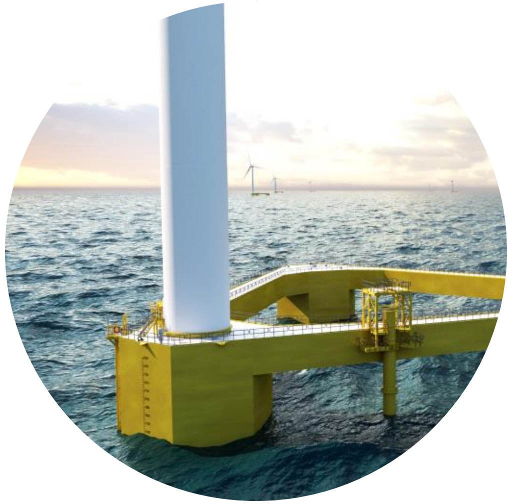
Windfloat® design portfolio enables wind turbine standardization and maximizes compatibility with existing fabrication capabilities

WTGs with "Soft-Stiff" Tower

WTGs with "Stiff-Stiff" Towers



WindFloat T
Tubular Design, with unparallel operational track record



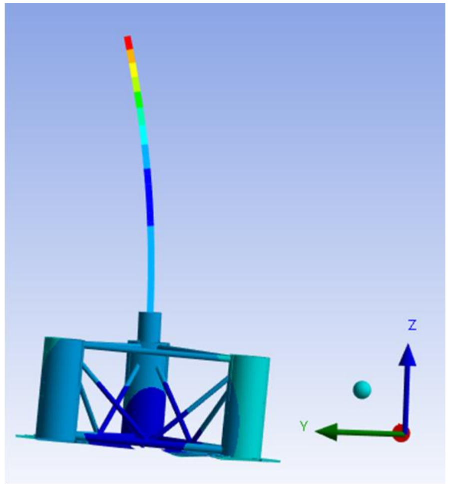
WindFloat F
Flat-panel, pontoon-based solution, with established flat panel construction methods

WindFloat TC
Tubular, with center column, optimized for 15+ MW "Stiffer" Towers

WindFloat FC
Flat Panel, center column, optimized for 15+ MW "Stiffer" Towers

Eigenfrequency on project execution

- **Eigenfrequency** and **contingency management** are complex topics in floating wind projects due to the very “coupled” nature of the designed system.
- **Eigenfrequency calculation methodologies** are company-dependent (existing standards deal with integrity, not system performance).
  - Requires a deep technical engagement on both sides (WTG and Platform).
  - Must align on conventions, assumptions, model setups, etc.
- WTM and platform designer need to **run Integrated Load Analysis (ILA)** with inputs from other party.
  - Modeling and exchanging data are critical for efficient ILA convergence.
  - Our processes and models are proven (3 complete project cycles).
- System eigenfrequency is a **shared interface between developer, WTM and designer** that cannot be transferred and must be actively managed:
  - Shared responsibility define “coupled-system” inputs performed with imperfect information about the full system behavior (e.g., no blade model).
  - Design Basis should define process from engineering to commissioning, including measurement of as built performance during operations.
- Principle Power is applying our lessons learned **to build robust processes for commercial scale projects.**



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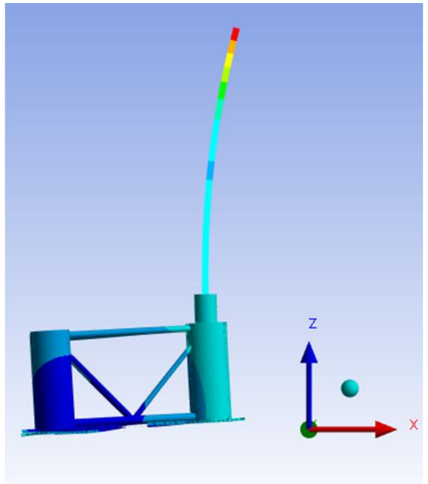

Mode 8 - FA

Please reach out for additional information

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